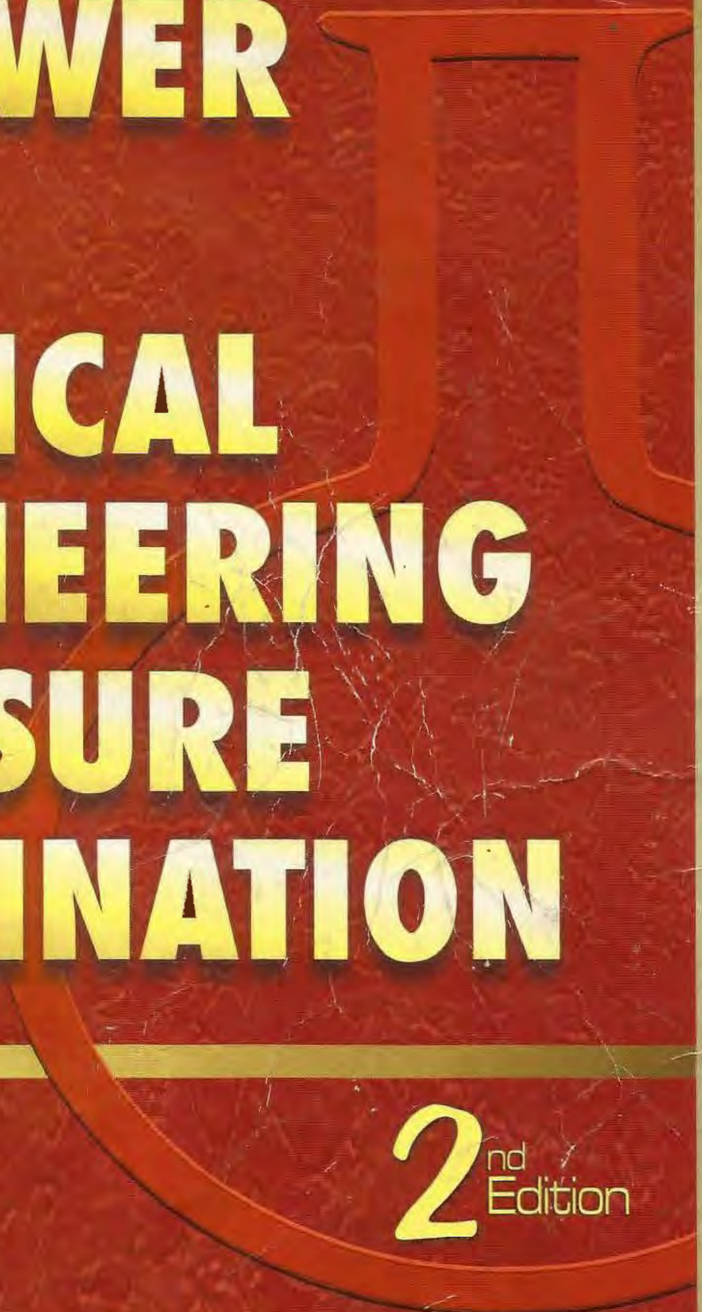
REVIEWER FOR CHEMICAL ENGINEERING LICENSURE EXAMINATION



2nd Edition

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With contributions from
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Preface

The purpose of publishing this reviewer is found in the preface to the first edition and will not be repeated here.

The publisher and contributors hope that the first edition was able to help students and board examinees review fundamental concepts in Chemical Engineering.

This revised edition is a much improved version of the first where various kinds of errors, as pointed out by readers, were corrected and eliminated. Many of the problems in the first edition were retained since these are important in illustrating basic concepts and principles, although additional problems were provided and some questions removed. There are more than 1700 questions and problems with answers in this reviewer. The discussion of the topics in most sections were improved and expanded to provide an outline form of the theory. These, however, are not complete and the reader should refer to the appropriate textbooks and lecture notes.

The arrangement of the topics were slightly revised to conform with the new distribution as provided in the syllabus issued by the Board of Chemical Engineering dated March 1, 2002. The Ch.E. Law, ***R.A. 318*** is no longer included since the new "Ch.E. Law of 2004" known as ***R.A. 9297*** has been approved and signed by **President Gloria Macapagal-Arroyo** last May 13, 2004. The new Ch.E Act is a consolidation of Senate Bill No. 2685 and House Bill No. 46. The Senate Bill was approved during the 3rd and last reading at 4:05 pm on February 6, 2004 while the House Bill was approved on February 7, 2004. An electronic copy of this new law is available at the National PIChE website, http://www.piche.org.ph.

We would like to acknowledge the help of **Ms. Carmencita C. Hervas** and **Engr. Arthur B. Yñiguez** for their invaluable contributions to the first edition. Unfortunately, due to certain circumstances, they could not join the team anymore in the publication of this edition. We would likewise extend our appreciation to **Engr. Ricardo F. del Rosario**, **Ms. Ma. Revelyn DR Lameyra** and **Ms. Ma. Rowena DR Almera** of MRII for their support in the preparation of this manuscript.

Many thanks are accorded to **Ms. Grace F. Adalia** and **Ms. Nikki D. Abalos** for their efforts in arranging the materials. The assistance from **Ms. Cattleya Rose F. Bayot**, **Ms. Maricel C. Mendez** and **Mr. Chalmer P. Bokingkito**, able members of the office staff of MRII is also acknowledged.

Again, we would appreciate very much if users of this book can give us feedback on how to improve the presentation and most of all to point to us errors which might have escaped the prying eyes of the editor and contributors.

Servillano S.B. Olaño, Jr. (Editor)
May 2004

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Preface to the First Edition

This book is primarily designed to assist chemical engineering graduates pass the Licensure Examinations in Chemical Engineering based on the new computerized method of evaluation. Many of the questions and problems were compiled from previous ChE board examinations to provide examinees ideas on the type of questions and problems they might encounter during the examination. Although these questions may not appear anymore in the board examination, it is important that examinees realize the extent of topics and fundamental concepts they have to be familiar with in order to pass the examination. Other questions were either formulated by the contributors or selected from standard textbooks or references for a more comprehensive treatment of the subject matter. This book may also be used by undergraduate ChE students to supplement the materials they are using in their classes.

The review materials and questions provided in this compilation can surely help students review and practice for the board examination. It is important that this book should not be used as a stand alone textbook for review. Comprehensive review should be reinforced using the standard textbooks and references in the Chemical Engineering Curriculum, especially the Chemical Engineers' Handbook which is the only book allowed to be brought in the examination room.

The contents of this book are divided into three parts following the three major subjects given in the Ch.E. board examination. These are ***Physical and Chemical Principles***, ***General Engineering,*** and ***Chemical Engineering***. Under each subject, the various topics, based on the syllabus provided by the **Professional Regulation Commission** (**PRC**), are presented. Under a particular topic, review concepts and equations are included, when necessary, for quick reference. Sample multiple-choice questions are then provided with answer keys given at the end of the book. It is important that the reviewee should conscientiously answer these questions first and then check his work by comparing his answers with those given in the book.

Practice problem sets on the three major subjects are included which are no longer classified according to topics to provide a comprehensive review on them. The reviewee can consider this set as a three-day pre-board examination which he can simulate on his own by answering the questions according to the day the subject is given in the examination. All in all, there are about 1,400 questions and problems in this reviewer.

Other useful materials needed by the reviewees such as the entire provisions of the *Chemical Engineering Law*, *Engineering Code of Ethics*, the syllabus followed in the Ch.E. licensure examinations, rules and policies for the applicant to follow and other useful information are also found in this book.

The authors would like to acknowledge the assistance of **Engr. Ricardo F. del Rosario**, the President of the Manila Review Institute, Inc., **Mrs. Ma. Revelyn DR Lameyra** and **Mrs. Ma. Rowena DR Almera** of MRII for allowing us the use of the facilities and many of the handouts successfully utilized in the conduct of Chemical Engineering review classes for the past 25 years. Special thanks to **Mrs. Grace F. Adalia** for the patience and hard work in meticulously arranging the materials in their present form and to **Ma. Carmina D. Olaño** for typing most of the equations found in Unit Operations.

Besides the authors, there are those who in one way or the other contributed materials found in this manuscript as Ch.E. reviewers in the past. To the best of our recollection, we acknowledge the following: **Engr. Eduardo Ignacio (+), Dr. Cristy Hernandez, Engr. Evelyn Masaoy, Engr. Caridad Goze, Engr. Catalina Mijares, Engr. Pamela Concepcion, Engr. Luz Paca, Dr. Susan Gallardo, Engr. Yolanda Brondial, Engr. Ronald Mendoza, Engr. Joselito Uy, Engr. Stanley Santos, Engr. Joseph Auresenia,** and **Engr. Rizalino Nocon.**

Again, the primary objective of this manuscript is to help chemical engineering graduates or senior students prepare for the board examination. It is never guaranteed that they can pass the examination by relying on this book alone. It will take much more preparation and hard work to successfully hurdle the board examination. This compilation of review materials is just an initial attempt to be of help. There are still many things to be done in order to improve the presentation and contents of this book. We would appreciate it very much if readers can make suggestions and point out possible errors so that this manuscript can be further improved for the benefit of future examinees.

Servillano S.B. Olaño, Jr. (Editor)
June 2000

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Table of Contents

Part III. GENERAL ENGINEERING

A. Mathematics

PRACTICE PROBLEMS

Part I

PHYSICAL AND CHEMICAL PRINCIPLES

A. GENERAL INORGANIC CHEMISTRY

Table of Common Names of Chemical Compounds

COMMON NAME	CHEMICAL NAME	FORMULA
Acetylene	Ethyne	C_2H_2
Agua oxinada	Hydrogen Peroxide	H_2O_2
Alum	Sodium Aluminum Sulfate Dodecahydrate	$NaAl(SO_4)_2 \cdot 12H_2O$
Ammonia water	Aqueous Solution of Ammonia	NH_4OH
Aqua fortis	Nitric Acid	HNO_3
Aqua regia	Mixture of concentrated HCl and HNO_3	3 HCl : 1 HNO_3
Baking soda	Sodium Hydrogen Carbonate	$NaHCO_3$
Bleaching powder	Calcium Hypochlorite	$Ca(ClO)_2$
Blue vitriol	Copper Sulfate Pentahydrate	$CuSO_4 \cdot 5H_2O$
Borax	Sodium Tetraborate Decahydrate	$Na_3B_4O_7 \cdot 10H_2O$
Borazon	Boron Nitride	BN
Brine	Aqueous Soln. of Sodium Chloride	$NaCl_{(aq)}$
Butter of antimony	Antimony (III) Chloride	$SbCl_{3(aq)}$
Calcite or Limestone	Calcium Carbonate	$CaCO_3$
Calomel	Mercurous Chloride	Hg_2Cl_2
Carborundum	Silicon Carbide	SiC
Caustic potash	Potassium Hydroxide	KOH
Caustic soda or Lye	Sodium Hydroxide	NaOH
Chalcocite	Copper (I) Sulfide	Cu_2S
Chalcopyrite	Copper Ferrous Sulfide	$CuFeS_2$
Chile saltpeter	Sodium Nitrate	$NaNO_3$
Chloroform	Trichloromethane	$CHCl_3$
Common table salt	Sodium Chloride	NaCl

Copperas	Ferrous Sulfate Heptahydrate	$FeSO_4 \cdot 7H_2O$
Corundum	Aluminum Oxide	Al_2O_3
Cream of tartar	Potassium Bitartrate	$KHC_4H_4O_6$
Epsom salt	Magnesium Sulfate Heptahydrate	$MgSO_4 \cdot 7H_2O$
Galena	Lead (II) Sulfide	PbS
Glauber's salt	Sodium Sulfate Decahydrate	$Na_2SO_4 \cdot 10H_2O$
Grain alcohol	Ethyl Alcohol	C_2H_5OH
Gypsum	Calcium Sulfate Dihydrate	$CaSO_4 \cdot 2H_2O$
Hematite	Iron (III) Oxide	Fe_2O_3
Iodoform	Triiodomethane	CHI_3
Laughing gas	Dinitrogen Oxide	N_2O
Limewater	Calcium Hydroxide Solution	$Ca(OH)_{2(aq)}$
Litharge	Lead Oxide	PbO
Lunar caustic	Silver Nitrate	$AgNO_3$
Magnesia or Periclase	Magnesium Oxide	MgO
Magnesia alba	Basic Magnesium Carbonate	$Mg_4(OH)_2(CO_3)_3 \cdot 5H_2O$
Magnesite	Magnesium Carbonate	$MgCO_3$
Magnetite or Magnetic iron oxide	Iron (II,III) Oxide	Fe_3O_4 or $FeO \cdot Fe_2O_3$
Marsh or Swamp gas	Methane	CH_4
Milk of magnesia	Magnesium Hydroxide	$Mg(OH)_{2(aq)}$
Monosilane	Silicon Hydride	SiH_4
Muriate of potash	Potassium Chloride	KCl
Muriatic acid	Hydrochloric Acid	HCl
Norbide	Boron Carbide	B_4C
Oil of vitriol	Sulfuric Acid	$H_2SO_{4\,(aq)}$

Phosgene	Carbon Oxychloride	$COCl_2$
Phospine	Phosphorus Trihydride	PH_3
Pitchblendé	Uranium Oxide	U_3O_8
Plaster of Paris	Calcium Sulfate Hemihydrate	$CaSO_4 \cdot ½H_2O$
Potash	Potassium Carbonate	K_2CO_3
Prussian's blue	Ferric Ferrocyanide	$Fe_4[Fe(CN)_6]_3$
Prussic acid	Hydrocyanic Acid	HCN
Pyrite	Iron Sulfide	FeS_2
Pyrolusite	Manganese Dioxide	MnO_2
Quartz or White sand	Silicon Dioxide	SiO_2
Quicklime or Lime	Calcium Oxide	CaO
Quicksilver	Mercury	Hg
Rochelle's salt	Sodium Potassium Tartrate	$NaKC_4H_4O_6$
Rutile or Anatase	Titanium Dioxide	TiO_2
Sal ammoniac	Ammonium Chloride	NH_4Cl
Saltpeter	Potassium Nitrate	KNO_3
Slaked lime	Calcium Hydroxide	$Ca(OH)_2$
Soda ash	Sodium Carbonate	Na_2CO_3
Sugar of lead	Lead Acetate	$Pb(CH_3COO)_2$
Tartar emetic	Potassium Antimonyl Tartrate	$KSbOC_4H_4O_6$
Turnbull's blue	Ferrous Ferricyanide	$Fe_3[Fe(CN)_6]_2$
Washing soda	Sodium Carbonate Decahydrate	$Na_2CO_3 \cdot 10\ H_2O$
Witherite	Barium Carbonate	$BaCO_3$
Wood alcohol	Methanol	CH_3OH

The Atomic Theory

Dalton's Atomic Theory

John Dalton (English chemist, mathematician and philosopher)

1. Elements are composed of tiny indivisible particles called *atoms*. Atoms of different elements are chemically different; however, atoms of a given element are of the same size, shape, mass and chemical properties.
2. *If two elements combine to form more than one compound, the ratio of the mass of an element to a fixed mass of the other element is a whole number or a simple fraction
3. **A chemical reaction only involves separation, combination or rearrangement of atoms

* *Law of Multiple Proportions*
***Law of Conservation of Mass*
Law of Definite Proportions states that a pure compound is made up of elements in the same proportion by mass. (*Joseph Louis Proust*, French chemist)

The Electron

Cathode Ray Tube or *Geissler Tube (Sir William Crookes* and *Heinrich Geissler)*
It is a glass tube with two metal plates connected to a high-voltage source which emitted a ray drawn from the negative plate towards the positive plate. The ray emitted has the same nature regardless of the material of construction of the glass tube, electrode and the gas used.

Joseph John Thomson (British physicist, recipient of Nobel Prize in Physics in 1906) determined the ratio of electric charge to the mass of an electron to be -1.76×10^{8} coul/gram.

Robert Andrews Millikan (American physicist, recipient of Nobel Prize in Physics in 1923) determined the charge of an electron to be -1.60×10^{-19} coul.

Radioactivity

Wilhelm Konrad Rontgen (German physicist, recipient of Nobel Prize in Physics in 1901) discovered the X-rays, which penetrated matter, darkened unexposed photographic plates and caused metals to emit unusual rays.

Antoine Henri Becquerel (French physicist, recipient of Nobel Prize in Physics in 1903) discovered radioactivity in uranium.

Marya Skolodowska Curie (Polish chemist and physicist, recipient of Nobel Prizes in Physics in 1903 and Chemistry in 1911) discovered radioactivity in uranium and polonium.

The Proton and the Nucleus

Ernest Rutherford (New Zealand chemist, recipient of Nobel Prize in Chemistry in 1908) performed the gold foil experiment wherein a thin foil of gold was bombarded with alpha particles. He made the following generalizations:

1. Most of the atom is an empty space
2. The positive charge of an atom is concentrated in the nucleus

The positively charged particle in the nucleus is the *proton* and carries the same quantity of charges as an electron. It has a mass of 1.6752×10^{-24} gram – about 1837 times the mass of an electron.

The Neutron

James Chadwick (British physicist, recipient of Nobel Prize in Physics in 1935) discovered neutron by bombarding a beryllium atom with alpha particles producing an electrically neutral particle having a mass slightly greater than that of a proton.

Charge and Mass of Subatomic Particles

	MASS (gram)	CHARGE (coulomb)
Neutron	1.67495×10^{-24}	0
Proton	1.67252×10^{-24}	1.6022×10^{-19}
Electron	9.1095×10^{-28}	-1.6022×10^{-19}

Atomic number is the number of protons in the nucleus of an atom. An atom is electrically neutral where the number of protons is equal to the number of electrons.
Mass number is the total number of protons and neutrons in the nucleus of an atom.
Isotopes are atoms that have the same atomic number but different mass number.
Average atomic mass of an element is the weighted average of the atomic masses of the isotopes based on their percentage abundance.

The Quantum Numbers

1. *Principal Quantum Number* (n) pertains to the average distance of the electron from the nucleus in a particular orbital. It has integral values 1, 2, etc.
2. *Azimuthal/Angular Momentum Quantum Number* (l) tells the shape of the orbital. It has values from 0 to $n-1$
3. *Magnetic Quantum Number* (m_l) describes the orientation of orbitals in space. Its allowable values are $-l$ to 0 to $+l$
4. *Spin Quantum Number* (m_s) shows the spin of electrons. Its values are $+½$ (clockwise) and $-½$ (counter clockwise)

Electronic Structure of Atoms

Rules and Principles in Writing Electronic Configuration

1. *Aufbau Principle* – the orbitals of an atom must be filled up in increasing energy levels.
2. *Pauli's Exclusion Principle* – no two electrons in an atom can have the same set of quantum numbers and an atomic orbital must contain a maximum of two electrons with opposite spins (*Wolfgang Pauli*, Austrian physicist, recipient of Nobel Prize in Physics in 1945).
3. *Hund's Rule of Multiplicity* – the most stable arrangement of electrons in subshells is the one with more parallel spins (*Frederick Hund*, German physicist).

Periodic Table of Elements

In 1829, *Johann Wolfgang Dobereiner*, German chemist, arranged the elements in triads like Li–Na–K, Ca–Sr–Ba, and Cl–Br–I.

In 1864, *John AR Newlands*, English chemist, arranged the elements in atomic mass and found out that every eight element has similar properties.

In 1869, Russian chemist *Dmitri Ivanovich Mendeleev* and German chemist *Julius Lothar Meyer* arranged the elements in the periodic table according to their recurring periodic properties.

In 1913, a young English physicist, *Henry Gwyn–Jeffreys Moseley* discovered the relationship between the elements' atomic number and the frequency of X–rays generated by bombarding the element with high-energy electrons.

Modern Periodic Law – the properties of the elements are functions of their atomic numbers.

Some Atomic Properties

1. *Atomic Size (Atomic Radius)* is the average distance between the nucleus and the valence electron.
2. *Ionization Energy* is the energy required to remove an electron from a gaseous atom in its ground state. The lower the IE, the easier it is for an atom to form a cation.
3. *Electron Affinity* is the change in energy when an electron is accepted by a gaseous atom to form an anion.
4. *Electronegativity* is the measure of the ability of an atom to attract towards itself a bonding electron.

The Electronegativities of Common Elements

Linus Carl Pauling (American chemist, recipient of Nobel Prize in Chemistry in 1954 and Nobel Peace Prize in 1962)

H 2.1						
Li 1.0	Be 1.5	B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.2	Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0
K 0.8	Ca 1.0					Br 2.8
						I 2.5

Variation of Physical Properties in the Periodic Table

Across a period…

←

B	C	N	O	F

Down a group …

↓

Li
Na
K
Rb
Cs
Fr

PROPERTY	INCREASING	DECREASING
Atomic Size	◆	
Metallic Property	◆	
Reactivity	◆	
Ionization Energy		◆
Electron Affinity		◆
Electronegativity		◆

Chemical Bonds

Covalent Bond – results from the attraction of the nucleus and the electron of two or more atoms (sharing of e^-)
– involves two non-metals

Ionic Bond – results from the attraction of two opposite charged particles (loss/gain of e^-)
– involves a metal and a non-metal

Properties of a Chemical Bond

1. *Bond Energy* is the amount of energy involved in the formation and breaking of a bond.
2. *Bond Length* is the distance between the nuclei of the atoms forming the bond.
3. *Bond Order* pertains to single bond, double bond, triple bond and those intermediate between single and double bonds, etc.

when a bond breaks – absorb energy
forms – [illegible]

Theories of Bonding

1. *Valence Bond Theory* – the formation of a bond is due to the overlap of two atomic orbitals.
2. *Molecular Orbital Theory* – a bond is formed when electrons in the bonding molecular orbital is greater than the electrons in the non-bonding molecular orbital.

Molecular Geometry

NUMBER OF ATOMS ATTACHED TO CENTRAL ATOM	GEOMETRY	BOND ANGLE(S)	FORMULA	EXAMPLE
2	linear	180°	AB_2	CO_2
3	trigonal planar	120°	AB_3	BF_3
	V-shaped or angular	less than 120°	$:AB_2$	SO_2
4	tetrahedral	109.5°	AB_4	CH_4
	trigonal pyramidal	107°	$:AB_3$	NH_3
	V-shaped	104.5°	$:\overset{\bullet\bullet}{A}B_2$	H_2O
5	trigonal bipyramidal	90°–120°–180°	AB_5	PCl_5
	see-saw	90°–120°–180°	$:AB_4$	SF_4
	T-shaped	90°–180°	$:\overset{\bullet\bullet}{A}B_3$	ClF_3
	linear	180°	$:\overset{\bullet\bullet}{\underset{\bullet\bullet}{A}}B_2$	XeF_2

Chemical Equations

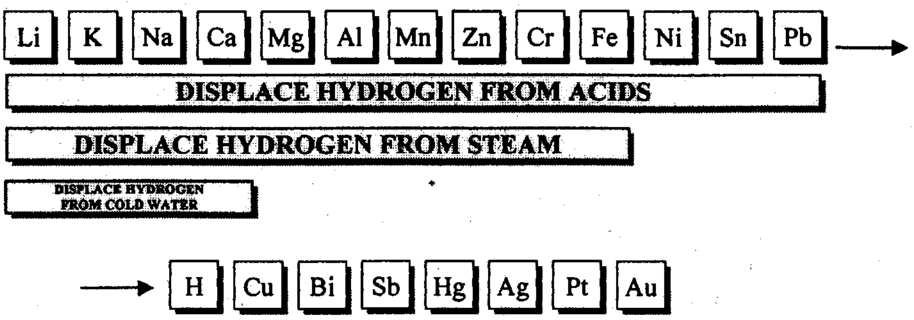
1. *Combination Reaction (Synthesis)* : $A + B \rightarrow AB$
   a. $2Mg + O_2 \rightarrow 2MgO$
   b. $2Na + \frac{1}{2}O_2 \rightarrow Na_2O$
   c. $S + O_2 \rightarrow SO_2$ (acidic oxide/acidic anhydride)
   d. $C + O_2 \rightarrow CO_2$
   e. non-metal oxide + water → acid
      i. $SO_2 + H_2O \rightarrow H_2SO_{3(aq)}$
      ii. $CO_2 + H_2O \rightarrow H_2CO_{3(aq)}$
   f. metal oxide + water → alkali/base
      i. $MgO + H_2O \rightarrow Mg(OH)_2$

2. *Decomposition* : $AB \rightarrow A + B$
   a. metal oxide $\xrightarrow[\Delta]{}$ metal + oxygen gas
      i. $HgO \xrightarrow[\Delta]{} Hg + \frac{1}{2}O_2$ (Joseph Priestley, 1774)
   b. metal carbonates $\xrightarrow[\Delta]{}$ metal oxide + CO_2
      i. $Na_2CO_3 \xrightarrow[\Delta]{} Na_2O + CO_2$
      ii. $CaCO_3 \xrightarrow[\Delta]{} CaO + CO_2$
   c. metal nitrates $\xrightarrow[\Delta]{}$ metal nitrites + O_2
      i. $NaNO_3 \xrightarrow[\Delta]{} NaNO_2 + \frac{1}{2}O_2$
   d. metal bicarbonates $\xrightarrow[\Delta]{}$ metal carbonate + H_2O + CO_2
      i. $2NaHCO_3 \xrightarrow[\Delta]{} Na_2CO_3 + H_2O + CO_2$
   e. metal oxyhalides $\xrightarrow[\Delta]{}$ metal halide + O_2
      i. $2KBrO_3 \xrightarrow[\Delta / MnO_2 / Fe_2O_3]{} 2KBr + 3O_2$

3. *Single Replacement* : $AB + C \rightarrow CB + A$
   a. Hydrogen Displacement Reactions
      i. $Na + H_2O_{(l)} \rightarrow NaOH + \frac{1}{2}H_{2(g)}$
      ii. $2Fe + 3H_2O_{(v)} \rightarrow Fe_2O_3 + 3H_{2(g)}$
      iii. $Zn + HCl_{(aq)} \rightarrow ZnCl_2 + H_{2(g)}$
   b. Halogen Displacement (Activity Series : $F_2 > Cl_2 > Br_2 > I_2$)
      i. $2KI + Cl_2 \rightarrow 2KCl + I_2$

4. *Double Decomposition (Metathesis)*
   a. Neutralization Reaction – reaction of an acid and a base forming salt and water
      i. $HCl + KOH \rightarrow KCl + H_2O$
   b. Precipitation Reaction – reaction which results in the formation of an insoluble product
      i. $Na_2CO_{3(aq)} + CaSO_{4(aq)} \rightarrow CaCO_{3(s)} + Na_2SO_{4(aq)}$

Activity Series of Metals
(arranged in decreasing activity)



Solubility Rules in Water at 25 °C

SOLUBLE COMPOUNDS	INSOLUBLE COMPOUNDS
All nitrates, bicarbonates, chlorates and compounds containing alkali metal ions and ammonium ion	All carbonates, phosphates, chromates and sulfides except that of alkali metal ions and ammonium ion
All halides except that of Ag^+, Hg_2^{2+} and Pb^{2+}	All hydroxides except that of alkali metal ions and Ba^{++}
All sulfates except that of Ag+, Ca^{++}, Sr^{++}, Ba^{++} and Pb^{++}	

Solutions

A *solution* is a homogeneous mixture consisting of solute and solvent.

Saturated Solution – solution containing the maximum amount of solute dissolved in a given solvent at a specific temperature

Solubility – the maximum amount of solute dissolved in a given solvent at a specific temperature

Methods of Expressing Concentrations of Solutions

Let A = solute and B = solvent

1. $$\%\ \text{wt/wt A} = \frac{\text{wt A}}{\text{wt A} + \text{wt B}} \times 100\% = \frac{\text{wt A}}{\text{wt solution}} \times 100\%$$
2. $$\%\ \text{wt/vol A} = \frac{\text{wt A (g)}}{\text{vol solution (mL)}} \times 100\%$$
3. $$\%\ \text{vol A} = \frac{\text{vol A}}{\text{vol A} + \text{vol B}} \times 100\% = \frac{\text{vol A}}{\text{vol solution}} \times 100\%$$
4. $$\text{Molarity (M)} = \frac{\text{mol A}}{\text{vol solution (L)}}$$
5. $$\text{molality (m)} = \frac{\text{mol A}}{\text{kg B}}$$
6. $$\text{Normality (N)} = \frac{\text{equiv A}}{\text{vol solution (L)}}$$ = M * f

Colligative Properties of Solutions of Non-Electrolytes

1. *Boiling Point Elevation (BPE)*

   $$BPE = T_{B,solution} - T_{B,solvent} = K_B m$$

   where m = molality
   K_B = ebullioscopic constant

2. *Freezing Point Depression (FPD)*

   $$FPD = T_{F,solvent} - T_{F,solution} = K_F m$$

   where K_F = cryoscopic constant

3. *Vapor Pressure Lowering (VPL)*

   $$VPL = P_{solvent} - P_{solution} = X_{solute} P_{solvent}$$

4. *Osmotic Pressure (π)*

   $$\pi = MRT$$

   where M = Molarity
   $R = 0.08205\ ^{L-atm}/_{K-mol}$

Cryoscopic and Ebullioscopic Constants of Common Solvents

SOLVENT	K_B	K_F	SOLVENT	K_B	K_F
Water	0.52	1.86	Camphor	-	37.7
Benzene	2.57	5.12	Ethanol	1.20	-
Acetic acid	3.07	3.90	Methanol	0.80	-

Chemical Equilibrium

Consider the hypothetical reaction: $aA_{(g)} + bB_{(g)} \leftrightarrow cC_{(g)} + dD_{(g)}$
For gases and aqueous solutions in the chemical reaction, K_C is used and concentrations are expressed in molarity. The equilibrium expression is written as... $K = \frac{[C]^c[D]^d}{[A]^a[B]^b}$

Since for gases, $M = \frac{P}{RT}$, the K_C expression will be...

$$K_C = \frac{\left[\frac{P_C}{RT}\right]^c\left[\frac{P_D}{RT}\right]^d}{\left[\frac{P_A}{RT}\right]^a\left[\frac{P_B}{RT}\right]^b} = \frac{[P_C]^c[P_D]^d}{[P_A]^a[P_B]^b}\cdot\frac{\left[\frac{1}{RT}\right]^c\left[\frac{1}{RT}\right]^d}{\left[\frac{1}{RT}\right]^a\left[\frac{1}{RT}\right]^b}$$

Combining terms with similar bases... $K_C = \frac{[P_C]^c[P_D]^d}{[P_A]^a[P_B]^b}\cdot\left[\frac{1}{RT}\right]^{c+d-a-b}$

Thus , we define... $K_P = \frac{[P_C]^c[P_D]^d}{[P_A]^a[P_B]^b}$

and

$$\Delta n\ gases = \Sigma n_{gas,\ product} - \Sigma n_{gas,\ reactant} = (c+d)-(a+b)$$

Therefore... $K_P = K_C(RT)^{\Delta n\ gases}$

Le Chatelier's Principle

A system in equilibrium when subjected to a stress will act in such a way to relieve the stress.

Consider the equilibrium reaction:

$$N_{2(g)} + 3\,H_{2(g)} \leftrightarrow 2\,NH_{3(g)} \qquad \Delta H = -45\text{ kJ/mol}$$

Effects of Changing the Concentration

Increasing (decreasing) the concentration of the **reactants** shifts the reaction forward (backward). Increasing (decreasing) the concentration of the **products** shifts the reaction backward (forward). In the given reaction, removing NH_3 in the reaction vessel shifts the reaction forward while adding some NH_3 shifts the reaction backward.

Effects of Changing the Pressure/Volume

Increasing the pressure (or similarly decreasing the volume) of a system in equilibrium shifts the reaction towards the formation of *less number* of gaseous molecules. On the other hand, decreasing the pressure (or similarly increasing the volume) of a system in equilibrium shifts the reaction towards the formation of *greater number* of gaseous molecules. In the reaction given above, increasing the pressure of the system will result in the formation of more ammonia.

Effects of Changing the Temperature

Increasing the temperature favors an endothermic reaction while decreasing the temperature favors an exothermic reaction. For the reaction above, increasing the temperature will favor the backward reaction being exothermic.

Effects of Adding the Catalyst

Adding a catalyst does not affect the equilibrium.

Solubility Product Constant (K_{SP})

A saturated solution of a sparingly soluble salt can be represented by the equation:

$$A_2B_{(s)} \rightleftarrows 2A^{+}_{(aq)} + B^{-2}_{(aq)}$$

The equilibrium constant expression for this reaction would be

$$K = \frac{[A^{+}_{(aq)}]^2[B^{-2}_{(aq)}]}{[A_2B_{(s)}]}$$

However, the concentration of the solid A_2B in the solution will be constant (the ratio of the number of moles of A_2B and the volume of the solid is constant). Thus,

$$(K)[A_2B_{(s)}] = [A^{+}_{(aq)}]^2[B^{-2}_{(aq)}] = K_{SP}$$

Solubility Product Constants (K_{SP}) at 25 °C

COMPOUND	K_{SP}	COMPOUND	K_{SP}
AgCl	1.82×10^{-10}	$Mg(OH)_2$	7.10×10^{-12}
AgBr	5.00×10^{-13}	$Ca(OH)_2$	6.50×10^{-6}
AgI	8.30×10^{-7}	$PbCl_2$	1.70×10^{-5}
$BaCO_3$	5.00×10^{-9}	PbI_2	7.90×10^{-9}
$Ba(IO_3)_2$	1.57×10^{-9}	Hg_2Cl_2	1.20×10^{-18}
$Al(OH)_3$	3.00×10^{-34}	Hg_2Br_2	5.60×10^{-23}
$CaCO_3$ (calcite)	4.50×10^{-9}	Hg_2I_2	4.70×10^{-29}

Ideal Gas Equation

$$PV = nRT$$

Values of R

$$8.314\frac{\text{m}^3-\text{Pa}}{\text{gmol}-\text{K}},\ 0.08314\frac{\text{m}^3-\text{bar}}{\text{gmol}-\text{K}},\ 0.08205\frac{\text{L}-\text{atm}}{\text{gmol}-\text{K}},$$

$$62.36\frac{\text{L}-\text{mm Hg}}{\text{gmol}-\text{K}},\ 1.987\frac{\text{cal}}{\text{gmol}-\text{K}}\ \ 10.73\frac{\text{ft}^3-\text{psia}}{\text{lbmol}-{}^\circ\text{R}}$$

Derivations of the Ideal Gas Equation of State

$$MW = \frac{\rho RT}{P}$$

where: MW = molecular weight of the gas
ρ = density of the gas

Other Gas Laws

1. At constant temperature (isothermal)... $PV = k$

   $P_1V_1 = P_2V_2$ **BOYLE'S LAW**

2. At constant pressure (isobaric)... $V = kT$

   $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ **CHARLES' LAW**

3. At constant volume (isochoric)... $P = kT$

   $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ **GAY-LUSSAC'S LAW**
   AMONTON'S LAW

Standard Temperature and Pressure (STP)

SI	$T = 273.15$ K	**AES**	$T = 491.67$ R
	$V_m = 22.4$ L/mol		$V_m = 359$ ft^3/lbmol
	$P = 1$ atm		$P = 1$ atm

SCM (standard cubic meter) or **SCF** (standard cubic feet) is used to denote volume at STP.

Ideal Gas Mixtures

Dalton's Law of Partial Pressure

The total pressure of an ideal gas mixture is equal to the sum of the partial pressures of the individual gases in the mixture at constant temperature and volume.

For a mixture of three ideal gases with n_A, n_B and n_C number of moles at temperature, T and occupying a volume, V...

$$P_T = P_A + P_B + P_C \qquad P_A = \frac{n_A}{n_A + n_B + n_C}P_T = \frac{n_A}{n_T}P_T = y_A P_T$$

Therefore... $\frac{P_A}{P_T} = y_A$ at constant temperature and volume. Similarly... $\frac{V_A}{V_T} = y_A$ at constant temperature and pressure (Amagat's Law of Partial Volume)

Nuclear Chemistry

Types of Emitted Particle/Radiation

PARTICLE	CHARGE	SYMBOL
beta particle or electron	- 1	$^{0}_{-1}\beta$ or $^{0}_{-1}e$
positron	+1	$^{0}_{+1}\beta$ or $^{0}_{+1}e$
proton or a hydrogen nucleus	+1	$^{1}_{+1}p$ or $^{1}_{+1}H$
neutron	0	$^{1}_{0}n$
gamma ray	0	$^{0}_{0}\gamma$
alpha particle or helium nucleus	+2	$^{4}_{+2}\alpha$ or $^{4}_{+2}He$

Ways of Expressing Quantity of Radiation

1. *Activity* – number of nuclear disintegrations per second
    a. SI Unit : Bq
    b. 3.7×10^{10} Bq (becquerel) = 1 Ci (curie)
    c. Curie is the rate of disintegration of 1 gram of Ra
2. *Radiation absorbed dose* (rd)
    a. SI Unit : Gy (gray)
    b. 1 Gy = 1 J/kg absorbing material
    c. 1 rd = 10^{-5} J/gram of tissue

Types of Radioactive Decay

1. Alpha Particle Decay : $^{212}_{84}Po \rightarrow ^{208}_{82}Pb + ^{4}_{2}\alpha$
2. Beta Particle Decay : $^{137}_{55}Cs \rightarrow ^{137}_{56}Ba + ^{0}_{-1}\beta$
3. Gamma Ray Emission: $^{211}_{83}Bi \rightarrow ^{207}_{81}Tl + ^{4}_{2}\alpha + ^{0}_{0}\gamma$
4. Positron Emission : $^{54}_{27}Co \rightarrow ^{54}_{26}Fe + ^{0}_{1}\beta$
5. Neutron Emission : $^{87}_{36}Kr \rightarrow ^{86}_{36}Kr + ^{1}_{0}n$
6. Electron Capture : $^{50}_{23}V + ^{0}_{-1}e \rightarrow ^{50}_{22}Ti + x - ray$

REVIEW QUESTIONS AND PROBLEMS

1. Arrange the proton, neutron and electron in increasing mass.
   a. proton < electron < neutron
   b. electron < proton < neutron
   c. electron < neutron < proton
   d. neutron < electron < proton

2. In Rutherford's experiment, which of the following is true?
   a. The proton is evenly distributed in the nucleus of an atom.
   b. The atom is almost an empty space.
   c. The nucleus contains proton, neutron and electron.
   d. All of the above

3. He was able to determine the mass to charge ratio of an electron.
   a. Joseph John Thomson
   b. Wilhelm Konrad Rontgen
   c. Henri Antoine Becquerel
   d. Ernest Rutherford

4. The sum of the number of protons, neutrons and electrons of a zinc ion, Zn^{+2} is
   a. 94
   b. 92
   c. 95
   d. 93

5. Atoms with the same atomic number but different mass number is called
   a. isobars
   b. isotopes
   c. isotherms
   d. isoelectronic

6. The atomic weight of chlorine is 35.45 and its naturally occurring isotopes are Cl–35 and Cl–37. What is the percentage abundance of Cl–35?
   a. 95.8%
   b. 98.7%
   c. 77.5%
   d. 75.0%

7. The region in space where an electron is most likely to be found is called
   a. orbital
   b. energy level
   c. shell
   d. nucleus

8. The quantum number that has an allowable value of 0, 1, 2, etc. is the
   a. Magnetic Quantum Number
   b. Spin Quantum Number
   c. Angular Momentum Quantum Number
   d. Principal Quantum Number

9. It states that no two atoms will have the same set of quantum numbers.
   a. Heisenberg Uncertainty Principle
   b. Pauli's Exclusion Principle
   c. Aufau Building Up Principle
   d. Hund's Rule of Multiplicity

10. The quantum number that tells the shape of orbitals.
    a. Principal Quantum Number
    b. Magnetic Quantum Number
    c. Angular Momentum Quantum Number
    d. Spin Quantum Number

11. What is the maximum number of electrons in an atom that can have the quantum number: $n = 2$, $m_s = -½$?
    a. 8
    b. 6
    c. 1
    d. 4

12. Which of the following properties do not depend on the electronic configuration of the atoms?
    a. physical
    b. chemical
    c. nuclear
    d. none of the above

13. Which of the following sets of quantum numbers is <u>incorrect</u>?
   a. $n=1, l=0, m_l=-1, m_s=-\frac{1}{2}$
   b. $n=1, l=0, m_l=0, m_s=+\frac{1}{2}$
   c. $n=3, l=1, m_l=0, m_s=-\frac{1}{2}$
   d. $n=4, l=2, m_l=-1, m_s=+\frac{1}{2}$

14. In what group of the periodic table is the element with the following electron configuration? $[Ar]\ 4s^2\ 3d^{10}\ 4p^3$
   a. 1A b. 2A c. 3A d. 5A

15. Which of the following pairs are isoelectronic?
   a. Mn^{+2} and Ar b. Zn^{+2} and Cu^{+2} c. S^{-2} and Cl^{-1} d. Na^+ and Cl^{-1}

16. The change in energy when an electron is accepted by a gaseous atom to form an anion.
   a. Electronegativity
   b. Electron Affinity
   c. Ionization Energy
   d. Activation Energy

17. Which of the following halogens is the most electronegative?
   a. F b. Cl c. Br d. I

18. Among the members of the Chalcogen Family, which is the most non-metallic?
   a. Sulfur b. Selenium c. Tellurium d. Oxygen

19. Arrange the following in increasing ionization energy:

C	Na	Mg	B	N
1	2	3	4	5

   a. 41532 b. 51432 c. 23415 d. 23514

20. The theory that states that bonding is caused by overlapping of two atomic orbitals.
   a. Valence Bond Theory
   b. Molecular Orbital Theory
   c. Vital Force Theory
   d. Valence Shell Electron-Pair Repulsion

21. It pertains to single bond, double bond, triple bond and those intermediate between single and double bonds, etc.
   a. Bond Order b. Bond Length c. Bond Strength d. Bond Degree

22. Which of the following bonds is the strongest?
   a. Covalent Bond b. Hydrogen Bond c. Ionic Bond d. Dative Bond

23. Which of the following molecules/compounds is formed by covalent bonds?
   a. LiF b. MgO c. ZnS d. NO_2

24. A compound whose molecules are <u>not</u> associated by hydrogen bonding is
   a. CH_3CH_2OH b. $(CH_3)_2NH$ c. HCOOH d. $(CH_3)_3COCH_3$

25. Which of the following does not assume the behavior of ideal gases?
   a. Boyle's Law
   b. Van der Waals Equation
   c. Graham's Law of Diffusion
   d. Dalton's Law of Partial Pressure

26. What is the volume of 18.0 grams of pure water at 4°C and 1 atm?
   a. 18 mL b. 22.74 L c. 22.74 mL d. 18 L

27. How many grams of $KClO_3$ are needed to prepare 1.8 L of O_2 gas that is collected over H_2O at 22°C and 760 torr? Vapor pressure of water at 22°C is 19.8 torr
    a. 5.1 b. 5.4 c. 5.9 d. 5.7

28. A sample of pure zinc metal reacts completely with an excess of hydrochloric acid. The hydrogen gas produced is collected over water at 25°C and 1 atm. If the metal weighs 253.02 mg, how much hydrogen gas is collected?
    a. 87.1 mL b. 78.0 mL c. 97.7 mL d. 94.7 mL

29. A certain gas weighs 2.478 grams and occupies a volume of 712.5 mL at 25°C and 1.2 atm. What is the molecular formula of the gas?
    a. H_2 b. Cl_2 c. F_2 d. N_2

30. Ammonia decomposes completely to hydrogen and nitrogen gas. If the total pressure of the reaction vessel at the end of the reaction is 250 mmHg, what is the partial pressure of nitrogen gas?
    a. 120.5 mmHg b. 187.5 mmHg c. 62.5 mmHg d. 125.0 mmHg

31. A quantity of 280.7 grams of a hydrate, Na_2CO_3 x H_2O was heated in an oven to drive off water. If the steam produced in a 5L vessel at 110°C exerted a pressure of 39.6 atm, what is the formula of the hydrate?
    a. $Na_2CO_3 \cdot H_2O$ b. $Na_2CO_3 \cdot 10H_2O$ c. $Na_2CO_3 \cdot 2H_2O$ d. $Na_2CO_3 \cdot 4H_2O$

32. A 10-L vessel containing 8.00 grams of O_2 is connected by means of a valve to a 5-L vessel containing 7.00 grams of N_2. When the valve was opened and the gases are allowed to mix, what will be the total pressure of the gas mixture at 25°C assuming the temperature was kept constant?
    a. 0.815 atm b. 0.971 atm c. 0.654 atm d. 0.711 atm

33. A common laboratory preparation of oxygen gas is the thermal decomposition of potassium chlorate over MnO_2 catalyst. Assuming complete decomposition, calculate the number of grams of oxygen gas that can be obtained from 45.7 grams of potassium chlorate.
    a. 23.87 g b. 19.27 g c. 24.91 g d. 17.90 g

34. Type of equilibrium that exists between similar phases is called
    a. physical equilibria c. chemical equilibria
    b. homogeneous equilibria d. heterogeneous equilibria

35. Which of the following equilibrium system will have its K_P equal to its K_C?
    a. $2\,NO_{(g)} + Br_{2(g)} \leftrightarrow 2NOBr_{(g)}$ c. $H_{2(g)} + I_{2(g)} \leftrightarrow 2HI_{(g)}$
    b. $CO_{(g)} + Cl_{2(g)} \leftrightarrow COCl_{2(g)}$ d. $N_{2(g)} + 3H_{2(g)} \leftrightarrow 2NH_{3(g)}$

36. Consider the following reaction at 1600°C: $Br_{2(g)} \leftrightarrow 2Br_{(g)}$.
    When 1.05 moles of Br_2 are placed in a 2 L flask, 2.50% of Br_2 undergoes dissociation. Calculate the K_P for the reaction.
    a. 0.20689 b. 0.001346 c. 3.7216 d. 0.0953

37. $NaClO_2$ is
    a. sodium chloride
    b. sodium hypochlorite
    c. sodium chlorite
    d. sodium chlorate

38. oxalic acid + sodium hydroxide → ____________ + H_2O
    a. Na_2CO_3
    b. $NaC_2H_3O_2$
    c. $NaCHO$
    d. $Na_2C_2O_4$

39. Which of the following is an acidic oxide?
    a. MgO
    b. SO_2
    c. Na_2O
    d. CaO

40. Consider the reaction: $PCl_{5(g)} \leftrightarrow PCl_{3(g)} + Cl_{2(g)}$ $\Delta H^\theta_{rxn} = 87.9$ kJ/mol
    Which of the following will result in the increase in concentration of Cl_2 gas?
    a. add PCl_3
    b. cool the mixture
    c. add PCl_5
    d. increase the pressure

41. Which of the following substances in aqueous solution of the same concentration will have the highest boiling point elevation?
    a. KCl
    b. Na_2SO_4
    c. CH_3COOH
    d. $NaCl$

42. The vapor pressure of water at 25°C is 23.756 torr. A solution consisting of 18.913 grams of a non-volatile substance in 36 grams of water has a vapor pressure of 20.234 torr. What is the molecular weight of the solute?
    a. 62
    b. 56
    c. 48
    d. 39

43. What is the freezing point of a 30% wt urea, $(NH_2)_2CO$ solution in water?
    a. −13.29°C
    b. −16.45°C
    c. −9.18°C
    d. −11.77°C

44. The osmotic pressure of a dilute aqueous ethyl alcohol solution at 25°C is 38 mmHg. Calculate the boiling point elevation of this solution.
    a. 0.0038°C
    b. 0.0025°C
    c. 0.0041°C
    d. 0.0011°C

45. Which of the following is a positron?
    a. ${}^{4}_{2}\alpha$
    b. ${}^{0}_{1}e$
    c. ${}^{0}_{-1}e$
    d. ${}^{0}_{0}\gamma$

46. Ra-226 decays by alpha emission. What is its decay product?
    a. ${}^{228}_{87}Fr$
    b. ${}^{222}_{86}Rn$
    c. ${}^{230}_{90}Th$
    d. ${}^{226}_{89}Ac$

47. The half-life of ${}^{90}Sr$ is 29 years. What fraction of the atoms in a sample of ${}^{90}Sr$ would remain 100 years later?
    a. 0.29
    b. 0.14
    c. 0.18
    d. 0.09

48. How old is a bottle of wine if the tritium ${}^{3}H$ content is 45% that of a new wine? The half-life of tritium is 12.5 years.
    a. 13.4 years
    b. 12.8 years
    c. 14.4 years
    d. 18.2 years

49. If ${}^{238}_{92}U$ undergoes decay and found to produce ${}^{234}_{90}Bi$, what other particle was emitted?
    a. alpha
    b. gamma
    c. positron
    d. electron

50. It is equivalent to the rate of disintegration of 1 gram of radium
    a. becquerels
    b. curie
    c. gray
    d. rem

B. ORGANIC CHEMISTRY

Organic Chemistry – branch of chemistry that deals with compounds of carbon

History of Organic Chemistry

Vital Force Theory

Organic compounds originated from living materials, either plants or animals. Such materials possess vital force and compounds that are extremely difficult to synthesize in the laboratory.

Friedrich Wohler

He synthesized urea in the laboratory from the inorganic compound, *ammonium cyanate*. Urea is a component of urine, and thereby ending the concept of vitalism.

$$NH_4CNO \xrightarrow[\Delta]{} (NH_2)_2CO$$

Structural Theory

1. Atoms in an organic compound have fixed number of bonds. This combining ability is termed as *valence*.
2. Carbon can form bonds with another carbon atom accounting for a high percentage of carbon in most organic compounds. This ability of carbon is called *catenation*.

Chemical Bonding

Dualism (Berzelius)

Atoms are being held by electrical attraction between species of opposite charge. Atoms form bonds to completely fill their valence shells. There are two ways by which an atom bonds with another atom:

1. by gaining or losing electrons forming *ionic bond*
2. sharing of electrons with another atom forming *covalent bond*

Ionic Bond

Atoms with high ionization energy tend to lose electrons easily while atoms with low electron affinity tend to gain electrons easily.

Covalent Bond

Atoms forming covalent bonds share electrons to acquire the configuration of the noble gases (octet rule). Hydrogen acquires the electron configuration of the noble gas helium.

Formal Charge = group number – ½ shared e^- – number of unshared e^-

Writing Lewis Structures

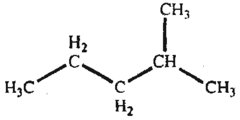
1. Determine the total number of valence electrons of all atoms (also equal to their group number) = ***n***
2. Determine the total number of electrons for each atom that will satisfy the octet rule = ***m***
3. The number of bonding electrons is ***m – n***
4. The number of electron – pair bonds is ½ (***m–n***)
5. Assign the correct formal charge for each atom
6. The following atoms are neutral:
   a. Carbon with four covalent bonds
   b. Oxygen atom with two covalent bonds and two lone pairs
   c. Nitrogen atom with three covalent bonds and an electron pair
   d. Halogens with one covalent bond and three lone pairs

Resonance Theory

A molecule or an ion represented in two or more Lewis structures that differ only in the positions of electrons exhibit the property of resonance. These structures are called *resonating structures* or *resonating contributors.*

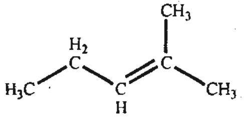
Classification of Organic Compounds

1. *Hydrocarbons* – compounds containing carbon and hydrogen
    a. Aliphatic – compounds whose carbon atoms are arranged in chains whether straight or branched
        i. *Alkanes* (C_nH_{2n+2}) – contain single bonds



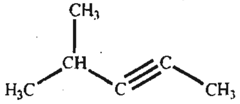
2-methylpentane

        ii. *Alkenes* (C_nH_{2n}) – contain double bonds



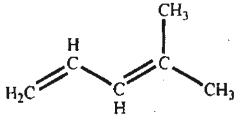
2-methyl-2-pentene

        iii. *Alkynes* (C_nH_{2n-2}) – contain triple bonds



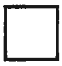
4-methyl-2-pentyne

        iv. *Alkadienes* (C_nH_{2n-2}) – contain two double bonds

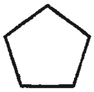


4-methyl-1,3-pentadiene

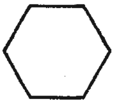
    b. Alicyclic – compounds containing carbon atoms in a ring system
        i. *Cycloalkanes* (C_nH_{2n}) – alkanes arranged in the form of a closed chain



cyclobutane

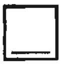


cyclopentane



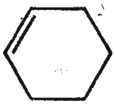
cyclohexane

        ii. *Cycloalkenes* (C_nH_{2n-2}) – non-conjugated alkenes in a ring system



cyclobutene

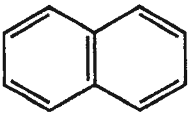
cyclopentene

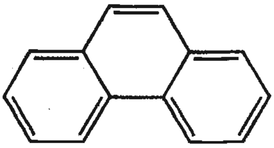


cyclohexene

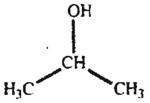
c. **Aromatic** – compounds containing carbon atoms with conjugated double bonds in a ring system


benzene

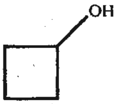

naphthalene


phenanthrene

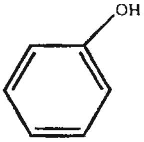
2. *Hydrocarbon Derivatives (classified according to heteroatoms present)*
   a. Derivatives containing Oxygen
      i. *Alcohols* (R–OH) *and Phenols* (Ar–OH) – hydrocarbons with one or more hydrogen atom replaced by –OH group



2-propanol

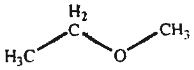


cyclobutanol

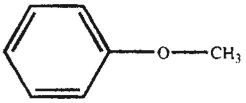


phenol

      ii. *Ethers* (ROR) – hydrocarbon derivatives with two hydrocarbon groups attached to oxygen

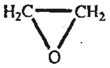


ethyl methyl ether



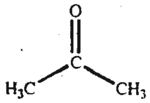
methyl phenyl ether

Epoxides – cyclic ethers in which the oxygen is included in a three-membered ring

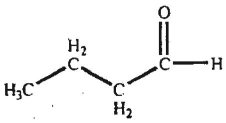


ethylene oxide

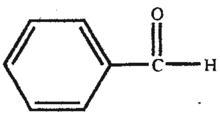
      iii. *Aldehydes* (RCHO) *and Ketones* (RCOR) – hydrocarbons with one or two alkyl groups attached to C=O



propanone

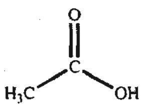


butanal

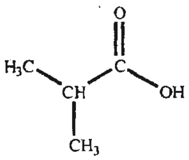


benzaldehyde

      iv. *Carboxylic Acids* (RCOOH) – hydrocarbons with the carboxyl group, –COOH

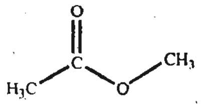


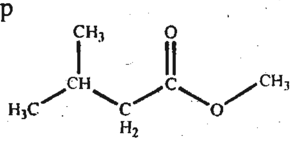
ethanoic acid



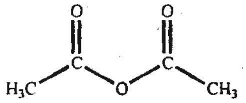
2-methylpropanoic acid

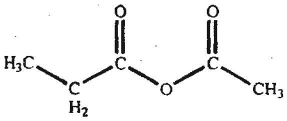
v. *Esters* (RCOOR) – carboxylic acid derivatives with the hydrogen atom replaced by an alkyl group


methyl ethanoate


methyl-3-methylbutanoate

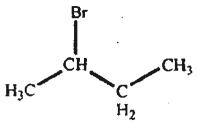
vi. *Acid Anhydride* – carboxylic acid derivatives with the hydrogen atom replaced by RC=O

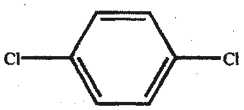

ethanoic anhydride

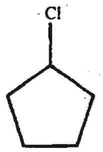

ethanoic propanoic anhydride

b. Derivatives containing Halogens

i. *Alkyl Halides and Aryl Halides* – hydrocarbons with the hydrogen atom replaced by one or more halogens

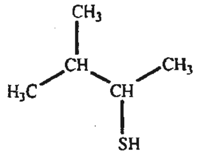

2-bromobutane

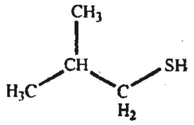

p-dicholorobenzene


chlorocyclopentane

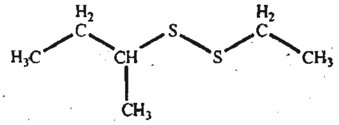
c. Derivatives containing Sulfur

i. *Thiols* – hydrocarbon derivatives with hydrogen atom replaced with –SH


3-methyl-2-butanethiol

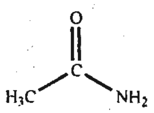

2-methyl-1-propanethiol

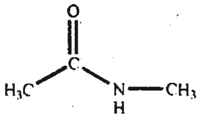
ii. *Disulfides* – hydrocarbon derivatives with general formula R–S–S–R

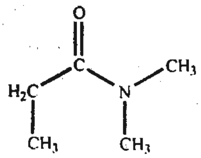

2-ethyldisulfanyl-butane

d. Derivatives containing Nitrogen

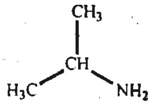
i. *Amides* – carboxylic acid derivatives with hydrogen atom replaced with $-NH_2$, –NHR', –NR'R"

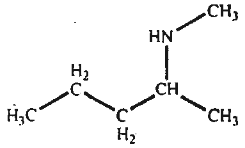

ethanamide


N-methylethanamide


N,N-dimethylpropanamide

ii. *Amine* – organic derivative of NH_3


2-aminopropane


2-*N*-methylaminopentane

ALKANES

- General Formula: C_nH_{2n+2}
- also called *paraffins*
- contains sp^3 hybridized carbon

Source of Alkanes

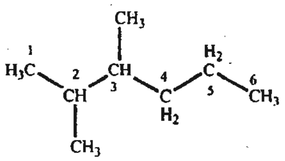
- obtained from fractional distillation of petroleum

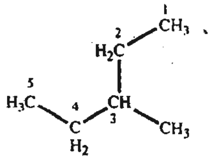
Physical Properties of Alkanes

1. Physical State at Room Temperature
   $C_1 - C_4$ gases
   $C_5 - C_{17}$ liquids
   $C_{18} - C_n$ solids
2. Solubility
   – practically insoluble in water due to non-polar character and inability to form hydrogen bonds
   – soluble in benzene, chloroform and carbon tetrachloride
3. Boiling Point
   – increases as length of carbon chain increases
   – decreases due to branching

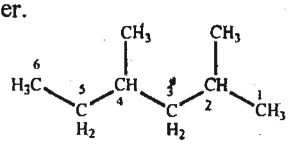
Nomenclature of Alkanes

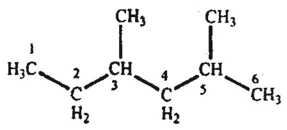
1. Choose the longest continuous carbon chain and the parent name is named according to the number of carbon present.


hexane

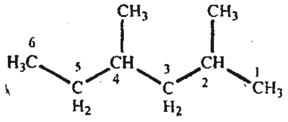

pentane

2. Number the chain in such a way that the substituents present are assigned with the lowest number.

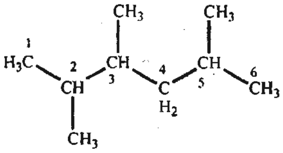

correct numbering


incorrect numbering

3. For identical substituents present more than once, the carbon numbers for which the substituents are attached and the prefixes *di*, *tri*, *tetra*, etc. are written before the name of the substituents.

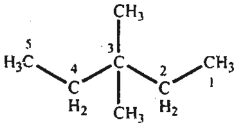


2,4 – dimethylhexane

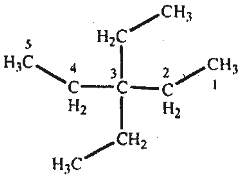


2,3,5 - trimethylhexane

4. For two identical substituents, the number is used twice and the prefix *di* is attached before the name of the substituent.

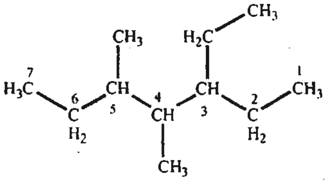


3,3 – dimethylpentane



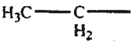
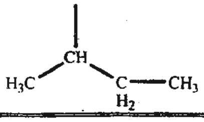
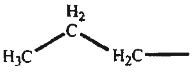
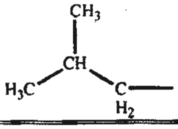
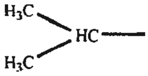
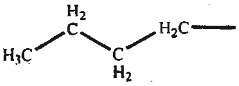
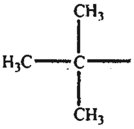
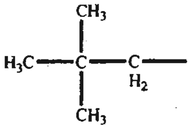
3,3 - diethylpentane

5. For two or more different alkyl substituents, names are written in alphabetical order giving no consideration on the prefixes.



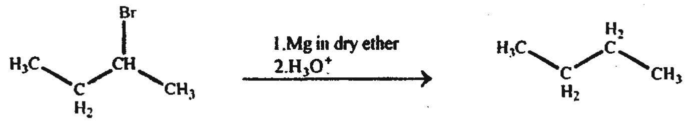
2 – ethyl – 3,4 – dimethylheptane

Common Alkyl Substituents

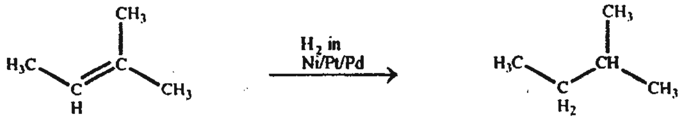
NAME	STRUCTURE	NAME	STRUCTURE
Ethyl		Sec-Butyl	
Propyl		Isobutyl	
Isopropyl		Butyl	
Tert-Butyl		Neopentyl	

Preparation of Alkanes

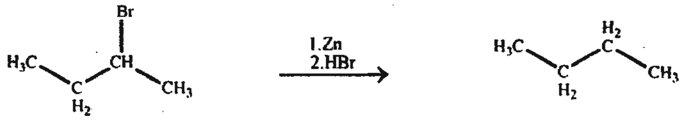
1. Grignard Synthesis using Alkyl Halide



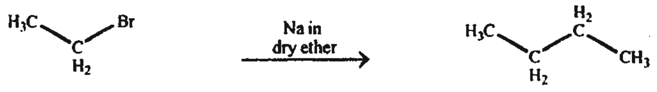
2. Hydrogenation of Alkene



3. Reduction of Alkyl Halide

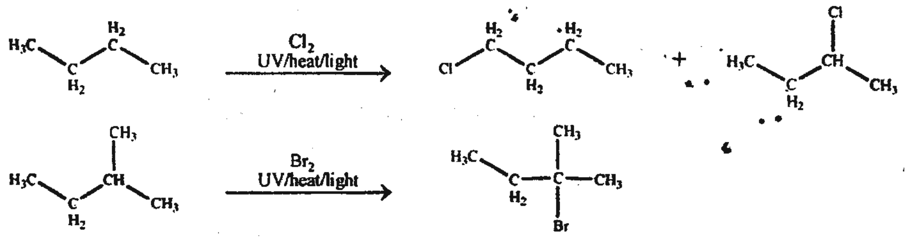


4. Wurtz Synthesis (Coupling Reaction)



Reactions of Alkanes

1. Halogenation



2. Combustion

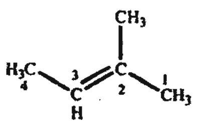
$C_nH_{2n+2} + {}^{(3n+1)}/_{2}\, O_2 \rightarrow nCO_2 + (n+1)\, H_2O$

ALKENES

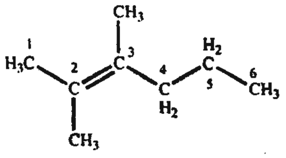
- General Formula: C_nH_{2n}
- also called *olefins*
- contains sp^2 hybridized carbon

Nomenclature of Alkenes

1. Select the longest parent carbon chain containing the double bond. The parent carbon chain is named like alkanes but the ending used is "ene".

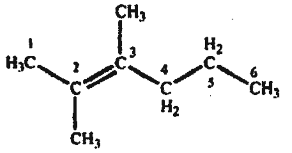


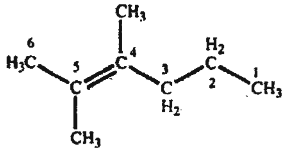
butene



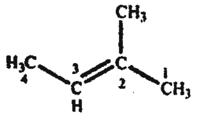
hexene

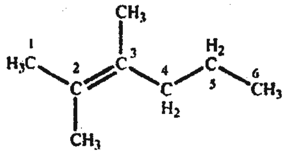
2. Lowest number is assigned for the carbon bearing the double bond.


correct numbering


incorrect numbering

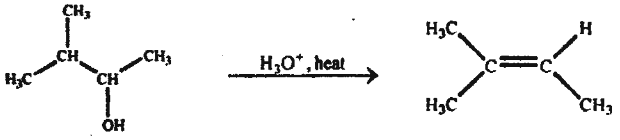
3. Substituents are named and numbered just the same with alkanes.


2 – methyl – 2 – butene

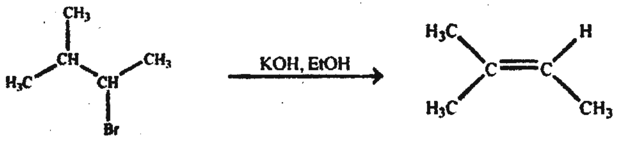

2,3 – dimethyl – 2 – hexane

Preparation of Alkenes

1. Dehydration of Alcohol

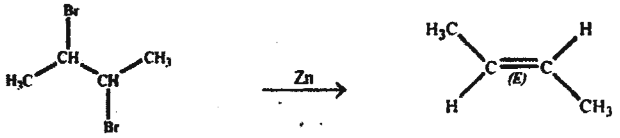


2. Dehydrogenation of Alkyl Halides



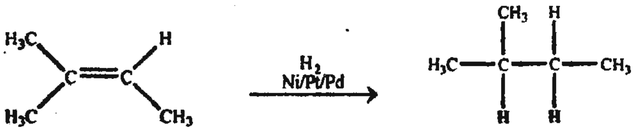
Saitsev's Rule – the alkene formed is the one that is more alkyl substituted

3. Debromination of Dibromides

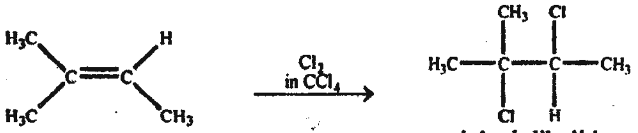


Reactions of Alkenes

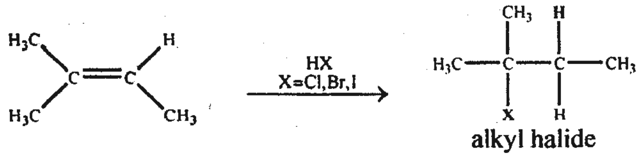
1. Hydrogenation


alkane

2. Halogenation

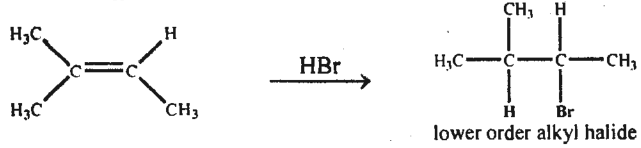

vicinal dihalide

3. Addition of HX

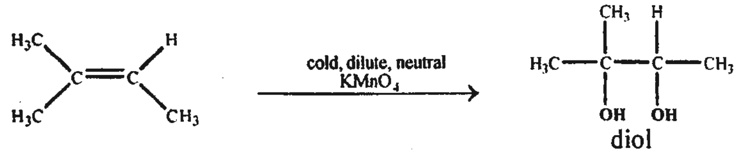


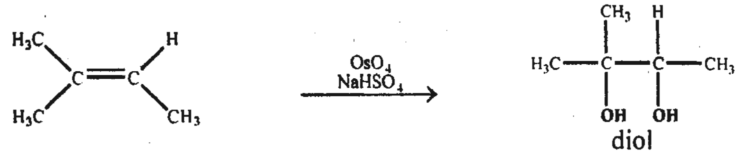
Markovnikoff's Rule, "The halogen attaches to the carbon that is more alkyl substituted thus producing a higher order alkyl halide."

Anti-Markovnikoff's Addition of HBr in the presence of Organic Peroxides

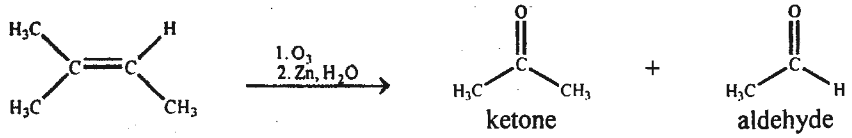


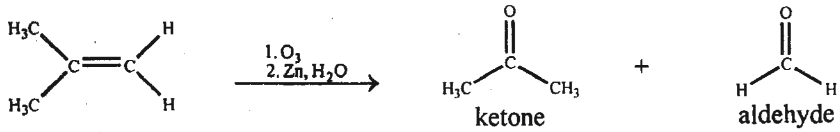
4. Hydroxylation



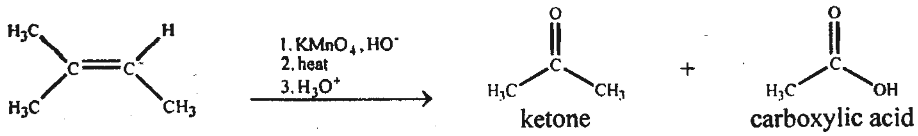


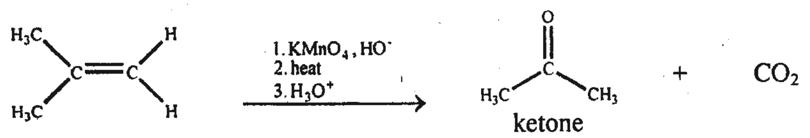
5. Ozonolysis



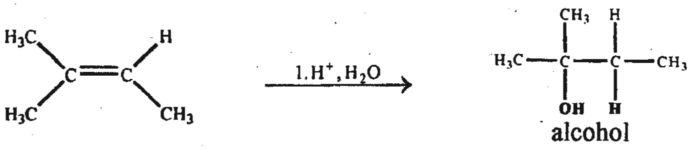


6. Oxidation

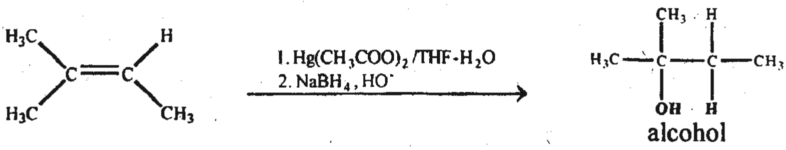




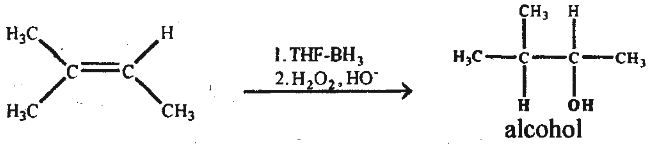
7. Acid–Catalyzed Hydration



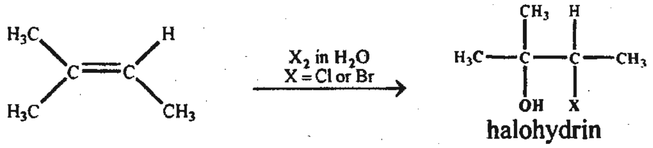
8. Oxymercuration–Demercuration



9. Hydroboration–Oxidation



10. Halohydrin Formation



Water attaches to carbon with more alkyl substituent

ALKYNES

- General Formula: C_nH_{2n-2}
- also called *acetylenes*
- contains sp hybridized carbon

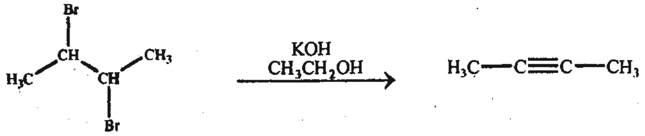
Preparation of Alkynes

1. Reaction of Sodium Acetylide with Alkyl Halides (Alkylation)

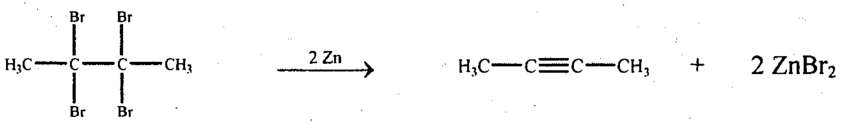
$$H_3C—C\equiv CH \xrightarrow{NaNH_2} H_3C—C\equiv \overset{-}{C}\ \overset{+}{Na} + NH_3$$

$$H_3C—C\equiv \overset{-}{C}\ \overset{+}{Na} \xrightarrow{CH_3Br} H_3C—C\equiv C—CH_3 + NaBr$$

2. Dehydrohalogenation of Vicinal Dihalides

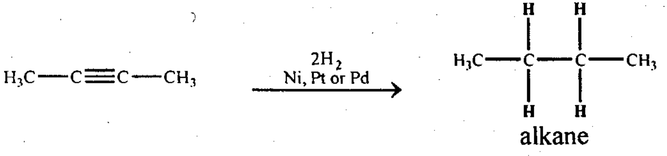


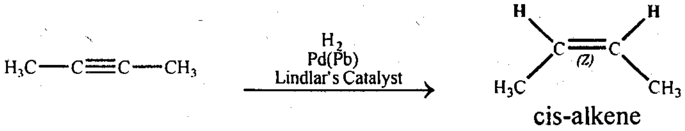
3. Dehalogenation of Tetrahalides

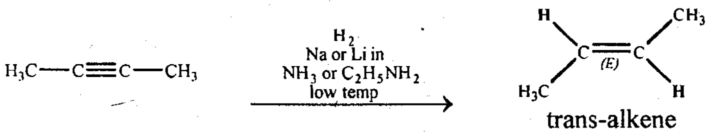


Reactions of Alkynes

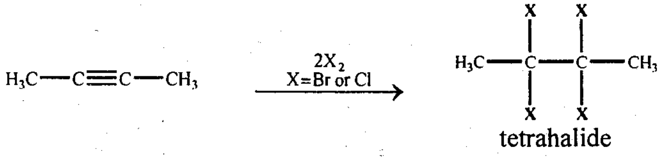
1. Hydrogenation



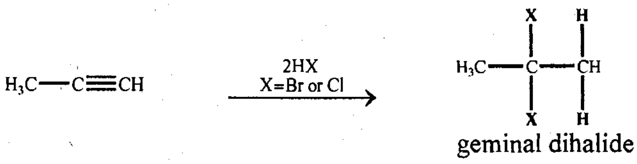




2. Halogenation

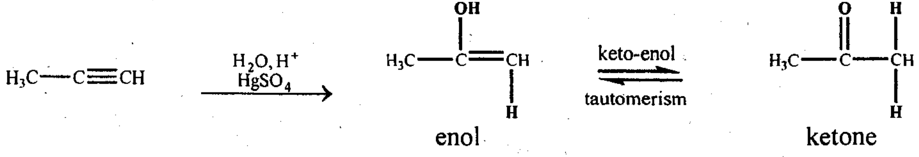


3. Addition of HX

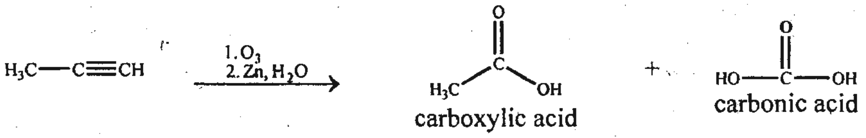


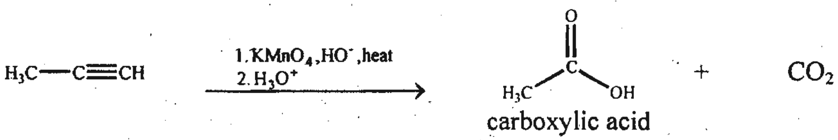
Follows Markovnikoff's Rule

4. Hydration



5. Oxidation





AROMATIC COMPOUNDS

- compounds containing benzene ring and behaves chemically like benzene
- compounds that are planar, cyclic and follows *Huckel's Rule*

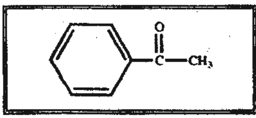
Huckel's Rule

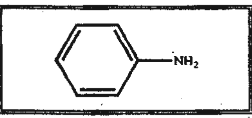
$4n + 2 = \pi$ electrons, where n must be a whole number

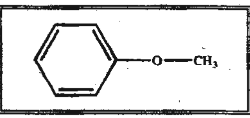
Nomenclature of Aromatic Compounds

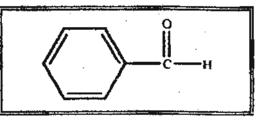
Monosubstituted Benzene

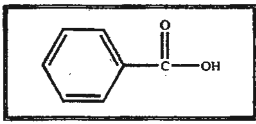
1. Name the substituent followed by the name "benzene".
2. IUPAC recognizes common name of monosubstituted benzene as follows:

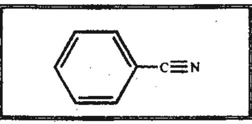

Acetophenone

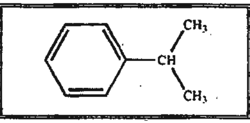

Aniline

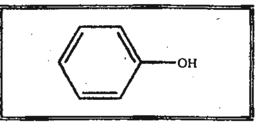

Anisole


Benzaldehyde

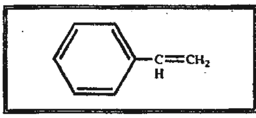

Benzoic Acid

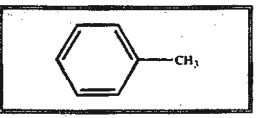

Benzonitrile


Cumene


Phenol

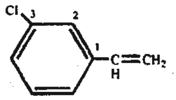
Carbolic Acid

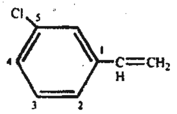

Styrene


Toluene

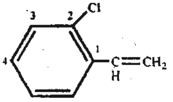
Disubstituted Benzene

3. The ring is numbered to give the lowest number for the substituents present.

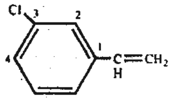

correctly numbered


incorrectly numbered

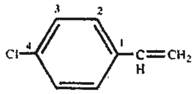
4. The prefixes *ortho-*, *meta-* and *para-* are also used to denote *1,2*, *1,3* and *1,4* positions of the substituents, respectively. If common names are to be used as parent name, the second substituent is numbered such that number 1 is assigned to the carbon bearing the substituent of the parent compound.



o-chlorostyrene

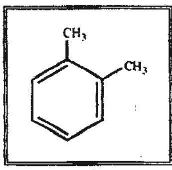
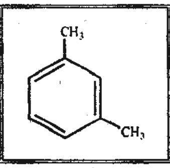
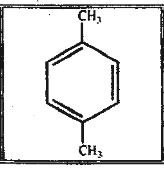
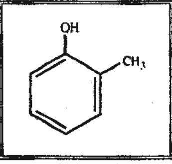
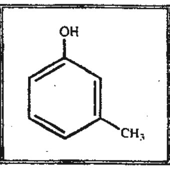
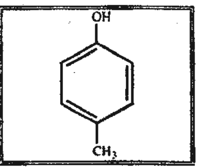
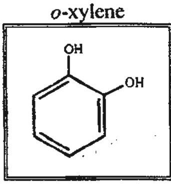
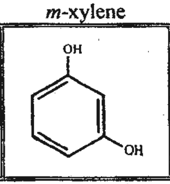
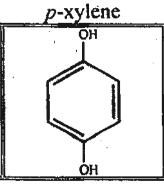
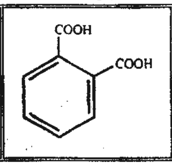
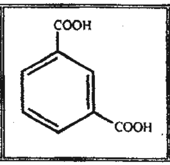
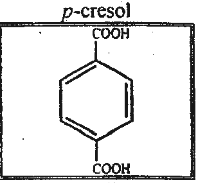


m-chlorostyrene



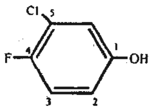
p-chlorostyrene

5. Disubstituted benzenes with common names are given as follows:

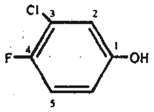
					
o-xylene	*m*-xylene	*p*-xylene	*o*-cresol	*m*-cresol	*p*-cresol
					
pyrocathecol	resorcinol	hydroquinone	phthalic acid	isophthalic acid	terephthalic acid

Polysubstituted Benzene

6. The ring is numbered to give the lowest number for the substituents present. If a parent compound is present, number 1 is assigned to the carbon to which the functional group of the parent compound is attached.



incorrectly numbered
5-chloro-4-fluorophenol



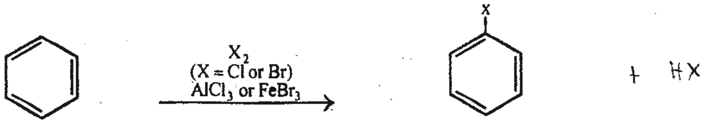
correctly numbered
3-chloro-4-fluorophenol

Source and Properties of Benzene

- obtained from catalytic dehydrogenation of cyclohexane and from coal tars
- stabilized by delocalization of π electrons
- all C–H bonds are equivalent
- does not decolorize $KMnO_4$
- H_2 does not add even in the presence of a metal catalyst
- undergoes substitution reaction

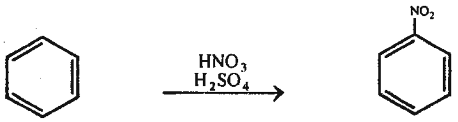
Reactions of Benzene

1. Halogenation (Bromination or Chlorination)



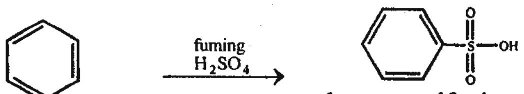
halobenzene

2. Nitration



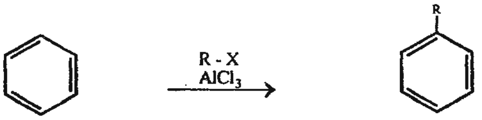
nitrobenzene

3. Sulfonation



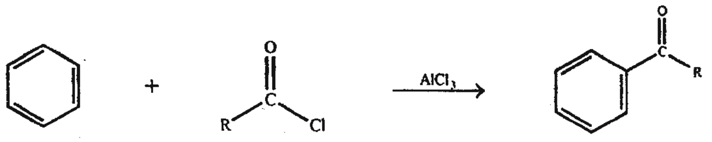
benzenesulfonic acid

4. Friedel-Crafts Alkylation



alkylbenzene

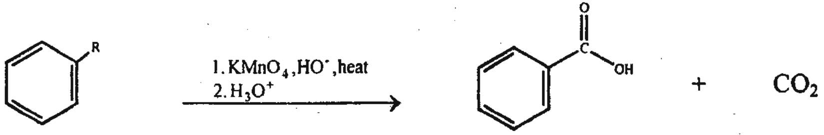
5. Friedel-Crafts Acylation



aromatic ketone

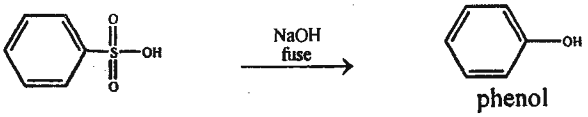
Reactions of Monosubstituted Benzenes

6. Oxidation of Alkylbenzenes



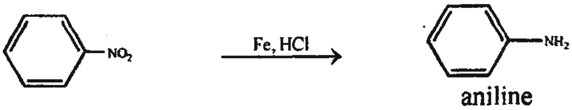
benzoic acid

7. Conversion of Benzenesulfonic Acid



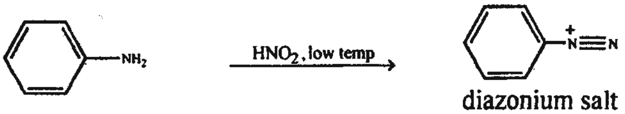
phenol

8. Reduction of Nitrobenzene



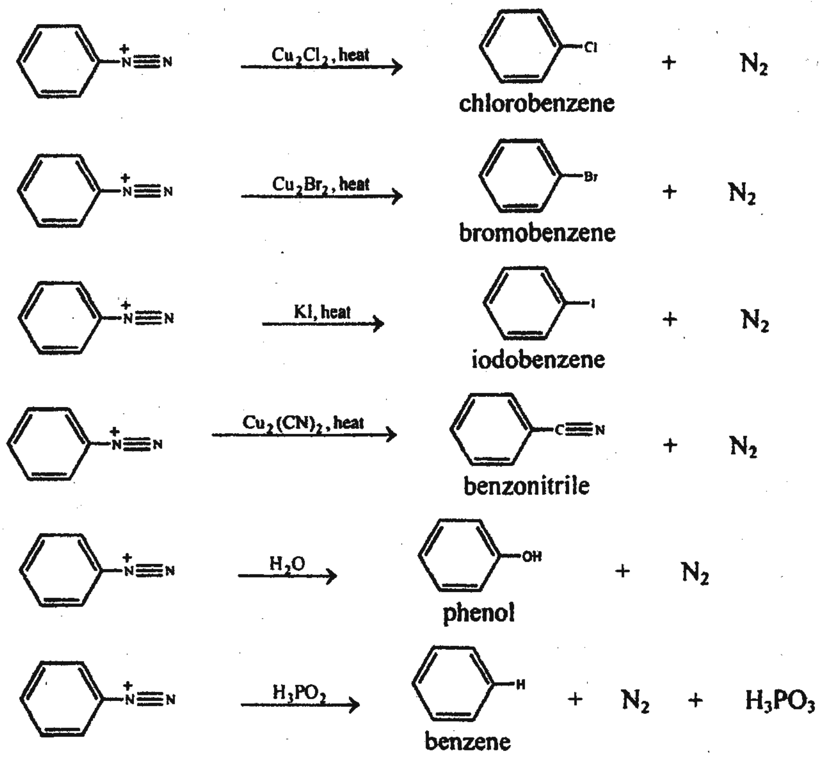
aniline

9. Preparation of Diazonium Salts



diazonium salt

10. Reactions of Diazonium Salts

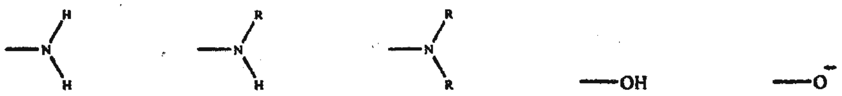


Effects of Substituents

- a monosubstituted benzene can undergo substitution reactions depending on the substituent initially present

Ortho–Para Directors

Strongly Activating



Moderately Activating

Weakly Activating

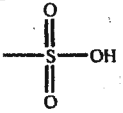
Weakly Deactivating

—F —Cl —Br —I

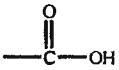
Meta Directors

Moderately Deactivating

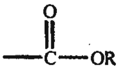
$-C\equiv N$



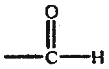
$-\overset{O}{\underset{O}{S}}-OH$



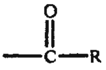
$-\overset{O}{C}-OH$



$-\overset{O}{C}-OR$

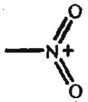


$-\overset{O}{C}-H$

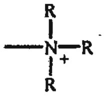


$-\overset{O}{C}-R$

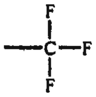
Strongly Deactivating



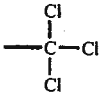
$-\overset{O}{\underset{O}{N^+}}$



$-\overset{R}{\underset{R}{N^+}}-R$



$-\overset{F}{\underset{F}{C}}-F$



$-\overset{Cl}{\underset{Cl}{C}}-Cl$

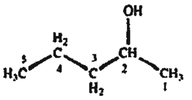
ALCOHOLS AND ETHERS

Alcohols

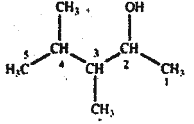
- contain the functional group –OH (hydroxyl group)

Nomenclature of Alcohols

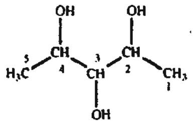
1. Alcohols are named as alkanol. The alkane is named and the "e" is dropped and replaced by "ol".
2. The substituents are numbered with the hydroxyl group given the priority in numbering.



2 – pentanol



3,4 – dimethyl–2–pentanol



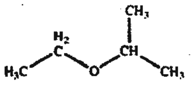
2,3,4 – pentanetriol

Ethers

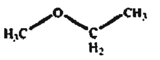
- contain the functional group –OR (alkoxy group)

Nomenclature of Ethers

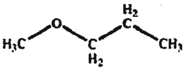
1. Ethers can be named by simply naming the substituent to the oxygen atom in alphabetical order followed by the word "*ether*".



ethyl isopropyl ether

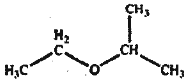


ethyl methyl ether

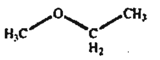


methyl propyl ether

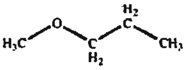
2. For complicated ethers, the –OR group is named as an alkoxy substituent to the longest parent carbon chain of the alkane.



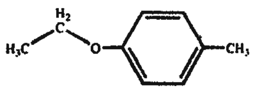
2-ethoxypropane



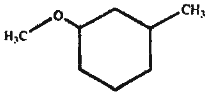
methoxyethane



1-methoxypropane



4-ethoxytoluene



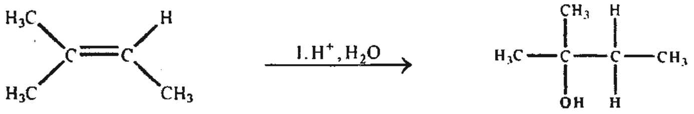
3-methoxy-1-methylcyclohexane

Physical Properties of Alcohols and Ethers

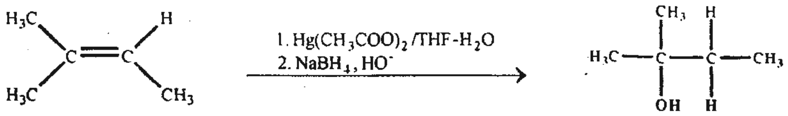
1. Boiling Point
   – alcohols have higher boiling points compared to ethers due to hydrogen bonding
2. Solubility in Water
   – solubility decreases as chain length increases

Preparation of Alcohols

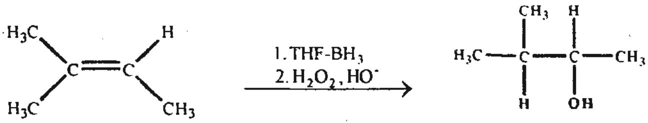
1. Acid – Catalyzed Hydration of Alkenes



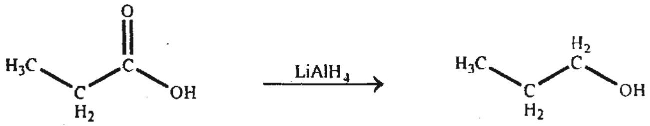
2. Oxymercuration–Demercuration



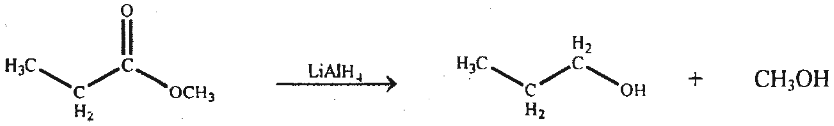
3. Hydroboration–Oxidation



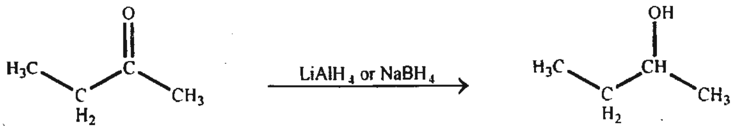
4. Reduction of Carbonyl Compounds



carboxylic acid

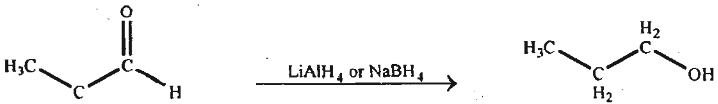


ester



ketone

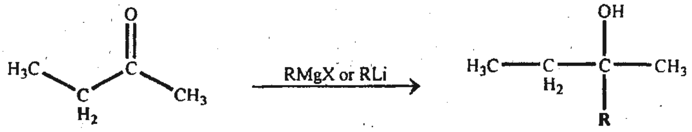
2° alcohol



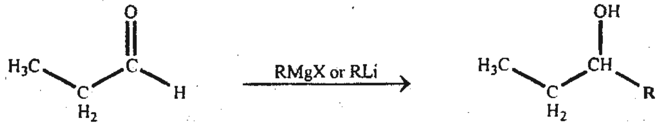
aldehyde

1° alcohol

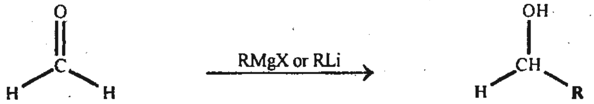
5. Using Grignard Reagent and Organolithium Compounds



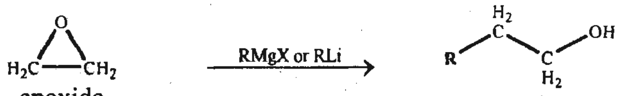
ketone → 3° alcohol



aldehyde → 2° alcohol



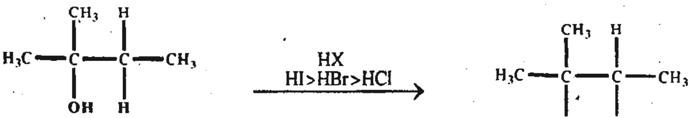
methanal → 1° alcohol



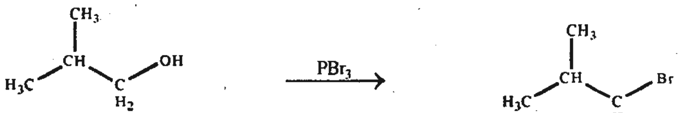
epoxide → 1° alcohol

Reactions of Alcohols

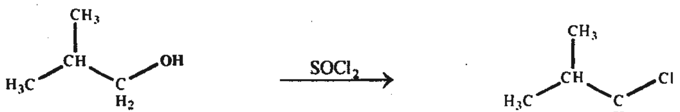
1. Conversion to Alkyl Halides



3°>2°>1°>methyl

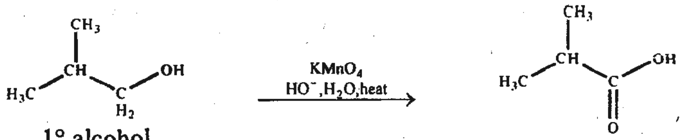


1° or 2°

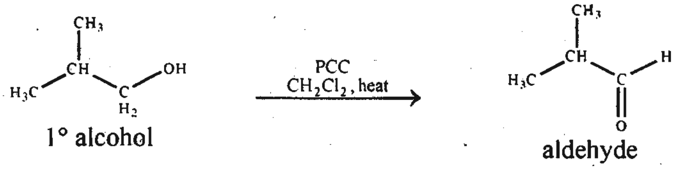


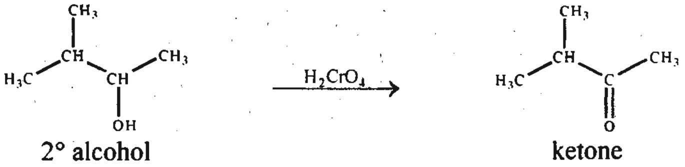
1° or 2°

2. Oxidation to Carbonyl Compounds



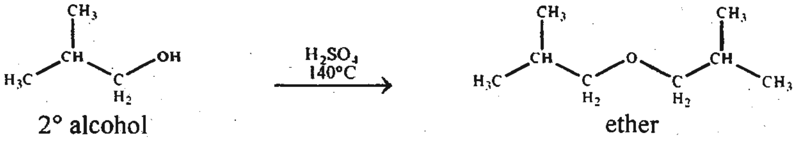
1° alcohol → carboxylic acid



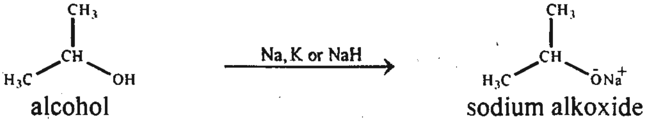


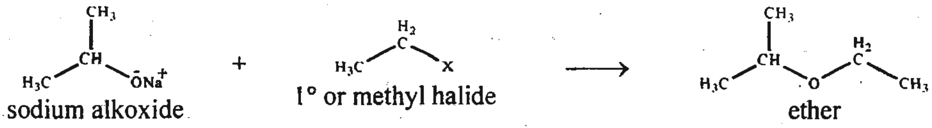
Preparation of Ethers

1. Dehydration of Alcohols (Preparation of Symmetrical Ethers)



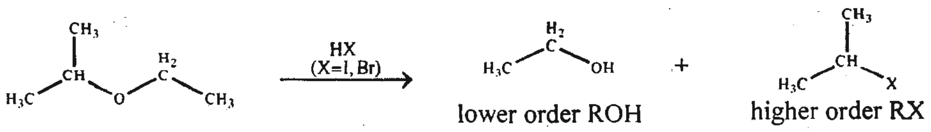
2. Williamson Synthesis (Preparation of Unsymmetrical Ethers)





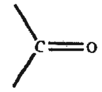
Reaction of Ethers

Acid Cleavage

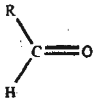


ALDEHYDES AND KETONES

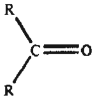
- contains the carbonyl group



carbonyl group



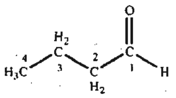
aldehyde

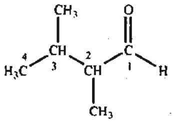


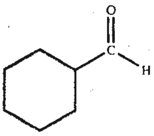
ketone

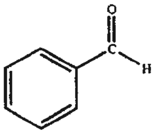
Nomenclature of Aldehydes and Ketones

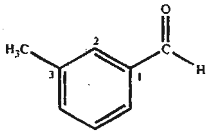
1. Aldehydes are named as alkanal. The alkane is named and the "e" is dropped and replaced by "al". The terminal carbon bearing oxygen is given number 1. For aldehydes in which the –CHO group is attached to the ring, the suffix *carbaldehyde* is used.


butanal

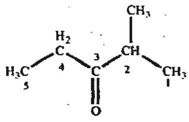

2,3–dimethylpentanal

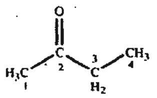

cyclohexane carbaldehyde

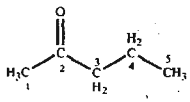

benzene carbaldehyde

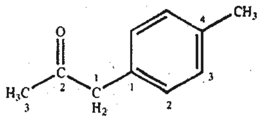

3-methylbenzene carbaldehyde

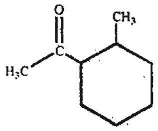
2. Ketones are named by naming the alkyl or aryl group attached to the carbon bearing the oxygen atom. For complicated ketones, the longest parent carbon chain is named as an alkane, the ending "e" is dropped and replaced by "one". The carbon bearing the oxygen atom is given the lowest number.


2-methyl-3-pentanone
(ethyl isopropyl ketone)


butanone
(ethyl methyl ketone)


2-pentanone
(methyl propyl ketone)


1-(4-methylphenyl)-2-propanone


(1-methylcyclohexyl)-ethanone

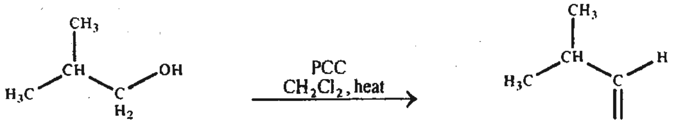
Physical Properties of Aldehydes and Ketones

1. Boiling Point
   – intermediate between alkanes and alcohols of the same molecular weight
2. Solubility in Water
   – due to high polarity, aldehydes and ketones are soluble in water

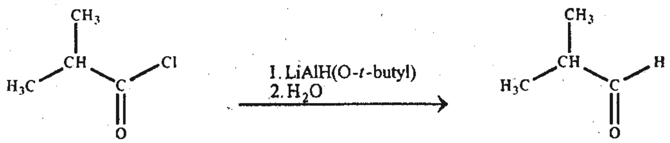
Preparation of Aldehydes and Ketones

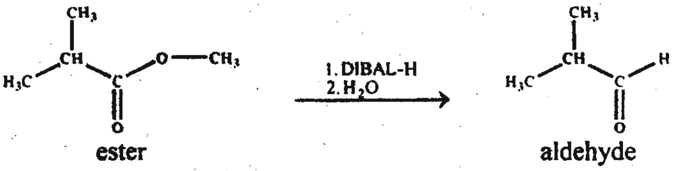
Aldehydes

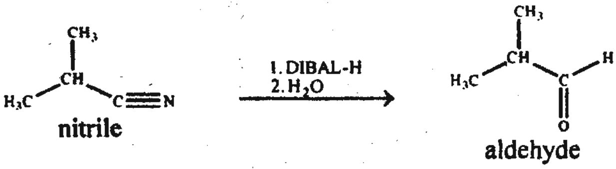
1. Oxidation of Primary Alcohols


1° alcohol
aldehyde

2. Reduction of Acyl Chlorides, Esters and Nitriles

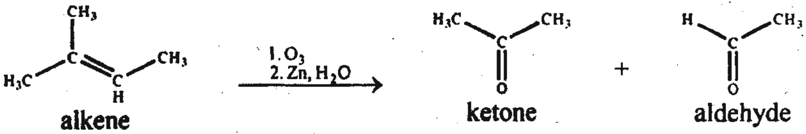

acyl chloride
aldehyde



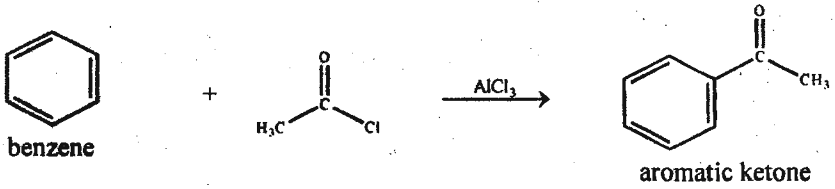


Ketones

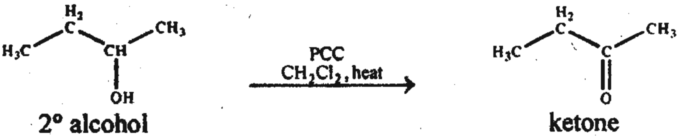
3. Ozonolysis of Alkenes



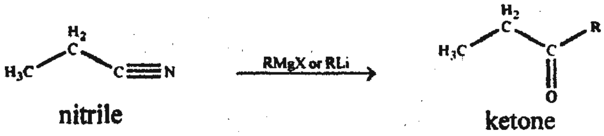
4. Friedel-Crafts Acylation



5. Oxidation of Secondary Alcohols



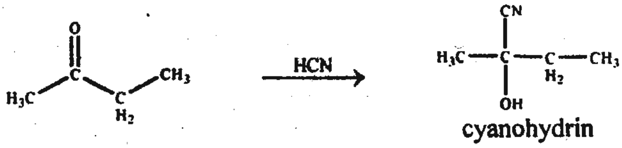
6. From Nitriles using Grignard or Organolithium Reagent

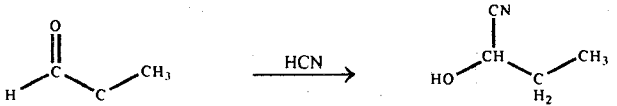


Reactions of Aldehydes and Ketones

Nucleophilic Addition

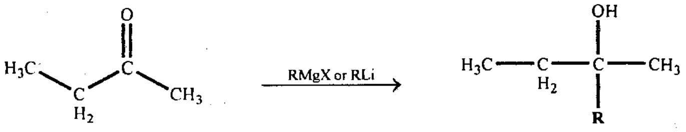
1. Addition of HCN





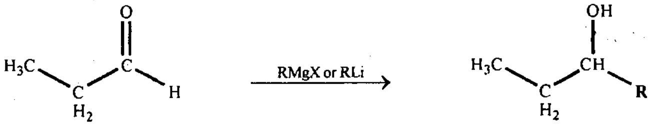
cyanohydrin

2. Addition of Grignard Reagent or Organolithium Compounds



ketone

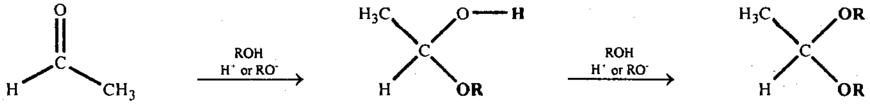
3° alcohol



aldehyde

2° alcohol

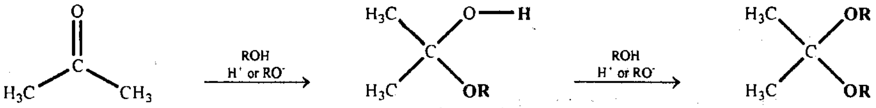
3. Addition of Alcohols



aldehyde

hemiacetal

acetal



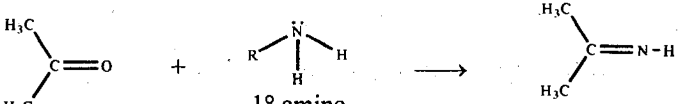
ketone

hemiacetal

acetal

4. Addition of Ammonia and Derivatives

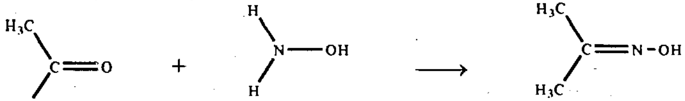
Addition of a Primary Amine



1° amine

imine

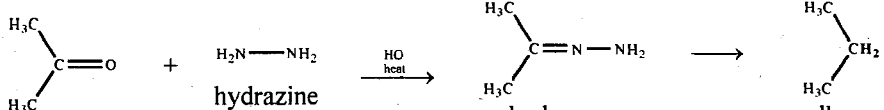
Addition of Hydroxyl Amine



hydroxylamine

oxime

Addition of Hydrazine (Wolff-Kishner Reduction)

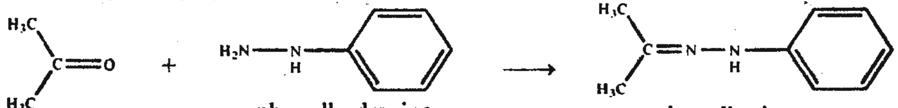


hydrazine

hydrazone

alkane

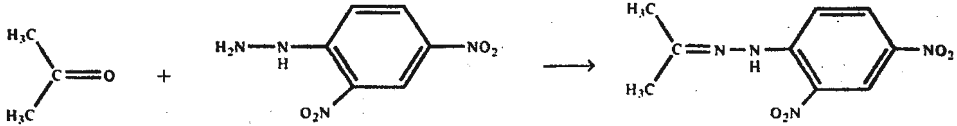
Addition of Phenylhydrazine



phenylhydrazine

phenylhydrazone

Addition of 2,4-Dinitrophenylhydrazine

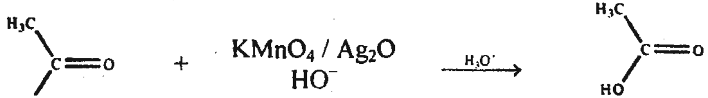


phenylhydrazine

2,4dinitrophenylhydrazone

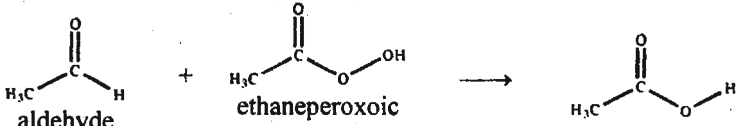
5. Oxidation of Aldehydes and Ketones

Oxidation of Aldehydes



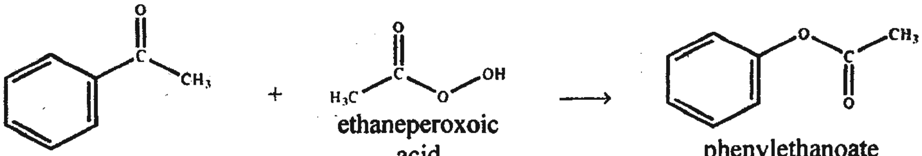
carboxylic acid

Baeyer-Villiger Oxidation of Aldehydes and Ketones



aldehyde

ethaneperoxoic acid



aldehyde

ethaneperoxoic acid

phenylethanoate

H > phenyl > 3° alkyl > 2° alkyl > 1° alkyl > methyl

CARBOXYLIC ACID AND DERIVATIVES

Carboxylic Acid

- contains the functional group –COOH (carboxyl group)

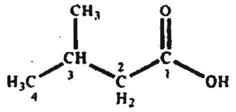
Carboxylic Acid Derivatives

- obtained by replacing the –OH group by chlorine, carboxylate, alkoxy and amino group

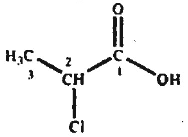
Nomenclature of Carboxylic Acid and Derivatives

Carboxylic Acid

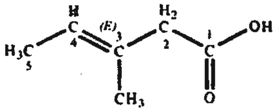
1. Carboxylic acids are named by naming the alkane, dropping the "e" and replaced by "*oic acid*". The carboxyl group is assigned number 1.



3-methylbutanoic acid

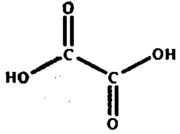


2-chloropropanoic acid

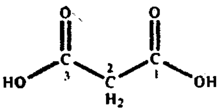


3-methyl-3-pentenoic acid

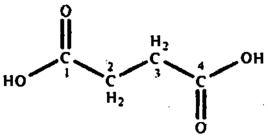
2. For dicarboxylic acids, the alkane followed by "*dioic acid*".



ethanedioic acid
(oxalic acid)



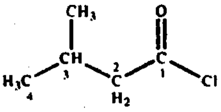
propanedioic acid
(malonic acid)



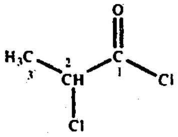
butanedioic acid
(succinic acid)

Acyl Chloride

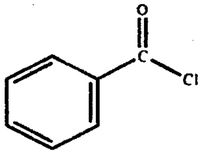
They are named by naming the carboxylic acid, dropping the "oic acid" and adding "oyl chloride".



3-methylbutanoyl chloride



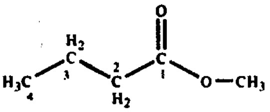
2-chloropropanoyl chloride



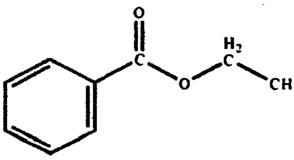
benzoyl chloride

Ester

The alkyl substituent is named first, then the carboxylic is named, the ending "oic acid" is dropped and replaced by "oate".



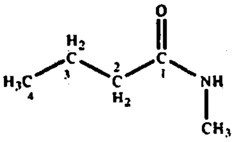
methyl butanoate



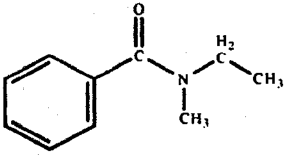
ethyl benzoate

Amide

The carboxylic is named, the ending "oic acid" is dropped and replaced by "amide". Alkyl substituents to the nitrogen atom is named as *N-alkyl.*



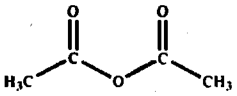
N-methylbutanamide



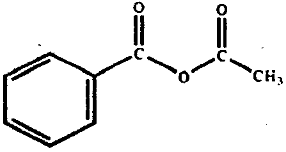
N-ethyl-*N*-methylbenzamide

Acid Anhydride

The carboxylic acids are named followed by "anhydride".



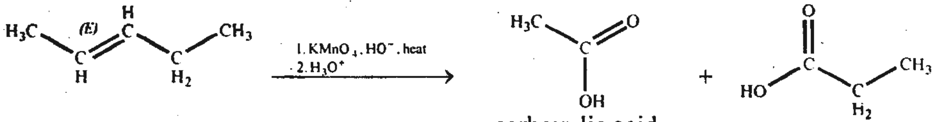
ethanoic anhydride



benzoic ethanoic anhydride

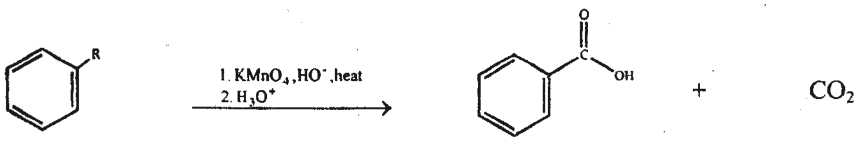
Preparation of Carboxylic Acid

1. Oxidation of Alkenes



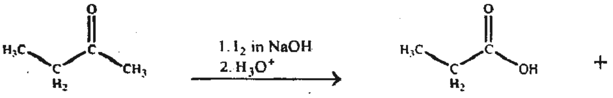
alkene — carboxylic acid — carboxylic acid

2. Oxidation of Alkylbenzenes



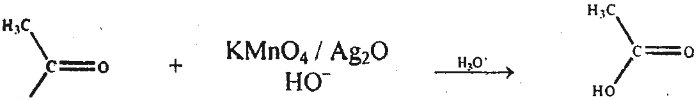
benzoic acid

3. Oxidation of Methylketones (Iodoform Reaction)



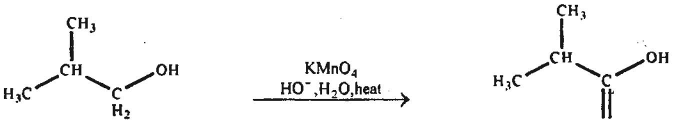
2-butanone — propanoic acid + CHI_3 Iodoform (yellow precipitate)

4. Oxidation of Aldehydes



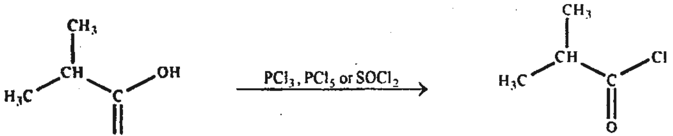
carboxylic acid

5. Oxidation of Primary Alcohols

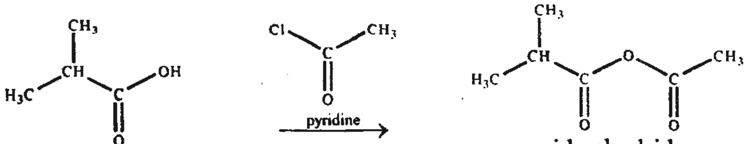


1° alcohol — carboxylic acid

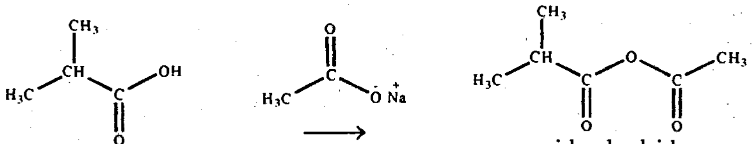
Reactions of Carboxylic Acid (Preparation of Carboxylic Acid Derivatives)



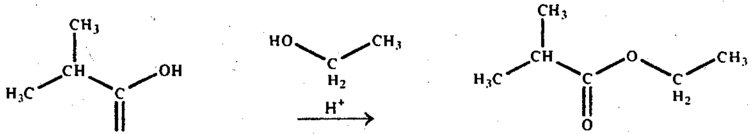
acyl chloride



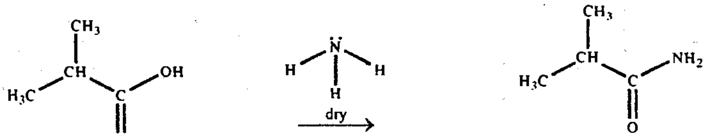
acid anhydride



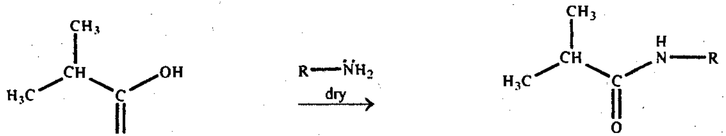
acid anhydride



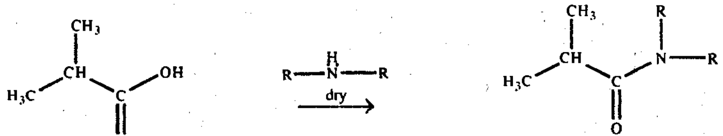
ester



amide



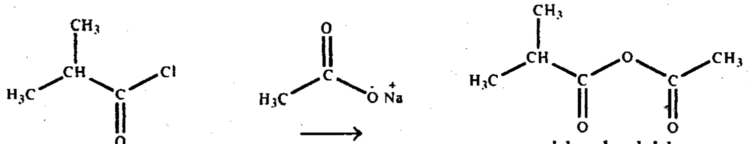
amide



amide

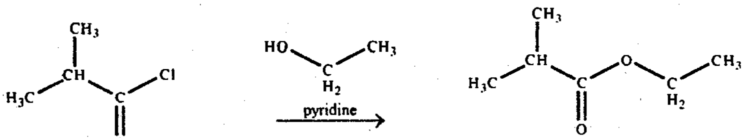
Reactions of Acyl Chloride

1. Conversion to Acid Anhydride



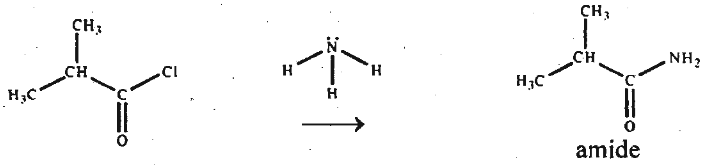
acid anhydride

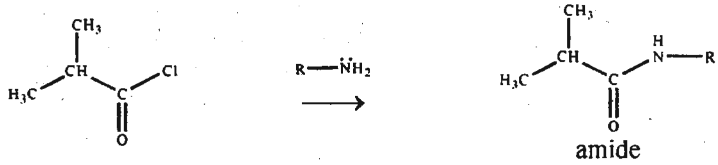
2. Conversion to Ester

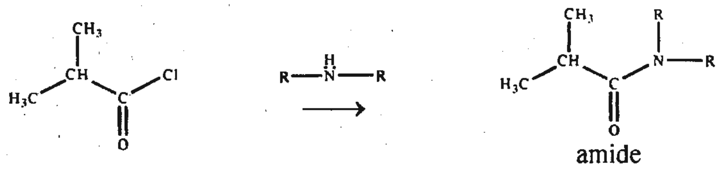


ester

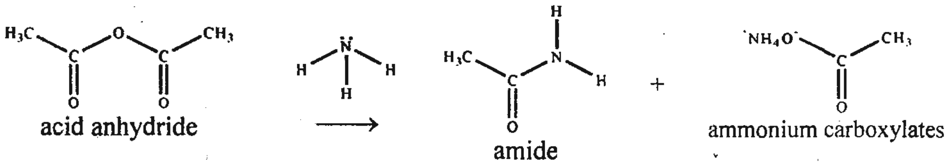
3. Conversion to Amide

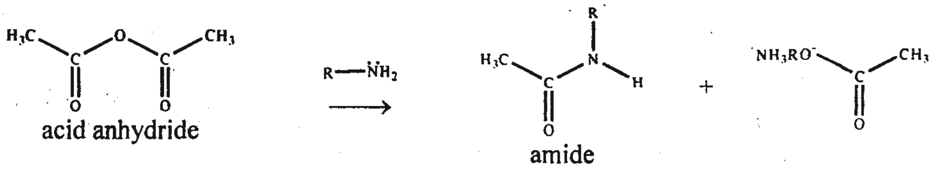


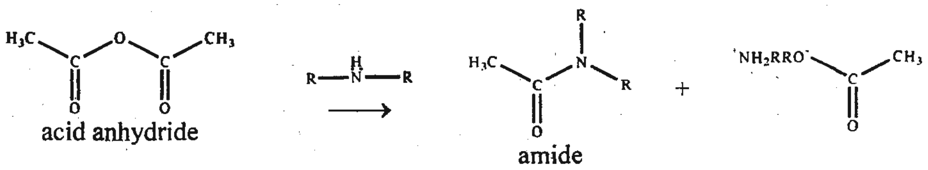


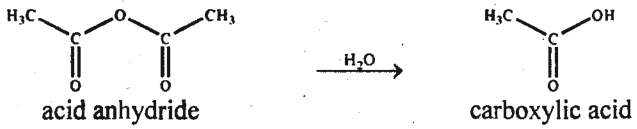


Reactions of Carboxylic Anhydride

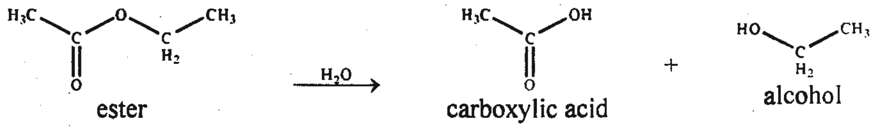


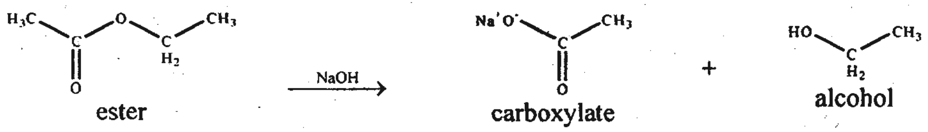




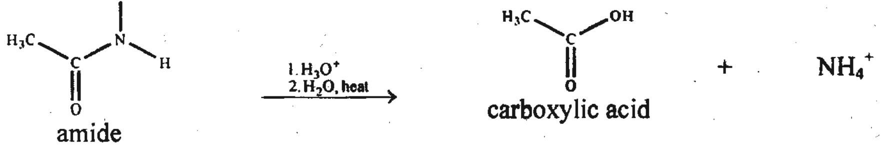


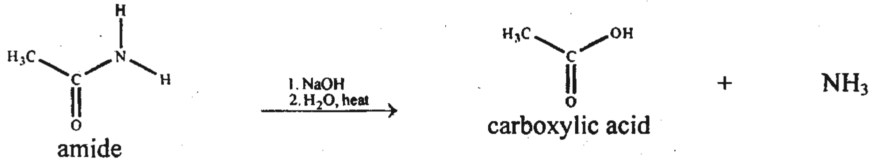
Reactions of Ester





Reactions of Amide



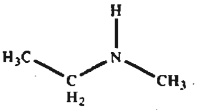


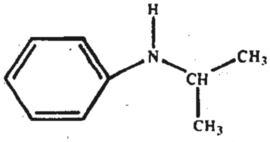
AMINES

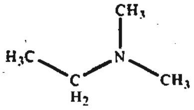
- contains the functional group $-NH_2$
- may be considered as derivatives of ammonia with alkyl or aryl substituents

Nomenclature of Amines

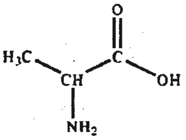
1. An amine can be named by naming the substituent in alphabetical order followed by the word "amine".

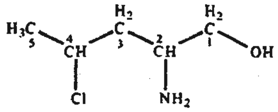

ethylmethylamine


phenylisopropylamine

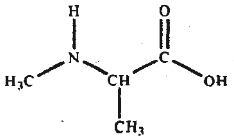

ethyldimethylamine

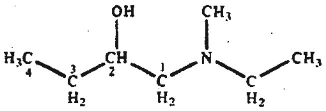
2. For complicated amines, the $-NH_2$ group is named as an *amino* substituent.


2-aminopropanoic acid


2-amino-4-chloropentanol

3. If an alkyl group is substituted to the amino group, it is named as *N*-alkylamino substituent.

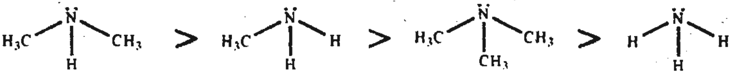

2-(N-methylamino)-propanoic acid


1-(*N*-ethyl-*N*-methylamino)-2-butanol

Physical Properties of Amines

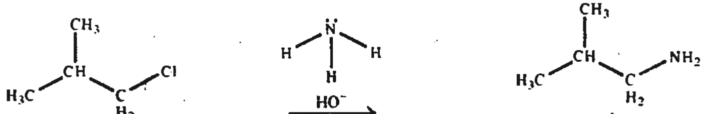
1. Boiling Point
   - primary and secondary amines are capable of hydrogen bonding and boils much higher than alkanes but lower compared to alcohols of the same molecular weight

   - tertiary amines do not form intermolecular hydrogen bonding and boils at a lower temperature compared to primary and secondary amines of the same molecular weight
2. Solubility in Water
   - aliphatic amines containing five carbon atoms are soluble in water
   - aromatic amines are slightly soluble in water
3. Basicity
   - In aqueous solutions, the order of basicity of amines is observed as follows:



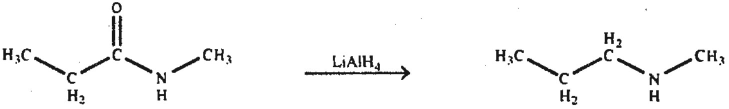
Preparation of Amines

1. Alkylation of Ammonia

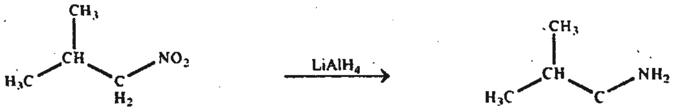


amine

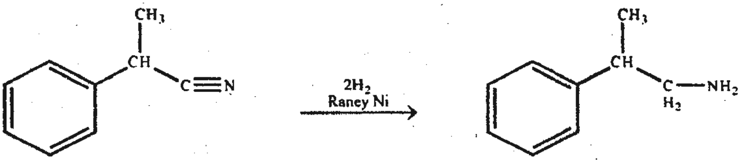
2. Reduction of Amides, Nitro Compounds and Nitriles



amide



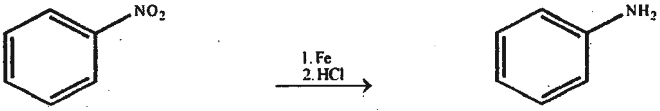
2-methyl-1-nitropropane



nitrile

amine

3. Reduction of Nitrobenzene

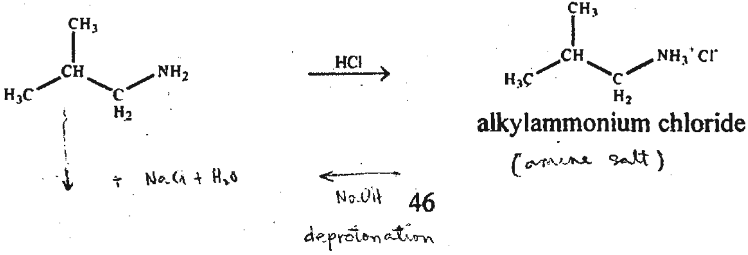


aniline

aniline

Reaction of Amines

1. Reaction with Strong Acids (Protonation)



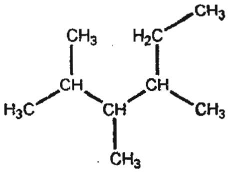
alkylammonium chloride
(amine salt)

REVIEW QUESTIONS AND PROBLEMS

1. Which of the following contains sp-hybridized carbon?
   a. C_4H_8 b. C_3H_6 c. C_5H_8 d. C_6H_{12}

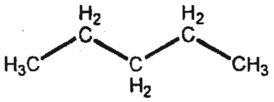
2. Bond formed in the head-on overlap of two orbitals
   a. sigma b. dative c. pi d. double

3. Which of the following molecules is unsaturated?
   a. C_3H_8 b. CH_3OH c. C_5H_{10} d. CH_4

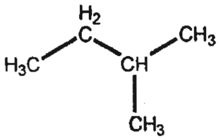


4. Name the alkane
   a. 2-ethyl-3,4-dimethylpentane
   b. 4-ethyl-2,3-dimethylpentane
   c. 3,4,5-trimethylhexane
   d. 2,3,4-trimethylhexane

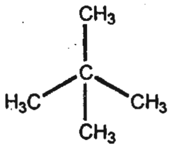
5. For the following alkanes, the one with the lowest boiling point is



(1)



(2)



(3)

   a. 3 b. 2 c. 1 d. can not tell

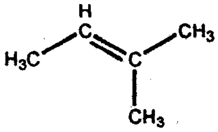
6. Which of the following alkanes is gas at room temperature?
   a. octane b. propane c. eicosane d. undecane

7. When ethyl bromide is treated with sodium in dry ether, the product is
   a. propane b. butane c. methylpropane d. ethane

8. The following reagents will produce an alkane from an alkyl halide <u>except</u>
   a. Zn / H^+ b. Na / dry ether c. alcoholic KOH d. all of these

9. In the halogenation of an alkane, which of the following is <u>true</u>?
   a. all halogens can be used for halogenation
   b. an alkyl halide is formed in a basic solution
   c. the halogen is cleaved heterolytically forming a free radical
   d. during halogenation, a free radical of the halogen is formed in the presence of light or heat

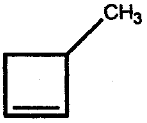
10. How many possible monochlorinated product is expected from the chlorination of propane?
    a. 1 b. 2 c. 3 d. 4

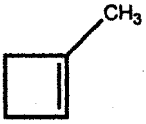


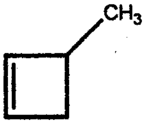
11. Name the alkene:
    a. 2-methyl-2-butene
    b. 3-methyl-2-butene
    c. 1,2-dimethylpropene
    d. none of the above

12. Which of the following alkenes exhibit geometric isomers?
    a. 1-butene
    b. methylpropene
    c. 2-butene
    d. all of these

13. When 1-bromo-2-methylcyclobutane is treated with alcoholic KOH, the dominant product is

a.


b.


c.


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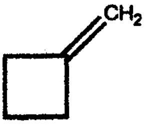


14. Among the following alcohols, methylpropene can be obtained from
    a. 1-butanol
    b. 2-butanol
    c. 2-methyl-2-propanol
    d. all of these

15. Alkenes are commonly prepared via elimination reaction, which of the following is <u>not</u> an elimination reaction?
    a. Dehydration of alcohol
    b. Dehydrohalogenation of alkyl halide
    c. Dehalogenation of vicinal dihalide
    d. Hydrogenation of alkynes

16. The following reagents will yield an alkyl halide from an alkene <u>except</u>
    a. Br_2 / uv or light
    b. Br_2 in CCl_4
    c. HCl
    d. HBr / peroxide

17. The rule which states that, "In the addition of HX to alkenes, the halogen attaches to the doubly bonded carbon with more alkyl substituent."
    a. Saitsev's Rule
    b. Hoffman Rule
    c. Markovnikoff's Rule
    d. None of these

18. The acid-catalyzed addition of water to 1-butene will form
    a. 1-butanol
    b. 2-butanol
    c. isopropyl alcohol
    d. propanol

19. Starting with 2-methyl-2-butene, which of the following processes must be used to produce a secondary alcohol?
    a. Acid-catalyzed hydration
    b. Oxymercuration-demercuration
    c. Addition of bromine water
    d. Hydroboration-oxidation

20. Which of the following reagents will yield a diol from a given alkene?
    a. hot, acidic $KMnO_4$
    b. O_3, Zn and H_2O
    c. OsO_4 in $NaHSO_4$
    d. H^+ / H_2O

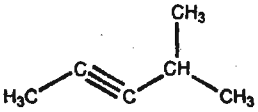
21. Hydrogenation of alkynes in the presence of a poisoned palladium catalyst produces
    a. alkane
    b. alkyne
    c. alcohol
    d. alkene

22. Addition of HBr to alkynes results in the formation of
a. geminal dihalide b. vicinal dihalide c. tetrahalide d. enol

23. When 2-butyne undergoes ozonolysis, the main product is
a. carbon dioxide b. acetic acid c. acetaldehyde d. acetone

24. In hydration of alkynes, the enol formed is found to transform into a ketone. This form of isomerism is known as _________.
a. geometric isomerism c. keto-enol tautomerism
b. structural isomerism d. positional isomerism

25. Name the alkyne:

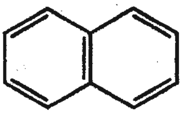


a. 4-methyl-2-butyne c. 2-propynyl-propane
b. 2-methyl-3-butyne d. none of these

26. Which of the following alkynes contain acidic hydrogen?
a. 2-pentyne b. 3-pentyne c. 2-butyne d. propyne

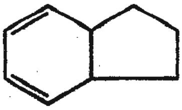
27. Among the following molecules, which is <u>not</u> aromatic?

a.



c.

b.



d. all of these

28. Arrange the following processes to produce 3-methylaniline from benzene
1. Friedel-Crafts Alkylation
2. Nitration
3. Reduction with Fe in HCl
a. 231 b. 213 c. 123 d. 321

29. All of the following are ortho and para directing substituents <u>except</u>
a. – OH b. – F c. – OR d. – NO_2

30. How many isomers does xylene have?
a. 1 b. 2 c. 3 d. 4

31. Vinylbenzene is also known as
a. styrene b. cumene c. mesitylene d. durene

32. Chlorination of aniline will produce dominantly
a. 2,2–dichloroaniline c. 4-chloroaniline
b. 3-chloroaniline d. *N*-chloroaniline

33. Which of the following carbonyl compounds produce a secondary alcohol with $LiAlH_4$?
    a. aldehyde b. ketone c. ester d. carboxylic acid

34. Addition of methyl magnesium bromide to acetaldehyde produces
    a. ethanol b. 1-propanol c. methanol d. 2-propanol

35. Oxidation of isopropyl alcohol with $KMnO_4$ will yield
    a. acetone b. acetaldehyde c. acetic acid d. nothing

36. Which of the following alcohols will undergo bimolecular nucleophillic substitution?
    a. 2-methyl-2-propanol c. 2-propanol
    b. 1-propanol d. all of these

37. In Williamson synthesis of methyl isopropyl ether, the alcohol used is
    a. methanol c. n–propyl alcohol
    b. isopropyl alcohol d. ethanol

38. Acid-catalyzed ring opening of an epoxide will result in the formation of a/an
    a. monohydric alcohol b. dihydric alcohol c. trihydric alcohol d. enol

39. Which of the following tests will distinguish 1-propanol from 2-propanol?
    a. Fehling's Test b. Tollen's Test c. Benedict's Test d. Lucas Test

40. The following reagents will give an alkyl halide from an alcohol except
    a. NaCl b. PBr_3 c. PCl_3 d. $SOCl_2$

41. Which among the following is a ketone?
    a. CH_3COCH_3 b. $(CH_3)_2CHOH$ c. $CH_3OCH_2CH_3$ d. CH_3CHO

42. Which of the following processes will yield an aldehyde?
    a. Oxidation of alcohols using $KMnO_4$ in basic medium
    b. Oxidation of alcohols using chromic acid
    c. Ozonolysis of alkenes
    d. Ozonolysis of alkynes

43. A tertiary alcohol is produced using Grignard Reagent using a/an
    a. ketone b. aldehyde c. alkyl halide d. epoxides

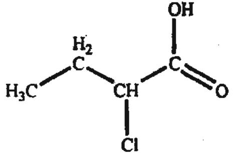
44. Carbonyl compounds can be obtained by reduction using the following except
    a. ester b. acyl chloride c. nitrile d. amide

45. Addition of hydrazine to carbonyl compounds produces a/an
    a. imine b. oxime c. hydrazone d. semicarbazone

46. Reduction of alkyl phenyl ketones to aromatic hydrocarbons done by Wolf-Kishner Reduction uses
    a. Zn(Hg), HCl b. NH_2NH_2, KOH c. $LiAlH_4$ d. H_2 with Ni or Pt

47. With the same molecular weight, a carboxylic acid will have a/an _______ boiling point than an alcohol
    a. lower b. equal c. higher d. no basis

48. Which of the following is the least acidic?

a.


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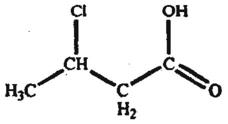

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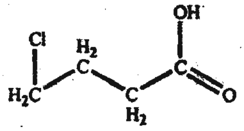

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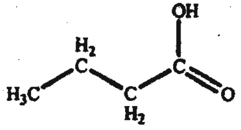
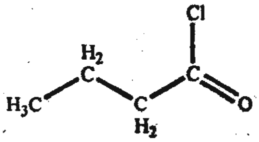


49. Acid anhydrides upon hydrolysis yield
    a. esters b. amides c. carboxylic acid d. acyl halide

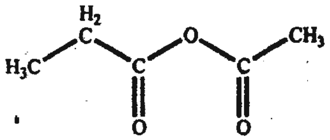
50. Hexanedioic acid is also known as
    a. malonic acid b. succinic acid c. glutaric acid d. adipic acid

51. Reaction of alcohol and a carboxylic acid is known as
    a. saponification b. neutralization c. esterification d. epoxidation

52. Name the acyl halide:


    a. butanoyl chloride
    b. chlorobutanoic acid
    c. propanoyl chloride
    d. none of these

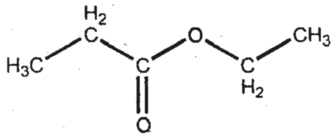
53. Addition of an alcohol to acyl halides produces
    a. carboxylic acid
    b. ester
    c. carboxamide
    d. none of these

54. Name the acidic anhydride:


    a. acetic anhydride
    b. propanoic anhydride
    c. acetic propionic anhydride
    d. none of these

55. Addition of water to acid anhydrides produces
    a. carboxylic acid b. ester c. amide d. none of these

56. Addition of ammonia to acid anhydrides produces
    a. carboxylic acid b. ester c. amide d. none of these



57. Name the ester:
    - a. ethyl propanoate
    - b. propyl ethanoate
    - c. methyl acetate
    - d. ethyl acetate

58. When an ethyl acetate is reduced by $LiAlH_4$ the product is
    - a. acetic acid
    - b. acetaldehyde
    - c. acetone
    - d. ethanol

59. Cyclic esters are known as
    - a. acetals
    - b. diglyme
    - c. lactones
    - d. osazone

60. The scent of a banana is due to the ester
    - a. ethyl formate
    - b. *i*-pentyl acetate
    - c. n-octyl acetate
    - d. ethyl butyrate

C. ANALYTICAL CHEMISTRY

Analytical Chemistry – branch of chemistry that deals with the separation, identification and composition of matter.

Qualitative Analysis (what is present)
- type of analysis that reveals the components of the sample

Quantitative Analysis (how much is present)
- type of analysis that determines the amount of components present in a sample

Methods of Analyses

A. Classical Methods
   1. *Gravimetric Method* – deals with the measurement of the mass of a substance that is chemically related to the analyte.
   2. *Volumetric Method* – measures the volume of solution necessary to react completely with the analyte.

B. Modern Methods
   1. *Spectroscopic Method* – measures the electromagnetic radiation produced by the analyte or its interactions with it.
   2. *Electroanalytic Method* – measures the electrical properties of the analyte such as current (A), potential (V), resistance (Ω), and amount of charge (coul).

Quantitative Analysis

Gravimetric Method of Analysis

Basic Steps on Precipitation Method

1. Sample is dissolved in an appropriate solvent.
2. A precipitant is used to convert the analyte into a sparingly soluble precipitate.
3. The precipitate is converted into a product of known composition by a suitable heat treatment.
4. The percentage of the analyte in the sample is calculated using the gravimetric factor (GF):

$$\text{\% analyte in the sample} = \frac{\text{wt. of precipitate} \cdot \text{GF}}{\text{wt. of sample}} \times 100\%$$

$$\text{GF} = \frac{\text{molar mass of analyte}}{\text{molar mass of precipitate}} \times \frac{\text{x analyte}}{\text{y precipitate}}$$

Volumetric Methods of Analysis

Standard Solution – solution of known concentration
Standardization – process of determining the concentration of an unknown solution
Primary Standard – a substance of high purity used for standardization

Characteristics of a Good Primary Standard

1. High purity and high equivalent weight
2. Stable towards air, high temperature and humidity
3. Soluble in water

Conditions for a Volumetric Analysis

1. The reaction must be rapid and can be represented by a simple balanced equation.
2. The reaction must be complete and no side reaction occurs.
3. An appropriate indicator must be available in order to detect the end point of the reaction.

Types of Titration

1. *Direct Titration* – the analyte reacts with the standard solution directly
2. *Back Titration* – an excess standard solution is added and the excess is determined by the addition of another standard solution
3. *Replacement Titration* – the analyte is converted to a product chemically related to it and the product of such reaction is titrated with a standard solution

Acid–Base Titration

Concepts of Acids and Bases

	LEWIS	BRONSTED-LOWRY	ARRHENIUS
ACID	Electron-pair acceptor	Proton donor	Produces *H_3O^+ in solution
BASE	Electron-pair donor	Proton acceptor	Produces **HO^- in solution

* *hydronium ion, protonated water or solvated proton*
** *hydroxide ion*

Strength of Acids and Bases

Ionization Reaction – reaction involving formation of ions

Strong Acids/Bases – completely ionized in solution

$$HCl + H_2O \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$
$$NaOH + H_2O \rightarrow Na^+_{(aq)} + HO^-_{(aq)}$$

Weak Acids/Bases – partially ionized in solution

$$HF + H_2O \leftrightarrow H_3O^+_{(aq)} + F^-_{(aq)}$$
$$NH_3 + H_2O \leftrightarrow NH_4^+_{(aq)} + HO^-_{(aq)}$$

Autoprotolysis of Water

$$H_2O + H_2O \leftrightarrow H_3O^+_{(aq)} + HO^-_{(aq)} \quad K_W = 1 \times 10^{-14} \text{ at } 25°C$$

Strong Acids : HCl, HBr, HI, $HClO_4$, HNO_3, H_2SO_4 (only on the first ionization)
Strong Bases : Bases of Group 1A and 2A
Weak Acids : HF, HCN, H_2SO_3, H_3PO_4 and organic acids
Weak Bases : Ammonia and derivatives

Calculation of pH

Strong Acids : $\mathrm{pH} = -\log\left[C_{acid}\right]$

Strong Bases : $\mathrm{pH} = 14 + \log\left[n_{HO^-} C_{base}\right]$

Weak Acids : $\mathrm{pH} = -\frac{1}{2}\log\left[K_a C_{acid}\right]$ when $C_{acid}/K_a >> 1000$

Weak Bases : $\mathrm{pH} = 14 + \frac{1}{2}\log\left[K_b C_{base}\right]$ when $C_{base}/K_b >> 1000$

At 25°C… $pH + pOH = 14$

Hydrolysis of Salts

Acid and base reacts to form salt and water. As a general rule, salts coming from weak acids or weak bases hydrolyze in water, that is, only the strong conjugate hydrolyzes in water. An *acidic salt* is formed from the reaction of a strong acid and weak base. A *basic salt* results from the reaction of a strong base and a weak acid. Thus, a *neutral salt* is a product of the reaction between a strong acid and a strong base.

Hydrolysis Reaction of Salts

Acidic Salt : **NH_4Cl**

$$NH_4^+ + H_2O \leftrightarrow H_3O^+ + NH_3 \qquad K_H = \frac{K_W}{K_{NH_3}}$$

Basic Salt : **NaCN**

$$CN^- + H_2O \leftrightarrow HO^- + HCN \qquad K_H = \frac{K_W}{K_{HCN}}$$

pH of Salts

Acidic Salt : $pH = 7 - \frac{1}{2}\log\left[\frac{C_{salt}}{K_b}\right]$ when $\frac{C_{salt}}{K_H} >>> 1000$

Basic Salt : $pH = 7 + \frac{1}{2}\log\left[\frac{C_{salt}}{K_a}\right]$ when $\frac{C_{salt}}{K_H} >>> 1000$

Buffer Solutions

Solutions that contains weak acid or weak base and its conjugate salt. These solutions tend to resist changes in *pH.*

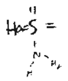
pH of a Buffer Solution

$$pH = pK_a - \log\frac{[\text{acidic component}]}{[\text{basic component}]}, \quad \textit{Henderson – Hasslebalch Equation}$$

If K_b is given… $pH = 14 - pK_b - \log\frac{[\text{acidic component}]}{[\text{basic component}]}$

Primary Standards for Bases

1. Benzoic Acid, C_6H_5COOH
2. Oxalic Acid, $H_2C_2O_4 \cdot 2H_2O$
3. Potassium Biiodate, $KH(IO_3)_2$
4. Potassium Hydrogen Phthalate (KHP), $C_6H_4(COOH)(COOK)$
5. Sulfamic Acid (HSO_3NH_2) 1 OH^-



Primary Standards for Acids

1. Calcium Carbonate, $CaCO_3$ 2 H^+
2. Mercuric Oxide, HgO
3. Sodium Carbonate, Na_2CO_3
4. Tris-hydroxymethylaminomethane (THAM), $(CH_2OH)_3CNH_2$

Indicators for Acid-Base Titration

1. Bromocresol Green
   - ✓ pH Transition Range: 3.8 – 5.4
   - ✓ changes from yellow to blue
   - ✓ $pK_a = 4.66$
2. Bromothymol Blue
   - ✓ pH Transition Range: 6.2 – 7.6
   - ✓ changes from yellow to blue
   - ✓ $pK_a = 7.10$

3. Methyl Red
   - ✓ pH Transition Range: 4.2 – 6.3
   - ✓ changes from red to yellow
   - ✓ $pK_a = 5.00$
4. Methyl Orange
   - ✓ pH Transition Range: 3.1 – 4.4
   - ✓ changes from orange to yellow
   - ✓ $pK_a = 3.46$
5. Phenolphthalein
   - ✓ pH Transition Range: 8.3 – 10.0
   - ✓ changes from colorless to pink
   - ✓ $pK_a = 9.00$

Applications of Acid-Base Titration

Kjeldahl Method (Determination of Organic Nitrogen)

Step 1. Digestion

- The sample is oxidized in hot, concentrated sulfuric acid, H_2SO_4 and turns black...
  To convert . . . *Carbon and Hydrogen* to . . . *CO_2 and H_2O*
  To convert . . . *Amides and Amines* to . . . NH_4^+
  To convert . . . *Azo, Azoxy and Nitro Group* to . . . *N or its oxide*
- Catalysts
  Potassium Sulfate (K_2SO_4) – increases the boiling point of sulfuric acid
  Mercuric Oxide (HgO) – increases the rate of reaction
  Selenious Acid (H_2SeO_3) – best catalyst

Step 2. Distillation

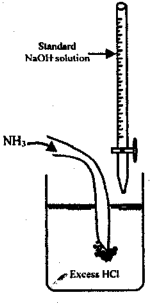
- The oxidized solution is cooled and then treated with NaOH to liberate ammonia gas:

$$NH_4^+ + HO^- \rightarrow NH_{3(g)} + H_2O$$

- Glass or porcelain beads are added to avoid bumping
- In some modifications, hydrogen peroxide is added to decompose organic matrix formed
- If mercuric oxide, *HgO* is used as a catalyst, it is necessary to add sodium thiosulfate, *$Na_2S_2O_3$* to precipitate mercuric sulfide, *HgS.*

$$Hg^{2+} + S_2O_3^{-2} + 2HO^{-1} \rightarrow HgS_{(s)} + SO_4^{-2} + H_2O$$

Step 3. Titration



1. Using an excess amount of HCl...

$$NH_3 + HCl \rightarrow NH_4Cl$$

The excess HCl is determined using a standard NaOH solution

$$HCl + NaOH \rightarrow NaCl + H_2O$$

2. Ammonia distilled is collected in a boric acid solution...

$$NH_3 + H_3BO_3 \rightarrow NH_4^+ + H_2BO_3^{-2}$$

Titrate the H_3BO_3–NH_3 solution with standard acid...

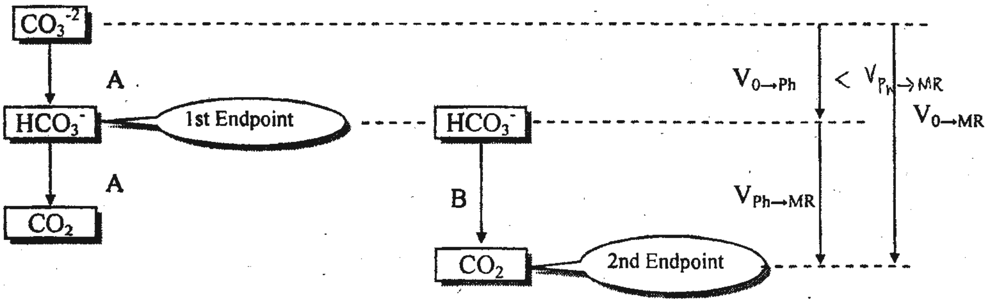
$$H_2BO_3^{-2} + H_3O^+ \rightarrow H_3BO_3 + H_2O$$

Percentage Protein in the Sample

% protein = % N * f = 5.70 (cereals)
= 6.25 (meat products)
= 6.38 (dairy products)

Double Indicator Method (Mixture of Bases)

Mixture Na_2CO_3 and $NaHCO_3$



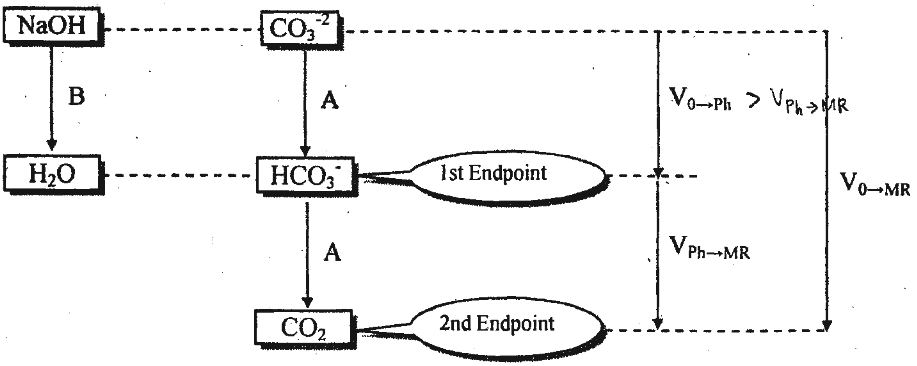
The first endpoint is detected by phenolphthalein indicator and the second endpoint by methyl red.

✓ $$\text{mg } Na_2CO_3 = 2(V_{0\to Ph})(M_{HCl}) \times \frac{1\text{ mmol } Na_2CO_3}{2\text{ mmol HCl}} \times \frac{106.00\text{ mg } Na_2CO_3}{1\text{ mmol } Na_2CO_3}$$

✓ $$\text{mg } NaHCO_3 = (V_{Ph\to MR} - V_{0\to Ph})(M_{HCl}) \times \frac{1\text{ mmol } NaHCO_3}{1\text{ mmol HCl}} \times \frac{84.01\text{ mg } NaHCO_3}{1\text{ mmol } Na_2CO_3}$$

$$\text{mg } NaHCO_3 = (V_{0\to MR} - 2V_{0\to Ph})(M_{HCl}) \times \frac{1\text{ mmol } NaHCO_3}{1\text{ mmol HCl}} \times \frac{84.01\text{ mg } NaHCO_3}{1\text{ mmol } Na_2CO_3}$$

Mixture of Na_2CO_3 and NaOH



✓ $$\text{mg } Na_2CO_3 = 2(V_{Ph\to MR})(M_{HCl}) \times \frac{1\text{ mmol } Na_2CO_3}{2\text{ mmol HCl}} \times \frac{106.00\text{ mg } Na_2CO_3}{1\text{ mmol } Na_2CO_3}$$

$$\text{mg } Na_2CO_3 = 2(V_{0\to MR} - V_{0\to Ph})(M_{HCl}) \times \frac{1\text{ mmol } Na_2CO_3}{2\text{ mmol HCl}} \times \frac{106.00\text{ mg } Na_2CO_3}{1\text{ mmol } Na_2CO_3}$$

✓ $$\text{mg NaOH} = (V_{0\to Ph} - V_{Ph\to MR})(M_{HCl}) \times \frac{1\text{ mmol NaOH}}{1\text{ mmol HCl}} \times \frac{40.00\text{ mg NaOH}}{1\text{ mmol NaOH}}$$

$$\text{mg NaOH} = (2V_{0\to Ph} - V_{0\to MR})(M_{HCl}) \times \frac{1\text{ mmol NaOH}}{1\text{ mmol HCl}} \times \frac{40.00\text{ mg NaOH}}{1\text{ mmol NaOH}}$$

Precipitation Titration

One of the oldest analytical techniques that started in the mid–1800's. Silver nitrate ($AgNO_3$) is commonly employed in such technique. Titration with $AgNO_3$ is often termed as *argentometric titration*.

Indicators in Precipitimetry

The equivalence point can be observed by the following:

a. formation of a colored secondary precipitate
Mohr Method (K.F. Mohr, Germany, 1865)
Direct method for halides and cyanides
Titrant: Silver nitrate, $AgNO_3$
Titration Reaction: $Ag^+ + Cl^{-1} \rightarrow \underset{white}{AgCl_{(s)}}$
Indicator: sodium chromate, Na_2CrO_4

Indicator Reaction: $2Ag^+ + CrO_4^{2-} \rightarrow \underset{red}{Ag_2CrO_{4(s)}}$
Primary Standard for $AgNO_3$: NaCl

Titration is carried out between pH of 7–10. Usually, a low concentration of chromate is desired to detect the end point clearly since a chromate ion imparts an intense yellow color.

b. formation of a colored complexion
Volhard Method (Jacob Volhard, Germany, 1874)
Direct method for silver – Indirect method for halides
Titrant: Potassium thiocyanate, KSCN
Direct Titration Reaction: $Ag^+ + SCN^{-1} \rightarrow \underset{white}{AgSCN_{(s)}}$
Indirect Titration Reactions: $\underset{excess}{Ag^+} + Cl^{-1} \rightarrow \underset{white}{AgCl_{(s)}}$
$Ag^+ + SCN^{-1} \rightarrow \underset{white}{AgSCN_{(s)}}$
Indicator: ferric alum
Indicator Reaction: $Fe^{+3} + SCN^{-1} \rightarrow \underset{red}{Fe(SCN)^{2+}}$

Titration is carried out in acidic condition to hasten precipitation of ferric ion to its hydrated oxide form.

c. formation of a colored adsorption complex
Fajans Method (K. Fajans, Poland, 1874)
Titrant: Silver nitrate, $AgNO_3$
Titration Reaction: $Ag^+ + Cl^{-1} \rightarrow \underset{white}{AgCl_{(s)}}$
Indicator: dichlorofluorescein, best for determination of halides and cyanides
End point: color change from yellow to pink

Titration is carried out between pH of 4-7. Dextrin is added to prevent excessive coagulation of the AgCl precipitate.

Complex Formation Titration

This type of titration is used for the determinations of cations. Typical reagents used are organic compounds containing groups which are electron donors and have the ability to form multiple covalent bonds with the metal ion.

Determination of Cyanide by the Liebig Method

The titration is carried by the dropwise addition of $AgNO_3$ in a solution of a cyanide forming a soluble cyanide complex of silver: $2CN^{-1} + Ag^{+} \rightarrow Ag(CN)_2^{-1}$. The endpoint of the titration is the formation of a permanent faint turbidity: $Ag(CN)_2^{-1} + Ag^{+} \rightarrow Ag[Ag(CN)_2]_{(s)}$

Determination of Nickel

An ammoniacal solution of nickel is treated with a measured excess of standard cyanide solution and the excess is determined by a standard $AgNO_3$ solution according to the reactions:

Addition of Excess Cyanide : $Ni(NH_3)_6^{+3} + 4CN^{-1} + 6H_2O \rightarrow Ni(CN)_4^{-1} + 6NH_4OH$
Back Titration with Ag^{+}: $2CN^{-1} + Ag^{+} \rightarrow Ag(CN)_2^{-1}$
Endpoint : $Ag(CN)_2^{-1} + Ag^{+} \rightarrow Ag[Ag(CN)_2]_{(s)}$

Titration with Ethylenediaminetetraacetic Acid (EDTA)

The structure suggests six potential sites (*hexadentate*) for metal bonding: the four carboxyl groups and two amino groups. Commercially, the free acid and the dehydrate are available. Solutions of EDTA combines with any metal ions in a 1:1 ratio. The indicator used for titration is the Eriochrome Black T®. For metal ion detections, it is necessary to adjust the pH to 7 or above so that the blue form predominates in the absence of a metal cation. Generally, metal complexes with EDTA are red as H_2In^{-1}. When an excess EDTA is added, the solution turns blue according to the reaction:

$$\underset{\text{red}}{MIn^{-1}} + HY^{-3} \rightarrow \underset{\text{blue}}{HIn^{-2}} + MY^{-2}$$

Direct Titration with Added Metal Ions

In the determination of Ca^{2+}, small amount of magnesium chloride is added to EDTA. Initially, Ca^{+2} displaces Mg^{+2} in the EDTA complex and the latter combines with EBT producing a red complex. When all the calcium is titrated, the liberated Mg^{+2} is released, combined with the EDTA and the endpoint is observed.

Introduction to Electrochemistry

An oxidation/reduction reaction is one in which electrons are transferred from one reactant to another. *Oxidation reaction* involves an increase in the oxidation state of an element while *reduction reaction* involves a decrease in the oxidation state. Consider the reaction:

$$Ce^{4+} + Fe^{2+} \rightarrow Ce^{3+} + Fe^{3+}$$

In this reaction, Ce^{4+} ion acquires an electron from Fe^{2+}. Such strong electron affinity for electrons makes Ce^{4+} an oxidizing agent or an oxidant. On the other hand, Fe^{2+} readily gives its electron and is a reducing agent or reductant.

For oxidation reaction...**LEORA**
Loss of Electron(s), Oxidation, substance oxidized is the Reducing Agent
For reduction reaction...**GEROA**
Gain of Electron(s), Reduction, substance reduced is the Oxidizing Agent

Balancing Redox Reactions

Step 1. Assign oxidation numbers of each of the species in the reaction

$$\underset{+7\ -2}{MnO_4^{-1}} + \underset{+3\ -2}{NO_2^{-1}} \rightarrow \underset{+2}{Mn^{2+}} + \underset{+5\ -2}{NO_3^{-1}} \quad \text{(acidic medium)}$$

Step 2. Write the half–cell reactions. Identify oxidation and reduction reactions. If compounds are present in the reaction, use the ions in the half–cell reaction

OXIDATION: $\underset{+3}{NO_2^{-1}} \rightarrow \underset{+5}{NO_3^{-1}} + 2e$

REDUCTION: $\underset{+7}{MnO_4^{-1}} + 5e \rightarrow \underset{+2}{Mn^{+2}}$

Step 3. Balance the reaction by multiplying a factor so that the number of electrons on both sides is the same.

OXIDATION x 5: $\underset{+3}{5NO_2^{-1}} \rightarrow \underset{+5}{5NO_3^{-1}} + 10e$

REDUCTION x 2: $\underset{+7}{2MnO_4^{-1}} + 10e \rightarrow \underset{+2}{2Mn^{+2}}$

Step 4. Balance by adding H_2O to the oxygen deficient side and H+/OH$^-$ on the other side.

OXIDATION x 5: $\underset{+3}{5NO_2^{-1}} + 5H_2O \rightarrow \underset{+5}{5NO_3^{-1}} + 10H^+ + 10e$

REDUCTION x 2: $\underset{+7}{2MnO_4^{-1}} + 16H^+ + 10e \rightarrow \underset{+2}{2Mn^{+2}} + 8H_2O$

- -

$$2MnO_4^{-1} + 5NO_2^{-1} + 6H^+ \rightarrow 2Mn^{+2} + 5NO_3^{-1} + 3H_2O$$

Electrochemical Cells

Electrochemical cells have two electrodes, which are immersed in an electrolyte solution. Salt bridges are used to prevent the two solutions from mixing.

The cathode in an electrochemical cell is the electrode where reduction occurs. The anode, on the other hand, is where oxidation occurs.

A galvanic or voltaic cell is an electrochemical cell that stores electrical energy. The reaction at the anode and the cathode occurs spontaneously and allows flow of electrons from the anode to the cathode with the aid of an external conductor.

In contrast, an electrolytic cell requires an external source of electrical energy to operate.

Schematic Representation of Cells

Cu / Cu^{2+} (0.0200M) // Ag$^+$ (0.0200M) / Ag
ANODIC REACTION CATHODIC REACTION

Electrode Potentials

An electrode potential is the potential of a cell with the hydrogen electrode as the *anode. Standard Hydrogen Electrode (SHE)* is assigned a value of 0.000V at all temperatures. The *standard electrode potential, E°* of a half reaction is the electrode potential when the activities of all reactants and products are unity (1 M molar concentration and 1 atm partial pressure).

Standard Reduction Potential

A positive value of the standard reduction potential of an electrode implies that it was used as cathode with the *SHE* as *anode.* High positive value of a reduction potential also indicates that the electrode is a *good oxidizing agent.*

Thermodynamic Potential of an Electrochemical Cell, E_{cell}

This potential can be computed at standard conditions as follows:

$$E_{cell} = E_{cathode} - E_{anode}$$

Effect of Concentration on Electrode Potentials: Nernst Equation

$$E = E^\circ - \frac{RT}{nF}\ln\frac{[C]^c[D]^d\ldots}{[A]^a[B]^b\ldots} \quad \text{Nernst Equation}$$

$$\text{At } 25^\circ\text{C}\ldots \quad E = E^\circ - \frac{0.0592}{n}\log\frac{[C]^c[D]^d\ldots}{[A]^a[B]^b\ldots}$$

where: R = gas constant, 8.314 $J/K-mol$
T = temperature in Kelvin
n = number of electrons that appear in the half-cell reaction
F = Faraday's constant, 96487.38 $coul/mole\ e^-$

Oxidation–Reduction Titration

a. ***Permanganate Process ($KMnO_4$)***

In acidic medium… $MnO_4^{-1} + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$
In basic/neutral medium… $MnO_4^{-1} + 2H_2O + 3e^- \rightarrow MnO_2 + 4HO^-$

Standardization of $KMnO_4$ solution
Indicator: self indicating

Primary Standards

1. Against $Na_2C_2O_4$
   Rxn: $C_2O_4^{-2} \rightarrow 2CO_2 + 2e^-$
2. Against As_2O_3
   Rxn: $As^{3+} + 4H_2O \rightarrow H_3AsO_4 + 5H^+ + 2e^-$
3. Against Ferrous solutions
   Rxn: $Fe^{2+} \rightarrow Fe^{3+} + e^-$
4. Against pure Fe
   Rxn: $Fe \rightarrow Fe^{2+} + 2e^-$

Applications of Permanganimetric Titrations

1. $Fe^{2+} \rightarrow Fe^{3+} + e^-$
2. $Sn^{2+} \rightarrow Sn^{4+} + 2e^-$
3. $NO_2^- \rightarrow NO_3^- + 2e-$
4. $H_2O_2 \rightarrow O_2 + 2e^-$
5. $Mo^{3+} \rightarrow MoO_4^{2-} + 3e^-$
6. $Ti^{3+} \rightarrow TiO^{2+} + e^-$

b. ***Dichromate Process***

Rxn: $Cr_2O_7^{2-} + 6e- \rightarrow 2Cr^{3+}$
Indicator: sodium diphenylbenzidine sulfonate
barium diphenylamine sulfonate

Applications of Dichromate Process

1. $Fe^{2+} \rightarrow Fe^{3+} + e^-$
2. $U^{4+} \rightarrow UO_2^{2+} + 2e^-$
3. $Cu^+ \rightarrow Cu^{+2} + e-$

c. ***Iodometric Titration (Indirect Titration with Iodine)***

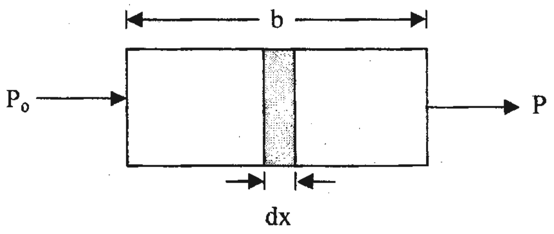
Rxn: $I_2 + 2e^- \rightarrow 2I^-$
Titrant: $Na_2S_2O_3$
Indicator: starch
Primary Standard: $K_2Cr_2O_7$ ($Cr_2O_7^{-2} + 6I^- \rightarrow 2Cr^{3+} + 3I_2$)
Titration Reaction: $2S_2O_3^{-2} + I_2 \rightarrow S_4O_6^{-2} + 2I^-$

The Absorption of Radiation: Ultraviolet and Visible

If a beam of light passes through a glass container filled with liquid, the emergent radiation is always less powerful than that entering. If the energy absorbed is greater for some visible wavelengths than for others, the emergent beam will appear colored.

Beer's Law

The absorption of radiant energy by matter can be described using Beer's Law. Consider a block of an absorbing material of concentration, *c* and thickness, ***b***:



$$-\int_{P_o}^{P}\frac{dP}{P} = ac\int_0^b dx$$

$$-\ln\frac{P}{P_o} = abc$$

$$A = \log\frac{P_o}{P} = \varepsilon bc$$

$$A = \log\frac{1}{T} = \varepsilon bc$$

where:
T = transmittance
A = absorbance
P = emergent radiation
ε = molar absorptivity
P_o = entering radiation

REVIEW QUESTIONS AND PROBLEMS

1. Chemicals which are tested by the manufacturers showing the actual percentages of impurities and labeled on the containers are called
   a. reagent grade chemicals
   b. analytical reagent
   c. certified reagent
   d. all of the above

2. What is the normality of a sulfuric acid solution that is 18 M?
   a. 9 N   b. 36 N   c. 6 N   d. 12 N

3. Calculate the molar concentration of a solution that is 30% wt NH_4NO_3 and has a specific gravity of 1.1252.
   a. 4.22 M   b. 6.85 M   c. 5.27 M   d. 3.08 M

4. A sample containing NaBr and KBr only weighs 253.02 mg. The sample was dissolved in water and treated with excess $AgNO_3$. The precipitate formed was found to weigh 429.85 mg. Calculate the %NaBr in the sample.
   a. 45%   b. 55%   c. 49%   d. 51%

5. The aluminum in a 759.08 mg of impure ammonium aluminum sulfate sample was precipitated as $Al(OH)_3$ and ignited at 1100°C to yield a precipitate of Al_2O_3 weighing 387.953 mg. Express the result of analysis in terms of % Al.
   a. 27.05%   b. 13.53%   c. 18.67%   d. 23.29%

6. What weight of an impure NaCl sample must be taken for analysis so that the weight of AgCl precipitate obtained in mg will be equal to the % Cl in the sample?
   a. 19.76 mg   b. 12.66 mg   c. 24.73 mg   d. 4.04 mg

7. A 250 mg sample containing 45% $MgCO_3$ and 55% $CaCO_3$ was ignited producing CO_2 as decomposition product. Assuming that the decomposition reaction is complete, what is the change in weight of a NaOH solution used to absorb CO_2?
   a. 58.73 mg   b. 47.70 mg   c. 119.24 mg   d. 60.51 mg

8. The solubility of salt A in 100 g H_2O is 25 grams at 25°C. A solution is prepared by adding 30 grams of salt A in 100 grams of H_2O at 25°C. The resulting solution after mixing is a/an
   a. unsaturated   b. saturated   c. supersaturated   d. dilute

9. Which of the following salts is insoluble in water at 25°C?
   a. $NiNO_3$ b. Na_2CO_3 c. KI   d. $CaCO_3$

10. The following primary standards can be used for the standardization of bases <u>except</u>
    a. $CaCO_3$ b. Oxalic acid   c. KHP   d. Benzoic acid

11. For titration of weak acid with a strong base, which indicator can be used?
    a. bromocresol green
    b. phenolphthalein
    c. methyl orange
    d. methyl red

12. Dilution of a buffer will cause ________ in its pH.
    a. an increase   b. a decrease   c. no change   d. none of these

13. In the reaction: $\underset{(1)}{H_2CO_3} + \underset{(2)}{H_2O} \rightarrow \underset{(3)}{HCO_3^{-1}} + \underset{(4)}{H_3O^+}$
    Determine which is the Bronsted acid?
    a. 1 and 3   b. 1 and 2   c. 1 and 4   d. 2 and 3

14. Calculate the pH of 3.5×10^{-3} M HNO_3
    a. 2.46   b. 0.54   c. 3.00   d. 3.46

15. The pH of a $Ba(OH)_2$ solution is 10.0. What is the H^+ ion concentration?
    a. 4.0×10^{-11} M   b. 1.6×10^{-10} M   c. 1.3×10^{-5} M   d. 1.0×10^{-10} M

16. Which of the following solutions have lowest pH?
    a. HCN   b. HNO_3 c. NaCl   d. NaOH

17. What is the pH of the resulting solution made by mixing 25 mL of 0.1M HCl and 15 mL of 0.1M NaOH?
    a. 1.40   b. 1.60   c. 1.00   d. 0.40

18. When 0.02 mole of a monoprotic acid is dissolved in 350 mL of water, the pH is 3.05. What is the ionization constant of this acid?
    a. 1.4×10^{-4} b. 1.4×10^{-5} c. 1.4×10^{-6} d. 1.4×10^{-7}

19. What mass in grams of $NaC_2H_3O_2$ must be dissolved with 500 mL of 0.100M acetic acid to make a 2L of buffer solution of pH=5? $K_A = 1.8 \times 10^{-5}$
    a. 2.28 g   b. 7.19 g   c. 7.38 g   d. 2.12 g

20. What is the pH of 0.256 M NH_4Cl? K_B, $NH_3 = 1.8 \times 10^{-5}$?
    a. 2.64   b. 9.90   c. 11.36   d. 4.92

21. What is the pH of the resulting solution made by mixing 5 mL of 0.2178 M HCl and 15 mL of 0.1156 M NH_3? K_B, $NH_3 = 1.8 \times 10^{-5}$?
    a. 9.49   b. 11.00   c. 9.02   d. 12.74

22. Which of the following primary standards for bases require a blank determination?
    a. $KHC_8H_4O_4$ c. C_6H_5COOH
    b. $KH(IO_3)_2$ d. none of these

23. In the standardization of an acid solution with sodium carbonate, why is it necessary to boil the solution before completing the titration?
    a. to eliminate the reaction product, carbon dioxide and carbonic acid
    b. to destroy the buffering action of the resulting solution due to the presence of carbonic acid and unreacted hydrogen carbonate
    c. to achieve a sharper endpoint due to the large decrease in pH
    d. all of these

24. The volume of a solution chemically equivalent to a mass of a solid reagent
    a. titer b. aliquot c. molarity d. ppm

25. For the acid HA, $K_A = 5.8 \times 10^{-10}$, the pH when the anion and the molecular acid concentrations are equal is
    a. 5.7 b. 6.3 c. 7.3 d. 9.24

26. Process of determining the nitrogen content of organic materials by mixing the sample with powdered copper (II) oxide and ignited to a combustion tube giving CO_2, H_2O, N_2 and small amounts of nitrogen oxides.
    a. Kjeldahl Method c. Winkler Method
    b. Dumas Method d. Wij's Method

27. What is the best basis for choosing the right indicator for a given acid-base titration from among the following?
    a. type of acid c. pH at equivalence point
    b. type of base d. molarity of the acid or base

28. Calculate the molarity of NaOH solution if 12.25 mL was used to titrate 0.2615 gram of primary standard KHP.
    a. 0.1045 b. 0.1354 c. 0.2509 d. 0.1697

29. In standardizing a solution of NaOH against 1.431 grams of KHP, the analyst uses 35.50 mL of the alkali and has to run back with 8.25 mL of acid (1mL = 10.75 mg NaOH). What is the molarity of the NaOH solution?
    a. 0.2118 M b. 0.2044 M c. 0.7831 M d. 0.2598 M

30. A solution that may contain NaOH, Na_2CO_3 and $NaHCO_3$, alone or in compatible combination was titrated with 0.1200 M HCl. The volume of the acid required to reach the phenolphthalein endpoint was 25.67 mL while 38.13 mL to reach the methyl red endpoint. What are the components of the mixture?
    a. NaOH and Na_2CO_3 c. Na_2CO_3 only
    b. Na_2CO_3 and $NaHCO_3$ d. NaOH only

31. A sample consisting of Na_2CO_3, NaOH and inert matter weighs 1.179 grams. It is titrated with 0.2239 M HCl with phenolphthalein as the indicator, and the solution became colorless after the addition of 45.62 mL. Methyl orange is then added and 12.85 mL more of the acid are needed for the color change. What is the percentage of Na_2CO_3 in the sample?
    a. 24.89% b. 64.95% c. 76.12% d. 25.87%

32. A sample consisting of Na_2CO_3, $NaHCO_3$ and inert matter weighs 1.179 grams. It is titrated with 0.1000N HCl with phenolphthalein as the indicator, and the solution became colorless after the addition of 24.00 mL. Another duplicate sample was titrated with HCl using methyl orange as indicator. It required 50.25 mL of the acid for the color change. What is the percentage of $NaHCO_3$ in the sample?
    a. 1.60% b. 5.17% c. 12.56% d. 21.58%

33. A 758-mg sample of full cream milk was analyzed by the Kjeldahl method; 38.61 mL of 0.1078 M HCl were required to titrate the liberated ammonia. Calculate the % N in the sample.
    a. 12.04% b. 7.73% c. 15.69% d. 10.93%

34. A 5.8734-gram sample of beef was analyzed for its N content and the liberated NH_3 was collected in a 50.00 mL of 0.4691 M HCl and a 12.55 mL back titration with 0.0256 M NaOH was required. Calculate the percentage protein in the beef sample.
    a. 17.32% b. 5.54% c. 34.64% d. 11.08%

35. Which of the following methods is NOT used for the direct determination of halides?
    a. Volhard
    b. Mohr
    c. Fajans
    d. none of these

36. What is the molar concentration of $AgNO_3$ solution standardized against 712 mg primary standard NaCl (58.45 $^{g}/_{mol}$) requiring 23.8 mL of the solution for titration?
    a. 0.5027 M b. 0.5118 M c. 0.5263 M d. 0.5329 M

37. Which of the following is not a correct analytical method–titrant pair?
    a. Mohr–$AgNO_3$
    b. Fajans – $AgNO_3$
    c. Volhard – $AgNO_3$
    d. Liebig – $AgNO_3$

38. A mixture of LiBr and $BaBr_2$ weighing 800 mg is treated 50.00 mL of 0.1879 M $AgNO_3$ and the excess is found to require 8.76 mL of 0.3179 M KSCN for back titration, using ferric alum as indicator. What is the percentage of $BaBr_2$ in the sample?
    a. 67.95% b. 32.05% c. 35.62% d. 64.38%

39. A 1.500-gram sample of impure $AlCl_3$ was dissolved in water and treated with 45.32 mL of 0.1000 M $AgNO_3$ using Mohr method. Determine its purity. $AlCl_3$(133.33)
    a. 40.28% b. 13.43% c. 4.48% d. 27.36%

40. A 500-mg sample containing NaCN required 23.50 mL of 0.1255 M $AgNO_3$ to obtain a permanent faint turbidity. Express the result of this analysis as % CN^-.
    a. 15.34% b. 23.01% c. 17.25% d. 30.67%

41. A 750.25-mg alloy of nickel was dissolved and treated to remove the impurities. The ammoniacal solution was treated with 50 mL of 0.1075 M KCN and the excess cyanide required 2.25 mL of 0.00925 M $AgNO_3$. Determine % Ni in the alloy.
    a. 20.86% b. 37.69% c. 10.53% d. 41.72%

42. An EDTA solution prepared from its disodium salt was standardized using 506.3 mg of primary standard $CaCO_3$ and consumed 28.50 mL of the solution. The standard solution was used to determine the hardness of a 2L sample of mineral water, which required 35.57 mL EDTA solution. Express the analysis in terms of ppm $CaCO_3$.
    a. 89 ppm b. 316 ppm c. 158 ppm d. 269 ppm

43. What volume of 0.0305 M EDTA is needed to titrate the Ca in 178.56 mg of $CaCO_3$?
    a. 58.54 mL b. 29.27 mL c. 43.91 mL d. 14.64 mL

44. Ethylenediamminetetraacetic acid (EDTA) is a ____________ ligand.
    a. bidentate
    b. tridentate
    c. hexadentate
    d. tetradentate

45. Commonly, the analyte in a sample is present in two different oxidation states. Pre-reduction is necessary before titration. One of the metallic reductors is zinc soaked in a dilute solution of mercuric chloride. This reductor is also known as
    a. Walden reductor
    b. Devarda alloy
    c. Lindlars catalyst
    d. Jones reductor

46. What is the molarity of a $KMnO_4$ solution standardized against 1.356 gram $Na_2C_2O_4$ (134 $^{g}/_{mol}$) requiring 25.1 mL of the solution in acidic medium?
    a. 0.161 M
    b. 0.403 M
    c. 1.008 M
    d. 0.856 M

47. The percentage of MnO_2 in a 500 mg sample which after the addition of 80.00 mL of 0.1056 M $FeSO_4$ solution required 8.50 mL of 0.0867 M $K_2Cr_2O_7$ is
    a. 33.52%
    b. 35.00%
    c. 17.50%
    d. 67.04%

48. A 240-mg sample of pyrolusite was treated with excess KI. The iodine liberated required 46.24 mL of 0.1105 M $Na_2S_2O_3$ solution. Calculate % MnO_2 in the sample.
    a. 46.27%
    b. 30.85%
    c. 92.54%
    d. 76.12%

49. A sample of iron ore weighing 385.6 mg was dissolved in acid and passed through a Jones reductor. If the resulting solution required 52.36 mL of 0.01436 M $K_2Cr_2O_7$ for titration, calculate % Fe_3O_4 (231.55 $^{g}/_{mol}$) in the ore sample.
    a. 15.05%
    b. 45.15%
    c. 90.30%
    d. 67.98%

50. A solution containing 4.48 ppm $KMnO_4$ has a transmittance of 0.576 in a 1.00 cm cell at 520 nm. If the transmittance of an unknown solution is 0.735, what is the concentration of the unknown $KMnO_4$ solution in ppm?
    a. 2.50 ppm
    b. 3.85 ppm
    c. 2.15 ppm
    d. 1.65 ppm

D. PHYSICAL CHEMISTRY

Physical Chemistry – branch of chemistry which deals with the study of the physical properties and structure of matter, the laws of chemical interaction as well as the theories governing these interactions.

Gases

Ideal Gas – ideal behavior occurs at low pressure and a relatively high temperature. At these conditions, the free space within the gas is large and the attractive forces among molecules are small.

Gas Laws

a. *Boyle's Law* – the volume of any definite quantity of gas at constant temperature varies inversely as the pressure on the gas.

$$PV = k$$

b. *Charles or Gay-Lussac Law* – the volume of a definite quantity of gas at constant pressure is directly proportional to the absolute temperature.

$$V = kT$$

c. *3rd Gas Law* – the pressure of a definite quantity of gas at constant volume is directly proportional to the absolute temperature.

$$P = kT$$

d. *The Combined Gas Law* – simultaneous variations of volume with temperature and pressure complete the relationship among P, V, and T of any gas.

$$PV = kT$$

Ideal gas equation $PV = nRT$

e. *Dalton's Law of Partial Pressure* – at constant temperature, the total pressure exerted by a mixture of gases in a definite volume is equal to the sum of the individual pressures which each gas would exert if it occupied the same total volume only.

$$P_{total} = P_1 + P_2 + P_3 + \ldots + P_i$$

where: $\boldsymbol{P_1, P_2, P_3, \ldots P_i}$ = partial pressures of the respective gases

For ideal gases, the partial pressure ($\boldsymbol{P_i}$) of any component in a gas mixture is equal to the mole fraction of that component (N_i) multiplied by the total pressure ($\boldsymbol{P_t}$).

$$P_i = N_i P_t$$

f. *Amagat's Law of Partial Volume* – in any gas mixture the total volume may be considered to be the sum of the partial volumes of the constituents of the mixture.

$$V_{total} = V_1 + V_2 + V_3$$

where: V_1, V_2, V_3, etc., are partial volumes

g. *Graham's Law of Diffusion* – at constant temperature and pressure the rates of diffusion of various gases, *r*, vary inversely as the square roots of their densities or molecular weights.

$$\frac{r_1}{r_2}=\frac{\sqrt{\rho_2 V_m}}{\sqrt{\rho_1 V_m}}=\frac{\sqrt{M_2}}{\sqrt{M_1}}$$

where: M_1 and M_2 are molecular weights, ρ_1 and ρ_2 are densities and V_m is the molar volume.

Effusion is a process whereby gas molecules leak out through an orifice of molecular size and for a gaseous mixture the rate *(r)* of effusion is given as,

$$\frac{r_1}{r_2}=\frac{p_1\sqrt{M_2}}{p_2\sqrt{M_1}}$$

where: p_i is the partial pressure of gas component *i*.

Under identical pressures for each gas,

$$\frac{r_1}{r_2}=\frac{\sqrt{\rho_2 V_m}}{\sqrt{\rho_1 V_m}}=\frac{\sqrt{M_2}}{\sqrt{M_1}}=\frac{t_2}{t_1}=\sqrt{\frac{\rho_2}{\rho_1}}$$

Kinetic Molecular Theory

- attempts to explain the properties of gases and gas laws
- first proposed by Bernoulli (1738) and extended by Clausius, Maxwell, Boltzmann, Van der Waals and Jeans

Equations

1. $PV=\frac{1}{3}mu^2$
2. $E_k=\frac{3}{2}nRT$
3. $E_k=\frac{3}{2}PV$
4. $u=\sqrt{\frac{3RT}{M}}$

Kinetic energy of translation (E_k)– energy ascribed to gas molecules due to molecular motion along the three coordinate axes.

$$\frac{E_k}{N}=\frac{3RT}{2N}=\frac{3}{2}kT$$

where: $k = R/N$ = Boltzmann constant = 1.3805×10^{-16} erg per degree

Frequency of Collisions (Z)

$$Z=\sqrt{2}\pi v\sigma^2(n_5)^2$$

where: Z = total number of colliding molecules per cu cm per sec
v = average molecular velocity in cm/s
σ = average molecular diameter in cm
n_5 = total number of molecules per cu cm.

Mean free path (l)

$$l=\frac{1}{\sqrt{2}\pi\sigma^2 n_5}$$

Deviation from Ideal Behaviour

1. ***Compressibility Factor, Z***

$$Z = PV/nRT$$

For ideal gases, $Z = 1$ at all T and P.

$Z > 1$, high pressures, repulsive forces are dominant

$Z < 1$, intermediate pressure, attractive forces are dominant

2. ***Van der Waals Equation of State***

– accounts for both the volume occupied by the molecules and the attractive forces between them

$$\left[P + \frac{n^2 a}{V^2}\right](V - nb) = nRT$$

3. ***Kamerlingh-Onnes Equation of State***

$$PV_m = A + BP + CP^2 + DP^3 + \ldots$$

4. ***Berthelot Equation***

$$PV = nRT\left[1 + \frac{9\,PT_c}{128\,P_c T}\left(1 - \frac{6\,T_c^2}{T^2}\right)\right]$$

5. ***Beattie-Bridgeman Equation of State***

$$P = \frac{RT}{V_m} + \frac{\beta}{V_m^2} + \frac{\gamma}{V_m^3} + \frac{\delta}{V_m^4}$$

Methods of Molecular Weight Determination

1. *Regnault's Method*: for molecular weights of gaseous substances at room temperature
2. *Dumas' Method*: for molecular weights in the vapor phase of readily volatilized liquids
3. *Victor Meyer Method*: simpler method than Dumas' method for vapor density determination
4. *Exact Molecular Weight Determination*: method of limiting densities

I. Liquids

– from the kinetic theory viewpoint, a liquid may be considered as a continuation of the gas phase into a region of small volumes and very high molecular attractions

Critical Phenomena of Liquids – saturated vapor pressure of a liquid = characteristic for each liquid and is fixed at any given temperature

Critical Point – the temperature at which the physical properties of liquid and vapor become identical and no distinction can be observed between the two

Temperature = critical temperature (T_c)

Pressure = critical pressure (P_c)

Molar Volume = critical volume (V_c)

For water the critical constants are: $T_c = 374.4°C$, $P_c = 219.5$ atm, $V_c = 58.7$ mL/mol

Viscosity

- common property for both liquids and gases
- resistance that one part of a fluid offers to the flow of another part of the fluid
- produced by the shearing effect of moving one layer of the fluid past another layer

η – viscosity coefficient of the fluid or simply viscosity – force per unit area required to move a layer of fluid with a velocity difference of 1 cm per second past another parallel layer 1 cm away.

Viscosity of Ideal Gases

$$\eta = \frac{1}{3} v l \rho$$

where: v = is the average velocity of the gas molecules; l = is the mean free path; ρ = is the density of the gas

Viscosity of Liquids

Poiseuille equation for the viscosity of a liquid

$$\eta = \frac{\pi \Pr^4 t}{8LV}$$

where: V = is the volume of the liquid; t = time of flow through a capillary tube of radius r and length L under a pressure head of P

Using the same capillary tube, for two liquids,

$$\frac{\eta_1}{\eta_2} = \frac{P_1}{P_2}\frac{t_1}{t_2} = \frac{\rho_1}{\rho_2}\frac{t_1}{t_2}$$

Stoke's Law – concerned with the fall of bodies through fluid media

$$\eta = \frac{2r^2(\rho - \rho_m)g}{9v}$$

where: r = is the radius of a spherical body of density ρ, falling through a fluid of density ρ_m at a constant velocity v

Stoke's law is the basis of the falling sphere viscometer

Ratio of two viscosities yields,

$$\frac{\eta_1}{\eta_2} = \frac{(\rho - \rho_{m1})t_1}{(\rho - \rho_{m2})t_2}$$

Temperature dependence of viscosity of liquids, $\eta = Ae^{\Delta E/RT}$

That is, ln η varies linearly with $^1/_T$, where T is the absolute temperature

$$\ln \eta = \ln A + \frac{\Delta E}{RT}$$

where : ΔE is the heat of viscosity $\approx 0.3\, \Delta E_{vap}$ and is constant

II. Solids

– definite shape and volume, rigid and exhibits certain hardness

Crystalline – constituent structural units are arranged in a definite geometrical configuration characteristic of the substance
– melts sharply at a constant and definite temperature

Amorphous – does not show a definite configurational arrangement
– not considered as true solids but highly supercooled liquids with very high viscosity
– melts gradually over a temperature interval

Heat of Crystallization – amount of heat evolved during crystallization or solidification per mole of substance at a given temperature and pressure

Heat of Fusion – the reverse of heat of crystallization = amount of heat that must be absorbed in the transition of one mole of solid to liquid

Crystallography

– a study dealing with the geometry, properties and structure of crystals and crystalline substances.

Crystal Systems

– 230 possible crystal forms
– according to symmetry; may be grouped into 32 classes.

Six Crystal Systems

SYSTEM	AXIAL CHARACTERISTICS	MAXIMUM SYMMETRY	EXAMPLES
Cubic	Three axes at right angles a = b = c	Nine planes Thirteen axes	NaCl, KCl, Alum, Diamond, CaF_2
Tetragonal	Three axes at right angles with two equal lengths $a = b \neq c$	Five planes Five axes	TiO_2, $ZrSiO_4$, SnO_2
Hexagonal	Two axes of equal lengths in one plane making an angle of 120° with each other A third axis at right angles to these and of unequal lengths $a = b \neq c$	Seven planes Seven axes	PbI_2, Mg, Beryl, CdS, ZnO
Orthorhombic (Rhombic)	Three axes at right angles, but all of different lengths $a \neq b \neq c$	Three planes Three axes	KNO_3, Rhombic sulfur, K_2SO_4, $BaSO_4$, $PbCO_3$
Monoclinic	Three axes at right angles, but all of different lengths $a \neq b \neq c$	One plane One axis	$Na_2SO_4 \cdot 10H_20$, $CaSO_4 \cdot 2H_2O$, Monoclinic sulfur
Triclinic	Three axes at right angles, but all of different lengths $a \neq b \neq c$	No planes No axes	$CuSO_4 \cdot 5H_2O$, K_2CrO_7, H_3BO_3

Polymorphism

– existence of substances in more than one modification
Example: Carbon exists as diamond or graphite, calcium carbonate as calcite or aragonite
Allotropy – polymorphism occurring in elements
– transformation from one form to another takes place at a temperature known as transition temperature or transition point

Solutions

Colligative properties – depend on the number of solute particles and not on the nature of the solute or solvent

The presence of solute in a given solution will bring about the following:

2. *Lowering of Vapor Pressure*

$$\Delta P = P^{\circ}N_l$$

where: P° = vapor pressure of pure solvent
N_l = mole fraction of the solvent in the solution
ΔP = extent of vapor pressure lowering

3. *Elevation of Boiling Point*

$$\Delta t_b = k_b m$$

where: $\Delta t_b = t_{b\ solution} - t_{b\ solvent}$
k_b = ebullioscopic constant
m = molality

4. *Depression of Freezing Point*

$$\Delta t_f = k_f m$$

where: $\Delta t_f = t_{f\ solvent} - t_{f\ soln}$
k_f = cryoscopic constant

5. *Osmotic Pressure (π)*
– minimum pressure required to prevent osmosis

$$\pi V = n_2 RT$$

where: n_2 = moles of solute
V = volume of solution
R = gas constant
T = absolute temperature

For solution of electrolytes, there is an increase in the number of particles due to ionization. To account for this increase, the use of Van't Hoff factor, *i*, in the equations above is required. The Van't Hoff factor may also be related to the degree of dissociation (L) of the electrolyte

$$L = \frac{i-1}{v-1}$$

where: v = number of ions formed upon dissociation of one molecule of the electrolyte

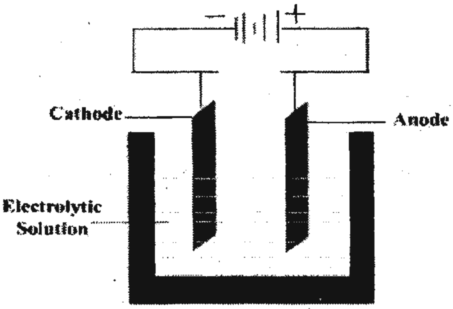
Electrolysis

– a redox reaction brought about by the passage of a direct current through a solution of an electrolyte

In electrolytic conduction, the following phenomena occur:

a. *mass movement of ions*
+ ions → cathode (-)
- ions → anode (+)

- this migration involves not only transfer of electricity from one electrode to the other, but also a transport of matter from one part of the conductor to the other.



b. *occurrence of REDOX reactions*

Example: electrolysis of aqueous NaOH

$NaOH \rightarrow Na^+ + OH^- \rightarrow$ (+) anode
$H_2O \rightarrow H^+ + OH^-$ (slight)
$\downarrow$
cathode

anode: $2\,OH^- \rightarrow 2H^+ + O_{2\,(g)} + 4e^-$
cathode: $2H^+ + 2e^- \rightarrow H_{2(g)}$
overall: $2OH^- + 2H^+ \rightarrow O_{2(g)} + 2H_{2(g)}$

Types of Electrochemical Cells

1. *Galvanic cell* – produces electricity as a result of the spontaneous reactions occurring inside it. In a galvanic cell, the cathode has a higher potential than the anode.
2. *Electrolytic cell* – non-spontaneous reaction is driven by an external source of current. They have a common electrolyte and no salt bridge.

Faraday's Law

- mass of substance involved in the reaction at the electrode is proportional to the quality of electricity passed through the solution.

The following relations maybe used in electrolysis:

1. equivalent weight = $\dfrac{\text{atomic wt.}}{\text{change in valence}}$

2. gram-equivalent weight = $\dfrac{wt}{eq.wt}$

   Faraday – number of coulombs involved in the oxidation or reduction of 1 gew; 1 F = 96,500 coulombs

3. 1 F = 1 gew

4. Q (coulombs) = $I \times t$ [Charge = (current) (time)]

$$w = E\,I\,t = E\,Q \qquad p = E\,I = \frac{EQ}{t}$$

5. $$F = \frac{Q}{96{,}500} \qquad gew = \frac{It}{96{,}500} \qquad \frac{wt}{eq.wt} = \frac{It}{96{,}500}$$

Cell Reactions

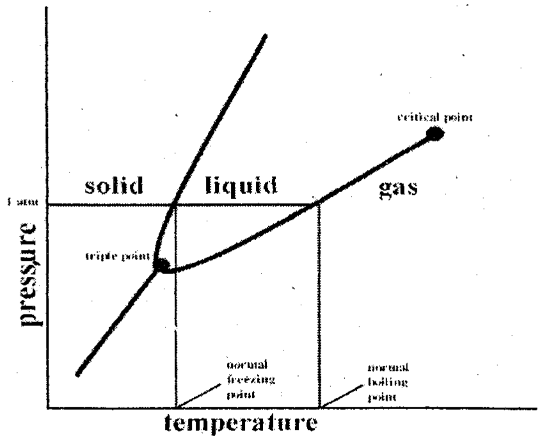
– reactions in the cell written on the assumption that the right hand electrode is the anode.

Example: $Zn_{(s)}\mid ZnSO_{4(aq)}\parallel CuSO_{4(aq)}\mid Cu_{(s)}$

Their reduction half reaction are

Left: $Zn^{+2}_{(aq)} + 2e \rightarrow Zn_{(s)}$
Right: $Cu^{+2}_{(aq)} + 2e \rightarrow Cu_{(s)}$
Overall: $Cu^{+2} + Zn \rightarrow Cu + Zn^{+2}$

Phase Diagram



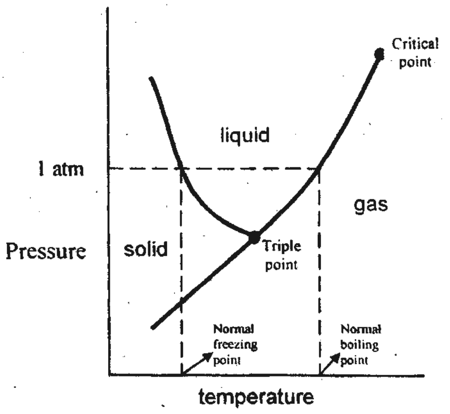
Generally, heating causes a solid to melt (at the melting or freezing point). Continued heating (to the boiling point) produces a gas. Following the horizontal line beginning at the pressure axis at 1 atm, the substance begins as a solid, passes the normal freezing (or melting) point into a liquid, then boils to a gas.

For most substances, at higher pressures, the freezing and boiling points are higher. Once boiling begins, the temperature remains fixed at the boiling point until all of the liquid is converted to gas. Thus, at the boiling point, liquid and gas coexist in equilibrium. Similarly, solid and liquid coexist in equilibrium at the melting point.

The triple point is the temperature and pressure at which all three phases can exist in equilibrium. When liquid is warmed at constant pressure, a point is reached at which the boundary between the liquid and the gas phases disappears. This point is known as the critical point and the substance is said to be in the critical state. Above the critical point, gases are unable to liquefy.

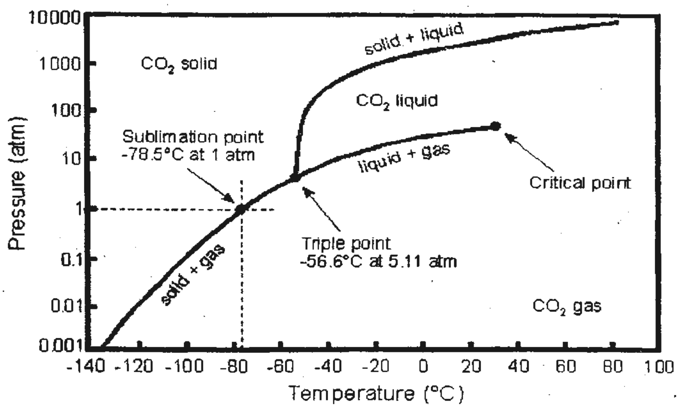
The heat of fusion is the amount of energy given off when a substance freezes (or the amount of energy the substance requires to liquefy). The heat of vaporization is the amount of energy given off when a ~~gas~~ liquid vaporizes (or the amount of energy needed to condense a vapor).

Two Special Cases



1. **Water.** The same diagram for water shows the characteristic negative slope on the solid-liquid equilibrium line that accounts for why water floats. The hydrogen bonds which form in liquid water make the liquid unusually dense, even denser than the solid, hence the ice floats. The melting point of water decreases as the pressure increases. The difference between the freezing point and the triple point is only 0.01°C. The normal freezing point is 273.15 K and the triple point is 273.16 K. The curve slopes to the left because the density of the solid is less than that of the liquid.

2. **CO_2**



Pressure-Temperature phase diagram for CO_2.

CO_2 is different from many substances in that its triple point is at a pressure above 1 atm. The result is the practical phenomena of dry ice.

REVIEW QUESTIONS AND PROBLEMS

b 1. One of these statements is not correct for ideal gases.
   a. The volume occupied by the gas is negligible compared to the volume of the containing vessel.
   b. The product of PV is a constant.
   c. The ratio of density/pressure is constant at a given temperature.
   d. PV/T is a constant for a known quantity of a gas.

b 2. For ideal gas possessing only translational energy, the following relationships are valid except
   a. $C_p = 2.5\ R$
   b. $C_p = C_v - R$
   c. $C_v = 1.5\ R$
   d. $C_p/C_v = 1.67$

b 3. If a given gas has a compressibility factor, Z>1, this means that _____ exist between the molecules of gases.
   a. attractive forces
   b. repulsive forces
   c. negligible forces of attraction
   d. negligible repulsive forces

a 4. All of the following may be deduced from the kinetic theory of gases except
   a. a derivation of the Van der Waals equation
   b. derivation of Boyle's and Charles' Law
   c. relation of average kinetic energy of gases to temperature
   d. Graham's law of diffusion

5. In the Van der Waals equation for non ideal gases,

$$\left(P+\frac{n^2a}{V^2}\right)(V-nb)=nRT$$

   It is not true that
   a. $\frac{n^2a}{V^2}$ correct for intermolecular forces
   b. *nb* correct for the volume occupied by gas molecules
   c. at high densities, the operation reduces to the ideal gas law
   d. all of the above are correct

6. All of the following factors increase the strength of Van der Waals forces between molecules except by an
   a. increase in the molecular weight of the molecules
   b. increase in the number of atoms in the molecules
   c. increase in the number of electrons in the molecules
   d. increase in the ionic strength of the molecule

d 7. Which of the following statements is not valid?
   a. Above the critical temperature, the given substance has a single phase occupying the entire volume of the container.
   b. The T_c of O_2 is 155 K, this means that it is impossible to produce O_2 if its T is above 155 K.
   c. To liquefy a given substance at T_c, high pressure must be applied.
   d. Liquid and vapor both exist at T_c and both phases are distinct.

c 8. Which of the following is the best explanation for the effect of increase in temperature on the rate of reaction?
   a. It increases the number of particles with the necessary activation energy.
   b. It enables the reacting particles to gain the necessary activation energy.
   c. It lowers the activation energy for the reaction.
   d. It enables the activated complex to be more easily converted to products.

a 9. For a chemical reaction in a state of equilibrium, a decrease in temperature will
   a. favor the reaction that is exothermic
   b. favor the reaction that is endothermic
   c. have no effect on the system
   d. increase the equilibrium constant of the system

c 10. One colligative property of solutions is its freezing point depression. Which observation will show that the solute is an electrolyte *($\Delta t_f/m$)*?
   a. is not a constant
   c. is less than K_f
   b. is not K_f
   d. is greater than K_f

a 11. Which of these 0.1 m solutions will give the highest boiling point at 1 atm?
   a. table salt solution
   c. barium chloride
   b. sugar solution
   d. potassium chloride

b 12. The evidence that the solute does not freeze with the solvent is that
   a. the first crystals formed are precipitates of the solute
   b. the freezing point of the solution that remains a liquid is getting lower and lower as freezing proceeds
   c. the crystals formed could clearly be seen as that of the solution
   d. the freezing point is a constant

b 13. Conductance measurements at infinite dilution will be valid for the determination of the solubility of difficultly soluble salts at saturation point because
   a. they have very low concentrations at their saturation point
   b. they conduct minimal current
   c. at infinite dilution the concentration cannot be achieved
   d. they are strong electrolytes

a 14. A chemical process may mean any of the following: removal of oxygen, decrease in valence and addition of hydrogen is called
   a. reduction
   c. combustion
   b. oxidation
   d. combination

b 15. What term is used to define the phenomenon of emission of light in a chemical reaction?
   a. Photosensitisation
   b. Chemical luminiscence
   c. Photosensitisation and Chemical luminescence
   d. None of these

16. An electrochemical cell in which chemical reaction is forced to occur by the application of an outside source of energy is
   a. galvanic   b. electrolytic   c. electrical   d. chemical

a 17. The equation: $\varepsilon_{glass} = \varepsilon^{0}\ (2.3026\ RT/F)\ pH$
   a. relates pH to electromotive force
   b. shows how potentiometric titration works
   c. shows the relationship between a calomel electrode with a silver- silver chloride
   d. shows emf relationship

b 18. The reaction that occurs in the anode is
   a. reduction   c. either oxidation or reduction
   b. oxidation   +7   d. combination

-2

c 19. In redox reaction, reduction of MnO_4^- to Mn^{+2} requires the presence of a/an
   a. base   b. salt   c. acid   d. metal

20. The half-life period of any first-order reaction is
   a. half the specific rate constant
   b. independent of the initial concentration
   c. is always the same whatever is the reaction
   d. is directly proportional to the initial concentration of the reactant.

c 21. The vapor pressure of a liquid
   a. always increases with temperature   c. is independent of temperature
   b. always decreases with temperature   d. increases only up to boiling point

22. The law relating the solubility of the gas to its pressure is called
   a. Raoult's Law   c. Henry's Law
   b. Distribution Law   d. Arrhenius' Law

23. Absolute zero maybe regarded as that temperature at which
   a. all gases become liquids   c. molecular motion ceases
   b. all substances are solids   d. water freezes

b 24. For the process $C_{(s)} + O_{2(g)} \leftrightarrow CO_{2(g)}$, it is found that ΔG at a given temperature is –10 kcal/mole. Which statement is correct at this temperature?
   a. The system is in equilibrium.
   b. CO_2 will be formed spontaneously.
   c. CO_2 will decompose spontaneously.
   d. The process will proceed reversibly.

25. When a liquid is in dynamic equilibrium with its vapor, the following conditions could exist:
   a. There is no transfer of molecules between liquid and vapor.
   b. The vapor pressure has a unique value.
   c. The opposing process (liquid to vapor and vapor to liquid) proceed at equal rates.
   d. The concentration of vapor is dependent on time.

   Which of the above choices are applicable ?
   a. (a)
   b. (b) and (c)
   c. (a), (b) and (c)
   d. (b) and (d)

d 26. As the atmospheric pressure decreases, the boiling point of a liquid
   a. cannot be determined
   b. is not affected
   c. increases
   d. decreases

27. All the half-cell potential (ε°) use the _____ as the reference.
   a. Hydrogen electrode
   b. oxygen half-cell
   c. carbon half-cell
   d. arbitrarily net zero point

a 28. The more negative the value of ε°, the more likely the reaction is to proceed from
   a. left to right
   b. right to left
   c. either way
   d. can't be determined

a 29. For ideal solutions, the activity of each constituent under all conditions of temperature and pressure is equal to its
   a. mole fraction
   b. molality
   c. density
   d. molarity

b 30. When evacuated or empty, a gas density bulb weighs 29.3215 grams. First, CO_2 gas was used to fill the bulb at 40°C and 1.0 atm pressure and it weighed 30.0079g. The bulb was then evacuated and filled with a mixture of CO and CO_2 under the same temperature and pressure. With this mixture the bulb weighed 29.9332g. Determine the % of CO in the mixture.
   a. 21   b. 29   c. 32   d. 15

31. The following data were obtained in the determination of a HC gas containing 92.3 % wt C at -9°C at various pressure:

P	1	2	3
p	1.45	1.7	1.95

   Identify the gas.
   a. CH   b. C_2H_2 c. C_3H_8 d. C_2H_6

32. At what temperature will the velocity of CO_2 molecules equal the velocity of oxygen molecules at 0°C
    a. 102°C b. 632°C c. 132°C d. 125°C

33. A mixture of 0.660 grams of camphor and 0.050 gram of an organic solute freezes at 157°C. If the solute contains 10.5% H by weight, determine the molecular formula of the solute if the freezing point of camphor is 178.4°C and the value of K_f is 38.
    a. $C_{10}H_{12}$ b. C_2H_6 c. C_6H_6 d. C_8H_{16}

34. A 0.2 m aqueous solution of KCl freezes at – 0.680°C. The osmotic P at 0°C is
    a. 9.8 atm b. 16.3 atm c. 8.2 atm d. 10.8 atm

35. An aqueous solution of gold nitrate is electrolyzed with a current of 0.555 ampere until 1.32 g of Au has been deposited on the cathode. If the atomic weight of Au is 197, determine the duration of the electrolysis.
    a. 65.43 min b. 23.67 min c. 58.28 min d. 60 min

36. Ethyl alcohol is to be used in an automobile carburetor that is adjusted to give a 9 to 1 air-fuel ratio (mass ratio). If the temperature in the manifold is 60°F and the pressure is atmospheric, what percentage of the alcohol will be evaporated assuming that equilibrium between vapor and liquid is reached ?
    a. 55% b. 75% c. 65% d. 90%

37. If ethanol and methanol are mixed 50/50 by weight at 60°C, and the solution assumed ideal, the composition of the vapor above the solution is
    a. 28% ethanol, 72% methanol c. 59% ethanol, 41% methanol
    b. 72% ethanol, 28% methanol d. 41% ethanol, 59% methanol

38. A solvent- water mixture is to be distilled at 95°C. The vapor pressure of the solvent at this temperature is 130 mmHg and that of water is 640 mmHg. The solvent is immiscible in water and has a molecular weight of 150. The weight of the solvent in kilograms that will be carried over in the distillate with 200 kg of water is
    a. 358.73 b. 423.57 c. 338.54 d. 524.63

39. $PCl_{5(g)}$ dissociates into $PCl_{3(g)}$ and $Cl_{2(g)}$ when heated at 250°C and 1 atm. If the density of the gas mixture at equilibrium is 4.4 g/L, the fraction of PCl_5 (g) dissociated is
    a. 0.103 b. 0.328 c. 0.725 d. 0.209

40. At 3000 K and 1 atm, CO_2 is 40% dissociated to CO and O_2. Its percentage dissociation when the pressure is increased to 2 atm is
    a. 0.350 b. 0.335 c. 0.425 d. 0.375

E. BIOCHEMICAL ENGINEERING

Biochemical Engineering – concerned with conducting biological processes on an industrial scale, providing the link between Biology and Chemical Engineering. It is concerned with the:

1. study of the numerous fermentation process in which the production of alcohols, organic acids, glycerol, acetone and other substances are end-products
2. study of certain aspects of food manufacturing processes such as the making of cheese, butter and pickles in which microbic agency takes a significant part
3. study of food conservation methods
4. study of biological waste disposal

Common Features of Biological Systems

1. Organisms share a common physical structure in that the cell is the fundamental unit structure of living organism.
2. They share common chemical composition as shown by the presence of protein, DNA and RNA.
3. They perform common metabolic activities; while these metabolic or chemical activities differ in detail, the resemblance are more than the differences.

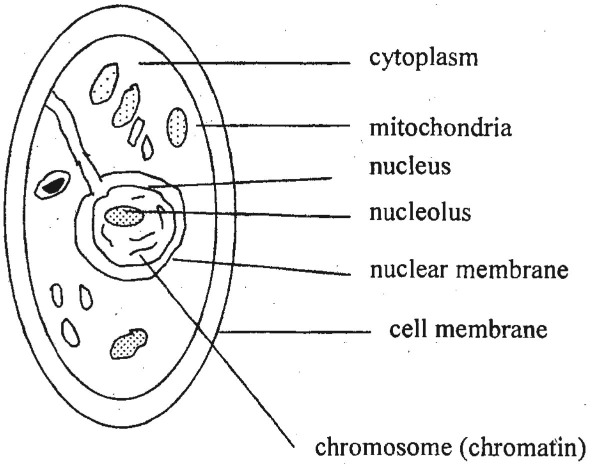
Biochemical Industries

1. Food Industries
2. Pharmaceutical Industries
3. Brewery and Distilling Industries
4. Waste Treatment

Products of Microbial Activity Having Commercial Importance

1. Antibiotics – Penicillin, Streptomycin, Tetracyclines
2. Organic Solvents – ethanol, butanol, acetone
3. Gases – CO_2, H_2, CH_4
4. Beverages – wine, beer, distilled spirits
5. Foods – cheese, fermented milk, soy sauce, vinegar, citric acid, yeast
6. Flavoring Agents – Monosodium Glutamate, soy sauce, Nucleotides
7. Organic Acids – lactic acid, acetic acid, butyric acid, propionic acid, citric acid
8. Glycerol
9. Amino Acids – lysine, alanine
10. Steroids
11. Food and Feed Yeast – Baker's Yeast, Brewer's Yeast, Fodder's Yeast
12. Legume Inoculant
13. Bacterial Insecticides
14. Vitamins – Vit. B_{12}, Riboflavin, Vit. A, gibberilline
15. Enzymes – amylase , protease, pectinase, invertae

Cell and Its Parts



1. *Cell membrane* – composed of proteins and lipids, and serves as a barrier from the external environment. It is semi-permeable and selectively permits passage of substance into the cell while allowing exit of waste.
2. *Cytoplasm* – contains other organelles and the nucleus.
3. *Nucleus* – regulates metabolic and reproductive activities.
4. *Mitochondria* – contains the respiratory system.
5. *Chloroplasts* – mitochondria of photosynthetic organism.
6. *Golgi bodies* – transport materials of cellular product.
7. *Cell wall* – protective substance of the cell.

Characteristics of Biological Material

Microorganisms are chemically very similar to higher animal cells and they can perform many of the same biochemical reactions. Generally, microorganism exists as single cell.

There are four groups of organisms which a biochemical engineer is interested with namely:

a. Bacteria
b. Fungi including yeasts and actinomycetes
c. Protozoa including algae
d. Viruses including bacteriophage

The characteristics of biological material could be summarized:

1. *Bacteria* contain 50-60% protein, yeast 40-50% and mold 20%, most of which in enzymic. Some species have a high lipid (or carbohydrate) content but generally, less than 10%. *Viruses* contain up to 50% nucleic acid, bacteria 20%, yeast 10% and mold 3%.

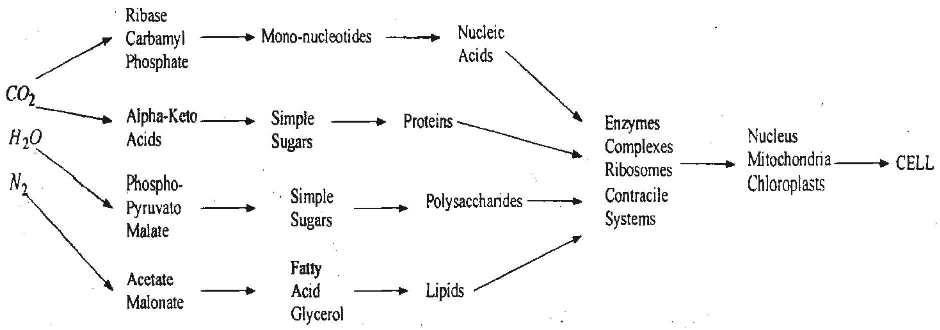
2. *Viruses* are obligate parasites and require a specific host cell for their multiplication, often killing the host in the process. Bacteria are largely unicellular and haploid (one set of genes) with the nuclear material lying free in the cytoplasm. They multiply by simple fission, though a primitive mating system had been found in the enteric bacteria. Fungi are multicellular with many migrating nuclei. They multiply by apical extension of the hythal filaments and may produce both sexual and asexual spores. Yeast, however, grow by budding from single ovoid cell.

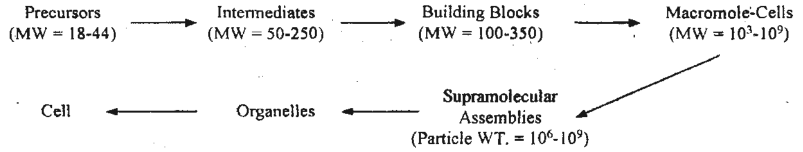
3. The microbial cell genetic properties are preserved in their DNA. Four nucleotive (NMP, TMP, CMP, GMP) are polymerized in two strands bonded to each other to form a double helix. The bases are arranged such that adenine in one strand is complementary to thiamin in the other, while guanine is complementary to cytosine. When the DNA replicates, the order of bases in DNA is conserved by the two separate strands, each acting as template, while the nucleotive complementary to those existing strands are polymerized to form two double-stranded molecules identical with the original one. Errors which may occur in the copying process give rise to mutant.

4. When protein is required by a cell, the information for its synthesis is transcribed from one strand of the DNA into m-RNA; the order of bases in DNA code is the order of bases in m-RNA. The m-RNA associated with ribosomes (non-specific, relatively stable organelles) where the protein is synthesized. The amino acids are activated and associated with a specie of t-RNA. The t-RNA has a triplet base (anticodon) which is complementary to the triplet of bases (codon) in m-RNA specifying the particular amino acid.

5. Each amino acid is specified by at least one codon but may have as many as six at the ribosome. Amino acids are polymerized into protein in the order specified by m-RNA; the growing polypeptide is attached to the ribosome until the last amino acid is added when the ribosome is free to combine with new m-RNA. Free of ribosome, m-RNA is hydrolyzed and its component nucleotive enters the nucleotive pool for resynthesis.

Cell Hierarchy – Order of molecular organization of a cell





Haeckel Theory – division in the living world

A. Plant Kingdom – Flora
B. Animal Kingdom – Fauna
C. Microorganism – Protist
   1. Higher Protist or Eucaryotes
   2. Lower Protist or Procaryotes

Types of Cellular Organisms

1. Unicellular
2. Multicellular
3. Coenocytic

Chemical Make-Up of Bacterial Cells

1. *Proteins* – made up of amino acids joined by peptide linkage
2. *Lipids or Fats* – made up of fatty acids; water insoluble components of the cells that can be extracted by non-polar solvents
3. *Carbohydrates* – polyhydroxy aldehyde or ketone
4. *Nucleotides* – monomeric units of nucleic acid macromolecules third -OH of one nucleotide and fifth -OH of another nucleotide

Cultivation

1. Chemical conditions
2. Temperature
3. Gas requirement
4. pH
5. Other factors

Isolation

1. *Pour Plate* – suspension of cell is mixed with the melted agar at 45°C and poured into a petri dish. When agar solidifies, cells are immobilized in the agar and grow into colonies.
2. *Streak Plate* – the sterile, melted and cooled medium is first poured into a sterile petri dish and allowed to harden thoroughly; then the surface of the hardened agar is inoculated by streaking the needle of swab across it.

Bacterial Culture System

A. *Batch Culture* – growth curve characterized by the lag phase, exponential phase, stationary phase and decline phase.

Lag Phase – physiological adjustment of the organism to the environment following inoculation.

Logarithmic or Exponential Phase – exhibits a constant rate of growth where the rate of increase of cells can be expressed as:

$$\frac{dx}{dt} = Ux$$

U = growth
x = microbial concentration
t = time

Stationary Phase – growth ceases completely due to the exhaustion of nutrients, accumulation of waste products, change in pH.

Decline Phase – irreversible loss of ability to regenerate or reproduce.

B. *Continuous Culture* – utilizes the bacterial kinetics of the exponential phase. This demands a continuous flow-in of the nutrients of growth and the corresponding outflow of the products of the culture.

Sterilization
1. Chemical
2. Mechanical
3. Thermal
4. Radiation

Energy Yielding Metabolism: Metabolism of carbohydrates, such as glucose

A. *Anaerobic Fermentation*
   1. Glycolysis or EMP Pathway
   2. Alcoholic Fermentation
B. *Aerobic Respiration* – TCA (Tricarboxylic Acid Cycle) or Kreb's Cycle

Enzymes

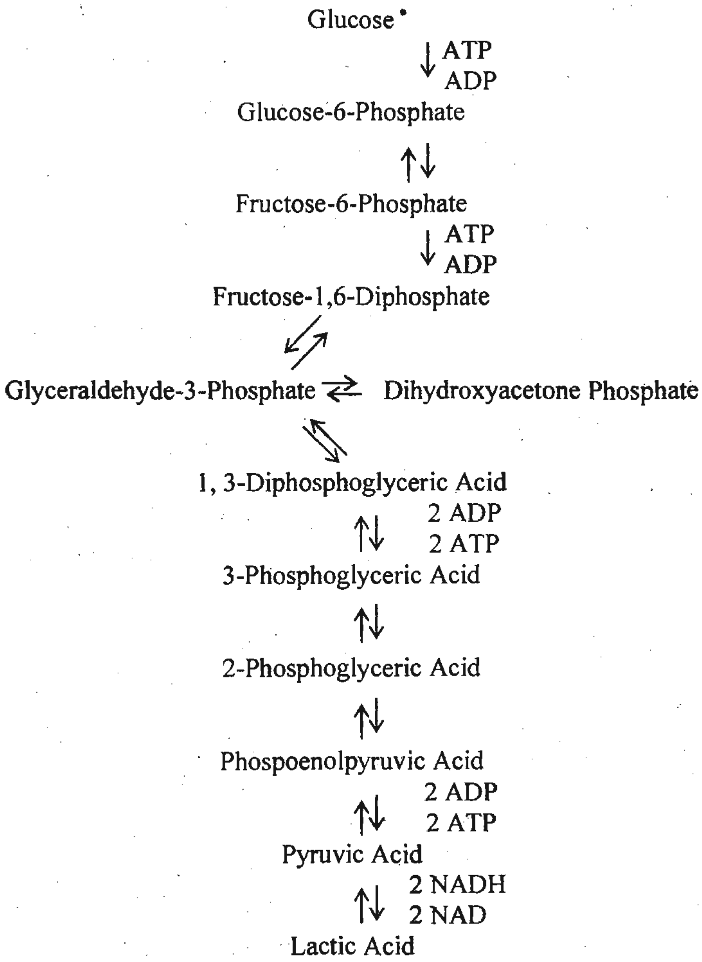
A. *Sources* – plant, animal organs, microbial cells
B. *Types*
   1. Endo enzyme or Intracellular enzyme
   2. Exo enzyme or Extracellular enzyme
C. *Enzyme Theories*
   1. *Lock and Key Theory (Emil Fischer)* – illustrates the precise fit between enzyme and substrate.
   2. *Induced Fit Theory (Koshland)* – enzyme undergoes structural or conformational changes brought about or induced by the substrate.
   3. *Michaelis-Menten Theory* – enzyme activity depends on substrate concentration.

Equation:

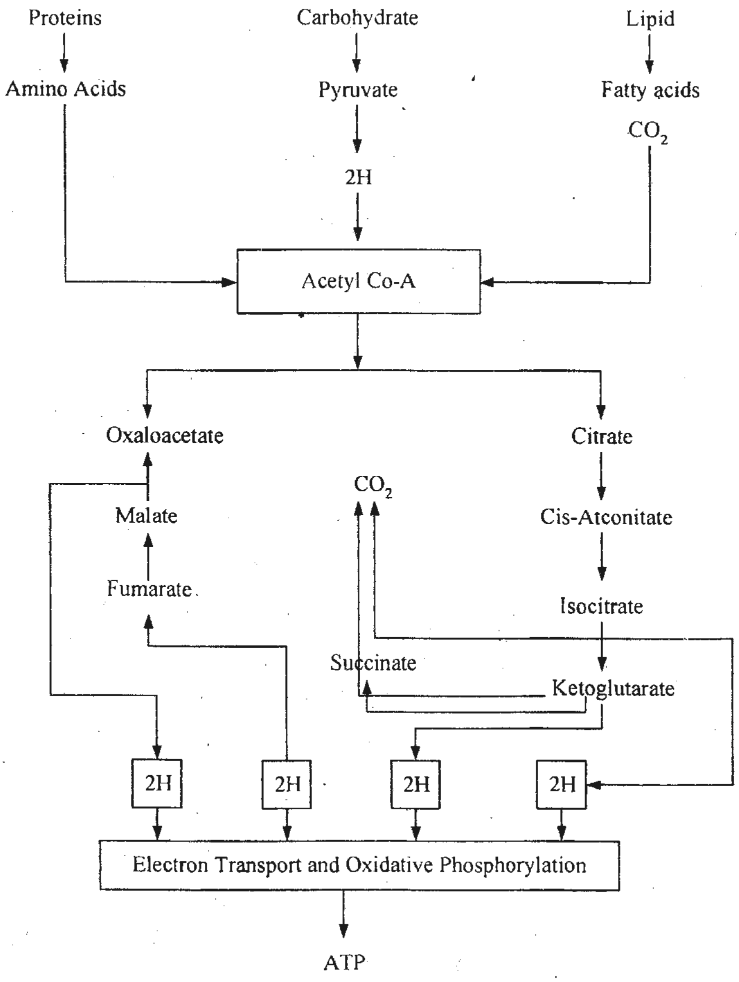
$$V = \frac{Vm\,x\,(S)}{Km + (S)}$$

where: V = velocity of enzymatic reaction, Vm = limiting (maximum) velocity
S = substance concentration, Km = Michaelis-Menten constant

EMP Pathway



TCA or Kreb's Cycle



General Properties of Enzymes

1. Enzymes are proteins.
2. Enzymes have electrical charges which depends on the pH and two pK values.
3. Enzymes have four definite dimensional structures:
    a. *primary structure* – amino acid sequence of the polypeptide chain (most important and specific structure; determines secondary and tertiary structures);
    b. *secondary structure* – spatial arrangement of polypeptide chains into helices, pleated sheet and random coil structures;

c. *tertiary structure* – three dimensional arrangement of helices, pleated sheet and random coil structures in enzyme; and,
d. *quaternary structure* – aggregation of enzyme submits or molecules into multi-submit or multi-enzyme complexes.

Non-covalent bonds that contribute to the four dimensional structure of enzymes:
1. Hydrogen Bond – Interpeptide Hydrogen Bond; Side Group Hydrogen Bond
2. Ionic Bond (Electrostatic Attraction)
3. Non-polar Side Chain Interaction (Hydrophobic Bond)
4. Polar Side Chain Interaction

Six General Classes of Enzymes and Functions
1. *Oxido-reductases* – oxidize or reduce substrates by transferring hydrogen or electrons.
2. *Transferases* – remove groups (excluding hydrogen) and transfer them to acceptor molecules (excluding water); transfer of groups.
3. *Hydrolases* – for hydrolytic reactions. It catalyzes the splitting of a covalent bond of the substrate and that of a water molecule with the subsequent addition of the hydrogen and hydroxide to the two fragments of the substrate molecule.
4. *Lyases* – remove groups from the substrate by hydrolysis to form a double bond or conversely, add groups to the double bonds.
5. *Isomerases* – catalytic isomerizations. It causes isomerization to the substrate.
6. *Ligases or Synthetases* – cause condensation of two molecules by splitting a phosphate bond.

Enzyme Nomenclature
1. *Based on their source*
   Papais – papaya
   Bromelin – pineapple
   Pepsin – stomach

2. *Based on the substrate used*
   Urease – urea
   Protease – protein
   Cellulase – cellulose
   Sucrase – sucrose

3. *Based on their function*
   Lysozyme – to loosen
   Catalase – catalyst
   Oxidase – oxidation

4. *Systematic method*
   Substrate – nature of reaction
   1. glucose – oxidase
   2. glycerol ester – hydrolase

Definition of Terms

Aerobe – an organism that grows in the presence of air or O_2.

Amino Acid – a sub-unit of the protein structure.

Anaerobe – an organism that grows in the absence of oxygen.

Autolysis – dissolution of the cells by self-produced lytic enzyme.

Autotrophs – an organism that grows or uses CO_2 as its principal carbon source.

Auxotrophs – nutritional mutant which requires one or more nutrients in addition to those required by its wild type.

Bacteriacidal – an agent that kills bacteria.

Bacteriostatic – an agent that inhibits the bacterial growth by its presence without causing death.

Binary Fission – cell division where the mother cell splits into daughter cells.

Biomass – cellular mass (e.g. bacterial cell or fungal mass).

Biosynthesis – a change occurring within the bacterial cell such as the building up of protein and carbohydrates from simple cell.

Broth – a liquid medium wherein an active growth of microorganism is in progress; fermentation liquor wherein the process of fermentation is in progress.

Beer – fermentation liquor wherein the fermentation process had just terminated.

Enzyme – an organic catalyst produced by the cell. Constitutive – always present in the cell; substrate independent. Induced – present in the cell only when needed, substrate dependent. Extracellular (exo enzyme) – activity is outside the cell; digestive or hydrolytic in its activity. Intracellular (endo enzyme) – activity inside the cell that is usually involved in the bio-synthesis of macromolecules and energy-yielding reactions.

Facultative – having the characteristics that permit alternate responses under different conditions (e.g. facultative anaerobe can grow aerobically).

Fermentation – process in which chemical changes are brought about in an organic substance through the action of enzyme elaborated by microorganism.

Generation Time – time required for a mother cell to divide into two daughter cells.

Inoculant – starting microbial culture in fermentation process.

Heterotroph – an organism that uses predominantly organic carbon for energy and photoplasmic building block.

Lag Phase – early period of growth where the organism adjusts to its new environment.

Logarithmic Growth – phase in the microbial life cycle when the cells are dividing exponentially.

Mesophile – an organism that grows optimally at 20°C to 37°C.

Microbial – something of the organism; from the word microbe which means microorganism.

Microaerophile – an organism that prefers to grow under reduced oxygen tension but sometimes under increased carbon dioxide tension.

Mutation – a chemical change in the genetic code of the cell.

Mycelium – a mass of hyphae of a mold or actinomycetes colony.

Obligate – strict or restricted; e.g. obligate aerobe can grow only in the presence of oxygen; obligate thermophile can grow only at elevated temperatures in relation to others.

Phage – a bacterial virus.

Photoplast – part of the cell which includes the cell membrane and its content.

Phototroph – an organism exhibiting wild type nutrition.

Putrefaction – decomposition of protein under anaerobic conditions.

Respiration – oxidation of the chemical compound by the organism coupled with the release of energy; aerobic-final oxygen acceptor is an inorganic substance like SO_3, NO_3 other than molecular oxygen.

Strain – a classification of specie of an organism identifying is a part from the rest by virtue of specificity of source.

Substrate – nutrient for cellular growth.

Thermophile – an organism that grows optimally above 45°C.

Viable – states of a living cell that is still capable of division.

D N A (*deoxyribonucleic acid*) – holder of the genetic information of the cell.

R N A (ribonucleic acid) – responsible for the coding and the transfer of genetic information.

SCP (single cell protein) – protein obtained for the growth or culture of unicellular microorganism.

Cultivation – process of propagating organism by providing the proper environmental condition such as nutrient, temperature and PA.

Isolation – separation of a particular microorganism from the mixed population that exists in nature.

Psychrophile – organism whose optimum temperature for growth is 10°C.

Inoculum – serum containing microorganism.

Some beneficial uses of microorganisms are the following:

1. Food Processing
   soy sauce – aspergillus sojae
   vinegar – acetobacter
   nata – acetobacter xylinum
   pickles – lactic acid bacteria
   milk products like cheese and sour cream
   tempe – soybean – rhizopus oligosporus
   ontjom – peanut cake – neurospora sitophilia
2. Alcoholic Beverages
   wine, beer, sake, tapuy, basi, whisky, rum, lambanog
3. Fuel
   alcohol – saccharomyces cerevisial xymomones mobilis
   biogas – mixture of microorganisms
   methane – producing bacteria
4. Production of:
   a. antibiotics
      penicillin – penicillium chrysogenum
      streptomycin – streptomyces griseus
      tetracyclines – streptomyces aureofaciens
      polymixins – bacillus polymyxa
   b. amino acids
      glutamic acid – corynabacterium glutamicum
   c. vitamins
      β-carotene – choanspore conjuncta
      Blakaslea trispora
      riboflavin – ashbye gossypti
      Enemothecium ashbili
      Vitamin B_{12}
   d. hormones
      Gibberallins – Gibberella fugikunol

REVIEW QUESTIONS AND PROBLEMS

1. Enzymes are
   a. proteins that catalyze chemical reactions, but do not have the usual chemical and physical properties of a protein
   b. proteins containing a high concentration of D-amino acids
   c. proteins that may be considered as such chemically and physically
   d. compounds of amino acids, but cannot be hydrolyzed to form free amino acids

2. The mechanism of enzymatic action involves
   a. slow degradation of the enzyme to form an enzyme-substrate complex
   b. temporary union of enzyme with substrate
   c. resistance to deactivation by high temperature
   d. rapid degradation of the enzyme to form an enzyme-substrate complex

3. Factor(s) that influence(s) enzymatic activity is (are)
   a. temperature c. concentration, substrate and cofactors
   b. pH d. all of these

4. The process of fermentation can be considered to be
   a. oxidation c. aerobic respiration
   b. dehydration d. anaerobic respiration

5. A study was made to evaluate the constants so that the Michaelis-Menten relationship could be used to describe waste utilization by bacteria. It was found that one gram of bacteria could decompose the waste at a maximum rate of 20 grams per day when the waste concentration was high. Also, it was found that this same quantity of bacteria would decompose waste at a rate of 10 grams/day when the waste concentration surrounding the bacteria was 15 mg/L. The rate of waste decomposition by 2 grams of bacteria if the waste concentration were maintained at 5 mg/L is
   a. 10 g/day b. 20 g/day c. 5 g/day d. 15 g/day

6. Bacteria which convert alcoholic solution to vinegar are
   a. coli b. acetobacters c. bacilli d. proteins

7. The biological decomposition of organic matter accompanied by the production of foul smelling products in an anaerobic condition is
   a. pollution b. putrefaction c. dissolution d. stabilization

8. A waste treatment process by which biologically active growths are continuously circulated with incoming biodegradable waste in the presence of oxygen is
   a. activated sludge process c. agitation process
   b. stabilization process d. trickling filter process

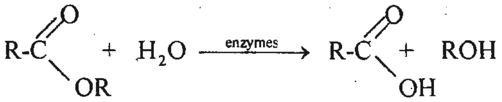
9. Materials in which microorganisms are grown in a laboratory are
   a. nutrients b. substrates c. enzymes d. culture media

10. Group of microorganisms that grow in the presence of low oxygen concentration are
    a. pathogens b. bacteria c. fungi d. microaerophiles

11. The rate of microbial growth is temperature-dependent. Bacteria which grow over the temperature range of 30°C to 40°C are called
    a. psychrophiles c. mesophiles
    b. hydrophiles d. thermophiles

12. There are several forms suggested by which the hyperbolic Michaelis Menten equation may be expressed linearly. If the substrate concentration, S, is plotted against reaction velocity, V; a linear plot is obtained. The equation is called
    a. Lineweaver and Burke equation
    b. Eadie-Hofstee equation
    c. Hanes-Woolf equation
    d. Eisentahl and Cornish Bowden equation

13. The enzymatic hydrolysis of an ester occurs according to the following reactions:



$$R\text{-}C(=O)OR + H_2O \xrightarrow{\text{enzymes}} R\text{-}C(=O)OH + ROH$$

The following data on the rate of formation of $R\text{-}C(=O)H$ at 25°C and pH = 6.5 were obtained:

Substrate concentration, Millimoles $R\text{-}C(=O)OR$ per liter	2.5	5	10	15	20
Reaction velocity, Millimoles $R\text{-}C(=O)OH$ per li-sec	0.024	0.036	0.053	0.06	0.064

The Michaelis constant, km in millimoles per liter is
a. 6.39 b. 9.36 c. 3.69 d. 5.19

Problems *14* and *15* are based on the following information:
A continuously stirred tank reactor (CSTR) with a working volume of 5,000 liters is used for the production of baker's yeast. The instantaneous concentration of the biomass in the vessel is 42.45 g/L. The overall reaction for aerobic fermentation is expressed as:
$0.556\ C_6H_{12}O_6 + 0.301\ NH_3 + 1.43\ O_2 \longrightarrow 0.301\ C_6H_{10}O_3N + 2.283\ H_2O + 1.532CO_2$
The empirical formula for the biomass is $C_6H_{10}O_3N$ and molasses contains 51.2% glucose.

14. The specific growth rate of the yeast in order to maintain a daily production of one ton is
    a. 0.5628/day b. 0.2865/day c. 0.8265/day d. 0.6825/day

15. The daily molasses consumption if the residual sugar in the outgoing broth is 0.5% glucose (weight/volume) is
    a. 4133 L/day b. 3143 L/day c. 3314 L/day d. 3413 L/day

16. It is desired to reduce the bacterial count of polluted water from 8 million organisms per mL to 17 organisms per mL. The number of completely mixed chlorine contact chambers in series, each having a detention time of 40 minutes, that would be required if the first order removal rate constant is 8 per hour is
    a. 5 vessels b. 7 vessels c. 10 vessels d. 8 vessels

17. Given a specie of a microorganism that doubles every 2.5 hours, the mass of biomass that may be expected from 500 liters of seed if each liter contains 5 grams biomass and the fermentation culture was maintained for 12 hours is
    a. 63 kg b. 55 kg c. 85 kg d. 70 kg

18. The Philippine Cornstarch Corporation prepares pharmaceutical glucose from cornstarch by enzyme hydrolysis. It was observed that when the starch concentration of the slurry was 5%, the rate of conversion of starch to glucose was 0.04 kg per second. When the starch concentration was made 10%, the turnover rate was 0.07 kg per second. The maximum production level of glucose that can reasonably be attained per shift of 8 hours is
    a. 6084 kg b. 8064 kg c. 1008 kg d. 0.28 kg

19. In a 1,000 liter vessel operating at 80% capacity, it takes 10 minutes to reduce the vegetative cell population by one fifth and 20 minutes to reduce the spore population by the same ratio. If the spore population is initially 1×10^3 per cc and vegetative cells were 1.5×10^4 per cc, the efficiency of sterilization if such were carried for 30 minutes is
    a. 52.5% b. 57.4% c. 74.5% d. 47.5%

20. A water solution of molasses contains 10% by weight sucrose ($C_{12}H_{22}O_{11}$). The CO_2 formed in the reaction can be considered as having a negligible solubility in the solution and 10% of the sugar can be assumed as unchanged. The weight percent of ethyl alcohol in the solution after 90% of the sucrose has been converted to ethyl alcohol by fermentation is
    a. 5.1% b. 1.5% c. 4.6% d. 6.5%

Problems *21* and *22* are based on the following information:

Albizzia Falcataria, a specie, of plywood, after an initial thermochemical hydrolysis yielded 25% maltose, 3% sucrose, 12% cellubiose, 43% oligosaccharides and 17% non carbohydrates residues. The resulting hydrolyzate is passed through a column of immobilized enzyme systems so that all types of dissacharides are converted further to hexose units.

In alcohol fermentation, the rule of thumb is 10% of the substrate is converted to biomass and 90% to alcohol.

21. If one metric ton of pulpwood is processed daily, the mass of glucose that may be expected to be produced per six-day week is
    a. 2,500 kg b. 2,526 kg c. 2,256 kg d. 5,262 kg

22. If the resulting hydrolyzate were fermented to ethanol, the mass of refined alcohol that may be expected to be recovered if distillation efficiency is 95% is
    a. 1,200 kg b. 1,162 kg c. 1,223 kg d. 1,322 kg

23. One metric ton of wild potatoes were hydrolyzed enzymically and the hydrolyzate contained the following:
    maltose = 15% xylose = 3%
    glucose = 18% oligosaccharides = 34%
    pentose = 3% others = 27%

    It was observed that of the hydrolyzate, only maltose and glucose were fermentable by alcohol yeast. Assuming 5% of the fermentables were used for the maintenance and growth of the organism, the mass of alcohol that can theoretically be expected from the hydrolyzate is
    a. 173 kg b. 158 kg c. 338 kg d. 127 kg

24. The nutrient for cellular growth is called
    a. protein b. substrate c. carbohydrate d. lipid

25. This is the early period of growth where the organism adjusts to its new environment
    a. stationary phase c. lag phase
    b. logarithmic phase d. decline phase

26. Genetic information is stored in the structure of the DNA molecule. Which of the following obtains the code for protein synthesis from DNA and serves as the template for peptide formation
    a. transfer RNA c. ribosomal RNA
    b. messenger RNA d. colon

27. a. Endoenzymes b. Exoenzymes c. Isoenzymes d. Allosteric enzymes are those that exhibit sigmoidal curves when activity is plotted against substrate concentration.

28. The isoelectric point of isoleucine (2.36, 9.68) is
    a. 6.02 b. 6.06 c. 5.98 d. 5.97

29. Hydrolysis of one mole of sucrose gives
    a. 1 mole of glucose and 1 mole of galactose
    b. 1 mole of glucose and 1 mole of fructose
    c. 2 moles of glucose
    d. 1 mole of mannose and 1 mole of glucose

30. Denaturation of protein
    a. involves conformational changes in the structure without hydrolysis of peptide bonds
    b. involves changes in the secondary, tertiary and quarternary structures of the protein molecules
    c. is often an irreversible process
    d. all of these

31. a. Glycolysis b. Alcoholic Fermentation c. Methane Fermentation
    d. Kreb's Cycle is the aerobic metabolism of the carbohydrates

32. Proteins that act as catalyst in biochemical reactions involving living organisms are
    a. amino acids b. enzymes c. inhibitors d. polysaccharides

33. If the BOD = 300 mg/L for a 1 mgd (million gallon daily) sewage plant, determine the number of pounds of organic load present in the water per day.
    a. 2600 lbs/day b. 2501 lbs/day c. 3000 lbs/day d. 5000 lbs/day

34. a. Lyophitization b. Pasteurisation c. Fermentation d. Putrefaction
    is the method used to free milk from disease germs

35. a. Nucleus b. Mitochondria c. Lysosone d. Cytoplasm
    is the power house of the cell

36. a. SCP b. TDP c. TDT d. ATP
    is the temperature at which a microorganism is killed within a period of 10 minutes.

37. A visible concentrated growth of algae or other aquatic life/plants is called
    a. phytoplankton b. amoeba c. bloom d. zoo-plankton

38. In treating 25 million gallons of water daily, 167 lbs. of liquid chlorine are applied, what is the dosage in mg/L?
    a. 0.801 mg/L c. 1.2 mg/L
    b. 0.502 mg/L d. 0.608 mg/L

39. Which of the following organisms is considered coenocytic?
    a. protozoa b. algae c. molds d. fungi

40. Production of ethanol from cassava and banana peels involves
    a. fermentation c. hydrolysis
    b. enzymatic action d. all of these

41. The microorganism utilized in the production of pickles is
    a. acetobacter c. streptomyces griseus
    b. lactic acid bacteria d. aspergillus sojae

42. a. Algae b. Amoeba c. Slime Molds d. Yeast
    are multicellular seaweeds.

43. a. Zoology b. Biochemistry c. Botany d. Microbiology
    is the study of living organisms too small to be seen clearly by the naked eyes.

44. The color of fruit like papaya is attributed to a pigment which is a precursor of Vitamin A. This substance is
    a. lecithin b. carotene c. lipoprotein d. riboflavin

45. The citric acid cycle is considered an aerobic pathway because
    a. oxygen is a substrate in some of the cycle reactions.
    b. the reduced cofactors are all oxidized through the electron transport chain.
    c. the cycle enzymes are all oxidative by nature.
    d. water is a product of the cycle.

46. _______ is the enzyme in the stomach.
    a. urease b. papase c. pepsin d. bromelis

47. The organism that reproduce by sparulation is
    a. bacteria b. molds c. protozoa d. yeast

48. _______ is an organism that grows or uses CO_2 as its principal carbon source.
    a. autotroph b. aerobe c. mesophile d. heterotroph

49. A basic amino acid is
    a. alamine b. lysine c. serine d. cystein

50. _______ is a continuous system cultivator.
    a. chemostat b. sterilizer c. scrubber d. precipitator

F. ENVIRONMENTAL ENGINEERING

Environmental Pollution – any alteration in the physical, chemical or biological properties of the environment (air, water and land) which adversely affects its aesthetic quantity and/or beneficial use.

Water Quality Management

1. ***Water Classification***

The setting of water quality standards depend on the uses of water, namely for domestic water supply, industrial purposes, irrigation, transportation, habitat for marine life and fish, and recreation and on how the standards may contribute to the environment making the community more pleasant to live in.

Streams are classified according to the highest beneficial use that can be obtained from them.

SOURCE: DENR Administrative Order No. 34 Series 1990

SUBJECT: Revised Water Usage and Classification/Water Quality Criteria Amending Section Nos. 68 and 69, Chapter 3, of the 1978 NPCC Rules and Regulation

Section 68. *Water Usage and Classification.* The quality of the Philippine waters shall be maintained in a safe and satisfactory condition according to their best usages. For this purpose all waters shall be classified according to the following beneficial usages:

a. *Fresh Surface Waters* (rivers, lakes, reservoirs, etc.)

Classification	**Beneficial Use**
Class AA	*Public Water Supply Class I.* This class is intended primarily for waters having watersheds which are uninhibited and otherwise protected and which require only approved disinfection in order to meet the National Standards for Drinking Water (NSDW) of the Philippines.
Class A	*Public Water Supply Class II.* For sources of water supply that requires complete treatment (coagulation, sedimentation, filtration and disinfection) in order to meet the NSDW.
Class B	*Recreational Water Class I.* For primary contact recreation such as bathing, swimming, diving, etc. (particularly those designated for tourism purposes).

Class C	1. *Fishery Water* for the propagation and growth of fish and other aquatic resources. 2. *Recreational Water Class II* (e.g. boating, etc.) *Industrial Water Supply Class I* (For manufacturing processes after treatment).
Class D	1. For agriculture, irrigation, livestock watering, etc. 2. *Industrial Water Supply Class II* (e.g. cooling, etc.) 3. Other in-land waters, by their quality belong to this classification.

b. *Coastal Marine Waters*

Classification	**Beneficial Use**
Class SA	1. Waters suitable for the propagation, survival and harvesting of shellfish for commercial purposes. 2. Tourist zones and national marine parks and reserves established under Presidential Proclamation No. 1801; existing laws and/or declared as such by appropriate government agency. 3. Coral reef parks and reserves designated by law and concerned authorities.
Class SB	1. *Recreational Water Class I* (Areas regularly used by the public for bathing, swimming, diving, etc.) 2. *Fishery Water Class II* (Commercial and sustenance fishing).
Class SC	1. *Recreational Water Class II* (e.g. boating, etc.) 2. *Fishery Water Class II* (Commercial and sustenance fishing). 3. *Marshy and/or mangrove areas* declared as fish and wildlife sanctuaries.
Class SD	1. *Industrial Water Supply Class II* (e.g. cooling, etc.) 2. *Other coastal and marine waters* by their quality, belong to this classification.

2. ***Characteristics of Wastewater***

a. *Physical Characteristics*

Color – generally an indication of the age of sewage

$$\text{sewage}\left\{\begin{array}{l}\text{fresh – grayish}\\ \text{septic – black}\end{array}\right.$$

Measure:

- Visual Comparison Method
  Nessler Tubes – color comparison tubes containing water of different colors and assigned a color unit ranging from 1 to 70.
  1 color unit Pt = ½ mg/L Co
- Photoelectric Colorimeters

Odor – comes from septic decomposition at organic wastes and is due to the presence of gases such as:

Amines	fishy	$CH_3NH_2(CH_3)_3N$
Ammonia	ammoniacal	NH_3
Diamines	decayed fish	$NH_2(CH_2)_4NH_2$, $NH_2(CH_2)_5NH_2$
Hydrogen sulfide	rotten eggs	H_2S
Mercaptans	skunk	CH_3SH, $CH_3(CH_2)_3SH$
Organic sulfides	rotten cabbage	$(CH_3)_2S$, CH_3SSCH_3
Skatole	fecal	$C_8H_5NHCH_3$

Measure:

- Olfactometer
- Sensory Method – a panel of human subjects are initially exposed to odor free air and then sampled air which has been diluted with odor free air to give the MDTOC. The number of dilutions give TON.
  – MDTOC / TON
  where:
  MDTOC – minimum detectable threshold odor concentration
  TON – threshold odor number

$$\text{TON} = \frac{\text{vol. of sample air} + \text{vol. of fresh air}}{\text{vol. of sample air}}$$

Turbidity – the amount of suspended matter in water/wastewater and is obtained by measuring its light scattering ability. It is also a measure of the ability of sunlight to pass through water and the ability of water to disperse different materials disposed into it. A typical clear lake has a turbidity of about 25 units while muddy water exceeds 100 units.

Measure:

- Jackson Turbidimeter – JTU (Jackson Turbidity Unit)
  1 unit = 1 mg/L silica in H_2O
- Secchi Disk Depth – depth in which a secchi disk may still be visible to the naked eye when submerged in water.

Temperature – lowers the solubility of oxygen in water and increases the rate at which oxygen-consuming microbes attack organic waste.

Total Solids – solid residue when water is evaporated at 103-105°C

b. *Chemical Characteristics*

pH – a measure of the acidity or alkalinity of water.

Calcium and Magnesium Salts – cause hardness in water and the formation of scales and deposits on pipelines and fittings if used in industry.

Nitrogen and Phosphorous – basic components of fertilizer, serves as nutrients for microbial growth in particular algae. Excessive amounts lead to algae blooms which cause *eutrophication* or the overabundance in the growth of algae giving water a "pea-soup appearance".

Trace Metals – refers to heavy metals which are toxic even in small concentrations.

Biomagnification – involves the accumulation of trace metals through each specie of the food chain.

mercury – easily converted into the toxic methyl mercury which causes *minamata disease* – a neurological disease characterized by trembling, inability to walk and speak and even serious convulsions that can lead to death.

cadmium – responsible for the Itai-itai disease; an extremely painful disease that causes disintegration of the bones.

Itai-Itai – Japanese word meaning "ouch-ouch"

silver – causes argyria, the blue-gray discoloration of the skin and mucous membrane.

arsenic – recognized poison, carcinogenic

chromium – causes neurological disease

lead – leads to fetal malformation, mental disability, irritability, loss of appetite and reduction of sex drive

Proteins – principal constituents of animal organisms and in large quantities causes extremely foul odors.

Carbohydrates – include sugars, starches, cellulose and wood fiber.

$$\text{sugar} + \text{bacteria} \xrightarrow{\text{ferment}} \text{alcohol} + CO_2$$

Oils, Fats, Greases – prevent natural aeration reducing the use of stream for fishing.

Surfactants – substances that cause foaming in H_2O.

Phenols – cause taste problems in water particularly when the H_2O is chlorinated.

Pesticides and Agricultural Chemicals – have the capacity to biomagnify and at certain concentrations are carcinogenic.

c. *Biological Characteristics*

Measure:

$\frac{MPN}{100\ ml}$ where: MPN = Most Probable Number

Uses: Escherichia Coli

3. ***Measures of Organic Content***

Winkler Method

a. *Dissolved Oxygen* (DO) – actual quantity of free O_2 present in water

b. *Theoretical Oxygen Demand* (ThOD) – a measure of the amount of O_2 needed to oxidize completely an organic matter whose chemical formula is known.

c. *Biological Oxygen Demand* (BOD) – a measure of the amount of O_2 needed by microorganism to decompose biodegradable organics at a specified time (5 days), temperature (20°C) and pH (7).

d. *Chemical Oxygen Demand* (COD) – a measure of the amount of O_2 needed to oxidize organics using strong oxidizing agents ($KMnO_4$ or $K_2Cr_2O_7$) in acid media.

e. *Total Oxygen Demand* (TOD) – organics are converted into stable end products in a Pt-catalyzed combustion chamber and is determined by monitoring the O_2 content present in the products.

f. *Total Organic Carbon* (TOC) – organic matter is oxidized in a high-temperature furnace to convert C to CO_2.

Kinetics of BOD

Let L = amt. of O_2 present in H_2O at anytime, t.
L_o = amt. of O_2 present in H_2O at t = 0

BOD_t = BOD at anytime t
k = deoxygenation constant, time^{-1}

For polluted H_2O & Wastewater $k_{20°C} = 0.10/day$
For sewage $k_{20°C} = 0.23/day$

At different temperatures: $k_T = k_{20}\,\theta^{(T-20)}$

θ = 1.056 if T is 20-30°C
1.135 if T < 20°C
1.047 if T > 30°C

$$L_T = L_o\,e^{-Kt}$$

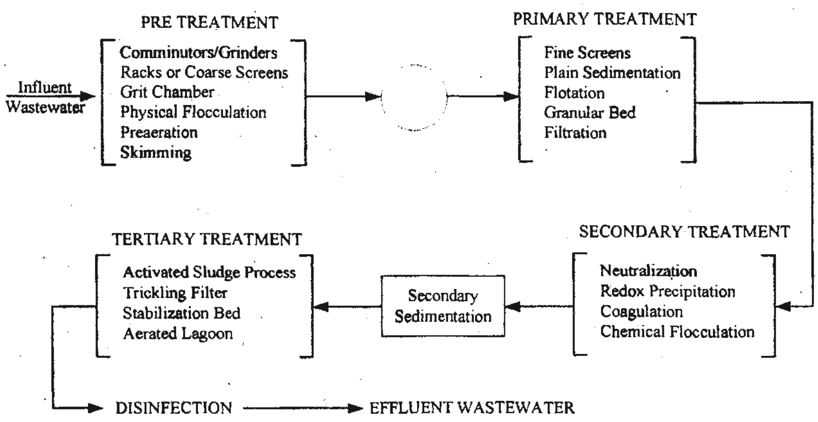
$$BOD_t = L_o - L_t$$

$$BOD_t = L_o\left(1 - e^{-Kt}\right)$$

4. ***Wastewater Treatment Methods***

Wastewater Treatment – defined as the separation of solid and liquid impurities, suspended or dissolved in the carrier water.

SCHEMATIC DIAGRAM OF WASTEWATER TREATMENT METHODS



a. *Physical Treatment Methods*

Screening – treatment used for the removal of coarse and settleable solids by interception.

Types of Screens

a. racks or bar screens – composed of parallel bars or rods which maybe hand cleaned or mechanically cleaned.
b. fine screens – wire/cloth mesh or perforated plate

Purpose of Screening

To remove material which would:

1. damage equipment
2. interfere with the satisfactory operation of a process
3. cause objectionable shore line conditions

Comminutors – devices that cut-up solids into smaller and more uniform sizes.

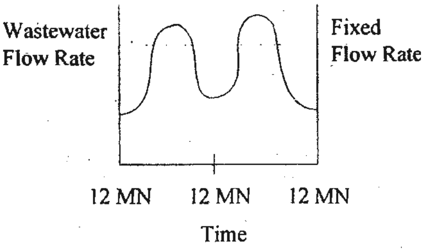
Grit Chamber – an enlarged channel where the velocity of wastewater flow is controlled to allow only the heavier solids to settle out.

Skimming – method of removing impurities that float on the surface of the wastewater.

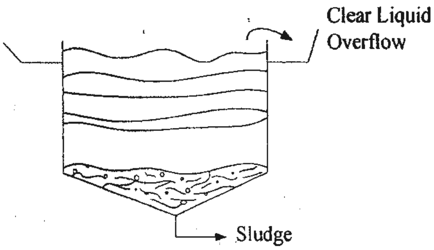
Preaeration – introduction of air into a tank in order to remove grease, odor, improve the treatability of wastewater and promote uniform distribution of suspended and floating solid and to increase BOD removals.

Physical Flocculation – aggregations of finely divided solids to a size large enough to settle out using agitation or stirring.

Equalization Basin – maintain a constant volumetric flow of wastewater from pretreatment to other downstream operations.



Sedimentation Tank – consists of cylindrical or rectangular tanks where settleable solids are removed by gravity.



Flotation – removal of finely divided solids and grease by floating them to the surface.

Steps in Flotation

1. Addition of conditioners
   >> promoters and activators – form a film and the solids to be floated
   >> frothers – stabilize air bubbles

2. Introduction of air bubbles
   >> direct diffusion
   >> pressurizing wastewater

3. Lifting of solid pollutants to surface due to buoyant force provided by air bubbles.
4. Skimming of solids which have risen to surface.

b. *Chemical Treatment Methods*

Neutralization – a chemical treatment whereby either acids or bases are added to the influent wastewater in order to neutralize any acids or bases present and thus control pH.

Chemical Precipitation – involves the addition of chemicals for the express purpose of improving plant performance and removing specific components contained in the waste water.

Common Precipitants

1. Lime - Ca $(OH)_2$
2. Soda ash - Na_2CO_3
3. Alum - $Al_2(SO_4)_3.14H_2O$
4. Ferric chloride - $FeCl_3$
5. Ferric sulfate - $Fe_2(SO_4)_3$
6. H_2SO_4 and SO_2

Coagulation – an electrochemical process used in the removal of colloidal matter in wastewater through the addition of coagulating agents which reduce the electrostatic charges surrounding colloidal matter, thereby allowing natural Van der Waals forces of attraction to predominate and allowing solids to cluster.

Common Coagulants

1. Alum - $Al_2(SO_4)_3 . 14 H_2O$
2. Copperas - Fe $SO_4 . 7 H_2O$

Chemical Flocculation – a physico-chemical process used in the removal of finely divided solids, a polyelectrolyte is added to wastewater which can form "bridges" that will join together the solids.

Disinfection – refers to the destruction of water forms pathogens (bacteria, viruses, amoebic cysts) for the sole purpose of preventing transmission of disease through water.

Ozonization – ozone (O_3) comes from the Greek Word *"ozein"* which means to smell. It is a very unstable gas and a very powerful oxidant capable of oxidizing 200 to 300 times more than chlorine. It can reduce complex taste, odor and color. However, it has no lasting effect and is quite expensive and found to be toxic to fishes.

Chlorination – addition of Cl_2 and its compounds (Cl^-, $HClO^-$)
Chlorine when added to wastewater is broken down into:

1. chlorine demand of water – amount of Cl_2 that will oxidize organic matter, and
2. residual chlorine – amount of Cl_2 that will disinfect water.

c. *Biological Treatment Methods*

– duplication of nature's self-purification process under contained and controlled conditions.
– use microorganisms to reduce the biodegradable organic content of the wastewater by using them as food for metabolism converting the organics into harmless stable products.

General Biochemical Reaction:

Organic Matter (CHONSP) + cells + $O_2 \rightarrow$ simple compounds + more cells
(soluble/biodegradable)

a. *Activated Sludge Process* – a continuous recirculating aerobic biochemical process that keeps cells in suspended growth.

b. *Trickling Filters* – a fixed bed where wastewater is intermittently discharged and contacted with biological slimes that have grown in the filter media.

c. *Stabilization Ponds* – a large shallow lagoon divided by thermal stratification into an aerobic surface and anaerobic bottom.

d. *Aerated Lagoon* – stabilization ponds provided with surface aerators.

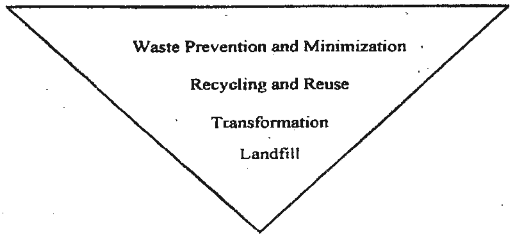
e. *Anaerobic Digestion or Decomposition* – generally employed for treatment of organic sludges and concentrated organic industrial wastes.

Solid Waste Management

Integrated Solid Waste Management (ISWM)

- ISWM – the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives.
- Includes factors like: frequency of collection, type of wastes collected, location of disposal site and environmental acceptability of disposal system and level of satisfaction of the customers.

Hierarchy of SWM



Solid Waste Management Techniques

Route Balancing – process of determining the optimum number of services that constitute a fair day's work and dividing the collection task among the crews so that all have equal loads.

Heuristic Routing – process of determining the path or route for the collection vehicle to follow as it collects waste from each service in a specific area.

Air Quality Management

Air Pollution – presence in the atmosphere of substances whose concentration, quality and duration affect the usefulness of air resources.

Air Pollutant Classifications

Primary Pollutant – emitted by an identifiable source
Secondary Pollutant – formed by chemical reactions
Criteria Pollutant – likely to exist in all urban areas
Non-Criteria Pollutant – industry specific

Major Air Pollutants

a. CO_2
   - Main product of fossil fuel combustion; major greenhouse gas when it displaces O_2 in the air causes suffocation due to binomia

b. CO
   - Product of incomplete combustion (low temperature) of fossil fuels
   - Reacts with hemoglobin forming carboxyhemoglobin
   - Strong affinity of hemoglobin for CO causes O_2 to leave the tissue resulting in anoxicity

c. SO_x
   - SO_x compounds are acid rain precursors produced when they combine with water droplets in air to form sulfuric acid, H_2SO_4

$$SO_2 + O_2 \rightarrow SO_3$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

d. NO_x
   - NO_x stands for an indeterminate mixture of nitric oxide, NO, and nitrogen dioxide, NO_2
   - Nitrogen oxides, NO_x, are formed mainly from N_2 and O_2 during high-temperature combustion of fuel in cars
   - They cause the reddish-brown haze in city air, which contributes to heart and lung problems and may be carcinogenic
   - Nitrogen oxides are major contributors to the formation of ground level 'bad' ozone

e. *Trophospheric Ozone*
   - Major constituent of photochemical smog
   - Ozone is formed from the ozone precursors, VOCs, and nitrogen oxides
   - Alters vision which prevents the eyes from focusing properly and increases the calcification of bones resulting in premature aging and depletes body fat

f. *Chlorofluorocarbons*, *CFCs*
- Artificial gases, used as coolants in refrigerators and air conditioners
- The most abundant CFCs are CFC-11 (or $CFCl_3$), and CFC-12 (or CF_2Cl_2)
- Non-toxic, non-flammable, non-biodegradable
- CFCs are not water-soluble, therefore, are not washed from the atmosphere by rain
- Stable and can reach the stratosphere

g. *Particulates*
- PM_{10}, PM, Total Suspended Particulates (TSP);
- PM (10) are particles with diameter less than 10 μm
  - Cause diverse health effects
  - Contribute to urban haze, cause visibility reduction
  - Play a key role in the Earth's radioactive budget and global change

Air Pollution Control Equipment

- *Settling Chamber* – device where particulate removal is by gravity. Recommended for particulate sizes in the range of 50 microns and higher.
- *Cyclone Collector* – dirty gas is fed peripherally into the device. Particulate removal is by centrifugal impaction on the cyclone wall from where it falls to the bottom. Recommended for particulates of 20 to 45 microns in size.
- *Scrubber* – uses water to effect particulate separation from the gas stream. It may also use a counter-current flow of gas in a spray tower. Recommended for particulates of 5 to 20 microns and must have high affinity for water.
- *Filter* – separates the particulates from the main stream by direct interception. Filter medium is cloth (canvass or silicon-coated cloth) – 1 to 10 microns or acetate membrane filters – 0.1 micron.
- *Electrostatic Precipitators* – most efficient method. Recommended for all sizes of particulates especially those below 1 to 10 microns. Gas is given an electrical charge as it enters the device. The gas stream that passes between charged plates which electrically attract the particulates.

Philippine Environmental Laws

R.A. 3931 (July 10, 1967) – an act creating the National Water and Air Pollution Control Commission
P.D. 824 (November 7, 1975) – created the Metro Manila Commission
P.D. 984 (August 8, 1976) – provides policy for pollution control including land pollution.
P.D. 1151 (June 6, 1977) – Philippine Environmental Policy
P.D. 1152 (June 6, 1977) – Philippine Environmental Code
P.D. 1181 – installation of pollution control device for all motors and vehicles
P.D. 1396 – created the Human Settlement Ministry

L.O.I. 551 under P.D. 984 – gave N.P.C.C. the power to close industries violating P.D. 1181. Whereas Circular No.1 prescribe the pollutants emitted by a motor vehicle as follows:

CO – 3.0%
NO_2 – 800 ppm
HC – 350 ppm
Smoke – not more than 20% dense

L.O.I. 558 – providing for a pollution control officer for all industries, factories, agencies, organizations, be it public or private.

Commonwealth Act – an act to punish the dumping into any river or refuse wastewater or substances of any kind whatsoever that may bring about the rise of filing in of river beds or cause artificial alluvial formations.

P.D. 825 (November 7, 1985) – providing penalty for improper disposal of garbage and other forms of uncleanliness and for other purposes.

P.D. 856 – Code on Sanitation of the Philippines

P.D. 600 – Prevention and Control of Marine Pollution

P.D. 1586 – Environmental Impact Assessment Law

P.D. 274 – seeks to develop Pasig River and its environs within 3 years

P.D. 281 – created Pasig River Development Council to see that the program is implemented.

P.D. 602 – establishes oil pollution operations center in the Philippine Coast Guard Headquarters.

– **P.D. 1067** – Water Code of the Philippines; integrates all laws governing the ownership, appropriation, use, exploitation, development, conservation and protection of the country's water resources; answers the need based on rational concepts of integrated and multipurpose management of water resources, and sufficiently flexible to adequately meet future developments; contains measures to prevent flood and other calamities caused by abuse in the use of water

P.D. 1160 – empowers barangay officials to arrest violators of laws for the protection of the environment.

R.A. 7924 – created the Metro Manila Development Authority, defining its powers and functions, providing funds thereof and other purposes.

R.A. 6969 – an act to Control Toxic Substances and Hazardous and Nuclear Wastes providing penalties for violation thereof.

R.A. 8749 – Clean Air Act of the Philippines

R.A. 9003 – Ecological Solid Waste Management Act

– **R.A. 9275** – Clean Water Act of the Philippines

REVIEW QUESTIONS AND PROBLEMS

1. The portion of the rainfall that flows on the ground surface is called
   a. yield b. water-table c. spring d. run-off

2. The level of the upper surface of the ground water is called
   a. Water table c. Ground level
   b. Hydraulic gradient d. Saturation gradient

3. A structure used to collect raw water from a source such as river is called
   a. aqueduct b. appurtenance c. intake d. valve

4. The permissible color for domestic water supply in ppm is
   a. 5 b. 10 c. 15 d. 20

5. The resistance of water to the passage of light through it is a measure of the
   a. colour b. turbidity c. hardness d. dissolved gases

6. The total solids in water are due to the presence of
   a. Suspended and dissolved solids c. Colloidal and settleable solids
   b. Suspended and floating solids d. Colloidal and bacterial load

7. Temporary hardness in water is due to the presence of
   a. Chloride c. Calcium
   b. Carbonate d. Manganese

8. Nitrates more than 50 ppm in water leads to a disease called
   a. Typhoid c. Gastroenteritis
   b. Mathenoglobenemia d. Mottled tee

9. The presence of manganese in water causes growth of
   a. mosquitoes b. microorganism c. flies d. algae

10. The red brownish color of water is due to the presence of dissolved impurities of
    a. bicarbonate c. arsenic
    b. sulphate d. iron and manganese

11. The process of killing infective bacteria in water is called
    a. sterilization c. coagulation
    b. disinfection d. sedimentation

12. When a sample of water is added to a medium of agar and incubated at 37°C for 24 hours, colonies of bacteria formed are countered. This test is called
    a. Total Count Test c. Confirmative Test
    b. Presumptive Test d. Completed Test

13. Aeration of water is done to remove
    a. suspended impurities c. dissolved salts
    b. floating impurities d. dissolved gases

14. Very fine suspended and colloidal impurities are removed by a process called
    a. softening b. disinfection c. coagulation d. plain sedimentation

15. The difference between the water levels in the filter chamber and the outlet chamber is known as
    a. Negative Head c. Working Head
    b. Pressure Head d. Static Head

16. The removal of a bacteria accomplished in slow sand filter by means of a jelly like substance is called
    a. Zoogleal b. Metabolism c. Schutdecke d. Pskytobolism

17. Insufficient washing of sand grains in a rapid sand filter causes
    a. air-binding c. shrinkage of media
    b. mud balls d. expansion of media

18. In double filtration, the first filter is
    a. Roughing filter c. Rapid sand filter
    b. Pressure filter d. Gravity filter

19. A common disinfectant used in village wells is
    a. Ozone gas c. Potassium permanganate
    b. Iodine and bromine d. Free chlorine

20. Normal dosage of chlorine in public water-supply scheme is
    a. 0.05 to 0.2 ppm c. 0.5 to 1.0 ppm
    b. 0.2 to 0.5 ppm d. more than 1.0 ppm

21. The amount of chlorine available in water after the disinfection is called
    a. Free chlorine c. Free available chlorine
    b. Residual chlorine d. Combines available chlorine

22. If the organic content in water is high, the type of chlorination to be adopted is
    a. Superchlorination c. Double chlorination
    b. Breakpointchlorination d. Post-chlorination

23. What substance in water is removed by *Lime Soda Process*?
    a. Odour and taste c. Iron and manganese
    b. Temporary hardness d. Permanent hardness

24. The type of reservoir generally used when large quantity of raw water is to be stored before filtration.
    a. Surface reservoir c. Elevated reservoir
    b. Earthen reservoir d. Clear water reservoir

25. Scour pipes are provided in all service reservoirs to
    a. discharge surplus water c. supply water during an emergency
    b. supply water to consumers d. drain out and flush the tank

26. A valve in an inflow pipe which prevents water from returning into the pipe is called
    a. Sluice valve b. Gate valve c. Reflux valve d. Air valve

27. Water distribution system in which a large number of cut-off valves are necessary is called
    a. Tree system b. Ring system c. Grid iron system d. Radial system

28. The type of layout distribution system adopted for unplanned cities and for irregularly growing town is
    a. Grid iron b. Circular c. Radial d. Dead end

29. The reservoir is placed centrally in each zone in the case of
    a. Tree system c. Grid iron system
    b. Ring system d. Radial system

30. The distribution system wherein the mains and branches are interconnected so as to make water available from all direction at a point is
    a. Tree system c. Radial system
    b. Circle or ring system d. None of these

31. The (a) Montreal Protocol (b) Earth Summit (c) Kyoto Protocol (d) Stockholm Convention is a global undertaking on persistent organic pollutants.

32. The (a) Montreal Protocol (b) Earth Summit (c) Kyoto Protocol (d) Stockholm Convention is a global undertaking on global warming and greenhouse gases.

33. (a) Synergism (b) Eutrophication (c) Biomagnification (d) Thermal stratification is the process where more harmful substances are produced from less harmful ones.

34. A trace metal which causes the Itai-itai disease is (a) cadmium (b) silver (c) mercury (d) chromium

35. (a) BOD (b) COD (c) ThOD (d) TOC maybe used to measure the assimilative capacity of a stream.

36. A wastewater with a BOD/COD = 1 indicates that
    a. chemical treatment is required
    b. biological treatment is most practical
    c. the wastewater is highly polluted
    d. does not indicate anything.

37. (a) Coagulation (b) Neutralization (c) Flocculation (d) Precipitation is an electrochemical process used in the removal of colloidal matter in wastewater through reduction of electrostatic charges surrounding the solids.

38. What is the atmospheric condition when the lapse rate is >10°C/km?
    a. adiabatic b. subadiabatic c. superadiabatic d. none of these

39. This provides the blue print for action towards sustainable development
    a. Earth Summit b. Agenda 21 c. Montreal Draft d. POP's Convention

40. Major contributors to ground level 'bad ozone' (a) SO_x (b) NO_x (c) CO_2 (d) CO

Part II

CHEMICAL ENGINEERING PRINCIPLES

A. CHEMICAL ENGINEERING CALCULATIONS

Stoichiometry – a branch of chemistry which deals with mass and volume relations in unit operations and unit processes.

A. UNITS AND DIMENSIONS

Dimension – property that can be measured such as length, time, mass or temperature or calculated such as density, volume, or velocity.

Measurable Units – specific values of dimensions that have been defined by convention, custom, or law, such as gram for mass, second for time, etc.

Systems of Units

Système Internationale d' Unitès (SI) – commonly used in the engineering and scientific community, also referred to as the MKS system

CGS System – a system similar to SI but uses cm, gram and seconds for length, mass and time respectively.

American Engineering System (AES) – a system that uses ft, pound and seconds for length, mass and time respectively.

Fundamental Quantity (SI)

QUANTITY	UNIT	SYMBOL	QUANTITY	UNIT	SYMBOL
Length	Meter	m	Temperature	Kelvin	K
Mass	Kilogram	kg	Electric Current	ampere	A
Time	Second	s	Luminous Intensity	candela	cd
Amount of Substance	Mole	mol/gmol			

Derived Quantity (used in ChE Calculations)

QUANTITY	UNIT	SYMBOL	QUANTITY	UNIT	SYMBOL
Volume	Cubic meter	m^3	Pressure	Pascal	Pa, N/m^2
Force/Weight	Newton	N	Work/Energy	Joule	J, N-m

Derived Quantities are obtained by the products and quotients of fundamental units or arbitrarily defined such as Pa, N and J.

B. PROCESSES AND PROCESS VARIABLES

I. Density (ρ) and Specific Gravity (SG)

$$\rho = \frac{m}{V} \qquad SG_{subs} = \frac{\rho_{subs}}{\rho_{ref}}$$

Specific Gravity is the ratio of the density of the substance to a reference substance. For liquids, water at 4°C is used as reference while air is used for gases.

Specific Gravity Scales

a. Baumé Scale:

(i) lighter than water (SG<1): $^\circ\text{Be} = \dfrac{140}{\text{SG}} - 130$ (Range : °Be > 10)

(ii) heavier than water (SG>1): $^\circ\text{Be} = 145 - \dfrac{145}{\text{SG}}$ (Range : 0 < °Be < 145)

b. Twaddell Scale: $^\circ\text{Tw} = 200\left(SG^{60^\circ F}_{60^\circ F} - 1\right)$

c. API Scale (American Petroleum Industry): $^\circ\text{API} = \dfrac{141.5}{\text{SG}} - 131.5$

d. Brix Scale (Sugar Industry): $^\circ\text{Brix} = \dfrac{400}{\text{SG}} - 400$

II. Average Molecular Weight

$\overline{M} = \sum_{i=1}^{N} y_i M_i$ or $\overline{M} = \dfrac{1}{\sum_{i=1}^{N} \dfrac{x_i}{M_i}}$ where y_i = mole fraction, x_i = mass fraction

III. Temperature

Measure of the average kinetic energy possessed by the molecules of the substance.

Temperature–Measuring Devices

1. Pyrometer (spectra of emitted radiation)
2. Thermometer (volume of a fixed mass of fluid)
3. Thermocouple (potential difference on two junctions)
4. Resistance thermometer (electrical resistance of a conductor)

Conversion of Temperature Scales

$^\circ C = {}^5/_9\,(^\circ F - 32)$
$^\circ F = {}^9/_5\,^\circ C + 32$
$K = {}^\circ C + 273.15$
$^\circ R = {}^\circ F + 459.67$
$^\circ R = 1.8\,K$

IV. Force and Weight

Weight is the force exerted to an object by gravity.

$$W = m\frac{g}{g_C}$$

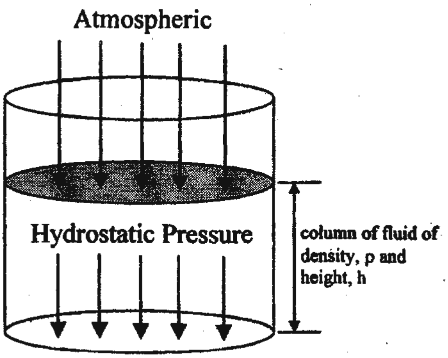
where m = mass of the object
g = acceleration due to gravity
g_C = conversion factor

Acceleration due to gravity, g...

$$g = 9.8066\,{}^{m}/_{s^2} = 32.174\,{}^{ft}/_{s^2} \text{ at sea level and } 45° \text{ Lat}$$

Conversion Factor, g_C...

$$g_c = 1\frac{kg\text{-}m/s^2}{N} = 32.1741\frac{lb_m\text{-}ft/s^2}{lb_f}$$



Derived Units of Force

SI	$1\ N = 1\ kg\text{-}m/s^2$
CGS	$1\ dyne = 1\ g\text{-}cm/s^2$
AES	$1\ lb_f = 32.174\ lb_m\text{-}ft/s^2$

V. Pressure

Measure of the force exerted per unit area

Hydrostatic Pressure

The pressure exerted by a column of fluid

$$P_{hydrostatic} = P_{atmospheric} + \rho\,{}^{g}/_{g_c}\,h$$

C. MATERIAL BALANCE

An exact accounting of all materials entering, generating, consumed, accumulating and leaving a system

The General Balance Equation :

INPUT + GENERATION = OUTPUT + CONSUMPTION + ACCUMULATION

I. Material Balances on Steady State and Non-Reactive Processes

Involves material balances of unit operations in Chemical Engineering

II. Material Balances Involving Reactive Processes

Limiting Reactant (LR) – reactant supplied in the least stoichiometric amount; defines the degree of completion of the reaction

Excess Reactant (ER) – reactant whose amount supplied for the reaction is greater than the theoretical amount

Theoretical Amount – amount of reactants or products involved in a complete reaction

$$\%\text{ conversion} = \frac{\text{amount of reactant converted to product}}{\text{amount of reactant supplied}} \times 100$$

$$\%\text{ excess} = \frac{\text{supplied amount - theoretical amount}}{\text{theoretical amount}}$$

$$\text{degree of completion} = \frac{\text{amount of LR converted to product}}{\text{amount of LR supplied}}$$

Yield – ratio of the moles of desired product formed to the moles of product that would have been formed if there were no side reactions and the limiting reactant had reacted completely

Selectivity – ratio of the moles of desired product formed to the moles of the undesired product formed

D. BEHAVIOR OF IDEAL GASES

I. Gas Laws

1. Boyle's Law : (constant T) : $PV = k$
2. Charles' Law : (constant P) : $\frac{V}{T} = k$
3. Gay Lussac's Law : (constant V) : $\frac{P}{T} = k$
4. Combined Gas Law : $\frac{PV}{T} = k$
5. Ideal Gas Equation : $PV = nRT$

II. Standard Values for P, V, T

Standard Pressure

1 atm	101.325 kPa
760 mmHg	29.92 in Hg
760 torr	1.01325 bar
14.7 psia	

Standard Volume	Standard Temperature
22.4 L/g-mol	273.15 K
22,400 ml /g-mol	0°C
22.4 m^3/kg-mol	491.67 R
359 ft^3/lb-mol	32°F

III. Dalton's Law of Partial Pressures

The total pressure exerted by a mixture of gases is equal to the sum of their partial pressures at constant volume and temperature.

$$P_T = P_A + P_B + P_C + \ldots$$

$$\frac{P_A}{P_T} = \frac{N_A}{N_A + N_B} \; ; \; \frac{P_A}{P_B} = \frac{N_A}{N_B}$$

IV. Amagat's Law of Pure Component Volume

Pure component volume is the volume occupied by a gas if it alone is present in a container at constant temperature and pressure.

$$V_T = V_A + V_B + V_C + \ldots \qquad \frac{V_A}{V_T} = \frac{N_A}{N_T}$$

COMBUSTION ENGINEERING

A. Classification of Fuels

I. GASEOUS FUELS

- **natural gas** that is found compressed in porous rocks and shale formations
- natural gas is composed of mixture of hydrocarbons like methane, ethane, propane, butane, pentane, hexane and some traces of sulfur and organic nitrogen
- **liquefied petroleum gas (LPG)** consists of ethane, propane and butane
- **producer gas** consists of CO, H_2 and about 55% N_2 and trace amounts of CO_2 obtained by passing small amount of air through a hot bed of coal, peat, wood and other biomass
- **water gas** consists of CO and H_2 with small amounts of N_2 obtained similar to a producer gas but blown with steam thereby decreasing the N_2 content and doubling the heating value

Characterization of Gaseous Fuels

Heating Value is the heat released when the fuel initially at 25°C reacts completely with oxygen and the products are returned to 25°C (Borman and Ragland, 1998). It is taken as the negative of the standard enthalpy of combustion of the fuel.

Higher Heating Value (Total Heating Value or Gross Heating Value) is the heating value when water comes out as liquid in the combustion reaction.

Lower Heating Value (Net Heating Value) is the heating value when water comes out as vapor in the combustion reaction.

$$\mathrm{HHV} = \mathrm{LHV} + \left(\frac{n_{H_2O} \text{ produced}}{n_{\text{fuel}} \text{ burned}} \cdot \Delta H^{\theta}_{\text{vap},H_2O} \right)$$

Standard Heat of Vaporization of Water

$$\Delta H^{\theta}_{\text{vap},H_2O} = 44.013 \text{ kJ/mol} = 18{,}934 \text{ BTU/lbmole}$$

For a mixture of fuels... $HV = \sum_{i=1}^{N} x_i HV_i$

II. LIQUID FUELS

- primarily obtained from crude oil, which is a mixture of hydrocarbons (about 84% C) up to 3%, 0.5% N_2 and 0.5% O_2
- obtained by several refining processes like fractional distillation, cracking, reforming

Characterization of Liquid Fuels

Pour Point is the indication of the lowest temperature at which a fuel oil can be stored and still be capable of flowing under low forces in a standard apparatus

Flash Point is minimum temperature at which fuel will rapidly catch fire when *exposed to an open flame located above the liquid*

Autoignition Temperature is the lowest temperature required to initiate *self-sustained combustion* in a standard container in atmospheric air *in the absence of a spark or a flame*

Smoke Point measures the tendency of the fuel to form soot. It is determined experimentally by burning the fuel in a special wick lamp and slowly increasing the height of the flame until smoke begins to appear. The maximum height of smokeless flame in millimeters is the smoke point. Hence, the higher the smoke point, the lower is the tendency of the fuel to form soot.

Octane Number indicates the tendency of gasoline to knock (onset of ignition) when the compression ratio in a spark-ignition engine is raised. It is measured by comparing the performance of the fuel with the performance of mixtures of isooctane (set at 100) and n-heptane (set at 0) in a standardized spark-ignition engine. The percentage of isooctane in the mixture with n-heptane is the octane number of the gasoline.

III. SOLID FUELS

- Naturally occurring solid fuels include wood, biomass, and coal
- Wood consists of cellulose, hemicellulose, lignin, resins and ash-forming minerals
- Biomass are materials obtained from agricultural products, marine and aquatic plant life, animal manure, and industrial or municipal wastes
- Charcoal is made from the destructive distillation of wood and can be pulverized easily and made into briquettes by the addition of binders such as starch

- Coal is a heterogeneous mineral consisting of carbon, hydrogen, and oxygen with trace lesser amount of pyritic sulfur and organic nitrogen.
- Coal is ranked from low rank lignite to high rank anthracite.
- Lignite is a brownish-black coal and is chemically similar to peat and contains a high percentage of water and volatiles
- Subbituminous coal is dull-black, shows little woody material with reduced moisture content
- Bituminous coal is dark black with low moisture content and more resistant to disintegration in air than lignite and subbituminous coals
- Anthracite coal is hard, brittle, has a bright luster and has almost no volatiles or moisture

Characterization of Solid Fuels

Proximate Analysis (ASTM D3172) determines the moisture, volatile combustible matter, fixed carbon and ash in a fuel sample

Ultimate Analysis (ASTM D3176) provides the major elemental composition of the fuel, usually reported on a dry ash-free basis

Hardgrove Grindability Test (ASTM D409) is used to determine the relative ease of pulverization of coals

Empirical Relations on Coal Analysis and Calorific Values

1. Dulong's Formula

$$Cv = 0.338\,C + 1.44\left(H - \frac{0}{8}\right) + 0.094\,S$$

where: $H - \frac{O}{8} = net\ H$

2. Calderwood Equation

$$C = 5.88 + 2.206\,(Cv - 0.094S) + 0.0053\,[80 - (100\ VCM/FC)]^{1.55}$$

where: Cv is in MJ/kg

Types of Combustibles Lost in the Refuse

1. Uncoked Coal – coal which has lost only its moisture content and VCM and FC content in the coal is the same as in the refuse

$$\left[\frac{VCM}{FC}\right]_{coal} = \left[\frac{VCM}{FC}\right]_{refuse}$$

2. Coked Coal – coal which has lost both moisture and VCM content, carbon and ash are the main constituents of the refuse

3. Combination of Coked and Uncoked Coal

$$\left[\frac{VCM}{FC}\right]_{coal} \neq \left[\frac{VCM}{FC}\right]_{refuse}$$

4. Partially Coked Coal – coal which has lost moisture but not all VCM
   – refuse shows significant VCM content

COMBUSTION CALCULATIONS

$$theo\ O_2 = \text{at}\ C + \text{at}\ S + \frac{\text{at}\ H}{4} - \text{moles}\ O_2$$

$$O_2\ supplied = theo\ O_2 + excess\ O_2$$

$$\%\ excess\ air = \%\ excess\ O_2$$

$$= \frac{excess\ O_2}{theo\ O_2} \times 100 = \frac{supplied\ O_2 - theo\ O_2}{theo\ O_2}$$

$$free\ O_2 = excess\ O_2 + O_2\ for\ unburnt\ combustibles$$

$$= excess\ O_2 + \frac{CO}{2} + \frac{H_2}{2}$$

REVIEW QUESTIONS AND PROBLEMS

1. The basis in all mass balance calculations is
   a. degree of completion of the process
   b. the temperature and pressure conditions
   c. the law of conservation of mass
   d. the limiting reactant

2. The percentage ratio of the excess to the amount that is theoretically required by the stoichiometric equation for combination with the limiting reactant is called
   a. % completion
   c. % yield
   b. % conversion
   d. % excess

3. Which gas law states that the total volume occupied by a mixture of gases is equal to the sum of their pure component volume at constant temperature and pressure?
   a. Amagat
   c. Graham
   b. Dalton
   d. Charles

4. What is produced when calcium carbide is mixed with water?
   a. acetylene
   c. propylene
   b. ethylene
   d. methane

5. The material which remains unchanged in a process is
   a. limiting reactant
   b. tie substance
   c. excess reactant
   d. product yield

6. The heating value measured when water formed from combustion is in the liquid state
   a. Gross Calorific Value
   b. Heat of Combustion
   c. Net Calorific Value
   d. Latent Heat of Condensation

7. In the combustion of solid fuels, the tie element between the feed and the refuse is the
   a. coked coal
   b. moisture
   c. volatile combustible matters
   d. ash

8. The coal analysis which is based upon the volatilization characteristics of the fuel is
   a. Proximate Analysis
   b. Modified Analysis
   c. Ultimate Analysis
   d. Elemental Analysis

9. An Orsat analysis of the flue gas when pyrite is roasted is on a/an
   a. SO_2-free basis
   b. SO_3-free basis
   c. O_2-free basis
   d. N_2-free basis

10. The empirical relation which allows one to compute for the net hydrogen in a given solid fuel is the
    a. Calderwood Equation
    b. Theoretical Oxygen Equation
    c. Dulong's Formula
    d. None of these

11. A 20% oleum product means
    a. 20% SO_3, 80% H_2SO_4
    b. 80% SO_3, 20% H_2SO_4
    c. 80% H_2SO_4, 20% H_2O
    d. 80% SO_3, 20% H_2O

12. The equivalent of 45°Tw in the Baume scale is
    a. 28.32
    b. 32.48
    c. 26.63
    d. 42.56

13. A 10 N aqueous solution of sulfuric acid (30°Tw) is made to react with a 55% aqueous solution of sodium hydroxide (64°Be) to form 1350 g of sodium sulfate per liter of sodium hydroxide solution. The volume ratio of the acid to the base solution is 2:1. The limiting reactant in the reaction is
    a. NaOH
    b. H_2SO_4
    c. Na_2SO_4
    d. H_2O

14. The degree of completion of the above reaction is
    a. 85%
    b. 92%
    c. 95%
    d. 72%

15. How many pounds of calcium fluoride rock is needed to produce 3000 lbs of a 60% HF per day if the yield is 90% and the rock contains 95% CaF_2?
    a. 4105.2
    b. 3694.7
    c. 3510.0
    d. 3900.0

16. The Rankine temperature at which 5000 grains of CO_2 occupies a volume of 30L at 150 psig is
    a. 730 b. 1003 c. 835 d. 664

17. The gas acetylene is produced by treating calcium carbide with H_2O. Calculate the number of hours of service that can be derived from 1 lb of carbide in an acetylene lamp burning 2 ft^3 of gas per hr at 75°F and 743 mm Hg.
    a. 2 b. 4 c. 3 d. 5

18. Which has the lowest water content, measured at the same temperature (25°C) and pressure (740 mmHg)?
    a. dew point at 20°C
    b. 70% RH
    c. absolute humidity of 0.05
    d. 60% RH

19. A gaseous mixture containing 50% mol H_2 and 50% mol acetaldehyde is initially contained in a rigid vessel at 1 atm, where formation of ethanol occurs.

$$C_2H_4O + H_2 \longrightarrow C_2H_6O$$

After some time it was noted that the pressure had dropped to 700 mmHg. The degree of completion of the reaction is
    a. 15.8% b. 20.3% c. 18.4% d. 7.6%

20. Formaldehyde is made by the catalytic air oxidation of methanol. When the process is operating properly, there is 30% conversion of the methanol to formaldehyde and 70% to formic acid according to the following reactions:

$$CH_3OH + O_2 \rightarrow HCHO + H_2O$$

$$CH_3OH + O_2 \rightarrow HCOOH + H_2O$$

Suddenly, the supervising engineer noted a drop in the formaldehyde production. An analysis of the sample taken at this time showed 63.1% N_2, 13.4% O_2, 5.9% H_2O, 4.1% HCHO, 12.3% CH_3OH, and 1% HCOOH. Determine the percentage conversion of methanol to formaldehyde based on the analysis reported by the engineer.
    a. 25 b. 27 c. 21 d. 23

21. Hydrogen chloride gas is produced by burning chlorine in methane and air as shown:

$$Cl_2 + CH_4 + O_2 \rightarrow HCl + CO_2$$

A ceramic-lined burner is used for a feed charge consisting of 80% Cl_2 and 20% CH_4 together with 10% excess air at 30°C and 29 inches Hg. After burning, the gases leaving shows 27.3% HCl. Calculate the degree of completion of the reaction.
    a. 0.80 b. 0.75 c. 0.65 d. 0.50

22. Which of the following best describes a limiting reactant?
    a. is the reactant that would disappear first if the reaction goes to completion
    b. is always in excess
    c. is usually the reactant present in smaller mass
    d. is present in more than its stoichiometric proportion relative to other reactants

23. One drier will dry a material from 45% moisture (w.b.) to 20% moisture (d.b.). From here the material enters another drier where the H_2O content is further reduced to give a final product weighing 1000 kg. If the total evaporation from both driers is 800 kg, the moisture of the final product is
    a. 5% b. 2% c. 3% d. 1%

24. The formula of the saturated hydrocarbon in hydrocarbon–N_2 mixture was determined by burning a sample of the mixture with 30% excess air. The combustion gases were analyzed & showed an Orsat analysis of 8.95% CO_2, 0.99% CO, 1.99% H_2, 6.46% O_2 and 81.61% N_2. The formula of the hydrocarbon is
    a. C_2H_6 b. C_4H_{10} c. C_3H_8 d. CH_4

25. Coal fired in a furnace has a heating value of 13,800 BTU/lb and contains 78.05% C and 1.2 % S. The proximate analysis shows 4% M, 24% VCM, 8% ash and the analysis of the refuse shows 8% VCM, 25% FC and 32% ash. Calculate the % of C lost in the refuse.
    a. 8% b. 4% c. 10% d. 17%

26. Ninety grams of ethane and 384 grams of oxygen are fed continuously to a laboratory furnace. The total combustion products collected was 16.2 g-mole with no carbon dioxide. However, not all of the ethane was burned due to faulty combustion. The fraction of ethane that was burned is equal to
    a. 90% b. 85% c. 80% d. 92%

27. The furnace at the Bataan Refinery is using a fuel gas which contains methane, ethane and 20% nitrogen. The Orsat analysis of the combustion products showed 7.8% CO_2, 7.4% O_2 and 84.8% N_2. The gas is burned with excess air. The % methane in the fuel gas is
    a. 22.76 b. 57.24 c. 50.20 d. 63.25

28. A high speed diesel engine burns fuel to give an exhaust gas analyzing 7.14% CO_2, 4.28% CO, 8.24% O_2 and 80.34% N_2. The cetane number of the fuel fired is
    a. 44.58 b. 45.20 c. 52.38 d. 50.28

29. Pyrite, containing 78% FeS_2 and 22% gangue, is burned with excess air to produce a stack gas with the following analysis: 7.29% SO_2, 8.92% O_2, 82.44% N_2 and 1.35% SO_3. If the cinder was found to have a partial analysis of 62.10% Fe_2O_3, the % of FeS_2 lost in the pyrite is
    a. 6.53% b. 3.52% c. 23.1% d. 7.86%

30. Assuming that air dominantly comprises nitrogen gas and oxygen gas, what is the mass percentage of oxygen in the air?
    a. 21 b. 23 c. 79 d. 78

B. CHEMICAL ENGINEERING THERMODYNAMICS

Thermodynamics – deals with energy in all its form, the conversion of energy from one form to another, the transfer of energy and its effect on the physical properties of substances.

Application of Thermodynamics

- Determination whether a given reaction is possible or not
- Determination of equilibrium conditions for chemical reactions and mass transfer between phases
- Determination of heat and work requirements of physical and chemical processes

I. *Fundamental Quantities*

1. *Time* (t)
   1 sec = time required for 9,192,631,770 cycles of radiation associated with the Cesium resonator

2. *Length* (L)
   1 m = 1,650,763.73 wavelengths of the orange-red light of Kr-86

3. *Mass* (m) – the primary standard is a cylinder of Platinum-Iridium alloy

4. *Temperature* (T) – the standard is Kelvin, K, equal to 1/273.16 of the thermodynamic temperature of the triple point of water

II. *Derived Quantities*

1. *Volume* – product of three length units
   specific volume (υ) = volume per unit mass
   density (ρ) = mass per unit volume

2. *Force* (F) – based from Newton's 2nd Law of Motion

   where: $F = ma$, m = mass, a = acceleration

3. *Pressure* (P)

   a. $P = \frac{Force}{Area} = \frac{F}{A}$ *unit of P: Pascal (Pa)* $= \frac{N}{m^2}$

   b. in terms of fluid height, $P = h\rho g$

   where: h = height of column, ρ = density, g = force due to gravity

   * 1 m = distance light travels in a vacuum during $\frac{1}{299{,}792{,}458}$ of a second

4. *Work* (W)
   a. linear work : $W = \int F dL$
   b. *PV* work : $W = \int P_{op}\, dV$ where: P_{op} = opposing pressure

5. *Energy*

   Kinetic Energy $k_E = \frac{1}{2} mu^2$ Potential Energy $P_E = mgz$

6. *Heat* (Q) – a "transient" energy, i.e. energy in transit from one body to another, or between a system and its surrounding

7. *Power* – rate of doing work

III. *First Law of Thermodynamics*

A. *Fundamental Equations*

– although energy assumes many forms, the total quantity of energy is constant; and when energy disappears in one form, it appears simultaneously in other forms

For non-flow processes involving ideal gas:

1. No work device
   – work involved is due to change in volume only
   $W = -\int P_{op} dV$ where: P_{op} = opposing pressure

2. 1st Law: Conservation of Energy : $\Delta U = Q + W$

3. Ideal Gas Equation : $PV = nRT$

4. Enthalpy (H): $\Delta H = \Delta U + \Delta (PV)$

5. $Cp = Cv + R$
   where: Cp = molal heat capacity at constant pressure
   Cv = molal heat capacity at constant volume

6. $\Delta H = n \int Cp dT$ $\Delta U = n \int Cv dT$

B. *Reversible Process*

– a process is reversible when its direction can be reversed at any point by an infinitesimal change in external conditions

$$W_{rev} = -nRT \ln\frac{V_2}{V_1} \qquad W_{rev} = -nRT \ln\frac{P_1}{P_2}$$

C. *Adiabatic and Reversible*

(1) $PV^{\gamma} = k$

(2) $TV^{\gamma-1} = k$

(3) $T^{\gamma}\ P^{\gamma-1} = k$ where: $\gamma = \dfrac{Cp}{Cv}$

D. *Clausius Equation* $\dfrac{dP}{dT} = \dfrac{\Delta H}{T\Delta V}$

where: ΔH = latent heat, T = absolute temperature, V = volume

E. *Clausius-Clapeyron Equation*

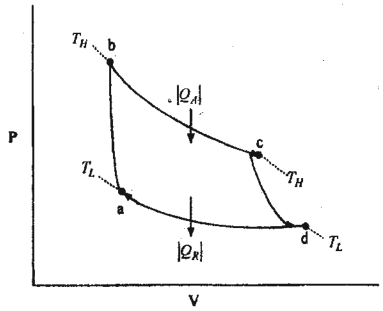
$$\ln\frac{P_2}{P_1} = \frac{\Delta H}{R}\,\frac{(T_2 - T_1)}{T_2 T_1}$$

IV. *Second Law of Thermodynamics*

A. *Heat Engines*

– absorb heat (Q_A) at a temperature (T_H). For a periodic engine, only a fraction of the heat absorbed is converted into work (W_{out}) because heat is rejected (Q_R) at a lower temperature (T_L) to enable the engine to return to its original state

CARNOT CYCLE



- $a \rightarrow b$: Adiabatic compression until temperature rises from T_L to T_H
- $b \rightarrow c$: Isothermal expansion to point c with absorption of heat $|Q_A|$
- $c \rightarrow d$: Adiabatic expansion until temperature decreases to T_c
- $d \rightarrow a$: Isothermal compression to the initial state with rejection of heat, $|Q_R|$

For any cyclic heat engine:

$$W_{out} = Q_A - Q_R \qquad \eta\,(eff) = \frac{W_{out}}{Q_A}$$

For Carnot engine, it gives the maximum work under reversible conditions

a. $W_{\max} = Q_A - Q_R$

b. $\eta = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$

c. $\frac{T_H}{T_L} = \frac{Q_A}{Q_R}$

B. *Entropy*

1. Heat exchange with reservoir, $\Delta S = \frac{Q_{rev}}{T} = \frac{Q}{T}$
2. Change in temperature :
   (i) at constant P, $\Delta S_p = Cp \ \ln\frac{T_2}{T_1}$
   (ii) at constant V, $\Delta S_v = C_v \ln\frac{T_2}{T_1}$
3. Change in phase, $\Delta S = \frac{\Delta H}{T}$

V. ***Free Energy and Equilibrium***

A. *Helmholtz Free Energy, A* : $\Delta A = \Delta U - T\Delta S = - W_m$

B. *Gibbs Free Energy, G* : $\Delta G = \Delta H - T\Delta S$

1. At constant temperature for gases : $\Delta G = nRT \ln\frac{P_2}{P_1}$
2. At constant temperature for solids and liquids : $\Delta G = V\,(P_2 - P_1)$
3. Change in pressure : $\Delta S = \frac{Q}{T} = R \ \ln\frac{P_1}{P_2}$
4. Entropy change in ideal gases : $\Delta S = nC_p \ln\frac{T_2}{T_1} - nR\ln\frac{P_2}{P_1}$

REVIEW QUESTIONS AND PROBLEMS

1. The study of the interrelation of the various forms of energy in a system is called
   a. physical chemistry
   b. chemistry
   c. physics
   d. thermodynamics

2. Which of the following thermodynamic quantities give a finite quantity when integrated?
   a. heat
   b. temperature
   c. entropy
   d. enthalpy

3. The heat content of the system is called
   a. sensible heat
   b. specific heat
   c. enthalpy
   d. heat capacity

4. The quantity of heat required to raise the temperature of a unit weight of a substance one degree temperature is called
   a. specific heat
   b. heat capacity
   c. sensible heat
   d. a or b

5. During adiabatic expansion of an ideal gas, work is done by the system and ΔU
   a. decreases b. increases c. does not change

6. Which law is the basis for the manufacture of thermometers?
   a. Boyle's Law
   b. Zeroth Law of Thermodynamics
   c. Raoult's Law
   d. Carnot's Principle

7. During the adiabatic reversible expansion of an ideal gas, the amount of heat absorbed by the gas is equal to
   a. zero
   b. one
   c. greater than zero
   d. ΔU

8. For a closed system, $dU = Q + W$. Which of the following statements is <u>false</u>?
   a. In a process where a gas is stored system.
   b. In an isobaric process, the heat in the equation is equal to the change in enthalpy of the system.
   c. In an isothermal process, the heat in the equation is equal to zero because the temperature of the system remains constant.
   d. In an adiabatic process, the work involved is equal to the change in internal energy.

9. The net work accomplished by an engine undergoing adiabatic compression is equal to
   a. ΔU
   b. ΔQ
   c. $-\Delta U$
   d. $-\Delta Q$

10. A sample of an ideal gas is allowed to escape reversibly and isothermally into a vacuum. Which statement is correct?
    a. $W = \Delta U = Q$ = a positive number
    b. $W = P\Delta V$, $\Delta U = 0$, $Q = P\Delta V$ and is a negative number
    c. $W = P\Delta V + V\Delta P$
    d. $W = Q = \Delta U = 0$

11. The amount of heat absorbed when CO_2 gas reacts with a solid CaO to form solid $CaCO_3$ is measured in a bomb calorimeter (at constant volume). The data obtained give a direct measure of
    a. ΔU
    b. $V\Delta P$
    c. ΔH
    d. C_p

12. Which of the following statements is correct?
    a. The standard heat of formation of an element is negative.
    b. Since $\Delta H = \Delta U + \Delta PV$ and can never be equal to ΔU.
    c. Q and W are state functions.
    d. $Q + W$ is a state function.

13. A more stable system with regard to ΔH are systems that have
    a. zero ΔH
    b. minimum ΔH
    c. maximum ΔH
    d. none of these

14. A measure of the total energy not available for useful work is the
    a. entropy
    b. free energy
    c. enthalpy
    d. none of these

15. The more stable system with regard to ΔS are systems that have
    a. minimum ΔS
    b. zero ΔS
    c. maximum ΔS
    d. none of these

16. The net energy available to a system is given by
    a. entropy
    b. free energy
    c. enthalpy
    d. none of these

17. If $\Delta G < 0$, then
    a. the reaction is at equilibrium
    b. a spontaneous reaction is possible
    c. no reaction is possible
    d. none of these

18. High values of entropy are associated with
    a. high possibility of a state
    b. high randomness of the state
    c. both a and b
    d. none of these

19. A newly designed refrigerator has a capacity of 3140 watts and an input rating of 735 watts. The coefficient of performance of the refrigerator is
    a. 5.67 b. 4.27 c. 3.26 d. 4.44

20. A Carnot cycle heat engine operating between 1540°F and 440°F has an efficiency of approximately
    a. 35% b. 82% c. 55% d. 25%

21. The COP of a refrigerator operating between 70°F and 20°F is
    a. 0.4 b. 9.6 c. 10.6 d. 11.6

22. Eight grams of oxygen gas at 27°C and 10 atm expands adiabatically and reversibly to final pressure of 1.0 atm. The work done in the process is
    a. 842 J b. 445 J c. 798 J d. 752 J

23. The turbine in a hydroelectric plant is fed by water falling from a height of 30 m. Assuming 95% efficiency of converting potential energy to electrical energy and 10% loss of resulting power in transmission, how many MT of water per hr are needed to keep a 100W light bulb burning?
    a. 1.43 b. 1.29 c. 1.63 d. 1.75

24. Liquid water at 0°C and atmospheric pressure has a density of 1.0 g/cc. At the same conditions, ice has a density of 0.917 g/cc. How much work is done in kJ at these conditions by 1.0 kg of ice as it melts to liquid water?
    a. 0.00917 c. −0.00917
    b. 0.0912 d. −0.0912

25. Three moles of an ideal gas at 1.0 atm and 20°C are heated at constant pressure until the final temperature is 80°C. ($C_v = 7.50 + 3.2 \times 10^{-2}T$, cal/mol-K). The change in internal energy of the process is
    a. 5429.16 cal c. 3210.50 cal
    b. 3425.27 cal d. 4590.42 cal

26. The difference between the heat of combustion of methane at constant pressure and at constant volume at 27°C when liquid water forms is
    a. − 1192.2 cal c. 1257.44 cal
    b. −2314.5 cal d. − 1257.44 cal

27. Calculate the mass of water in grams that could be heated from 20°C to 100°C by energy generated by an electric current of 10 A across a voltage of 10 V for 10 hours.
    a. 86,400 c. 14,512
    b. 10,755 d. 11,472

28. Superheated steam flows at a steady state through an insulated nozzle with an inlet diameter of 5 cm. At the nozzle entrance, steam pressure is 700 kPa, temperature is 300°C, and the velocity is 30 m/s. At the nozzle exit, the steam temperature and pressure are 233°C and 350 kPa respectively, the exit diameter of the nozzle is
    a. 3.26 cm b. 1.62 cm c. 0.38 cm d. 2.92 cm

29. A heat engine absorbs heat from the combustion of gasoline at 2200°C. The gasoline has a specific gravity of 0.8 and a heat of combustion of 11,200 cal/gram. The engine rejects heat at 1200°C. The maximum work in calories that can be obtained from the combustion of 1 liter of gasoline is
    a. 3.62×10^6 cal
    b. 4.53×10^4 cal
    c. 3.78×10^5 cal
    d. 4.22×10^6 cal

30. A 70% NaOH liquor at 160°F with a heat content of 325 BTU/lb is diluted with 20% NaOH liquor at 80°F with a heat content of 40 BTU/lb to give a final solution containing 40% NaOH (heat content is 94 BTU/lb). For every 100 lb of product, how much heat must be removed to maintain a final product temperature of 100°F?
    a. 6,000 BTU
    b. 20,100 BTU
    c. –11,700 BTU
    d. – 7,500 BTU

31. A certain process requires cooling of a brine solution continuously from 70°F to 30°F. The atmospheric temperature is 80°F. There is an available refrigerator with a power requirement of 40 kW. Can this refrigerator be used if 100 gallons of brine is to be cooled per minute? Density of solution = 1.2 kg/L and $c_{P,solution}$ = 3.3 kJ/kg-K
    a. Yes
    b. No
    c. can not be determined

32. It is proposed to warm a collector plate with solar energy. The collected energy is then transferred as heat to a fluid in a heat engine which in turn rejects heat to the atmosphere. If 200 BTU/hr-ft^2 of energy can be collected when the plate is operating at 190°F, estimate the minimum collector area required for a plant producing 1 kW of useful shaft power. Assume atmospheric temperature of 70°F.
    a. 86.2 ft^2
    b. 92.4 ft^2
    c. 97.5 ft^2
    d. 81.6 ft^2

33. An inventor claimed that he has devised an engine that absorbs 1000 kW of heat from the heat source and discards 700 kW of heat to the heat sink. If the engine operates between 500 K and 200 K, is the inventor's claim valid?
    a. Yes
    b. No
    c. can not be determined

34. The minimum work required for the manufacture of 5 lbs of ice cubes from water initially at 32°F is
    a. 87.6 BTU
    b. 73.0 BTU
    c. 90.2 BTU
    d. 70.0 BTU

    The surrounding air is 80°F and the latent heat of fusion of water is 143.4 Btu/lb

35. Calculate the change in entropy when 100 grams of ice at 0°C is converted to steam at 100°C and 1 atm.
    a. 645.23 eu
    b. 302.34 eu
    c. 205.28 eu
    d. 342.25 eu

36. At 90°C, the vapor pressure of acetic acid is 293 mmHg and its vapor pressure at 100°C is 417 mmHg. Calculate the normal boiling point of acetic acid.
    a. 271.4 K
    b. 391.3 K
    c. 298.2 K
    d. 303.0 K

37. Calculate the change in molar Gibb's energy of liquid H_2O treated as incompressible fluid when pressure is increased from 1.0 bar to 2.0 bar at 298 K
    a. + 1.82 J/mol
    b. – 1.82 J/mol
    c. + 1.82×10^{-4} J/mol
    d. – 1.82×10^{-4} J/mol

38. One mol of $N_2O_4(g)$ forms 2.0 mol of NO_2 (g) under standard conditions. If $\Delta S = 4.8$ J/K, the reaction is
    a. spontaneous
    b. non-spontaneous
    c. in equilibrium
    d. cannot be determined

39. The densities of liquid and solid mercury are 13.7 and 14.19 g/cc respectively at a melting point of – 38.87°C. The heat of fusion of Hg is 566 cal/mol. The change in melting point per atmospheric change in pressure is
    a. 0.505 K
    b. 0.0051 K
    c. 0.013 K
    d. 0.231 K

40. A copper block (C_p = 0.398 kJ/kg-K) having a mass of 15 kg and a temperature of 500K is placed in a well-insulated vessel containing 100 kg of water initially at 300K. The entropy change of the entire process is
    a. 0.893 kJ/K
    b. 0.893 J/kg-K
    c. –0.893 kJ/K
    d. ± 0.893 kJ/kg-K

C. REACTION KINETICS

THEORY AND EQUATIONS

Consider the homogeneous chemical reaction of species A, B, etc.,

$$aA + bB + \dots \rightarrow cC + dD + \dots$$

where : *a, b, ... c, d* represent the stoichiometric coefficients of the balanced chemical reaction. If the ratios, $\frac{C_{AO}}{a} < \frac{C_{BO}}{b}$, then A is considered as the limiting reactant where the rate of the reaction is usually referred to.

The Reaction Rate of A is: $r_A = -\frac{1}{V}\frac{dN_A}{dt} = -\frac{1}{V}\frac{(C_A V)}{dt} = -\frac{1}{V}\left[V\frac{dC_A}{dt} + C_A\frac{dV}{dt}\right]$

and the rate equation is $r_A = kC_A^{\alpha}C_B^{\gamma}\dots$

where: k = specific rate constant, α = order with respect to A, γ = order with respect to B.

The over-all order of the reaction is given by $n = \alpha + \gamma + \dots$ and the molecularity of the reaction $m = a + b + \dots$ If the reaction is an elementary reaction, $n = m$, and for non-elementary reactions, the order of the reaction is obtained from experimental data or from the actual mechanism of the reaction.

To relate the rates of the reaction of the other species participating in the reaction, we use

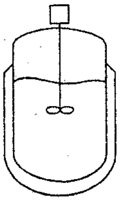
$$-\frac{r_A}{a} = -\frac{r_B}{b} = \dots = \frac{r_C}{c} = \frac{r_D}{d}$$

To express the rate equation in terms of temperature, we use the Arrhenius Equation:

$$k = \alpha_o e^{-\frac{E}{RT}}$$

where: α_o = frequency factor, E = activation energy, T = absolute temperature,
R = universal gas constant

Batch Reactor



For *Constant Volume Reaction* under batch conditions, the reaction time may be obtained from

$$r_A = -\frac{dC_A}{dt}$$

rearranging and integrating, we get

$$t = -\int_{C_{A_0}}^{C_A} \frac{dC_A}{r_A}$$

For *Variable Volume Reaction* under batch conditions, the rate equation may be expressed in terms of the change in volume as follows:

Consider the reaction: $aA + bB \rightarrow cC + dD$

Initial:	N_{a_0}	N_{b_0}	N_{c_0}	N_{d_0}
Change:	x	$(b/a)x$	$(c/a)x$	$(d/a)x$

Final: $N_a - x \qquad N_{b_o} - (b/a)x \qquad N_{c_o} + (c/a)x \qquad N_{d_o} + (d/a)x$

Total moles, $N_t = N_{a_o} - x + N_{b_o} - (b/a)x + N_{c_o} + (c/a)x + N_{d_o} + (d/a)x$

$$= N_{a_o} + N_{b_o} + N_{c_o} + N_{d_o} + (c+d-a-b)/a)x$$

$$N_t = N_{t_o} + \delta_a x$$

where: $\delta_a = \dfrac{(c+d)-(a+b)}{a}$ and $N_{t_o} = N_{a_o} + N_{b_o} + N_{c_o} + N_{d_o}$

The fractional conversion of A is $X_A = \dfrac{N_{a_o} - N_a}{N_{a_o}} = \dfrac{x}{N_{a_o}}$

Thus, the total moles in the system at any time is $N_t = N_{t_o} + N_{a_o}\delta_a X_A$

Using ideal gas law: $\dfrac{\pi V}{RT} = \dfrac{\pi V_o}{RT} + \dfrac{\pi V_{ao}\delta_a X_A}{RT}$, with the initial partial volume of A defined as $V_{a_o} = \dfrac{N_{a_o}}{N_{t_o}} V_o$

Therefore, at constant total pressure, π, the volume of the system is obtained as

$$V = V_o + \frac{N_{a_o}}{N_{t_o}} V_o \delta_a X_A = V_o(1 + \varepsilon_A X_A),$$

where: $\varepsilon_A = \dfrac{N_{ao}}{N_t}\delta_a$. substituting in the rate equation,

$$\therefore r_A = -\frac{1}{V_o(1+\varepsilon_A X_A)} \cdot \frac{d\left[N_{A_o}(1 - X_A)\right]}{dt}$$

$$r_A = \frac{C_{A_o}}{1 + \varepsilon_A X_A} \cdot \frac{dX_A}{dt}$$

$$\therefore t = \int_{X_{A_i}}^{X_{A_f}} \frac{dX_A}{r_A(1 + \varepsilon_A X_A)}$$

For *Variable Pressure Reaction* at constant volume, the rate equation can be expressed in terms of the total pressure, π. By similar approach:

$$\pi = \pi_o(1 + \varepsilon_A X_A)$$

integrating with respect to time, t:

$$\frac{d\pi}{dt} = \pi_o \varepsilon_A \frac{dX_A}{dt}$$

Since, $\dfrac{dX_A}{dt} = \dfrac{V_o}{N_{ao}} r_A$, therefore, $t = \dfrac{1}{RT\varepsilon_A}\displaystyle\int_{\pi o}^{\pi} \frac{d\pi}{r_A}$,

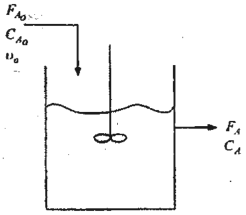
And r_A will have to be expressed in terms of π for the above equation to be integrated.

Backmix Reactor or C.S.T.R.

Material Balance: $$v_o C_{A_O} = vC_A + r_A V + \frac{d(C_A V)}{dt}$$

$$\tau = \frac{1}{s} = \frac{V}{v_o} = \frac{C_{A_O} - C_A}{r_{Af}} = \frac{C_{A_O} X_A}{r_{Af}}$$

or more generally, $$\tau = \frac{1}{s} = \frac{v_o C_{A_O}}{F_{A_O}} = \frac{C_{A_O}(X_{Af} - X_{Ai})}{r_{Af}}$$



$C_{A_0} = C_A + r_A \tau$

$C_{n-1} = C_n + r_n \tau_n$

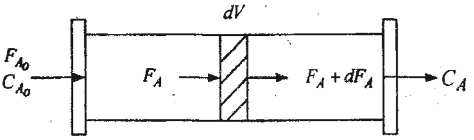
CSTR in series

Plug Flow Reactor

Material balance around element of volume, dV

$$F_A = (F_A + dF_A) + r_A dV$$

but $$dF_A = d\left[F_{A_o}(1 - X_A)\right] = -FA_o\, dX_A$$



$$\therefore F_{A_O} dX_A = r_A dV$$

integrating $$\int_o^v \frac{dV}{F_{A_O}} = \int_{X_{A_i}}^{X_{A_f}} \frac{dX_A}{r_A}$$

$$\frac{V}{F_{A_O}} = \frac{V}{\upsilon_O C_{A_O}} = \int_{X_{A_i}}^{X_{Af}} \frac{dX_A}{r_A}$$

or $$\tau = \frac{V}{\upsilon_O} = C_{A_O} \int_{X_{A_i}}^{X_{Af}} \frac{dX_A}{r_A}$$

For constant density systems:

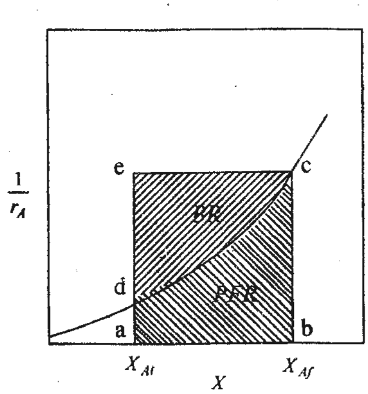
$$X_A = 1 - \frac{C_A}{C_{A_o}} \quad \text{and} \quad dX_A = -\frac{dC_A}{C_{A_o}}$$

$$\tau = \frac{V}{\upsilon_o} = C_{A_o} \int_{X_{A_i}}^{X_{Af}} \frac{dX_A}{r_A} = -\int_{C_{A_i}}^{C_{Af}} \frac{dC_A}{r_A}$$

Comparison of Reactors

Backmix Reactor – referring to the figure, the τ/C$_{\text{Ao}}$ for backmix reactor is represented by the area *abcea*.

Plug Flow Reactor – referring to the figure, the τ/C$_{\text{Ao}}$ for plug flow reactor is represented by the area *abcda*. This indicates that for simple ordered reactions, for the same conversion and throughput, the plug flow is smaller that the backmix reactor.



Batch Reactions

1. First order, constant volume reaction: $A \rightarrow$ Products

$$r_A = kC_A$$

$$\therefore t = -\int \frac{dC_A}{r_A} = -\frac{1}{k}\int_{C_{Ao}}^{C_{Af}} \frac{dC_A}{C_A} = \frac{1}{k}\ln\frac{C_{A_o}}{C_A}$$

or $$C_A = C_{Ao}\,e^{-kt}$$

Let half-life $t = t_{1/2}$ then $C_A = \frac{1}{2}C_{A_o}$ and $t_{1/2} = \frac{1}{k}\ln 2$ or $k = \frac{\ln 2}{t_{1/2}}$

First order, variable volume reaction

$$t = C_{A_o}\int_{X_{A_i}}^{X_{Af}} \frac{dX_A}{r_A(1-\varepsilon_A X_A)}$$

$$r_A = kC_A = k\left(\frac{N_A}{V}\right) = k\left[\frac{N_{A_o}(1-X_A)}{V_o(1+\varepsilon_A X_A)}\right] = kC_{A_o}\left(\frac{1-X_A}{1+\varepsilon_A X_A}\right)$$

$$\therefore t = \frac{1}{k}\int_o^{X_A}\frac{dX_A}{1-X_A} = -\frac{1}{k}\ln(1-X_A)$$

$$kt = -\ln\left(1-\frac{\Delta V}{\varepsilon_A V_o}\right)$$

2. Second order, constant volume reaction: $2A \rightarrow$ Products

$$r_A = kC_A^2$$

$$t = \frac{1}{k}\int_{C_{A_o}}^{C_A}\frac{dC_A}{C_A^2} = \frac{1}{k}\left[\frac{1}{C_{A_o}} - \frac{1}{C_A}\right]$$

Second order, variable volume reaction

$$r_A = kC_A^2 = kC_{A_o}\left(\frac{1-X_A}{1+\varepsilon_A X_A}\right)^2$$

$$\therefore t = \frac{1}{kC_{A_o}}\int_o^{X_A}\frac{(1+\varepsilon_A X_A)}{(1-X_A)^2}\,dX_A$$

$$kC_{A_o}t = \frac{(1+\varepsilon_A X_A)}{1-X_A} + \varepsilon_A\ln(1-X_A)$$

3. Complex reactions, constant volume

a. Parallel Reactions: $A \xrightarrow{k_1} R,\quad A \xrightarrow{k_2} S$

$$r_A = k_1C_A + k_2C_A = (k_1+k_2)C_A$$

$$r_R = \frac{dC_R}{dt} = k_1 C_A \qquad r_S = \frac{dC_S}{dt} = k_2 C_A \qquad \frac{dC_R}{dC_S} = \frac{k_1}{k_2}$$

integrating: $C_A = C_{A_0}{}^{-(k_1+k_2)t}$ $\qquad \dfrac{C_R - C_{R_o}}{C_S - C_{S_o}} = \dfrac{k_1}{k_2}$

b. Reactions in Series: $A \xrightarrow{k_1} R \xrightarrow{k_2} S$

$$r_A = -\frac{dC_A}{dt} = k_1 C_A;\ r_R = \frac{dC_R}{dt} = k_1 C_A - k_2 C_R;\ r_S = \frac{dC_R}{dt} = k_2 C_R$$

integrating: $C_A = C_{A_o} e^{-k_1 t}$

$$C_R = C_{A_0} k_1 \left[\frac{e^{-k_1 t}}{k_2 - k_1} + \frac{e^{-k_2 t}}{k_1 - k_2} \right] \qquad k_1 \neq k_2$$

$$C_S = \left(C_{A_o} + C_{B_o} + C_{S_o}\right) - \left(C_A + C_B\right)$$

c. Reactions of Shifting Order

$A \rightarrow R$ with $r_A = -\dfrac{k_1 C_A}{1 + k_2 C_A}$

At high C_A or $k_2 C_A >> 1$, zero order rate constant $\approx \dfrac{k_1}{k_2}$

At low C_A or $k_2 C_A << 1$, first order rate constant $= k_1$

integrating: $k_1 t = \ln \dfrac{C_{A_o}}{C_A} + k_2\left(C_{A_o} - C_A\right)$

REVIEW QUESTIONS AND PROBLEMS

1. The unit of k for a first order elementary reaction is
   a. 1/time
   b. concentration/time
   c. 1/concentration
   d. $(\text{concentration})^{-1}(\text{time})^{-1}$

2. In which of the following cases does the reaction go farthest to completion ?
   a. $k = 10^2$
   b. $k = 10^{-2}$
   c. k = 10
   d. k = 1

   (Note: k is the equilibrium constant)

3. If the temperature of a chemical reaction is raised by 10°C, the rate of reaction is increased by a factor of about
   a. 2
   b. 4
   c. 1.5
   d. 3

4. The activation energy, E of a reaction may be lowered by
   a. increasing the temperature
   b. decreasing the temperature
   c. adding a catalyst
   d. removing the products of the reaction

c 5. The mechanism of a reaction can sometimes be deduced from
   a. the temperature dependency of the rate
   b. the net reaction
   c. the rate equation
   d. the activation energy

6. The law governing the kinetics of a reaction is the law of
   a. constant composition
   b. chemical equilibrium
   c. constant temperature
   d. mass action

C 7. The equilibrium constant in a reversible chemical reaction at a given temperature
   a. depends on the initial concentration of the reactants
   b. depends on the concentration of one of the products at equilibrium
   c. does not depend on the initial concentrations
   d. is not a characteristic of the reaction

8. Which of the following statements is the best explanation for the effect of increase in temperature on the rate of reaction ?
   a. It increases the number of particles with the necessary activation energy
   b. It enables the reacting particles with the necessary activation energy
   c. It lowers the activation energy for the reaction
   d. It enables the activated complex to be more easily converted to the products

9. If the rate of reaction is independent of the concentration of the reactants, the reaction is said to be
   a. first order
   b. third order
   c. second order
   d. zero order

10. The specific rate of reaction is primarily dependent on
   a. time of reaction
   b. heat of reaction
   c. temperature
   d. concentration of the reactants

11. The rate of reaction is not influenced by
   a. concentration of the reactants
   b. molecularity of the reaction
   c. nature of reactants
   d. temperature

12. For the reaction $2A_{(g)} + 3B_{(g)} \rightarrow D_{(g)} + 2E_{(g)}$ with $r_D = kC_AC_B^2$ the reaction is said to be
   a. non-homogeneous
   b. elementary
   c. non-elementary
   d. consecutive

13. Chemical reaction rates in solution do not depend to any extent upon
   a. pressure
   b. temperature
   c. concentration
   d. catalyst

14. The overall order of reaction for the elementary reaction $A + 2B \xrightarrow{k} C$ is
   a. 0
   b. 1
   c. 2
   d. 3

15. If the volume of a container for the above reaction (Problem 14) is suddenly reduced to ½ its original volume with the moles of A, B & C maintained constant, the rate will increase by a factor of
   a. 2
   b. 4
   c. 8
   d. 16

16. The rate of formation of B in terms of r_A (where $r_A = -kC_AC_B^2$) is
    a. $\frac{1}{2} r_A$
    b. r_A
    c. $2r_A$
    d. $-\frac{1}{2} r_A$

17. The net rate of reaction of an intermediate is
    a. zero
    b. infinity
    c. greater than zero
    d. less than zero

18. For the reaction: $4A + B \rightarrow 2C + 2D$
    Which of the following statements is not correct?
    a. The rate of disappearance of B is one fourth the rate of disappearance of A.
    b. The rate of appearance of C is one half the rate of disappearance of A.
    c. The rate of disappearance of C is one half the rate of consumption of A.
    d. The rate of formation of C and D are equal.

19. The collision theory of chemical reactions maintains that
    a. A chemical reaction occurs with every molecular collision.
    b. Reactions in the gas phase are always first order.
    c. Reaction rates are of the order of molecular speeds.
    d. Rate is directly proportional to the number of collisions per second.

20. A reaction is known to be first order in A. A straight line will be obtained by plotting
    a. log C_A versus time
    b. C_A versus time
    c. log C_A versus reciprocal time
    d. $1/C_A$ versus time

21. If the reaction, $2A \rightarrow B + C$ is second order, which of the following plots will give a straight line ?
    a. C_A^2 vs. time
    b. $1/C_A$ vs. time
    c. log C_A vs. time
    d. C_A vs. time

22. The activation energy of a reaction can be obtained from the slope of a plot of
    a. log k vs 1/T
    b. k vs log T
    c. log k vs T
    d. k vs log 1/T

23. For the reaction $A + B \rightarrow 2C$, when C_A is doubled, the rate doubles. When C_B is doubled, the rate increases four fold. The rate law is
    a. $-r_A = k\, C_A^2\, C_B^4$
    b. $-r_A = k\, C_A\, C_B^2$
    c. $-r_A = k\, C_A$
    d. $-r_A = k\, C_B^2$

24. A pressure cooker reduces cooking time because
    a. The heat is more evenly distributed.
    b. The higher pressure tenderizes the food.
    c. The boiling point is elevated.
    d. A large flame must be used.

25. A catalyst can
    a. shift the equilibrium of reaction
    b. diminish the activation energy
    c. increase the rate constant of forward reaction
    d. decrease the pressure

26. It states that the rate of a chemical reaction is proportional to the activity of the reactants.
    a. Law of Mass Action
    b. Hess' Law
    c. Le Chatelier's Principle
    d. Second Law of Thermodynamics

27. Rapid increase in the rate of chemical reaction even for small temperature increase is due to
    a. rapid increase in kinetic energy of molecules
    b. rapid increase with temperature of the fraction of molecules with energies in excess of activation energy
    c. rapid increase in collision frequency
    d. increase in activation energy

28. The half-life of a material undergoing second order decay is
    a. proportional to the square of initial concentration
    b. independent of initial concentration
    c. proportional to initial concentration
    d. inversely proportional to initial concentration

29. The composition of the reaction component varies from position to position along a flow path in a/an
    a. CSTR
    b. adiabatic reactor
    c. batch reactor
    d. plug-flow reactor

30. A fluid flows through two stirred tank reactors in series. Each reactor has a capacity of 400,000 liters and the fluid enters at 100 liters per hour. The fluid undergoes a first order decay with a half life of 24 hours. Find the % conversion of the fluid.
    a. 85.3
    b. 74.7
    c. 66.8
    d. 99.14

31. A certain reaction is second order in *A*. When C_A is 0.03 mol/L, the rate is 3×10^{-3} L/mol-s. The rate when C_A is 0.015 mol/L in L/mol-s is
    a. 7.5×10^{-4}
    b. 1.5×10^{-3}
    c. 0.21
    d. 3.33

32. A certain reaction is first order in *A*. The specific rate constant is 3×10^{-3}/s. The half life is
    a. 2.1×10^{-3} s
    b. 100 s
    c. 231 s
    d. 768 s

33. A certain reaction is first order in *A*. In 30 minutes, *A* decreases from 0.55 to 0.15 mol/L. The time it will take for *A* to decrease from 0.35 to 0.15 mol/L is
    a. 10.4 min
    b. 19.1 min
    c. 19.6 min
    d. 45.1 min

34. A certain reaction has an activation energy of 125 kJ/mol. The rate constant is 0.033/s at 55°C. The value of the specific rate constant at 100°C is
    a. 1.3×10^{-4}/s
    b. 0.037/s
    c. 0.088/s
    d. 8.3/s

35. A certain reaction has a specific rate constant of 4.27×10^{-3}/s at 25°C and 7.35×10^{-2}/s. at 80°C. The energy of activation in kJ per mol is
    a. 5.44 c. 104
    b. 45.2 d. 860

36. The third order gas phase reaction $2NO + O_2 \rightarrow 2NO_2$ has specific reaction rate of $k_c = 2.65 \times 10^4\ L^2/gmol^2/s$ at 30°C and 1 atm. The value of K_p in gmol/L-atm^3-s
    a. 1.7239 c. 2.7193
    b. 1.2793 d. 1.9372

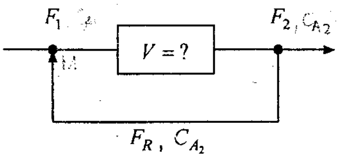
37. The isothermal irreversible aqueous phase reaction $A + B \rightarrow E$ at 100°F obeys

$$dC_E/dt = r_E = k\,C_A\,C_B \qquad k = 15\ ft^3/lbmol\text{-}h$$

    Using a 1000 ft^3 stirred tank reactor with an aqueous feed of 2000 ft^3/h, the outlet concentration of E if the inlet concentration of A and B are both 0.25 lbmol/ft^3 is
    a. 0.1332 lbmol/ft^3 c. 0.1223 lbmol/ft^3
    b. 0.3122 lbmol/ft^3 d. 0.4233 lbmol/ft^3

38. A reaction typically represented by $A \rightarrow B$ is to be conducted in a controlled tank reactor. The scheme of the operation is shown in the diagram. The reaction is first order with established rate, r = 20 lb-mole/hr-cu.ft. The feed (F_o) is to be 100 cu.ft./hr at a concentration of 1 lb-mole/cu.ft. The product removed contains 50 lb-moles/hr of unreacted A at steady-state conditions.
    If the hold-up time is 15 minutes, the reactor volume in cu.ft. will be
    a. 50 c. 45
    b. 60 d. 100

$F_o = 100$
$C_{A_o} = 1$



$\left.\begin{matrix} F_3 \\ C_{A_2} \end{matrix}\right\}$ 50 mols A unreacted
$F_3 C_{A_2} = 50$

$F_1 = F_0 + F_R$
$F_1 C_A = F_0 C_{A0} + F_R C_{A2}$

39. For the reaction $A \xrightarrow{k_1} B \xrightarrow{k_2} C,\ k_1 = k_2 = 0.35\,hr^{-1}$. The initial concentration of both B and C is 0.5 lb-moles/cu.ft. $C_{A_o} = 2.5$ lb-moles/cu.ft.
    A. The time at which the concentration of B is a maximum is
        a. 2.3 hours c. 4 hours
        b. 3 hours d. 2.5 hours
    B. The size of the reactor so that B is produced at an average rate of 300 moles/hr assuming that the time per batch is 1 hour and the time of cleaning and dumping is 30 minutes is
        a. 300 ft^3 c. 356 ft^3
        b. 450 ft^3 d. 536 ft^3

40. A second-order reaction involving reactants initially present at 0.10 moles/L is found to be 20% complete in 40 minutes, when the reaction temperature is 25°C, and 40% ~~complete in 40 minutes, when the reaction temperature is 25°C,~~ and 40% complete in 35 minutes when the reaction temperature is 50°C. The activation energy for this reaction is
    a. 8700 cal/gmol c. 8500 cal/gmol
    b. 8540 cal/gmol d. 9530 cal/gmol

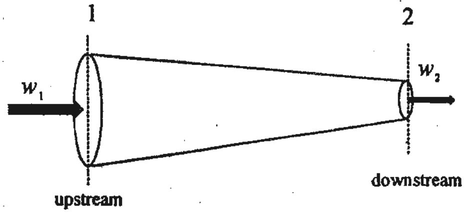
D. UNIT OPERATIONS

1. FLOW OF FLUIDS

THEORY AND EQUATIONS

Basic Equations of Fluid Flow

1. *Continuity Equation*



At steady state: $w_1 = w_2$

$$w = q\rho = VS\rho = GS$$

where: w = mass flow rate, Mt^{-1}; q = volumetric flow rate, $L^3 t^{-1}$
V = average velocity, Lt^{-1}; G = mass velocity, $ML^{-2}t^{-1}$
ρ = density, ML^{-3}; S = cross-sectional area, L^2

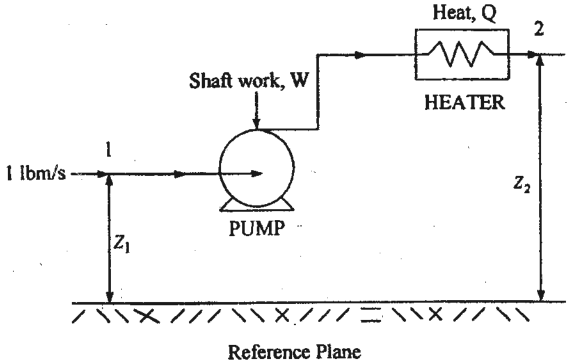
Example: Given V_1, find V_2

$V_1S_1\rho_1 = V_2S_2\rho_2$, therefore $\qquad V_2 = V_1 \times \dfrac{S_1}{S_2} \times \dfrac{\rho_1}{\rho_2}$

For liquids, $\rho_1 = \rho_2$ $\qquad \therefore V_2 = V_1 \times \dfrac{S_1}{S_2} = V_1 \times \dfrac{D_1^2}{D_2^2}$

For gases, $\rho = \dfrac{PM}{RT}$ $\qquad \therefore V_2 = V_1 \times \dfrac{S_1}{S_2} \times \dfrac{p_1}{p_2} \times \dfrac{T_2}{T_1}$

2. *Overall Energy Balance (OEB) Equation*



W = shaft work, ft-lb$_f$/lb$_m$; Q = heat transferred, Btu/lb$_m$; J = mechanical equivalent of heat, 778 $\frac{ft-lb_f}{Btu}$

Setting up an energy accounting around the control volume,

$$\underbrace{W}_{work}+\underbrace{JQ}_{heat}=\underbrace{\Delta Z\frac{g}{g_c}}_{PE}+\underbrace{\frac{\Delta V^2}{2\alpha g_c}}_{KE}+\underbrace{J\Delta U}_{Int.\ E}+\underbrace{\Delta(pv)}_{Flow\ E.}$$

where: α = velocity correction factor, $\alpha = 1$ for turbulent flow; $\alpha = 0.5$ for laminar flow

From Thermodynamics: $J\Delta H = J\Delta U + \Delta(pv)$

substituting, $W = \Delta Z\frac{g}{g_c}+\frac{\Delta V^2}{2\alpha g_c}+J\Delta H - JQ$

The enthalpy change is easily evaluated.

For liquids: $\Delta H = C_v\Delta T$; ideal gas: $\Delta H = C_p\Delta T$

For thermodynamic properties of real gas, use Charts
For steam, use Steam Tables

3. *Mechanical Energy Balance (MEB) Equation*

From Thermodynamics: $J\Delta H - JQ = F_p + \sum F + \int v dp$

Let $W' = W - F_p$ where W' is referred to as the Total Dynamic Head (TDH)

substituting, $$\therefore \underbrace{W'}_{TDH} = \underbrace{\Delta Z\frac{g}{g_c}}_{PEH}+\underbrace{\frac{\Delta V^2}{2\alpha g_c}}_{Vel.H.}+\underbrace{\int v dp}_{Static\ head}+\underbrace{\sum F}_{Friction\ head}$$

Power consumption of the pump:

Theo $HP = \frac{W'w}{550}$ $BHP = \frac{W'w}{550\eta_p}$ η_p = pump eff.

a. Flow of Incompressible Fluids

$$W' = \Delta Z\frac{g}{g_c}+\frac{\Delta V^2}{2\alpha g_c}+v\,\Delta p+\sum F$$

Evaluation of $\sum F$:

$$\sum F = \underbrace{F_L}_{line}+\underbrace{F_f}_{fitting}+\underbrace{F_c}_{contraction}+\underbrace{F_e}_{exp.}+\underbrace{F_m}_{meter}$$

Evaluation of F_L:

Fanning Equation

$$F_L = \frac{2fLV^2}{g_c D}$$

where: f = Fanning friction factor. See Figure 6-9, Perry 7/e

$f = \phi\left(N_{\mathrm{Re}}, \frac{\varepsilon}{D}\right)$ See Table 5-6 Perry, 6th edition or Table 6-1 Perry, 7/e

$$N_{\mathrm{Re}} = \frac{DV\rho}{\mu} = \frac{DG}{\mu}$$

D = inside diameter ft.; μ = viscosity $\mathrm{lb_m/ft\text{-}sec}$

If $N_{\mathrm{Re}} < 2100$, flow is laminar, $f = \frac{16}{N_{\mathrm{Re}}}$

If $2000 < N_{\mathrm{Re}} < 4200$, transition

If $N_{\mathrm{Re}} > 4200$, turbulent flow

Note: If conduit is non-circular, use D_e in place of D

$$D_e = 4R_H = 4\left(\frac{\text{cross.sectional area}}{\text{wetted perimeter}}\right)$$

See Table 5-B, Perry 6th edition or page 6-12, Perry 7/e for *De*

Evaluation of F_f: $F_f = K_f \frac{V_1^2}{2g_c}$

K_f = loss factor, see Table 5-19, Perry 6th edition or Table 6-4, Perry 7/e

or use $F_f = \frac{2fL_eV^2}{g_cD}$ L_e = equivalent length of the fitting

Evaluation of F_c and F_e:

$$F_c = K_c\frac{V_2^2}{2g_c} \quad ; \quad F_e = \frac{(V_1 - V_2)^2}{2g_c}$$

For Laminar Flow, $K_c < 0.10$

For Turbulent Flow, $K_c = 0.5\left(1 - \frac{S_2}{S_1}\right)$

For other equations, see page 6-16, Perry 7/e

b. Flow of Compressible Fluids

Types of compressible fluid flow:

Subsonic Flow, $N_{Ma} < 1.0$

Sonic Flow, $N_{Ma} = 1$

Supersonic Flow, $N_{Ma} > 1.0$

where: $N_{Ma} = \frac{u}{a} = \frac{\text{act. vel}}{\text{vel. of sound}}$ (Mach no.)

1. Subsonic Isothermal Flow
   MEB: for an element of length *dL* in a horizontal pipe:

$$dW = dZ + d\left(\frac{V^2}{2g_c}\right) + vdp + dF$$

   with $dW = 0$ and $dZ = 0$, integrating:

$$p_1^2 - p_2^2 = \frac{4z\,RTfL\,G^2}{Mg_cD}\left[\frac{2.3D}{2fL}\log\frac{p_1}{p_2} + 1\right]$$

   where: $z =$ average compressibility factor
   when: $L/_{D} > 100$,

$$p_1^2 - p_2^2 = \frac{4\,zRTfLG^2}{Mg_cD}$$

   For other equations to determine pressure drops, see page 6-22, Perry 7/e

2. Subsonic Non-Isothermal Flow
   Use equation for isothermal flow with terms affected by temperature average.

$$p_1^2 - p_2^2 = \frac{4\bar{z}\,R\bar{T}\bar{f}L\,G^2}{Mg_cD}\left[\frac{2.3D}{2\bar{f}L}\log\frac{p_1}{p_2} + 1\right]$$

   or from empirical equations, example:

$$p_1 - p_2 = \frac{G^2(v_2 - v_1)}{g_c} + \frac{2\bar{f}G^2\bar{v}L}{g_cD} + \Delta Z\bar{\rho}$$

Pumps and Compressors

Power Consumption:

a. For fans, use MEB Equation for incompressible fluids since $\rho_1 \approx \rho_2$, i.e. Δp is small.
b. For blowers and compressors, MEB equation yields,

$$W' = \int_{p_o}^{p_1} vdp$$

For adiabatic compression,

$$p_o v_o^{\gamma} = pv^{\gamma} \qquad \text{where } \gamma = \frac{C_p}{C_v}$$

$$\therefore W' = \frac{\gamma}{\gamma - 1}p_o v_o\left[\left(\frac{p_1}{p_o}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

For N stages,

$$W'_{\min} = \frac{N\gamma}{\gamma - 1}p_o v_o\left[\left(\frac{p_1}{p_o}\right)^{\frac{\gamma-1}{N\gamma}} - 1\right]$$

For isothermal compression, $pv = \text{constant}$

$$W' = p_o v_o \ln \frac{p_1}{p_o}$$

For homologous pumps: Effect of speed and diameter:

$$\text{Capacity: } \frac{q_2}{q_1} = \frac{D_2}{D_1}\frac{N_2}{N_1}$$

$$\text{Head: } \frac{H_2}{H_1} = \left(\frac{D_2}{D_1}\right)^2 \left(\frac{N_2}{N_1}\right)^2$$

$$\text{Power: } \frac{P_2}{P_1} = \left(\frac{D_2}{D_1}\right)^3 \left(\frac{N_2}{N_1}\right)^3$$

For the variation of capacity, efficiency and speed with developed head, see specific pump characteristics, example: Figures 10-28, 10-29, 10-45, 10-47, Perry 7/e

As a guide in selecting the type of pump to use, see Figure 10-26, Perry 7/e

Net Positive Suction Head (NPSH) = Suction Head – Vapor Pressure Head
If NPSH = < 0, cavitation will occur. See page 10-23, Perry 7/e

available → $NPSH_a = \frac{P_s}{\rho} - \frac{P_v}{\rho} = \left(\frac{P_1}{\rho} + z_1 \frac{g}{g_c} - \frac{V_s^2}{2g_c} - \Sigma F\right) - \frac{P_v}{\rho}$; P_s - pressure at suction point

P_v - vapor pressure of the liquid

→ NPSH [illegible]

Metering of Fluids

1. *U-Tube Manometer*
   Pressure balance

$$p_1 + (a + Hm)\rho = p_2 + (\Delta Z + a)\rho + Hm\rho_m$$

$$\frac{p_1 - p_2}{\rho} = \Delta H = Hm\left(\frac{\rho_m}{\rho} - 1\right) + \Delta Z$$

2. *Pitot Tube*
   For incompressible fluids,

$$V_{\max} = C\sqrt{2g_c \Delta H}$$

where: C = correction factor ≈ 1.0

$$\frac{\overline{V}}{V_{\max}} = \phi\left(N_{\text{Re}\max} = \frac{DV_{\max}\rho}{\mu}\right)$$

See Figure 5-14, Perry 6/e or Figure 10-7, Perry 7/e

For compressible fluids, see Equation 10-8, Perry 7/e

3. *Head Meters (Orifice, Venturi, Nozzles)*
   General Formula

$$w = CYS_2\ \rho_1\sqrt{\frac{2g_c\Delta H}{1-\beta^4}}$$

where: $\beta = \frac{D_2}{D_1}$

$Y =$ Coefficient of Volume Expansion
  For liquids, $Y = 1.0$
  For gases, see Figure 5-16, Perry 6/e or Figure 10-16, Perry 7/e
$C =$ Discharge Coefficient
  For square or sharp edged orifices,
    $C = 0.61$ for $\beta \leq 0.2$ for all taps except pipe tap
    $C = 0.61$ for $N_{\text{Re}} > 30{,}000$
    If $N_{\text{Re}} > 30{,}000$, see Figure 5-20, Perry 6/e or Figure 10-20, Perry 7/e
  For venturi meters, if $N_{\text{Re}} > 10{,}000$, $C = 0.98$

4. *Area Meters (Rotameters)*
   See Equation 10-34 and Equation 10-36, Perry 7/e

5. *Meters for Open Channel Flow*
   See Equation 10-37, Perry 7/e for Rectangular Weir
   See Equation 10-39, Perry 7/e for Triangular-notch Weir

Evaluation of F_m, friction loss due to meters

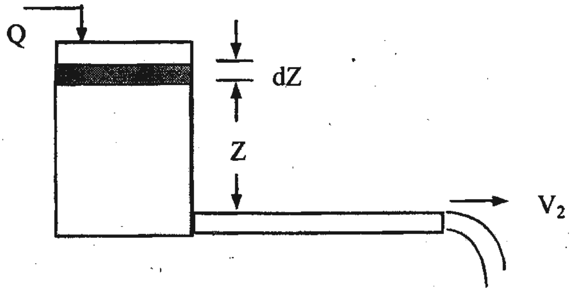
$$F_m = y\Delta H$$

where: $y =$ fraction of head lost due to friction
  For orifices, see Equation 10-30, Perry 7/e
  For venturi meters, $y = 0.10$

Branching

Use the continuity equation and the MEB equation to be solved simultaneously.

Unsteady Head Flow



A material balance around the tank gives, $Q_1 - V_2 S_2 = S_1 \dfrac{dZ}{dt}$

express V_2 in terms of Z using the MEB Equation and solve the differential equation for t in terms of Z, analytically or numerically.

Example: For orifice opening, $V_2 = 0.61\sqrt{2g_c Z}$, if $Q_l = 0$,

the integrated equation becomes, $t = \dfrac{2S_1}{0.61 S_2 \sqrt{2g_c}}\left[Z_1^{1/2} - Z_2^{1/2}\right]$.

REVIEW QUESTIONS AND PROBLEMS

1. What is the enthalpy of steam at 150 psia and 400°F?
   a. 1195.2 BTU/lbm
   b. 1220 BTU/lbm
   c. 1250 BTU/lbm
   d. 1275 BTU/lbm

2. Which of the following is not true?
   a. A pump will operate safely if its NPSH is greater than zero.
   b. Fans and blowers are used to transport gases.
   c. Pumps and blowers increase the mechanical energy of the fluid.
   d. The power loss due to friction in a venturi meter is greater than in an orifice meter.

3. A pump delivers 40 gpm of water with a total head of 40 ft. The efficiency of the pump is 65%. What is its BHP?
   a. 0.62
   b. 0.70
   c. 2.00
   d. 5.50

4. A fluid flowing at a rate of 25 cubic meters per hour in a 60-mm inside diameter pipe has an average velocity in meters/second equals to
   a. 5.9
   b. 2.5
   c. 1.5
   d. 0.6

5. The absolute pressure exerted by water 2 m below the surface of a swimming pool is
   a. 20 kPa
   b. 120 kPa
   c. 200 kPa
   d. 400 kPa

6. Turbulent flow generally occurs for cases involving
   a. very viscous fluid
   b. very narrow passages or capillary tubes
   c. very slow motions
   d. none of these

7. A rectangular duct 4m x 1.5 m in cross-section carries conditioned air. Its equivalent diameter is
   a. 1.50 m
   b. 2.18 m
   c. 2.18 ft
   d. 2.75 m

8. When the ID of the pipe through which a fluid flows is doubled, the pressure loss due to friction per unit length of pipe and for the same volumetric flow rate is changed by approximately a factor of
   a. 1/8 c. 1/32
   b. 1/16 d. 1/64

9. When two centrifugal pumps are connected in series, the discharge changes by factor of
   a. 1/2 c. 2
   b. 1 d. 4

10. When two reciprocating pumps are connected in parallel, the volumetric capacity of the system changes by a factor of
   a. 1/2 c. 2
   b. 1 d. 2^2

11. The pressure drop in a pipeline changes by a factor of
   a. 1/2 c. 2
   b. 1 d. 4

   when the velocity of the flowing fluid is doubled.

12. Machines which need electricity to run are
   a. generators c. turbines
   b. engines d. motors

13. Cavitation occurs in a centrifugal pump when
   a. the discharge pressure becomes too high c. suction is lost
   b. the discharge valve is closed d. the suction pressure is too high

14. Oil with a viscosity of 30 cP and a density of 60 lb/ft^3 flows through a 1/2-inch inside diameter pipe. Determine the velocity in ft/s below which flow will be laminar.
   a. 87.20 c. 13.10
   b. 0.63 d. 16.90

15. Water at 60°F is flowing through a 3-inch inside diameter smooth horizontal pipe. If the Reynolds number is 353,000, calculate the ratio of maximum velocity to average velocity
   a. 1.89 c. 1.22
   b. 1.05 d. 1.72

16. The pressure after the pump in a 6-inch inside diameter smooth pipe conducting water is 20 psia. The water is discharged at an open tank 100 ft. from the pump. Calculate the rate of discharge of water in ft^3/s.
   a. 21.0 c. 0.6
   b. 58.3 d. 3.58

17. A water storage tank supplies water into a factory. Water is supplied to the tank through a booster pump installed in the water line. The theoretical pump horsepower required is 3.25 hp. What is the monthly operating cost of the pump, if electric power cost on the average is ₱3.73/kWh. The pump is 65% efficient and operates for 12 hours a day.
    a. ₱3300
    b. ₱7000
    c. ₱5000
    d. none of these

18. When the impeller speed of an ideal centrifugal pump is doubled, the volumetric flow rate of the discharge is increased by a factor of
    a. 1/2
    b. 1.0
    c. 2.0
    d. 2exp (2)

19. The differential height between two points where a fluid has to be transferred is the
    a. potential head
    b. pressure head
    c. velocity head
    d. dynamic head

20. The bursting pressure of a pipe is directly proportional to its
    a. schedule number
    b. inside diameter
    c. outside diameter
    d. length

21. A device for measuring differential pressure is a
    a. potentiometer
    b. ammeter
    c. galvanometer
    d. manometer

22. The dimensionless number that characterizes the flow of fluids in a conduit is
    a. Nusselt Number
    b. Peclet Number
    c. Grashoff Number
    d. Reynolds Number

23. When a fluid flows through a reducer in a piping system the velocity at the outlet end is ____________ the velocity at the inlet
    a. less than
    b. more than
    c. the same as
    d. one-half

24. At a given flow rate through an orifice meter the differential pressure across the orifice will increase when
    a. the orifice flow area is decreased
    b. the density of the flowing fluid is decreased
    c. the orifice flow area is increased
    d. the thickness of the orifice is decreased

25. The prime mover of a jet pump is a/an
    a. motor
    b. fluid momentum
    c. turbine
    d. engine

26. The weight rate of flow of a fluid stream per unit of cross section perpendicular to the direction of flow is the
    a. mean linear velocity
    b. acoustic velocity
    c. velocity head
    d. mean mass velocity of the stream

9 27. In a reciprocating pump, the ratio of the quantity of liquid actually pumped to that which corresponds to the piston displacement is called
    a. hydraulic efficiency
    b. mechanical efficiency
    c. volumetric efficiency
    d. suction lift

28. The schedule number of the pipe is an indicator of the pipe's
    a. outside diameter
    b. thickness
    c. length per section
    d. material of construction

29. The higher the BWG rating of a tube is, the lower is the
    a. strength
    b. area of flow
    c. length of a tube section
    d. grade of metal used

30. The inside surface of a pipe has no effect on the friction factor when the flow is
    a. turbulent
    b. streamline
    c. passing through a pump
    d. by gravity

31. When the movement of a gas vapor is effected at a low pressure say, up to 0.1 kg/cm^2, the equipment used is a
    a. compressor
    b. blower
    c. jet
    d. fan

32. Four-inch (4 inch) Sch. 40 steel pipes are to be used to transport high-pressure steam. The pipe joints are to be butt-welded. The safe working fiber stress for butt-welded pipes is 457.1 kg/cm^2. Calculate the maximum steam pressure, in kg/cm^2 the pipes can handle.
    a. 38.2
    b. 18.3
    c. 10.8
    d. 150.0

33. The resistance of a layer of fluid to flow over the next layer is measured by
    a. viscosity
    b. friction factor
    c. surface tension
    d. momentum

34. Water at 80°F flows at 10 ft. per second through a 6-inch Sch. 40 steel pipe with length of 1000 ft. The Reynolds number is
    a. 334,000
    b. 500,000
    c. 255,000
    d. 30,000

35. Air is flowing at constant mass rate through a horizontally arranged pipe heater and heated from 70°F to 170°F. The pressure is normal at the inlet and the outlet pressure dropped by 1 inch H_2O. The average air velocity at the inlet is 20 ft/s. Assuming that $C_p = 0.24$ and perfect gas, the net heat input is
    a. 240 BTU/min
    b. 240 BTU
    c. 240 BTU/lbm
    d. 24 BTU/lbm

36. Natural gas at 70°F is flowing at a steady mass rate through a steel pipe with an inside diameter of 12 inches. Absolute pressure drops from 30 to 15 atm in 400 miles of horizontal pipe. M = 17, $\mu = 0.01$ cp. The volumetric flow rate per hour at 70°F and normal barometric pressure is
    a. 8600 ft^3
    b. 520,000 ft^3
    c. 8600 m^3
    d. 23000 ft^3

37. Calculate the radius of the capillary tube in mm, such that it is a flow of a viscous fluid.
    Kinematic viscosity = 0.000043 m^2/s
    Length of tube = 50.2 cm
    Mass flow rate = 0.003 kg/s
    Density of fluid = 955 kg/m^3
    Pressure drop = 4.77 atm
    a. 0.32
    b. 0.45
    c. 0.75
    d. 0.18

38. In a high pressure piping system where joints are regularly broken for maintenance, ________ joints are used
    a. welded
    b. threaded
    c. flanged
    d. ball and spigot

39. A mechanical vacuum pump that can be used for a final vacuum pressure of 1 mm Hg is
    a. two-stage reciprocating dry vacuum pump
    b. water sealed rotary vacuum pump
    c. rotary oil sealed vacuum pump
    d. multistage centrifugal pump

40. Air is to be delivered at a rate of 200 cfm and a pressure of 10 kPa. The appropriate equipment to use is
    a. fan
    b. blower
    c. compressor
    d. centrifugal pump

41. An axial flow pump operating at a speed of 880 rpm can supply water at a rate of 3000 gpm. The maximum head that this pump can deliver in feet of water is
    a. 36
    b. 63
    c. 20
    d. none of these

42. The power requirement of a fan in kW in order to supply air at a rate of 500 m^3/hr per hour at a total discharge pressure of 0.5 psia is ________ kW.
    a. 1
    b. 0.46
    c. 0.85
    d. 1.4

43. Specify the type of open impeller pump to use if the capacity is 400 gpm at a head of 200 ft of water __________.
    a. 3 x 2 x 8.5 E
    b. 4 x 3 x 8.5 E
    c. 4 x 3 x 6
    d. 3 x 2 x 13

Fig 10-28 44. What will be the rated capacity (in gpm) of a 4-1/2 inch impeller centrifugal pump operating at a speed of 3450 rpm capable of generating a head of 40 ft of water?
   a. 134 c. 248
   b. 95 d. 320

[illegible] 45. What type of pump would you recommend if the capacity is 5000 gal/min at a head of 15 ft of water __________.
   a. gear pump c. centrifugal pump
   b. axial flow pump d. screw pump

46. What is the entrance length in a 2- inch Sch. 40 pipe if the Reynolds number is 1800?
   a. 10 ft c. 17 ft
   b. 8 ft d. 25 ft

47. If the speed of a centrifugal pump is doubled, the energy requirement becomes approximately _____ times the original energy requirement.
   a. 2 c. 8
   b. 4 d. 10

48. A cylindrical tank 1ft in diameter discharges through a nozzle connected to the base. Find the time needed for the water level in the tank to drop from 4 ft to 2 ft above the nozzle. The diameter of the nozzle is 1 inch and its discharge coefficient may be taken as unity.
   a. 42 s c. 30 s
   b. 21 s d. 15 s

49. A pitot tube with a U-tube water manometer is attached to a horizontal oil pipe of 4 in. inside diameter. If the manometer reading is 15 in., determine the volumetric flow rate, in gpm, of oil in the pipe. The pitot opening is placed at the center of the pipe. The oil has a specific gravity of 0.84 and a viscosity of 0.0336 lb/ft-sec.
   a. 77 c. 32
   b. 55 d. 94

50. A sharp edged orifice is to be fabricated to measure water flowing at a rate not to exceed 1,200 cu.ft per hour, with a differential head of 10 ft. What orifice diameter in inches is required if D_2/D_1 is made 1/5 ?
   a. 1 c. 2
   b. 1.5 d. 2.5

2. FLOW OF HEAT

THEORY AND EQUATIONS

Mechanisms of Heat Flow

A. Heat Transfer by Conduction
B. Heat Transfer by Convection: either Natural or Forced or combination
C. Heat Transfer by Radiation

Heat Transfer by Conduction

1. ***Steady State Heat Flow***

By Fourier's Law

$$q = -kA\frac{dT}{dx}$$

or

$$q\int_{x_1}^{x_2} \frac{dx}{A} = -\int_{T_1}^{T_2} k\,dT$$

integrating,

$$q\left(\frac{x_2 - x_1}{A}\right) = \bar{k}(T_1 - T_2)$$

$$q = \frac{\Delta T}{\frac{\Delta x}{kA}} = \frac{\Delta T}{R}$$

where: q = rate of heat transfer, k = thermal conductivity, A = heat transfer area $\perp$ to the direction of heat flow

Evaluation of $\bar{A}$:

a. For Flat Walls: $\bar{A} = A_1 = A_2$

b. For Cylindrical Walls: $\bar{A} = 2\pi x_{\ln} L$ where: $x_{\ln} = \dfrac{x_2 - x_1}{\ln \frac{x_2}{x_1}}$

c. For Spherical Walls: $\bar{A} = 4\pi x_1 x_2 = \sqrt{A_1 A_2}$

Heat Conduction through Resistances in Series

$$R_T = R_1 + R_2 + R_3 = \frac{\Delta x_1}{k_1 A_1} + \frac{\Delta x_2}{k_2 A_2} + \frac{\Delta x_3}{k_3 A_3}$$

$$\therefore q = \frac{\sum \Delta T}{R_T}$$

Heat Conduction through Resistances in Parallel

$$q_T = q_1 + q_2 + q_3 = \frac{\Delta T_1}{R_1} + \frac{\Delta T_2}{R_2} + \frac{\Delta T_3}{R_3}$$

$$q_T = \Delta T\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right)$$

where $$\frac{1}{R_T} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

2. ***Unsteady State Heat Flow***

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial x^2} = \alpha\frac{\partial^2 T}{\partial x^2}$$

where: α = Thermal Diffusivity, t = time, T = Temperature

The solutions of the above partial differential equation are represented by charts given in Figure 5, Perry 7/e

Heat Transfer by Convection

1. ***Energy Balance (no change in phase)***

$$q = WC_p(T_1 - T_2) = wc_p(t_2 - t_1)$$

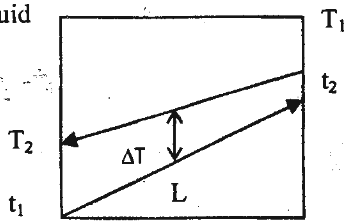
2. ***Rate of Heat Transfer***

$$dq = U(T-t)\,d\,A$$

$$\therefore A = \int\frac{dq}{U(T-t)} = \int\frac{WC_p\,dt}{U(T-t)}$$

the integral may be evaluated by graphical integration

where: W = hot fluid mass flow rate, w = cold fluid mass flow rate
T = temp. of hot fluid, t = temp. of cold fluid
U = over-all heat transfer coefficient
$T - t = \Delta T$ = temp. approach



Simplified Equations:
Case 1. U and $\Delta T = T - t$ are constant

$$\therefore q = UA\,\Delta T$$

Case 2. U is constant but ΔT varies

a. For Double Pipe Heat Exchangers where q is linear with ΔT

$$q = U\,A\,\Delta T_{\ln}$$

where: $$\Delta T_{\ln} = \frac{\Delta T_1 - \Delta T_2}{\ln\dfrac{\Delta T_1}{\Delta T_2}}$$

b. For Multipass and Crossflow Heat Exchangers

$q = UA\,F_T\,\Delta T_{\ln}$, where: F_T is a function of Z and X

$$Z = \frac{\text{Fall}\cdot\text{in}\cdot\text{Temp}}{\text{Rise}\cdot\text{in}\cdot\text{Temp}} = \frac{T_1 - T_2}{t_2 - t_1} = R$$

$$X = \frac{\text{Rise} \cdot \text{in} \cdot \text{Temp}}{\text{Max. Temp. Diff}} = \frac{t_2 - t_1}{T_1 - t_1} = S$$

For values of F_T (or Y) see page 11-6, Perry 7/e
For TEMA Heat Exchangers, see Figure 11-36, Perry 7/e

Case 3. U varies linearly with ΔT

$$q = A(U\,\Delta T)_{\ln} = A\frac{U_2 \Delta T_1 - U_1 \Delta T_2}{\ln(U_2\,\Delta T_1 / U_1 \Delta T_2)}$$

3. ***Overall H.T.C. (in terms of Individual H.T.C.)***

If U is based on outside Area, A_o

$$\frac{1}{U_o} = \frac{D_o}{h_i D_i} + \frac{D_o}{h_{d_i} D_i} + \frac{x D_o}{k \overline{D}} + \frac{1}{h_{d_o}} + \frac{1}{h_o}$$

If U is based on inside area A_i

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{1}{h_{d_i}} + \frac{x D_i}{k \overline{D}} + \frac{D_i}{h_{d_o} D_o} + \frac{D_i}{h_o D_o}$$

Rate of Heat Transfer: $q = U_o A_o \Delta T_{\ln} = U_i A_i \Delta T_{\ln}$

Note: U is based on the side where resistance is controlling, i.e., lower value of h. The h of the fluids may be determined by using the appropriate empirical formulas or Nomographs.

Example: Figure 5-9, Perry 7/e
For typical over-all HTC, see Tables 11-3 to 11-8, Perry 7/e

Heat Transfer by Radiation

1. ***Stefan-Boltzmann Law***

$W_B = \sigma T^4$ = Stefan –Boltzmann Constant, T = absolute temperature

$$W_B = 0.1713\left(\frac{T}{100}\right)^4$$

W_B = emissive power of a blackbody, Btu/hr-ft²

$\sigma = 0.1713 \times 10^{-8}$ Btu/ft²-hr-°R⁴ or 5.676×10^{-8} W/m²-K⁴

For real surfaces, using English System: $W = W_B \varepsilon = 0.1713\left(\frac{T}{100}\right)^4 \varepsilon$

See Table 5-6 and Table 11-10, Perry 7/e, for some values of ε

2. ***Radiation between Solid Surfaces.*** Non-gray body surrounded by a black body

$$q_{12,\,net} = 0.1713 A_1 \left[\epsilon_1 \left(\frac{T_1}{100}\right)^4 - \alpha_{1,2}\left(\frac{T_2}{100}\right)^4\right]$$

ISSIVITY, $\varepsilon = \frac{W}{W_b}$

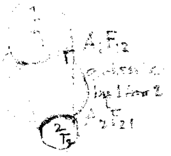
(Table 5-6)

steel pipe, ε = 0.79

where: $\alpha_{1,2}$ = fraction of radiation from (2) at T_2 absorbed by (1) at T_1

$\alpha_{1,2} =$
- For non-metals: $\alpha_{1,2} = \varepsilon_1$ at T_2
- For metals: $\alpha_{1,2} = \varepsilon_1$ at $\sqrt{T_1 T_2}$
- For gray bodies: $\alpha_{1,2} = \varepsilon$

See Table 5-12, Perry 7/e, for values of α



q emitted by 1 → 2

$q_{r,net\ 1\to2}$ = q emitted by 1 → 2 − q absorbed by 1 from 2

$= \sigma(T_1)^4 \varepsilon_1 A_1F_{12} - \sigma(T_2)^4 \alpha_1 A_2F_{21}$

$= 0.1713\, A_1F_{12}\left[\left(\frac{T_1}{100}\right)^4 \varepsilon_1 - \left(\frac{T_2}{100}\right)^4 \alpha_1\right]$

3. ***Geometric View or Angle Factor for Black Bodies***

$$q_{12,net} = 0.1713\, A_1 F_{12}\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]$$

and $$A_1 F_{12} = A_2 F_{21}$$

where: F_{12} = fraction of total radiation leaving the black surface (1) in all directions that is intercepted by surface (2)

Note: $\overline{F}$ is used if surfaces are connected by re-radiating non-conducting walls

See Figures 5-15 to 5-19, Perry, for values of F and $\overline{F}$

4. ***Radiation between Non-Black Surfaces***

$$q_{12,net} = 0.1713\, A_1 \Im_{12}\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]$$

$= h_r A_1 (T_1 - T_2)$

and $$A_1 \Im_{12} = A_2 \Im_{21}$$

$h_r = \dfrac{0.1713\, \mathcal{F}_{12}\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]}{T_1 - T_2}$

where: $\Im_{12}$ = overall interchange factor, function of $\varepsilon_1, \varepsilon_2, A_1, A_2, \overline{F}_{12}$

For gray surfaces:

$$\Im_{12} = \frac{1}{\dfrac{1}{F_{12}} + \left(\dfrac{1}{\varepsilon_1} - 1\right) + \dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2} - 1\right)}$$

5. ***Combined Heat Transfer by Conduction, Convection and Radiation***

$$q_K = q_c + q_r$$

but
$$q_c = h_c A (T_s - T_a)$$
$$q_r = h_r A (T_s - T_w)$$

where: $$h_r = \frac{0.1713\, \varepsilon_1\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_w}{100}\right)^4\right]}{T_s - T_w}$$

If $T_a = T_w$

$$q_k = (h_c + h_r) A (T_s - T_a) = \frac{T_h - T_a}{\dfrac{1}{h_i A_i} + \left(\dfrac{x}{k\overline{A}}\right)_m + \left(\dfrac{x}{k\overline{A}}\right)_i + \dfrac{1}{h_o A_o}}$$

REVIEW QUESTIONS AND PROBLEMS

1. A thick walled copper cylinder has an inside radius of 1 cm and an outside radius of 1.8 cm. The inner and outer surface temperatures are held at 305°C and 295°C, respectively. Assume k varies linearly with temperature, with $k_o = 371.9$ W/m-K and $b = -9.25 \times 10^{-5} K^{-1}$. Determine the heat loss per unit length.
   a. 1 W c. 1 kW
   b. 10 W d. 40 kW

2. The driving force in heat transfer is
   a. concentration gradient c. viscosity gradient
   b. temperature gradient d. thickness of the solid in question

3. If a man touches two metals which were kept together at room temperature, why would one metal feel colder than the other?
   a. one has a high heat transfer coefficient c. one has a lower temperature
   b. one has a high thermal conductivity d. one has a higher heat capacity

4. A furnace wall is constructed of firebrick 6 in. thick. The temperature of the inside of the wall is 1300°F, and the temperature of the outside of the wall is 175°F. If the mean thermal conductivity under these conditions is 0.17 BTU/h-ft-°F. What is the rate of heat loss through 10 sq. ft. of wall surface?
   a. 5700 BTU/hr c. 3825 BTU/hr
   b. 1070 kcal/hr d. 2354 kcal/hr

5. The transfer of heat from a point to another within a fluid, or between a fluid and a solid or another fluid, by the movement or mixing of the fluids involves.
   a. conduction c. convection
   b. radiation d. none of these

6. A composite wall consists of W_1 (outer layer) and W_2 (inner layer). W_1 and W_2 are both 5" thick. The thermal conductivity of W_1 is 1 BTU/ft-hr °F while that of W_2 is 0.1 BTU/ft-hr °F. The temperature of the outer layer is 500°F while that of the inner layer is 1500°F. Find q_{TOTAL} in BTU/hr-ft^2.
   a. 240 c. 321
   b. 218 d. none of these

7. For a furnace constructed with 0.7 ft thick of fireclay brick having k= 0.6 BTU/hr-ft-°F and covered on the outer surface with a layer of insulating material having k= 0.04 BTU/hr-ft-°F. The innermost surface is maintained at 1800°F while the outer surface of insulating material is maintained at 100°F. How thick must the insulator be to maintain a maximum allowable heat transfer rate of 300 BTU/hr-ft^2?
   a. 0.30 ft c. 0.10 ft
   b. 0.20 ft d. 0.40 ft

8. Heat is being transferred under steady conditions through a tapering shape of fire clay brick whose thermal conductivity varies with temperature according to the following table:

Temp, °F	392	1112	1832	2552
K, BTU/hr-ft-°F	0.58	0.85	0.95	1.02

The shape of this brick is 2 ft thick with one end having a dimension of 7" x 5" is maintained at 2200°F while on the other end, having a dimension of 4" x 3" is maintained at a temperature of 250°F. Calculate the rate of the heat transfer through the shape if all the other faces of the shape are perfectly insulated.

a. 95 BTU/hr
b. 125 BTU/hr
c. 230 BTU/hr
d. 200 BTU/hr

9. The term $\frac{hD}{k}$ is known as

a. Prandtl Number
b. Peclet Number
c. Nusselt Number
d. Reynold's Number

10. If the viscosity of the fluid will increase, the heat transfer coefficient in a turbulent flow system will

a. increase
b. remain the same
c. decrease
d. none of these

11. An industrial furnace wall is constructed of 0.7 ft thick fireclay having $k = 0.6$ BTU/hr-ft-°F. This is covered on the outer surface with a 0.1 ft. thick layer of insulating material having $k = 0.04$ BTU/hr-ft-°F. The innermost surface is at 1800°F and the outermost is 100°F. Calculate the steady heat transfer per square foot.

a. 464 BTU/hr-ft^2
b. 258 BTU/hr-ft^2
c. 364 BTU/hr-ft^2
d. 554 BTU/hr-ft^2

12. It is a method of developing the design for a heat exchanger wherein the engineer assures the existence of an exchanger and makes calculations to determine if the exchanger would handle the process requirements under reasonable conditions.

a. heat exchanger modeling
b. heat exchanger calculation
c. rating a heat exchanger
d. evaluation of heat exchanger performance

13. The formula for log-mean temperature between T_1 and T_2 is

a. $\frac{T_1+T_2}{2}$
b. $\frac{\ln(T_1/T_2)}{T_2-T_1}$
c. $\frac{T_2-T_1}{\ln(T_2/T_1)}$
d. $\frac{T_2-T_1}{\ln(T_1/T_2)}$

14. Water at 25°C is flowing through an elliptical conduit with semi-axis a = 4 and b = 3. What is the Reynolds Number of this flow if water is flowing at 9 m/s?

a. 1.1×10^6
b. 7.8×10^5
c. 9.5×10^5
d. 4.5×10^6

15. If the thermal conductivity of the fluid increases, the heat transfer coefficient will

a. increase
b. remain the same
c. decrease
d. none of these

16. A composite three layered wall is formed of a 0.5 cm thick aluminum plate, a 0.25 cm thick layer of sheet asbestos, and a 2.0 cm thick layer of rock wool (density = 64 kg/m^3); the asbestos is the center layer. The outer aluminum surface is at 500°C, and the other rock wool surface is at 50°C. Determine the heat flow per unit area. The thermal conductivities of the materials are as follows:

Substance	*Temperature*	*k(W/m-K)*
Aluminum	500°C	268.08
Asbestos	93°C	0.17
Rock Wool	51°C	0.05

a. 954 W/m^2
b. 1085 W/m^2
c. 456 W/m^2
d. 1840 W/m^2

17. Determine the steady state heat transfer per unit area through a 1.5-in thick homogenous slab with its two faces maintained at uniform temperatures of 100°F and 70°F. The thermal conductivity of the material is 0.11 BTU/hr-ft-°F.

a. 56.4 BTU/hr-ft^2
b. 13.4 BTU/hr-ft^2
c. 26.40 BTU/hr-ft^2
d. 21.70 BTU/hr-ft^2

18. A 6 inch thick wall is 12 ft high and 16 ft long. One face is at 1500°F and the other at 300°F. The total heat loss in BTU/hr is (k = 0.15 BTU/hr-ft-°F).

a. 69,900 BTU/hr
b. 69,120 BTU/hr
c. 12,960 BTU/hr
d. 91,260 BTU/hr

19. The equation $\frac{q}{A} = -k\frac{dT}{dx}$ is called

a. Fick's law equation
b. Fourier's law equation
c. Raoult's law equation
d. Nusselt equation

20. The heat transferred radially across an insulated pipe per unit area

a. remains constant
b. is inversely proportional to the thermal conductivity
c. decreases from pipe wall to the insulated surface
d. increases from pipe wall to the insulated surface

21. In a fluid, if the currents are set in motion by the action of a mechanical device, and the flow is independent of density gradients, the phenomenon is called

a. natural convection
b. forced convection
c. thermal conduction
d. centrifugation

22. A composite wall consists of 2" corkboard (inner), 6" concrete and 3" wood (outer). The thermal conductivity of the materials are 0.025, 0.8 and 0.065 BTU/ft-hr-°F. The temperature of the inner surface of the wall is 40°F while the outer surface of the composite wall is 78°F. What are the temperatures between the cork and concrete and between the concrete and wood?

a. 52.6°F , 73.2°F
b. 62.7°F , 64.9°F
c. 38.1°F , 67.4°
d. none of these

23. In heat transfer by conduction, due to symmetry the heat flow at a point is perpendicular to the isothermal surface through the point. This mode of conduction is characteristic of
    a. non-isotropic solids
    b. isotropic solids
    c. insulators
    d. conductors

24. The ratio of the internal thermal resistance of a solid to the boundary layer thermal resistance is described by
    a. Nusselt Number
    b. Prandtl Number
    c. Biot Number
    d. Reynolds Number

b 25. The measure of the relative effectiveness of momentum and energy transport by diffusion in the velocity and thermal boundary layers is given by
    a. Nusselt Number
    b. Prandtl Number
    c. Biot Number
    d. Reynolds Number

26. In using the design equation of heat transfer, $q = UA\Delta T_{ln}$ the U and A may either be based on the inside or outside area of the pipe. For a system where air is flowing inside a pipe while being heated by condensing steam outside the pipe, the proper U and A to be used is
    a. based on the inside area
    b. based on the outside area
    c. it does not matter
    d. none of these

27. When water inside a beaker is being heated over a hot plate, the mechanism of heat transfer through the water is considered to be
    a. conduction
    b. forced convection
    c. natural convection
    d. radiation

28. The property of the solid that provides a measure of the rate of heat transfer relative to the energy storage is referred to as
    a. thermal conductivity
    b. heat capacity
    c. thermal diffusivity
    d. viscosity

b 29. The range of wavelengths of electromagnetic waves that is associated with thermal radiation is from
    a. 10^{-5} to 10^{-2} μm
    b. 0.1 to 100 μm
    c. 100 to 10,000 μm
    d. none of these

30. An ideal surface that absorbs all incident radiation, regardless of wavelength and direction and is also considered to be a perfect emitter is referred to as a
    a. gray body
    b. black hole
    c. black body
    d. pin hole

31. The spectral distribution of a perfect emitter has a maximum and that the corresponding wavelength depends on temperature. The maximum spectral emissive power is displaced to shorter wavelengths with increasing temperature. These statements refer to
    a. Stefan-Boltzman Law
    b. Kirchoff's Law
    c. Wien's Law
    d. Planck's Law

32. The amount of radiation emitted in all directions and over all wavelengths by a perfect emitter is proportional to the fourth power of the absolute temperature of the emitter. This is the statement of
    a. Stefan-Boltzman Law
    b. Kirchoff's Law
    c. Wien's Law
    d. Planck's Law

33. The ratio of the emissive power of a body to its absorptivity is a constant and the same for all radiating bodies in a confined enclosure under thermal equilibrium. This is a statement of
    a. Stefan-Boltzman Law
    b. Kirchoff's Law
    c. Wien's Law
    d. Planck's Law

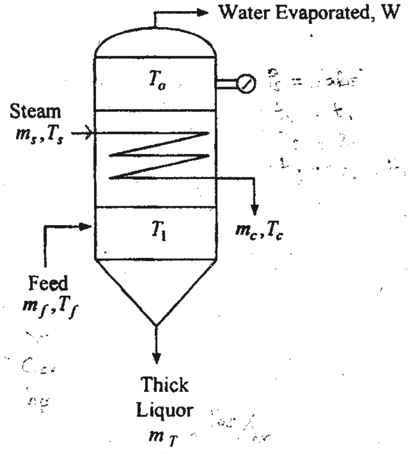
34. A theoretical body where the absorptivity and emissivity are independent of the wavelength over the spectral region of the irradiation and the surface emission is called
    a. black body
    b. gray body
    c. opaque body
    d. transparent body

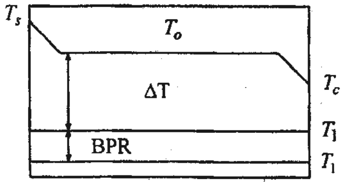
35. The view factor F_{21} of a sphere (1) of diameter D inside a cubical box (2) of length L = D is
    a. 1
    b. 3.14
    c. 1.57
    d. 0.524

3. EVAPORATION

THEORY AND EQUATIONS

Single Effect Evaporation





Capacity is the number of pounds of water vaporized per hour.

Economy is pounds of water vapor vaporized per pound of steam initially supplied.

Steam Consumption is the ratio of the capacity over the economy.

1. ***Capacity Equation (Rate of Heat Transfer Equation)***

$$q = UA\Delta T$$

where: U = over-all heat transfer coefficient. This is a function of the boiling point of the solution and ΔT. Example, see Figure 465, Brown, et al.

$\Delta T = T_o - T_l$ and $BPR = T_l - T_1$

Evaluation of BPR (Boiling Point Rise)

a. *Duhring's Rule* – for a given concentration, the boiling point of the solution is a linear function of the boiling point of the solvent. See Figure 467, Brown for $NaOH - H_2O$ system.

b. The BPR is negligible for dilute solutions or solutions of organic colloids.

c. The BPR is not negligible for concentrated solutions of inorganic solutes. For BPR of aqueous solutions, see Fig. 11-124 Perry 7/e.

2. ***Material Balance Equations***

O.M.B. $m_F = m_T + W$

Solute Balance: $m_F x_F = m_T x_T$

Solvent Balance: $m_F(1 - x_F) = m_T(1 - x_T) + W$

3. ***Enthalpy Balance Equations*** (used if the enthalpy-composition diagram of the solution is available)

$$VH_v + m_F h_F = WH_w + m_T h_T + Vh_v + R_1$$

Heat supplied by steam, $q = VH_v - Vh_v$

Note: H_W is a function of the pressure in the vapor chest and T_1, use the steam table.
R refers to radiation and convection losses

4. ***Heat Balance Equations*** (used if heat capacities and latent heats are known)
Heat given up by the steam:

$$\text{Steam } (T_s, P_s) \xrightarrow[H_o]{} \text{steam } (T_o) \xrightarrow[\lambda_o]{} \text{water } (T_o) \xrightarrow{} \text{water } (T_c)$$

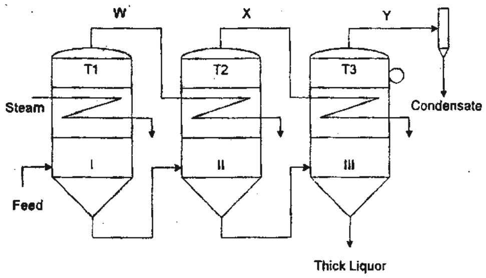
$$q = V\left[H_o + \lambda_o + 1\left(T_o - T_c\right)\right]$$

where: $H_o = 0.46\left(T_s - T_o\right)$

Heat absorbed by the liquor, Q. Let T_1 be the reference temperature.

$$Q = m_F C_{PF}\left(T_1 - T_F\right) + W\left(\lambda + H_1\right) + Q_1 + R_1 + m_T C_{PT}\left(T_1 - T_1\right)$$

Multiple Effect Evaporation



Types of Feeding: (a) Forward Feed, I – II – III; (b) Backward Feed, III – II – I; (c) Mixed Feed, II – III – I and other combinations; (d) Parallel Feed, simultaneous feeding to the three effects.

The design calculation is based on equal heat transfer areas, $A_1 = A_2 = A_3$. Temperature distribution may be estimated by assuming that $q_1 = q_2 = q_3$. Thus, $U_1\Delta T_1 = U_2\Delta T_2 = U_3\Delta T_3$ and $U_1 : U_2 : U_3 = \Delta T_1 : \Delta T_2 : \Delta T_3$. Therefore, if $\sum \Delta T = T_o - T_3 - \sum BPR$,

$$\Delta T_1 = \frac{\sum \Delta T \times \frac{1}{U_1}}{\frac{1}{U_1} + \frac{1}{U_2} + \frac{1}{U_3}} \quad \text{and} \quad \Delta T_2 = \Delta T_1 \times \frac{U_1}{U_2}$$

Material and Heat Balances can be generated to solve for q_1, q_2, and q_3. From the rate of heat transfer equation, A_1, A_2, and A_3 are solved. If these areas are not nearly equal, temperatures are redistributed and the procedure is repeated until $A_1 \approx A_2 \approx A_3$.

REVIEW QUESTIONS AND PROBLEMS

1. When the pressure of the heating steam in an evaporator is increased, the steam consumption for a given duty and heat transfer area will
   a. increase
   b. remain the same
   c. decrease
   d. none of these

2. Water enters the bottom of a vertical evaporator tube 20 ft long at a temperature of 130°F and a velocity of 1.5 ft/s. The tube is 2.0 in. OD with a wall of 0.065 in. thick. Heat amounting to 284,000 BTU/hr flows through the wall of the tube and is absorbed by the water. The pressure at the exit of the tube is 4 psia. Assuming the liquid and vapor mixture leaving the tube is in equilibrium, what fraction of the liquid water entering the bottom of the tube is vaporized?
   a. 0.0217
   b. 0.0350
   c. 0.0544
   d. 0.0150

3. Which of the two evaporator flow configurations needs fluid motive devices to transfer solution from one effect to the other effect?
   a. feedforward
   b. backward flow

4. When the pressure of the evaporator chamber is decreased, the boiling point of the solution inside the chamber will
   a. increase
   b. remain the same
   c. decrease
   d. none of these

5. A heat transfer device that is normally used to liquefy vapors is
   a. evaporator
   b. condenser
   c. reboiler
   d. none of these

6. In a country where capital is scarce and energy cost is low, which is appropriate to install?
   a. multiple effect evaporator
   b. single effect evaporator

7. In evaporation operation, the valuable product is called
   a. thick liquor
   b. vapor
   c. water
   d. residue

8. For the same duty and heat transfer area, the feedforward flow evaporator is __________ compared to the backward flow evaporator in terms of heat transfer.
   a. more efficient
   b. less efficient
   c. just the same
   d. none of these

9. A 7%-wt NaOH solution enters an evaporator at 98°F and evaporated to 18%-wt NaOH solution. The pressure in the vapor space is 5 psia. The number of BTU required to evaporate 1.5 lb of water from the entering solution is
   a. 1670 BTU
   b. 2100 BTU
   c. 540 BTU
   d. none of these

c 10. If the overall heat transfer coefficient of the evaporator of Problem *9* is 200 BTU/hr-ft^2-°F and the temperature driving force is 90°F, the heating area in square feet to process 1000 lb/hr of feed is

a. 56 b. 184 c. 38 d. none of these

a 11. The BPR of a 50% solution of NaOH at an evaporator pressure of 4.7 psia is

a. 73°F b. 53°F c. 85°F d. 103°F

12. A solution of organic colloids is to be concentrated from 20 to 65 wt-% solids in a single effect evaporator. Saturated steam is available at 172 kPa and the pressure in the condenser is 61.67 cm Hg vacuum. The feed enters at 25°C and its specific heat is 4.0 J/g-°C. The solution has negligible elevation in boiling point. The OHTC is 1800 watts/m^2-°C and the evaporator must evaporate 9000 kg/hr of water. Given these conditions, the steam consumption in kg/hr is

a. 5,000 b. 3,600 c. 10,500 d. 16,400

13. Referring to Problem *12*, the estimated heating surface required in square meters is

a. 35 b. 65 c. 85 d. 120

14. Referring to Problem *12*, the economy of evaporation is

a. 0.71 b. 0.86 c. 0.67 d. 0.91

15. A 10% wt NaOH solution at 80°F is to be concentrated in a single effect evaporator to 40% wt. Steam is supplied at 20 psig and the vacuum pressure of the barometric condenser is 26 in. Hg. One hundred gallons per minute of water at 70°F is fed to the condenser and the water leaving the condenser which includes the condensate, is at 100°F. The OHTC of the evaporator is 200 BTU/hr-ft^2-°F. Calculate the heating surface required for the evaporator in square feet.

a. 91 b. 127 c. 520 d. 1020

16. A triple effect evaporator is supplied with saturated steam at 250°F. The temperature at the last effect is 150°F. The OHTCs are 150, 200, and 250 BTU/hr-ft^2-°F in the 1st, 2nd, and 3rd effects, respectively. If the total BPR in the 3 effects is 55°F, the area of the first effect in square feet is _______ if the steam used is 10,000 lb/hr.

a. 2100 b. 3320 c. 4023 d. 1549

17. If the solution to be evaporated tends to strongly scale or form salt, the type of evaporator to be recommended is

a. long tube vertical
b. horizontal tube
c. forced circulation
d. natural circulation

18. The concentration of glycerine from a water solution by the application of heat is

a. distillation b. evaporation c. crystallization d. reverse osmosis

19. The boiling point rise of a 30%-wt NaCl aqueous solution at 1 atm is

a. 20°F b. 5°F c. 45°F d. 30°F

20. A double effect evaporator is heated with steam at 250°F. The 2nd effect is under vacuum at a temperature of 120°F. If $BPR_1 = 10°F$; $BPR_2 = 28°F$; $U_1 = 300$ and $U_2 = 250$, estimate the boiling point of the solution in the 1st effect.

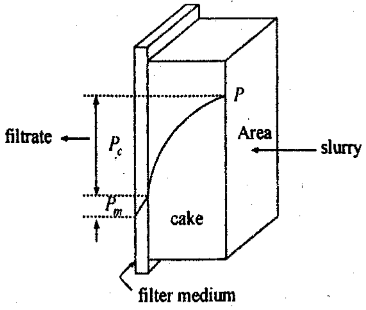
a. 200°F b. 210°F c. 198°F d. 153°F

4. FILTRATION

THEORY AND EQUATIONS

A. *Rate of Filtration*

Ruth Equation



$$\frac{dV}{d\theta}=\frac{(-\Delta P)g_cA^2}{\alpha C\mu(V+Ve)}=r_f$$

where: $\frac{dV}{d\theta}$ = rate of filtration, r_f

V = volume of filtrate collected at any time θ

$(-\Delta P)=(-\Delta P_c)+(-\Delta P_m)=P_T$

(if $P_2 = 0$ psig or atmospheric pressure)

$\alpha =$ average specific cake resistance, $\alpha = a_o(-\Delta P)^s$

α_o = constant, s = compressibility coefficient,

For rigid solids, $s = 0$, for compressible solids, $0.1 < s < 1.0$

C = mass of dry cake deposited per unit volume of filtrate collected

$$C=\frac{m_c}{V} \qquad C=\frac{x\rho}{1-mx}$$

ρ = density of filtrate, m_c = wt. of dry cake, x = mass fraction of solids in slurry

$$m=\frac{\text{mass of wet cake}}{\text{mass of dry cake}},\ m=\frac{\in\rho+(1-\in)\rho_p}{(1-\in)\rho_p},$$

$\in$ = porosity, ρ_p = density of solids

V_e = fictitious volume of filtrate collected to form a cake with resistance equal to that of filter medium

$R_m=\frac{V_eC\alpha}{A}$, filter medium resistance

$R_c=\frac{VC\alpha}{A}$, resistance of cake

Another form of the *Ruth Equation*

$$\frac{dV}{d\theta}=\frac{(-\Delta P)g_c A}{\mu\left(\frac{VC\alpha}{A}+R_m\right)}$$

B. *Constant Pressure Filtration*

Let $$K=\frac{2A^2(-\Delta P)g_c}{\alpha C\mu}$$

The *Ruth Equation* becomes,

$$\frac{dV}{d\theta}=\frac{K}{2(V+V_e)}=r_f \quad \text{(Rate of filtration at constant pressure)}$$

rearranging and integrating, $\int_0^\theta K d\theta = \int_0^V 2(V+V_e)\,dV$

$$K\theta = V^2 + 2VV_e$$

or $$\theta = \frac{V^2}{K} + \frac{2VV_e}{K}$$

Let $V_e^2 = K\theta_e$

$$V^2 + 2VV_e + V_e^2 = K\theta + K\theta_e$$

$$(V+V_e)^2 = K(\theta+\theta_e)$$

This is known as the *Original Ruth Equation*

To determine the constants of filtration $K, V_e, \alpha,$ etc. experimentally from a data of V vs. θ,

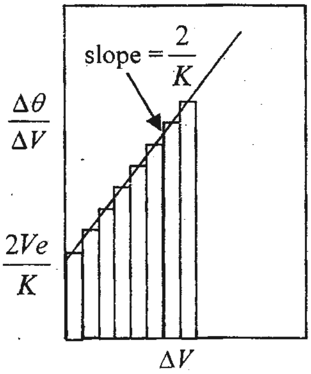
From $$\frac{dV}{d\theta} = \frac{K}{2(V+V_e)}$$

Taking the reciprocal of both equations, we get,

$$\frac{d\theta}{dV} \approx \frac{\Delta\theta}{\Delta V} = \frac{2}{K}V + \frac{2V_e}{K}$$

which is in the form of a straight line

$y = mx + b$. slope = 2/K, intercept = $2V_e/K$



If the resistance of filter medium is negligible, $V_e \approx 0$

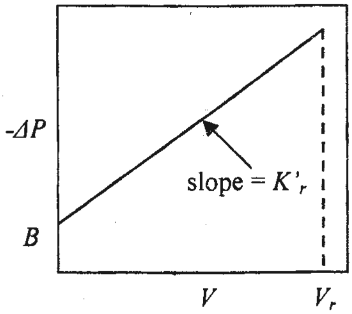
$$V^2 = K\theta$$

Note: If $(-\Delta P)$ is changed,

$$V^2 = \frac{2A^2(-\Delta P)g_c\theta}{\alpha_o(-\Delta P)^S C\mu} = k(-\Delta P)^{1-s}\theta$$

If A is changed, $V^2 = kA^2\theta$

C. *Constant Rate Filtration*



$$\frac{dV}{d\theta} = \frac{V}{\theta} = \frac{V_r}{\theta_r} = \text{constant}$$

$$\frac{V_r}{\theta_r} = \frac{(-\Delta P)g_c A^2}{\alpha C\mu(V+V_e)}$$

$$(-\Delta P) = \frac{\alpha C\mu}{g_c A^2}\left(\frac{V_r}{\theta_r}\right)V + \frac{\alpha C\mu}{g_c A^2}\left(\frac{V_r}{\theta_r}\right)V_e$$

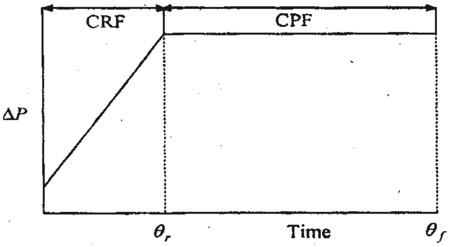
Let $K'_r = \frac{\alpha C\mu}{g_c A^2}\left(\frac{V_r}{\theta_r}\right)$, $B = \frac{\alpha C\mu}{g_c A^2}\left(\frac{V_r}{\theta_r}\right)V_e$

$$(-\Delta P) = K'_r V + B$$

or $$(-\Delta P) = K_r'\left(\frac{V_r}{\theta_r}\right)\theta + B$$

$$(-\Delta P) = K_r\theta + B \qquad \text{where:} \quad K_r = K_r'\left(\frac{V_r}{\theta_r}\right)$$

D. ***Constant Pressure Filtration Preceded by Constant Rate***



For Constant Pressure Filtration:

$$\int_{\theta_r}^{\theta_f} K d\theta = \int_{V_r}^{V} 2(V + V_e)\, dV$$

$$K(\theta_f - \theta_r) = V^2 - V_r^2 + 2V_e(V - V_r)$$

$$\theta_f - \theta_r = \theta_p = \frac{V^2 - V_r^2}{K} + \frac{2V_e(V - V_r)}{K}$$

At end of constant rate,

$$\left(\frac{dV}{d\theta}\right)_r = \left(\frac{dV}{d\theta}\right)_p$$

$$\therefore \frac{V_r}{\theta_r} = \frac{K}{2(V_r + V_e)} \qquad \text{thus} \quad K = \frac{2V_r(V_r + V_e)}{\theta_r}$$

If V_e is negligible,

$$\theta = \theta_r + \frac{V^2 - V_r^2}{K} \qquad \text{and} \qquad K = \frac{2V_r^2}{\theta_r}$$

E. ***Washing Time, θ_w***

$$\theta_w = \frac{V_w}{r_w}$$

V_w = vol. of wash water, r_w = rate of washing

F. ***Rate of Washing, r_w***

For Plate and Frame Filter Press,

$$r_w = \frac{1}{4} r_f = \frac{1}{4} \cdot \frac{K}{2(V_f + V_e)}$$

For Leaf Filters,

$$r_w = r_f = \frac{K}{2\left(V_f + V_e\right)}$$

G. ***Capacity of Filters,*** *y*

$$y = \frac{V_f}{\theta_T} = \frac{V_f}{\theta_f + \theta_w + \theta_c}$$

To get the maximum capacity, y_{max}, the right side of the above equation is expressed in terms of the variable, θ_f, and y is differentiated with respect to θ_f and equated to zero to get the θ_f, opt.

H. ***Continuous Filtration***

Basis: 1 Cycle or revolution,

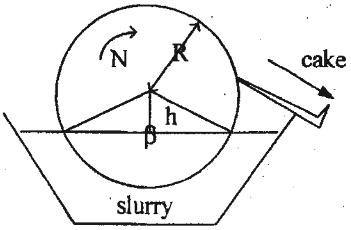
Effective filtration time per cycle,

$$\overline{\theta} = \frac{F}{N}$$

F = fraction of area immersed in slurry

$$F = \frac{2\beta}{360°} = \frac{2\,Cos^{-1}\left(\frac{h}{R}\right)}{360°}$$

N = number of revolution per unit time



Volume collected per cycle, $\overline{V}$ at constant pressure,

$$\overline{V}^2 + 2V_e\overline{V} = \overline{K}\,\overline{\theta}$$

where: $\overline{K} = \dfrac{2\overline{A}^2(-\Delta P)g_c}{\alpha C\mu}$ and $\overline{A} = FA_T = 2\pi RLF$

Capacity of the Filter, $y = \dfrac{\overline{V}}{\overline{\theta}}$

REVIEW QUESTIONS AND PROBLEMS

1. The operation by which solids are separated from liquids due to the difference in their respective densities is
   a. filtration
   b. sedimentation
   c. screening
   d. adsorption

2. In a filtration operation involving incompressible cakes, the flow rate is directly proportional to
   a. the viscosity of the filtrate
   b. the thickness of the filter cake
   c. the pressure applied
   d. the size of the cake particles

3. During filtration of a slurry, the filtration rate will start to fall once the pressure drop across the filter medium
   a. becomes constant
   b. begins to fall
   c. begins to rise
   d. becomes zero

4. During filtration on a rotary filter the precipitate is continuously removed from the filter medium by a scrapper in order to
   a. prevent the precipitate from mixing with the filtrate
   b. maintain a constant pressure drop across the filter
   c. keep the filter clean
   d. none of these

5. In filtration, the coarser the filtration medium __________ the constant rate period.
   a. the shorter
   b. does not effect
   c. the longer
   d. zero

6. In a plate-and-frame filter press, the rate of filtration is directly proportional to the
   a. resistance of the filter cake
   b. cross-section of the filter surface
   c. resistance of the filter medium
   d. viscosity of the filtrate

7. For a non-washing constant pressure filtration where the resistance of the filter medium is negligible, maximum capacity of the filter is attained when the filtration time is
   a. less
   b. equal
   c. greater
   d. cannot be determined

   compared to the dumping and cleaning time.

8. A rotary drum filter with 35% of its filtering area submerged in the slurry, turns at 0.5 rpm. The filtrate production is 0.61 cubic meter per min. per square meter of filtering area submerged when filtering lime slurry. Average production is 20.4 cubic meters of filtrate per hour. The estimated area of the filter cloth in square meter is
   a. 3.2
   b. 1.6
   c. 0.80
   d. none of these

9. Referring to the above problem, if the drum has a diameter of 1.0 m, the width of the drum, in centimeters is
   a. 2.5
   b. 100
   c. 51
   d. none of these

10. In a plate and frame filter press, the rate of washing is equal to
    a. ½
    b. ¼
    c. 1
    d. 2

    of the final filtration rate.

11. A plate and frame filter press is used to filter a certain sludge for 2 hours at constant pressure. Washing is done by using 10% of the filtrate volume collected. The time of washing is
    a. 100 min
    b. 96 min
    c. 1.6 min
    d. 100 hours

12. A plate and frame filter press contains 24 frames, each 1 inch thick and has inside dimensions of 2 ft x 2 ft. Filtering time is 2 hours. Wash water volume is 10% of the filtrate volume per cycle. Filtering and washing are done at the same pressure. The final cake is 0.05 ft^3/ft^3 of filtrate. If the time for cleaning and reassembling is 30 min/cycle, the capacity of the press is
    a. 900 ft^3/hour
    b. 936 ft^3/day
    c. 950 ft^3/day
    d. 950 ft^3/hour

13. The equation: $V_f^{\,2} = 22.5 \times 10^3(\theta_f + 0.11)$

    gives the relation between the filtrate volume and the operating time under constant pressure of a certain P and F filter press where V_f = ft^3 of filtrate delivered in time θ_f hour. If $\theta_c = 6$ hours/cycle (dismantling, dumping and reassembling), and $V_w = (1/16)V_f$ the total cycle time for maximum filtrate output during each 24 hour is
    a. 11 hours
    b. 12 hours
    c. 3.8 hours
    d. 2 hours

14. In the filtration of $Al(OH)_3$ the following data were obtained :
    (1) the pump is operated at maximum pressure of = 50 psia;
    (2) filtration was completed at constant pressure;
    (3) constant rate operation time is 15 min. and 1/3 of the total volume is obtained during this period. Given the above, the total filtration time is
    a. 20 min
    b. 25 min
    c. 50 min
    d. 75 min

15. If only ½ of the original filtrate volume of Problem *14* were to be collected with the area remaining unchanged, the new filtration time is
    a. 20.5 min
    b. 24.4 min
    c. 48.6 min
    d. 38.3 min

16. If a duplicate pump were installed in parallel with the present pump in Problem *14*, the percent reduction in filtration time is
    a. 50%
    b. 7.7%
    c. 12.5 %
    d. 36.8%

17. A plate and frame filter press with 10 frames is used to filter a slurry at a constant pressure. Total filtration area is 75 ft^2 and the filter delivers 400 lbs of filtrate in half an hour. If 10 more frames are added to the filter press, while other conditions remain the same, the time to produce 400 lb of filtrate, assuming $R_m = 0$, is
    a. 10 min
    b. 30 min
    c. 7.5 min
    d. 15 min

18. A rotary vacuum filter with negligible filter medium resistance delivers 125 ft^3 of filtrate per minute when a given $CaCO_3$-H_2O mixture is filtered under known conditions. If the pressure drop over the cake is doubled, all other conditions remaining constant, the volume of filtrate delivered per hour is
    a. 12,600 ft^3
    b. 177 ft^3
    c. 10,620 ft^3
    d. 7,500 ft^3

19. A small leaf filter is run at constant rate. It is found that the initial pressure is 5 psig and the pressure after 20 minutes of operation during which 30 gallons of filtrate is collected is 50 psig. If this filter is used with the same slurry in a constant pressure filtration at 50 psig, the filtrate collected in 20 minutes is
    a. 40 gal
    b. 42.4 gal
    c. 30 gal
    d. 45 gal

20. A standard leaf filter gives 20 cu. ft. of filtrate in two hours of filtration time per cycle. If washing time is 30 minutes, draining time is 20 minutes, filling time is 25 minutes and dumping, cleaning, etc. is 35 minutes, the capacity of the leaf filter, in cu. ft. per hour is
    a. 5.2
    b. 6.5
    c. 4.4
    d. none of these

21. A plate and frame filter press is used to filter a compressible sludge (S = 0.45) at 50 psia for 2 hours. Washing is done at 30 psi with wash water equal to 10% of the filtrate volume collected. The washing time is
    a. 100 min
    b. 127 min
    c. 85 min
    d. 205 min

22. The filter fabric (or filter medium) to use in which strong breaking tenacity and strong abrasion resistance are required is
    a. cotton
    b. acrylic
    c. polyester
    d. nylon

23. In a constant rate filtration test, the pressure rises from 4 to 45 psi in 10 minutes collecting 3 cu.ft. of filtrate. The equivalent resistance of the filter medium for this test is _______ cu.ft.
    a. 0.293
    b. 0.452
    c. 0.183
    d. 0.50

24. The capacity of a rotary vacuum filter will change by a factor of ______ if the submerged area is increased by 20% with the speed and pressure remaining the same.
    a. 2
    b. 1.20
    c. 1.1
    d. 1.5

25. The equation that is applied to describe the flow of a fluid through a porous medium under laminar condition is
    a. Fanning-Darcy Equation
    b. Ruth Equation
    c. Kozeny-Karman Equation
    d. Hagen-Poiseuille Equation

5. DIFFUSION

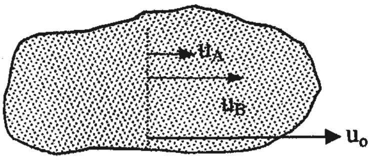
THEORY AND EQUATIONS

Fick's Law of Diffusion

For a binary mixture of components A and B, the Fick's Law gives the diffusion flux relative to the velocity of the bulk, u_o as

$$I_{OA} = c_A(u_A - u_o) = -D_{AB}\frac{dc_A}{dz}$$

$$I_{OB} = c_B(u_B - u_o) = -D_{BA}\frac{dc_B}{dz}$$



The diffusion flux relative to a stationary observer is given by

$$N_A = u_A c_A$$

$$N_B = u_B c_B$$

For binary mixture, it can be shown that $D_{AB} = D_{BA} = D_v$ and $I_{OA} + I_{OB} = 0$

If we solve for the total molar flux relative to a stationary observer using the Fick's Law of Diffusion, the following relation is obtained

$$\frac{N_A}{A} = -D_v\frac{dc_A}{dz} + \frac{c_A}{\rho_m}\frac{N_A + N_B}{A}$$

which shows that the total molar flux is a combination of molecular flux and convective flux. Another term used for convective flux is *phase drift.*

$$I_A = I_{OA} + I_{CA}$$

Equimolal Counter Diffusion

If the number of moles of A and B are diffusing equally in opposite direction, then

$$N_A = -N_B \text{ or } N_A + N_B = 0$$

the diffusion equation becomes, $\frac{N_A}{A} = -D_v\frac{dc_A}{dz}$

For ideal gases, the concentration of A can be expressed in terms of the partial pressure

$$c_A = \frac{p_A}{RT}$$

the diffusion equation becomes, $\frac{N_A}{A} = -\frac{D_v}{RT}\frac{dp_A}{dz}$

The above equation can be integrated depending on the variation of *z* with the area perpendicular to the direction of the moving components. [illegible]

$\frac{N_A}{A} = -D_v \frac{P}{RT} \frac{dy_A}{dz}$ $y = \frac{p_A}{P_T}$

Unicomponent Diffusion

For a case where only A is able to diffuse due to certain constraints where B becomes stagnant, then $N_B = 0$. The diffusion equation can be simplified to the form

$$\frac{N_A}{A} = -D_v \frac{dc_A}{dz} + \frac{c_A}{\rho_m} \frac{N_A}{A}$$

Since $\rho_m = C_A + C_B$, the above equation may be simplified to

$$\frac{N_A}{A} = -D_v \left(1 + \frac{c_A}{c_B} \right) \frac{dc_A}{dz}$$

And for ideal gases, this equation can be written as

$$\frac{N_A}{A} = -\frac{D_v P_T}{RT p_B} \frac{dp_A}{dz}$$

Evaluation of Diffusivity

From Empirical Equations

Chapman and Engskog Equation (Geankoplis, 1995)

$$D_{AB} = \frac{1.8583 \times 10^{-7} T^{3/2}}{P \sigma_{AB}^2 \Omega_{D,AB}} \left(\frac{1}{M_A} + \frac{1}{M_B} \right)^{1/2}$$

Chen and Othmer Equation (McCabe and Smith, 1993)

$$D_v = \frac{0.01498\, T^{1.81} \left(\frac{1}{M_A} + \frac{1}{M_B} \right)^{0.5}}{p \left(T_{C_A} T_{C_B} \right)^{0.1405} \left(V_{C_A}^{0.4} + V_{C_B}^{0.4} \right)^2}$$

Gilliland Equation (Brown, 1950)

$$D_G = \frac{0.0166 T^{3/2}}{P \left(V_A^{1/3} + V_B^{1/3} \right)} \sqrt{\frac{1}{M_A} + \frac{1}{M_B}}$$

For Liquids, Stokes-Einstein Equation (Geankoplis, 1995)

$$D_{AB} = \frac{9.96 \text{ x } 10^{-16} T}{\mu \mathrm{V}_{\mathrm{A}}^{1/3}}$$

For Liquids, Wilke and Chang Equation (Treybal, 1968)

$$D_{AB} = \frac{7.4 \left(10^{-8} \right) \left(\phi M_B \right)^{0.5} T}{\mu V_A^{0.6}}$$

From Experimental Data

If the diffusivity is given at a certain temperature and pressure, say at standard conditions, it is possible to estimate the diffusivity at a desired temperature and pressure by making use of the empirical equations as the basis. If the calculation is based on Chen and Othmer correlation, the equation becomes,

$$(D_v)_{T,p} = (D_v)_{273,1\,atm} \times \left(\frac{T}{273}\right)^{1.81}\left(\frac{1}{P}\right)$$

Mass Transfer Coefficients

For Turbulent Diffusion, $I_{OA} = -(D_{AB} + \varepsilon_M)\dfrac{dc_A}{dz}$

For equimolal counter diffusion, $I_{OA} = N_A/A$. The above equation can therefore be integrated across a film thickness of $(z_2 - z_1)$, to give

$$\frac{N_A}{A} = \frac{D_{AB} + \varepsilon_M}{z_2 - z_1}\left(c_{A_1} - c_{A_2}\right)$$

This equation is then simplified by expressing it in terms of a convective mass transfer coefficient, k_c' based on the entire bulk phase.

$$\frac{N_A}{A} = k_c'\left(c_{A_1} - c_{A_2}\right)$$

$k_c = k_c\ x_{B\ln}$

$k_G = k_G' / P_{B\ln}$

For mass transfer of A in a non-diffusing B,

$$\frac{N_A}{A} = \frac{(D_{AB} + \varepsilon_M)}{z_2 - z_1}\frac{c_{A_1} - c_{A_2}}{x_{B\ln}}$$

which may be simplified to

$$\frac{N_A}{A} = \frac{k_c'}{x_{B\ln}}\left(c_{A_1} - c_{A_2}\right) = k_c\left(c_{A_1} - c_{A_2}\right)$$

The mass transfer coefficients k_c' and k_c have a unit of m/s or ft/hr. It is possible to express these coefficients in terms of other units depending on the driving forces used in the equation. Examples are k_G, k_y and k_x defined by the equations

$$\frac{N_A}{A} = k_G\left(P_{A_1} - P_{A_2}\right) = k_y\left(y_{A_1} - y_{A_2}\right) = k_x\left(x_{A_1} - x_{A_2}\right)$$

Evaluation of Mass Transfer Coefficients

Dimensionless Numbers

The dimensionless numbers obtained by the usual dimensional analysis that are important in mass transfer operations are the following:

$$\text{Reynolds Number, } N_{Re} = \frac{Du\rho}{\mu} = \frac{\text{inertia forces}}{\text{viscous forces}}$$

Schmidt Number, $N_{Sc} = \dfrac{\mu}{\rho D_v} = \dfrac{\text{momentum}}{\text{mass diffusivity}}$

Sherwood Number, $N_{Sh} = \dfrac{k_c' L}{D_{AB}} = \dfrac{\text{turbulent diffusion}}{\text{molecular diffusion}}$

The mass transfer coefficient is correlated as a dimensionless, J_D factor given by

$$J_D = \frac{k_c'}{v}(N_{Sc})^{2/3} = \frac{k_c' P_T}{v\rho_m} = \frac{N_{Sh}}{N_{\text{Re}} N_{Sc}^{1/3}}$$

Mass, Heat and Momentum Transfer Analogies

Reynolds Analogy ($N_{Sc} = N_{Pr} = 1.0$)

$$\frac{f}{2} \approx \frac{h}{c_p G} \approx \frac{k_c'}{u_{av}}$$

Chilton-Colburn Analogy

$$\frac{f}{2} = J_H = \frac{h}{c_p G}(N_{\text{Pr}})^{2/3} = J_D = \frac{k_c}{u_{av}}(N_{Sc})^{2/3}$$

[illegible]

Flow Inside Pipes

For Laminar Flow, refer to Figure 7.3 –2, Geankoplis

For Turbulent Flow, for N_{Sc} of 0.6 to 3000

$$N_{Sh} = k_c' \frac{D}{D_{AB}} = 0.023 N_{\text{Re}}^{0.83} N_{Sc}^{0.33}$$

Flow Outside Solid Surfaces

For Parallel Flat Plates,

$$N_{Sh} = k_c' \frac{L}{D_{AB}} = 0.664 N_{\text{Re},L}^{0.5} N_{Sc}^{1/3}$$

Flow Past Single Spheres

For Gases, $N_{Sc} = 0.6$ to 2.7 and $N_{Re} = 1$ to 48,000

$$N_{Sh} = 2 + 0.552 N_{\text{Re}}^{0.53} N_{Sc}^{1/3}$$

For Liquids, $N_{Re} = 2$ to 2000

$$N_{Sh} = 2 + 0.95 N_{\text{Re}}^{0.5} N_{Sc}^{1/3}$$

N_{Re} = *2000 to 17,000*

$$N_{Sh} = 0.347 N_{\text{Re}}^{0.62} N_{Sc}^{1/3}$$

The representative equations given above are obtained from Geankoplis (1995). Many more correlations are available in Perry's Handbook (1984, 1997), and other references.

REVIEW QUESTIONS AND PROBLEMS

1. The enrichment of ethyl alcohol in the vapor phase from an aqueous ethyl alcohol solution during rectification is an example of
   a. unicomponent diffusion
   b. equimolal counterdiffusion
   c. phase drift
   d. convective diffusion

2. The transport mechanism analogy for momentum and heat transfer deviates with mass transfer due to
   a. different driving forces
   b. different transfer areas
   c. different resistances
   d. none of these

3. The diffusivity of a binary system as given in the equation of Fick's Law is usually measured relative to the
   a. stationary observer
   b. velocity of earth as it rotates around the sun
   c. mass-mean velocity of component A
   d. volume-mean velocity of components A and B

4. The diffusivity of a component A relative to itself, that is D_{AA}
   a. has no physical meaning
   b. has a physical meaning but can not be measured
   c. has a physical meaning and can be measured
   d. it can not be described

5. The Reynolds Analogy is applied when
   a. the Reynolds Number is less than 2100
   b. the Prandtl Number is unity
   c. the Prandtl Number is not equal to one
   d. no mass transfer is involved

6. The molar flux of component A in molecular diffusion is independent of
   a. mass transfer area
   b. concentration gradient
   c. total pressure
   d. temperature

7. A dimensionless number that represents the ratio of the mass transferred by molecular diffusion to the total mass transferred is
   a. Sherwood Number
   b. Reynolds Number
   c. Schmidt Number
   d. none of these

8. The molar diffusion flux of A relative to a stationary plane is a combination of
   a. N_A+N_B+ molecular diffusion
   b. Fick's law of diffusion and diffusivity
   c. phase drift + molecular diffusion
   d. bulk diffusion and pressure diffusion

9. The Fick's Law of Diffusion gives the rate of diffusion based on
   a. pressure driving force
   b. temperature driving force
   c. concentration driving force
   d. all of these

10. Equimolar counter-diffusion means that the
    a. bulk in terms of mass is not moving
    b. concentration driving force is zero
    c. convective flux is very high
    d. bulk in terms of moles is not moving

11. For a gas phase diffusion, unicomponent diffusion through a gas-liquid interface will likely to occur if
    a. one component is soluble and the other is not
    b. both components are soluble in the solvent
    c. both components are insoluble in the solvent
    d. none of these

12. The rate of mass transfer of component A through an interface in a turbulent flow system is less affected by
    a. concentration gradient of A
    b. mass transfer area
    c. thickness of the laminar films adjacent to the interface
    d. the flow rate of gas and liquid

13. For binary unicomponent diffusion, the concentration profile of the diffusing component along the diffusion path is
    a. linear
    b. quadratic
    c. logarithmic
    d. none of these

14. The analogy between mass and heat transfer is complete when
    a. the temperature gradient and concentration gradient are equal
    b. no convective flux or phase drift is involved
    c. the resistance to mass and heat transfer are negligible
    d. the momentum transfer rate is negligible

15. A wetted-wall column is usually used to determine mass transfer coefficient experimentally because
    a. the mass transfer area can be measured accurately
    b. the concentration gradient can be measured accurately
    c. there is no better device to use
    d. it is an inexpensive piece of equipment

16. It provides the basis for the quantitative description of the diffusional phenomena of molecules.
    a. Stokes-Einstein Postulation
    b. Kinetic Theory of Gases
    c. Thermal Diffusion
    d. Potential Theory

17. The method of solute transfer which involves rapid movement of large chunks of fluid in turbulent motion
    a. molecular diffusion
    b. eddy diffusion
    c. thermal diffusion
    d. kinetic transport

18. Ammonia (A) being absorbed from air (B) into water is an example of
    a. steady state equimolal diffusion
    b. steady state unicomponent diffusion
    c. steady state diffusion in multicomponent mixtures
    d. unsteady state equimolal diffusion

19. In steady-state equimolal counterdiffusion, the following are true:
    a. $N_B = 0$; N_A constant
    b. $N_A = - N_B$; $N_A + N_B$ is zero
    c. $N_A = 0$; N_B is nonzero *
    d. $N_A + N_B = \text{constant}$

20. The flux of A in unicomponent diffusion is greater than in equimolal diffusion because of
    a. the molecular diffusion of A relative to a fixed point
    b. the bulk motion of the phase
    c. the concentration gradient of B is zero
    d. the flux of A relative to the average molar velocity

21. It represents the total mass transferred to mass transferred by molecular diffusion
    a. Sherwood Number
    b. Schmidt Number
    c. Reynolds Number
    d. Nusselt Number

22. It is a measure of the diffusive mobility of individual molecules in solution
    a. eddy diffusivity
    b. diffusion coefficient
    c. mass transfer coefficient
    d. thermal diffusion

23. The volumetric diffusivity of a binary mixture is 0.934 ft^2/hr at 30°C and 2 atm. The molal diffusivity for a similar mixture is ______ lb mole/ft-hr.
    a. 4.688×10^{-3}
    b. 0.05
    c. 2.344×10^{-3}
    d. none of these

24. The diffusivity of benzene in air at 0°C and 1 atm is 0.299 ft^2/hr. The diffusivity of benzene in air at 22°C and 1 atm is
    a. 0.0772 cm^2/s
    b. 0.299 ft^2/hr
    c. 0.089 cm^2/s
    d. 0.0772 ft^2/hr

25. Ethyl alcohol is diffusing into an alcohol-water solution at 18°C. The concentration of alcohol in the bulk of the solution is negligible, while that at the surface of the solution is 0.12 g/cc. The film thickness is 0.15 cm and the diffusivity is 1×10^{-5} cm^2/s. The mass of alcohol diffusing through 100 ft^2 of interface per hour is
    a. 6 lb
    b. 5 lb
    c. 0.016 g-mole
    d. 0.0026 g-mole

26. The diffusivity of ethyl alcohol in air at 25°C and 1 atm is 0.135 cm^2/s. Based on Chen and Othmer diffusivity empirical correlation, the diffusivity at 80°C, in cm^2/s, is
    a. 0.1816
    b. 0.1740
    c. 0.3668
    d. 0.0994

27. The diffusivity of the air in ethyl alcohol at 25°C and 3 atm in ft^2/hr is
    a. 0.1744
    b. 1.569
    c. 0.523
    d. none of these

28. Using the appropriate analogy, estimate the MTC in ft/hr for NH_3-air-water system in a wetted wall column where N_{Re}= 25,000, N_{Sc} = 1.8 and the velocity of the gas is 1.2 ft/s.
    a. 6.8
    b. 5.6
    c. 0.578
    d. 8.76 ft/hr

29. Acetic acid is diffusing in aqueous solution at 298 K inside a 2-cm diameter tube 100 cm long. Determine the total diffusion rate of acetic acid in g-mole/s if the concentration at one end is 0.125 and on the other end 0.051 gmole/cm^3.
    a. 7.25×10^{-6}
    b. 1.54×10^{-8}
    c. 2.93×10^{-8}
    d. 2.9×10^{-6}

30. A 4 mm diameter tube, 40 cm long, closed at one end and standing vertically on its closed end, is partially filled with a liquid up to 18 mm from the open top. A gentle stream of air is flowing across the top of the tube. The temperature of the liquid remains constant at 17°C. Diffusion takes place through the still air in the tube above the liquid. After 4 hours and 10 min the liquid level in the tube goes down by 9.5 mm. The vapor pressure of the liquid is 165 mm Hg and atmospheric pressure is 1 atm. Density of the liquid is 790 kg/m^3. MW = 58. The mass diffusivity of the liquid vapor in air is
    a. 1.91×10^{-5} m^2/s
    b. 1.91×10^{-5} cm^2/s
    c. 1.75×10^{-5} m^2/s
    d. none of these

31. A sphere of naphthalene having a radius of 2 mm is suspended in a large volume of still air at 318 K and 1 atm. The surface temperature of the naphthalene can be assumed to be 318 K. The diffusivity at 318 K and 1 atm is 6.92×10^{-6} m^2/s and its vapor pressure at 318 K is 0.555 mm Hg. The rate of evaporation of naphthalene in g-mole/s is
    a. 4.9×10^{-9}
    b. 9.68×10^{-5}
    c. 4.5×10^{-9}
    d. 9.7×10^{-5}

32. The unicomponent mass transfer coefficient is 3.25×10^{-5} kg mole/s-m^2-mole at 300 K and 2 atm. If y_{A1} = 0.26 and y_{A2} = 0.01, the equimolal MTC is _______kg mole/s-m^2-mole.
    a. 2.792×10^{-5}
    b. 1.25×10^{-5}
    c. 5.65×10^{-5}
    d. 0.98×10^{-6}

33. The equivalent equimolal MTC for the above problem in lb mole/hr-ft^2-atm is
    a. 0.0543 b. 0.0205 c. 1.34 d. 0.069

34. Based on the penetration theory, the MTC will increase/decrease by a factor of ______ if the contact time of the diffusing phases is tripled.
    a. 0.421 b. 0.21 c. 1.62 d. 0.5773

35. The time it will take to evaporate a 10 mm unknown liquid at 25°C (density = 40 lb/ft^3, MW = 60) in a 5-m diameter circular tank is ____hr. The vapor pressure at 25°C is 180 mm Hg, pressure is atmospheric and D_v = 0.0329 ft^2/hr. Stagnant air film is 10 mm.
    a. 22 hr b. 45.3 hr c. 31.6 hr d. 5.2 hr

6. DISTILLATION

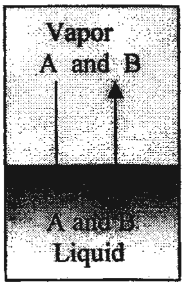
THEORY AND EQUATIONS

Introduction

Distillation involves the separation of two or more volatile components from a liquid solution by the application of heat. Due to the differences in the volatilities of the various components, the vapor generated contains improved concentrations of the more volatile components. This vapor is subsequently processed or condensed to generate an enriched concentration different from the original liquid solution. The chemical engineer is involved in the design of the various distillation equipment used for batch distillation, flash distillation, fractional distillation, steam distillation, etc.

Phase Equilibria

Phase Equilibria for Binary System



Consider a binary system composed of a liquid solution of component A designated as the more volatile component (MVC) and B as the less volatile component (LVC). If this liquid is partially vaporized in a closed container where the total pressure is maintained constant at P, the vapor and liquid will ultimately be in equilibrium with each other. If x refers to the concentration of MVC in the liquid phase and y the concentration of the MVC in the vapor phase, the Gibb's Phase Rule given by

$$\phi = C - P + 2$$
$$= 2 - 2 + 2 = 2$$

which indicates that there are two degrees of freedom. This means that if the pressure and the temperature are specified, the concentrations x and y become fixed. These concentrations are the equilibrium concentrations relating the vapor and the liquid phases. In distillation, these data referred to as the Vapor-Liquid Equilibria (VLE), are very important in the design of distillation processes.

Sources of Vapor-Liquid Equilibria

There are many methods recommended to generate VLE information both experimentally and theoretically, considering ideal or non-ideal conditions. Many theoretical correlations are based on thermodynamic considerations and molecular interactions. For simplicity, the following are the common sources of VLE data which will be used in this discussion:

1. *Vapor Pressure-Temperature* data for pure components

   Let $p_A^o, p_B^o, p_C^o, ...$ be the vapor pressures of components $A, B, C, ...$ at a given temperature. For a fixed total pressure P_T, by *Dalton's Law*,

   $$p_A^o x_A + p_B^o x_B + p_C^o x_c + ... = p_T$$

   and by *Raoult's Law*,

   $$y_A = \frac{p_A^o}{p_T} x_A; \quad y_B = \frac{p_B^o}{p_T} x_B; \quad y_c = \frac{p_C^o x_c}{p_T}, \; ....$$

The temperature chosen should yield concentrations that will satisfy the Material Balance for the liquid and vapor phases

$$x_A + x_B + x_C + \dots\dots\dots = 1.0$$

$$y_A + y_B + y_C + \dots\dots = 1.0$$

2. *Vapor Pressure-Temperature* using *Antoine Equation*

$$\ln P^\circ = A + \frac{B}{C+T}$$

where: A, B and C are constants for a particular component and T = temperature
See Table 13-4, Perry 7/e

3. *Boiling Point-Composition Diagrams*
This plot may be generated from the values of x and y at a given temperature determined from *Raoult's Law* and *Dalton's Law*.
4. *Equilibrium Curves*
This is a plot of x and y in a square diagram which gives a graphical relationship between the equilibrium concentrations of the MVC in the liquid and vapor phases.
5. *Relative Volatility*, α_{AB}
In some cases, the relative volatility of a binary system is known. This property may be utilized to generate the equilibrium concentrations x and y on the assumption that α_{AB} can be considered practically constant or the average value can be applied within the range of concentrations under study. By definition, where V_A and V_B refer to the volatilities of A and B, respectively is

$$\alpha_{AB} = \frac{v_A}{v_B} = \frac{p_A/x_A}{p_B/x_B} = \frac{y_A x_B}{y_B x_A}$$

expressing this in terms of the concentrations of the MVC,

$$\alpha_{AB} = \frac{y(1-x)}{x(1-y)}$$

or

$$y = \frac{\alpha_{AB}\, x}{(\alpha_{AB} - 1)x + 1}$$

6. *Distribution Coefficients*
Equilibrium data may also be determined from distribution coefficients defined by

$$K_i = \frac{y_i}{x_i}$$

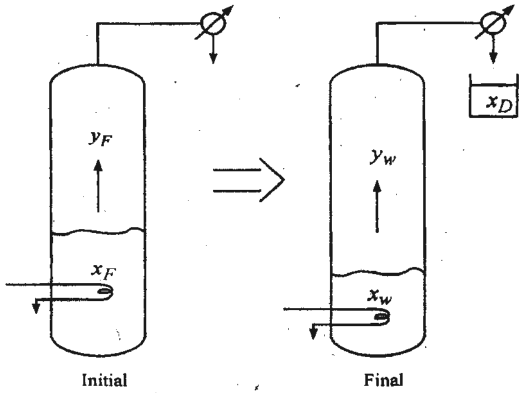
an example of a source of this is the *dePriestier Charts*, see Figure 13-14, Perry 7/e

Simple Batch or Differential Distillation

This process involves the batch vaporization of the liquid in a distilling still until a certain amount of the feed, F, is converted to the distillate which is composed of the collection of the condensed vapor. The liquid left in the still is the residue, W. The instantaneous concentrations of the liquid, x and the vapor generated, y are in equilibrium with each other. Since more of the MVC are converted to vapor, the temperature of the liquid in the still will increase. To relate the amounts of feed and residue, we apply the *Rayleigh's Equation*:

$$\ln \frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{y - x}$$

the integral may be evaluated by graphical method. To simplify the evaluation of the above equation certain assumptions may be considered.



Simplified Equations

1. Based on *Henry's Law* for dilute solutions, the partial pressure of the MVC is

$$\bar{p}_A = H_A x_A$$

where H_A is the Henry's constant. Solving for the concentration of the vapor

$$y = \frac{\bar{p}_A}{P_T} = \frac{H_A x_A}{P_T} \quad \text{and} \quad y = mx$$

substituting in the *Rayleigh's Equation* and integrating, we get

$$\ln\frac{F}{W} = \frac{1}{m-1}\ln\frac{x_F}{x_W}$$

2. Based on the Relative Volatility, α_{AB}, there are two ways of simplifying the *Rayleigh's Equation*

   a. In terms of composition. The first one is to solve for y in terms of α_{AB},

   that is
$$y = \frac{\alpha_{AB}x}{(\alpha_{AB}-1)x+1}$$

   substituting in *Rayleigh's Equation*

$$\ln\frac{F}{W} = \int_{x_w}^{x_f} \frac{dx}{\dfrac{\alpha_{AB}x}{(\alpha_{AB}-1)x+1} - x}$$

   integrating, assuming that α_{AB} is constant or can be averaged,

$$\ln\frac{F}{W} = \frac{1}{\alpha_{AB}-1}\left[\ln\frac{x_F}{x_W} + \bar{\alpha}_{AB}\ln\frac{1-x_W}{1-x_F}\right]$$

   the average $\bar{a}_{AB}$ may be evaluated using arithmetic mean or geometric mean.

$$\bar{\alpha}_{AB} = \frac{(\alpha_{AB})_F + (\alpha_{AB})_w}{2} \quad \text{or} \quad \bar{\alpha}_{AB} = \sqrt{(\alpha_{AB})_F(\alpha_{AB})_w}$$

b. In terms of the individual components. Here, the instantaneous amounts of pure components A and B evaporated are *dA* and *dB*. For an ideal gas, the mole ratio is given by

$$\frac{dA}{dB} = \frac{y_A}{y_B} \qquad \text{but} \qquad \frac{y_A}{y_B} = \alpha_{AB}\frac{x_A}{x_B}$$

or

$$\frac{y_A}{y_B} = \alpha_{AB}\frac{\frac{A}{A+B}}{\frac{B}{A+B}} = \alpha_{AB}\frac{A}{B}$$

substituting,

$$\frac{dA}{dB} = \alpha_{AB}\frac{A}{B} \qquad \text{or} \qquad \int_{A_1}^{A_2}\frac{dA}{A} = \int_{B_1}^{B_2}\alpha_{AB}\frac{dB}{B}$$

integrating,

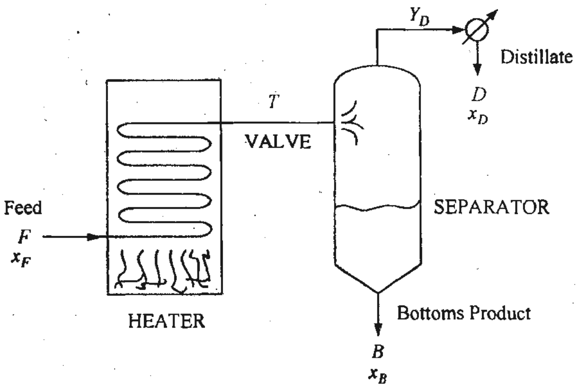
$$\ln\frac{A_1}{A_2} = \bar{\alpha}_{AB}\ln\frac{B_1}{B_2} \qquad \text{Note: } \bar{\alpha}_{AB} = \sqrt{\alpha_{AB_1}\alpha_{AB_2}}$$

This equation can be extended to multicomponent system. If another component, say T_1 is present with the α_{TA} known, then

$$\ln\frac{T_1}{T_2} = \bar{\alpha}_{TA}\ln\frac{A_1}{A_2}$$

Equilibrium or Flash Distillation

In this process, the feed, *F* is continuously heated where the potential vapor is allowed to be in intimate contact with the liquid at a certain temperature and pressure. This mixture is then allowed to pass through a pressure relief valve to separate the vapor from the liquid. The vapor is subsequently condensed to generate the distillate, *D* while the liquid is withdrawn from the separating still as bottoms product, *B*. The distillate in this case is always in equilibrium with the bottoms product. For binary system, the analysis may be done using algebraic or graphical method.



Binary System

Algebraic Method: An over-all material balance around the flash distillation unit gives $F = B + D$

An MVC Balance gives $Fx_F = Bx_B + Dy_D$

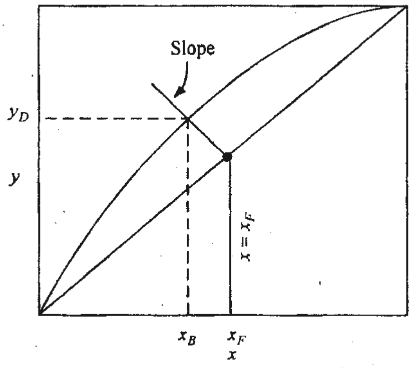
since x_B and y_D are in equilibrium, the system is defined.

Graphical Method: Suppose we let f be the mole fraction of feed vaporized. On the basis of $F = 1$ mole, an MVC Balance will give

$$(1)(x_F) = (1-f)x + fy$$

solving for y

$$y = -\frac{1-f}{f}x + \frac{x_F}{f}$$



this equation represents a straight line with slope $= -\frac{1-f}{f}$. The intersection of this line with the equilibrium curve determines the concentrations of the distillate, y_D and the bottoms product x_B.

Multicomponent System

The material balance for any component, i may be expressed in terms of the distribution coefficient, K_i, that is $K_i = \frac{y_i}{x_i}$. Substituting this in the component balance gives $x_{F_i} = (1-f)x_{B_i} + f\,K_i\,x_{B_i}$

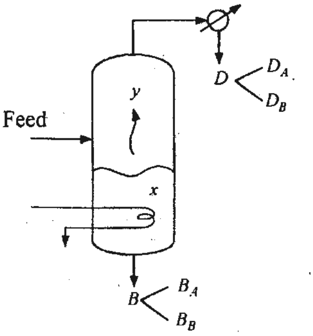
solving for x_{Bi} $\quad x_{B_i} = \frac{x_{Fi}}{1+f(K_i-1)}$ and $y_{D_i} = K_i\,x_{B_i}$

Since the operating pressure is usually fixed, the temperature should be chosen for a certain f such that the concentrations of the components satisfy the equations

$$\sum_{i=A}^{n} x_{B_i} = 1.0 \quad \text{and} \quad \sum_{i=A}^{n} y_{D_i} = 1.0$$

Simple Continuous Distillation

This process is similar to batch distillation except that a certain feed is introduced continuously in the distilling still and a product is also withdrawn continuously as the solution is vaporized to generate the distillate. At steady state, the amount and concentration of liquid in the still is maintained constant all throughout the operation. To relate the distillate and bottoms product, we assume that these are in equilibrium so the relative volatility can be used, that is



$$a_{AB} = \frac{y_A\, x_B}{x_A\, y_B} = \frac{\left(\frac{D_A}{D}\right)\left(\frac{B_B}{B}\right)}{\left(\frac{B_A}{B}\right)\left(\frac{D_B}{D}\right)} = \frac{D_A \cdot B_B}{B_A \cdot D_B}$$

and $$\frac{D_A}{D_B} = a_{AB}\left(\frac{B_A}{B_B}\right)$$

where: D_A = amount of A in distillate
B_A = amount of A in the bottoms product

Batch Open Steam Distillation

This process involves the separation of a volatile component, B not miscible in water, from a non-volatile impurity, O by allowing steam to flow directly through the mixture. The carrier steam, S, referred to as the open steam, carries some of the volatile component to the vapor phase. When this mixture is condensed the water can easily be separated mechanically from the volatile liquid. The problem of the chemical engineer is to design the distillation still and to determine the amount of open and close steam. The close steam is the heating steam used to prevent the open steam from condensing inside the still.

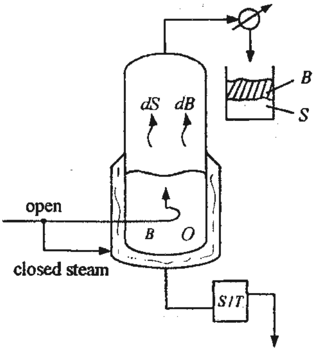
At a certain instant, a differential amount of open steam, dS will carry a certain amount of the volatile component, dB. Assuming ideal gas, the mole ratio becomes

$$-\frac{dS}{dB} = \frac{p_S}{p_B}$$

where p_S and p_B refer to the partial pressures of steam and B, respectively. The p_B may be expressed in terms of the vaporization efficiency, E by

$$p_B = p_{B,Theo}E = p_B^o x_B E \quad \text{also: } p_B + p_S = P_T$$

$$p_S = P_T - Ep_B^o x_B$$



substituting, $$-\frac{dS}{dB} = \frac{P_T - Ep_B^o x_B}{Ep_B^o x_B}$$

but, the composition of B in solution is $x_B = \dfrac{B}{B+O}$

substituting and simplifying, we get

$$-\frac{ds}{dB} = \left(\frac{P_T}{Ep_B^o} - 1\right) + \frac{P_T O}{Ep_B^o} \cdot \frac{1}{B}$$

Case 1. If the dissolved 'non-volatile' impurity is present in large amounts, the above equation yields,

$$S = \left(\frac{P_T}{Ep_B^o} - 1\right)(B_1 - B_2) + \frac{P_T O}{Ep_B^o} \ln \frac{B_1}{B_2}$$

where: B_1 = volatile liquid in the still initially; B_2 = volatile liquid left in the still

Case 2. If the dissolved 'non-volatile' impurity is negligible, $x_B = 1$, thus

$p_B = Ep_B^o$ = constant. This gives

$$-\frac{dS}{dB}=\frac{p_S}{p_B}\ ;$$

integrating
$$\frac{S}{B_1-B_2}=\frac{p_S}{p_B}$$

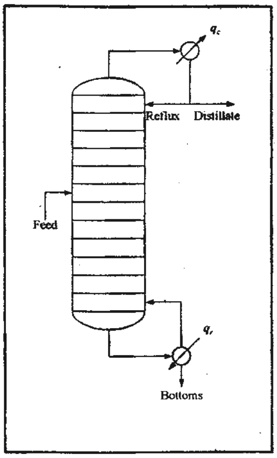
expressing in terms of the weight of Steam, W_S and the volatile component, W_B, we get

$$\frac{W_s/M_s}{W_B/M_B}=\frac{P_S}{P_B}\ ;\text{ or }\ \frac{W_S}{W_B}=\frac{P_S}{P_B}\cdot\frac{M_S}{M_B}$$

where M_S and M_B refer to the molecular weights of steam and the volatile component, respectively.

The amount of closed steam used may be evaluated by heat balance. The close steam is important since it will prevent the condensation of the open steam. This in effect will increase the number of degrees of freedom in the operation of the system.

Fractional Distillation or Rectification



The purity of the products using the previous distillation processes is very limited. In order to get high product concentrations, fractional distillation is applied. This operation involves sequence of stages where there is intimate contact between the liquid, at a lower temperature, coming from the top of the column with the vapor, at a higher temperature, flowing from the bottom. This contact results in the exchange of MVC from the liquid to the vapor and LVC from the vapor to the liquid. By continuous contact, the MVC content of the vapor increases as it flows from stage to stage until it goes through the condenser where the condensed product is split into the reflux and distillate product. Similarly, the LVC of the liquid increases as it flows from stage to stage to the bottom where it goes to a reboiler. The vapor generated goes back to the column while part of the liquid in the still is withdrawn as the bottoms product. The problem of the chemical engineer is to determine the number of stages needed, the heat requirements and to relate the flow rates of the products and the internal flow rates of the vapor and liquid to be able to design the plates and the distillation column.

For binary system, the determination of the theoretical number of stages depends on the nature of the components to be distilled. If the components follow Trouton's Rule, a simpler approach is given by the *McCabe-Thiele Method* where constant molal overflow can be applied. Otherwise, if the molal latent heat of vaporization of the components vary significantly from each other, the more general *Ponchon-Savarit Method* can be used. The discussion here will be limited to the McCabe-Thiele Method applied to binary system.

Determination of Theoretical Stages, N
McCabe-Thiele Method – assumes process to be at constant molal overflow, that is, the molal latent heats of vaporization of the two components are practically the same $\lambda_{m_A}\cong\lambda_{m_B}$.

An over-all material and component balances around the fractionating column yields

$$F = B + D$$

$$Fx_F = Bx_B + D_{x_D}$$

A heat balance around the column is

$$Fh_F + Bq_{RB} = Dh_B + Dq_{CD}$$

$$Fh_F = B(h_B - q_{RB}) + D(h_D + q_{CD})$$

where: $q_{CD} = q_C/D$ and $q_{RB} = q_R/B$.

A heat balance around the condenser gives $V_1H_1 = L_o h_D + D(h_D + q_{CD})$

Solving for q_{CD} gives $q_{CD} = (R_D + 1)(H_1 - h_D)$

Where R_D is the reflux ratio defined by $R_D = Lo/D$. Another way of defining the reflux ratio is R_V defined by $R_V = Lo/V$

McCabe-Thiele Method. The graphical procedure involves the derivation of operating line x from material balance equations, which can be plotted together with the equilibrium curve. From this plot the number of theoretical stages can be determined.

Rectifying Line. Over-all and component material balances around the rectifying section give

$$V_{n+1} = L_n + D$$

$$V_{n+1}\, y_{n+1} = L_n x_n + Dx_D$$

solving for y

$$y_{n+1} = \frac{L_n}{V_n} x_n + \frac{D}{V_n} x_D = \frac{L_n}{L_n + D} x_n + \frac{D}{L_n + D} x_D$$

At constant molal overflow: $L_1 = L_2 = ... = L_n = L$,

$$y_{n+1} = \frac{L}{L+D} x_n + \frac{D}{L+D} x_D \ ;$$

expressing in terms of $R_D = L/D$, we get

$$y_{n+1} = \frac{R_D}{R_D + 1} x_n + \frac{x_D}{R_D + 1}$$

This is an equation of a straight line with slope $R_D/(R_D + 1)$ and an intercept of $x_D/(R_D + 1)$.

Stripping Line. Material balances around the stripping section yield

$$L_m = V_{m+1} - B$$

$$L_m\, x_m = V_{m+1}\, y_{m+1} - Bx_B$$

solving for y

$$y_{m+1} = \frac{L_m}{V_{m+1}} x_m - \frac{Bx_B}{V_{m+1}}$$

at constant molal overflow: $L_m = L_{m+1} = \overline{L}$ and $V_{m+1} = \overline{V}$, this reduces the above equation to a straight line given by

$$y_{m+1} = \frac{\overline{L}}{\overline{V}} x_m - \frac{Bx_B}{\overline{V}}$$

Feed Line. The flow rates of the liquid and vapor within the column is affected by the condition of the feed. If we let f be the fraction of vapor in the feed, then a material balance around the feed plate gives

$$V = \overline{V} + fF$$
$$\overline{L} = L - (1 - f)F$$

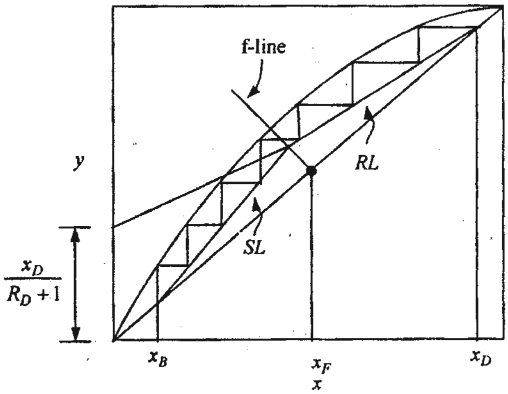
if these two equations are combined with the equations of the rectifying and stripping lines, we get the equation of the feed line $y = -\frac{1-f}{f}x + \frac{x_F}{f}$

The slope of the feed line, – (1 – f)/f is dependent on the condition of the feed. The possible conditions of the feed are:

(a) Cold feed, $f < 0$, (b) Saturated liquid, $f = 0$, (c) Partial vapor, $1 < f < 0$, (d) Saturated vapor, $f = 1.0$, (e) Supersaturated vapor, $f > 1.0$

With these three operating lines, the number of theoretical stages may be determined graphically following the McCabe-Thiele Method. The binary distillation operation at a fixed pressure is completely defined with the following given parameters x_{D_1}, x_F, x_B, R_D, and the condition of feed, *f*. The following procedure may be applied:

1. Plot equilibrium curve in x, y plane with a 45 diagonal as indicated
2. Plot the given x_D, x_B, x_F
3. From the given feed condition, solve for the slope of the f-line, then plot
4. Solve for the intercept or slope of rectifying line, then plot the line
5. Draw the stripping line
6. Using the operating lines and the equilibrium curve, draw the step down lines to determine the theoretical number of stages



To get the actual number of plates

1. Use over-all efficiency η_o, defined by

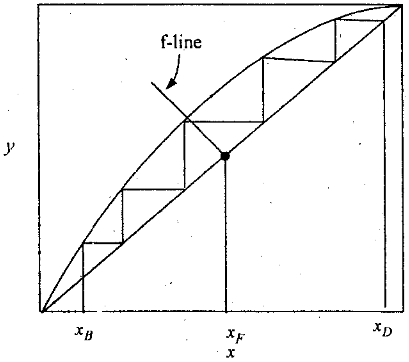
$$\eta_o = \frac{\text{no. of theoretical plates}}{\text{no. of actual plates}}$$

2. Use Murphree efficiency to plot the pseudo-equilibrium curve given by

$$y_e' = y + \eta_M (y_e - y)$$

The two important limiting operating conditions are minimum number of stages and the minimum reflux ratio.

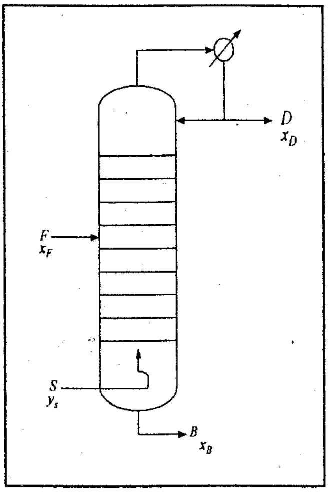
Minimum Number of Stages. This is obtained when the reflux ratio approaches infinity, that is all the liquid from the condenser is returned to the column as reflux. Under this total reflux condition, the slope of the rectifying line approaches unity or the intercept approaches zero making the operating line coincide with the diagonal. Thus, the minimum number of stages is obtained using the equilibrium curve and the diagonal to generate the stages.



The **Fenske Equation** may be used to estimate the minimum number of stages if the relative volatility of the binary system is known,

$$N_{\min} = \frac{\log \frac{x_D(1-x_B)}{x_B(1-x_D)}}{\log \alpha_{AB}}$$

Minimum Reflux Ratio, R_{D_m} . This is obtained when the number of stages approaches infinity. This condition is obtained when the rectifying line approaches the intersection of the feed line with the equilibrium curve, referred to as the pinch point. At this condition, the concentrations of the liquid and vapor become constant and independent of the number of stages. From the slope or intercept of this operating line, the minimum reflux ratio can be calculated. For azeotropic solutions, the pinch may be considered as the nearest point of tangency that the rectifying line can generate with the equilibrium curve.



Open Steam Rectification

This type of rectification uses open steam directly introduced at the bottom as the source of vapor instead of a reboiler. The analysis for the number of stages by McCabe-Thiele method is similar to ordinary distillation except for a slight change in the stripping section. An over-all and component balance around the stripping section gives

$$V_{m+1} + B = S + L_m$$

$$V_{m+1}y_{m+1} + Bx_B = Sy_S + L_m x_m$$

solving for *y*

$$y_{m+1} = \frac{L_m}{V_{m+1}}x_m + \frac{Sy_s}{V_{m+1}} - \frac{Bx_B}{V_{m+1}}$$

At constant molal overflow, $V_{m+1} = \overline{V} = S$ and $L_m = \overline{L} = B$. If the concentration of the MVC in the open steam, y_s is zero, the equation reduces to $y_{m+1} = \frac{B}{S}x_m - \frac{B}{S}x_B$

At $x = x_B$, then $y = 0$. That is the stripping line will intersect the x_B line at the *x –axis*.

Other variations that may be encountered are those that involve multi-feed, side-streams, reflux that is not saturated, and heat losses from the column that affects the reflux at certain stages.

Packed Column Distillation

Distillation may be carried out in a packed column instead of a plate column. The analysis using a packed column is based on a rate process using the mass transfer equation. Since this involves the equimolal counterdiffusion of components, the mass transfer equation may be represented by $dN_A = K_y a(y^* - y)SdZ$

The height of the packed column is obtained as $Z = \frac{V/S}{K_y a}\int \frac{dy}{y^* - y} = H_{OG}N_{OG}$

The number of transfer units can be evaluated by graphical integration. The values of y^* is obtained from the equilibrium curve while *y* comes from the operating line for a particular value of *x*.

The height of a packed column and the theoretical number of plates is related by the HETP which stands for the Height Equivalent to a Theoretical Plate.

REVIEW QUESTIONS AND PROBLEMS

1. The difference between stage operation (A) and a continuous phase contact operation (B) is that
   a. (A) is co-current flow while (B) is counter-current flow
   b. (A) yields discreet concentration changes while (B) yields infinitesimal concentration changes
   c. (B) yields discreet concentration changes while (A) yields infinitesimal concentration changes
   d. an ideal (B) yields equilibrium concentration while (A) does not

2. One hundred moles per hour of solution containing 80 moles of A, the rest B is subjected to a simple continuous distillation. D moles of distillate containing 72 moles A is obtained. If A is five times more volatile than B, the concentration of A in the distillate is
   a. 0.85
   b. 0.80
   c. 0.533
   d. none of these

3. The temperature of the solution in Problem *2* as distillation progresses at constant operating pressure is
    a. increasing   b. decreasing   c. constant

4. If the enthalpy of saturated vapor at 200°F referred to 32°F is 1300 BTU/lb while the enthalpy of saturated liquid ($C_p = 1$) referred to 0°F is 400 BTU/lb, then the latent heat of vaporization of the component at 200°F is
    a. 900 BTU/lb   c. 868 BTU/lb
    b. 932 BTU/lb   d. none of these

5. Desorption is another term for
    a. dephlegmation   c. flash distillation
    b. stripping   d. rectification

6. In a simple batch distillation, the boiling point of the distillate product compared to the residue is
    a. the same   b. lower   c. higher

7. When the feed to the rectifying column is a saturated liquid, the feed line is
    a. vertical   c. inclined to the left
    b. horizontal   d. inclined to the right

8. The distillation process involves
    a. momentum transfer   c. heat transfer
    b. mass transfer   d. heat and mass transfer

9. A liquid mixture containing 45% benzene and 55% toluene by weight is to be fed to a fractionating column at a rate of 5000 kg/hr. The feed rate in kg mols/hr is
    a. 58.74   c. 48.80
    b. 58.80   d. 28.846

10. A binary solution, where A is a low boiler, exhibiting a maximum boiling point, is subjected to flash distillation. If the feed has a concentration in A less than the azeotropic point, the concentration of the distillate will be
    a. higher in A   b. higher in B   c. same

11. The unit operation by which miscible liquids are separated from one another through heat and mass transfer is
    a. extraction   c. distillation
    b. sedimentation   d. filtration

12. When the relative volatility of two miscible components is close to 1.00, the components can be separated by
    a. simple fractionation   c. extractive distillation
    b. batch distillation   d. low pressure distillation

13. The degrees of freedom associated with a ternary distillation process, according to the Gibbs' phase rule, is
    a. 2   c. 4
    b. 3   d. 5

14. Vacuum distillation is resorted to in order to
    - a. reduce the number of trays in the column
    - b. use thinner shell plates for the column
    - c. avoid high feed and reboiler temperatures
    - d. obtain more bottom products

15. To improve the degree of separation of the more volatile component from the less volatile component through distillation, the chemical engineer may, without changing the other variables,
    - a. increase the feed temperature
    - b. reduce the column pressure
    - c. increase the reboiler temperature
    - d. increase the column pressure

16. Increasing the operating pressure of a distillation column
    - a. does not make a difference in components separation
    - b. makes separation difficult
    - c. sharpens separation
    - d. requires less heat in the feed heater

17. A reboiler provides heat to the
    - a. top
    - b. the intermediate reflux
    - c. the feed
    - d. the bottom of a distillation column

18. When the molal latent heat of vaporization of the binary system is very much dependent on concentration, the most appropriate method to use to determine the number of ideal stages is
    - a. Fenske-Underwood Method
    - b. McCabe-Thiele Method
    - c. Ponchon-Savarit Method
    - d. Lewis-Matheson Method

19. Open steam binary rectification may be applied with success if the less volatile component is
    - a. water
    - b. alcohol
    - c. benzene
    - d. acetone

20. At minimum reflux ratio, the number of plates is
    - a. minimum
    - b. infinite
    - c. maximum
    - d. between minimum and maximum

21. In a vacuum distillation column the vacuum is usually created by a
    - a. steam ejector
    - b. vacuum pump
    - c. compressor
    - d. centrifugal pump

22. The relative volatility of the mixture at the azeotropic point where the solution exhibits minimum boiling point is
    - a. less than 1
    - b. equal to 1
    - c. greater than 1

23. The ease or difficulty of separating components by distillation is determined by the
    - a. relative volatility
    - b. viscosity
    - c. mole-fraction
    - d. weight fraction of the components

24. A debutanizer is a
    a. heat transfer equipment
    b. mass transfer equipment
    c. fluid transfer equipment
    d. size reduction equipment

25. In distillation, the cooled liquid stream returned to the column to cool a plate or stage is called
    a. reboil
    b. reflux
    c. feed
    d. bottoms

26. A binary mixture of 2 moles benzene and 8 moles toluene will boil at
    a. 110°C
    b. 110°F
    c. 105°C
    d. 102°C

27. McCabe-Thiele method to determine the theoretical number of stages may be applied with acceptable result if
    a. the components have different boiling points
    b. the system follow Trouton's Rule
    c. the components have high relative volatility
    d. heat losses and heat of solution are negligible

28. The distribution coefficient of n-hexane at 10 atm abs and 200°C is
    a. 2.6
    b. 1.4
    c. 0.9
    d. none of these

29. The theoretical minimum reflux ratio in a distillation column is reached if the column has
    a. 1 plate
    b. 10 plates
    c. 100 plates
    d. an infinite number of plates

30. The physical separation of components in a miscible mixture by simultaneous evaporation and condensation is
    a. absorption
    b. extraction
    c. drying
    d. distillation

31. In batch open steam distillation, the solution to be open steam distilled should be
    a. miscible in water
    b. completely immiscible in water
    c. slightly miscible in water
    d. containing large non-volatile impurities

32. In a distilling column, the highest pressure will be at
    a. the top
    b. the feed plate
    c. the bottom
    d. between the feed plate and the top

33. The unit operations by which the lighter components in a multicomponent solution of volatile liquids are separated from the heavier components is called
    a. absorption
    b. drying
    c. distillation

34. In distillation where there are two components and both components are found in both phases, only one variable such as liquid phase concentration can be changed independently if the pressure is fixed and the temperature and vapor phase concentration will follow. This statement is ________
    a. true
    b. false

35. A heat transfer equipment to convert vapor to liquid is an/a
    a. evaporator
    b. reboiler
    c. condenser
    d. still

36. For a mass transfer to take place, there must be
    a. concentration gradient
    b. more than two components involved
    c. heat present
    d. enthalpy change

37. A 50% by weight benzene-toluene mixture is fed to a column at 180°F and 1 atm. The condition of this feed is
    a. saturated liquid
    b. saturated vapor
    c. sub cooled liquid
    d. mixture of liquid and vapor

38. A distillation column with a partial condenser is composed of 7 theoretical stages in the rectifying section and 8 theoretical stages in the stripping section. If the overall plate efficiency is 60%, then the actual feed plate is the
    a. 11th
    b. 13th
    c. 12th
    d. 8th from the top

39. Using the Antoine's Equation, the vapor pressure of tetrahydrofuran at 80°C is estimated to be _____ torrs.
    a. 2000
    b. 1518
    c. 1173
    d. 2562

40. The total actual number of plates of the distillation column of Problem *38* is
    a. 13
    b. 22
    c. 26
    d. 15

41. Strictly speaking, the relative volatility of most ideal binary solution is
    a. not affected by temperature
    b. greatly affected by temperature
    c. slightly affected by temperature
    d. greatly affected by pressure

42. The temperature in a distilling column, from bottom to top
    a. increases
    b. decreases
    c. maximum
    d. between minimum and maximum

43. The primary reason why close steam is used in an open batch steam distillation is to
    a. increase the number of degrees of freedom
    b. increase the operating temperature
    c. supply the heat needed by vaporizing liquid
    d. increase the operating pressure

44. In a two-component flash distillation process, when the operating pressure is specified, the concentration of the distillate may be improved in the more volatile component if
    a. the operating temperature is decreased
    b. the operating temperature is increased
    c. the amount of distillate is increased
    d. none of these

45. If the HETP of the column of Problem *38* is 2 ft then the height of the packed column is
    a. 30 ft
    b. 43 ft
    c. 26 ft
    d. none of these

46. The percentage change in the boiling point of a 20-mole benzene-toluene solution when the pressure is increased from 1 atm to 2 atm is
    a. 10.5% increase
    b. 25.5% increase
    c. 25.5% decrease
    d. none of these

47. The recent availability of digital computers resulted in the development of many analytical expressions for the evaluation of K-values. Which of the items below is a source of analytical method for K-values?
    a. NRTL
    b. Wilson Equation
    c. UNIQUAC
    d. all of these

48. The activity coefficient of a component in a non-ideal liquid solution at low pressure is approximated to be equal to
    a. one
    b. vapor pressure multiplied by the composition in the liquid phase in mole fraction
    c. vapor pressure divided by the total pressure
    d. none of these

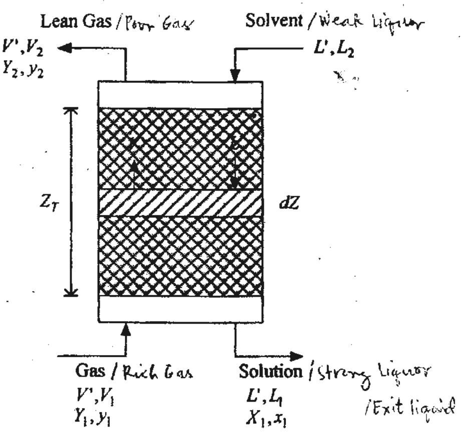
49. The approximate minimum number of stages for a binary system with relative volatility of 2.35, fractionally distilled to yield compositions of 0.98 in the distillate and 0.045 in the bottoms is
    a. 4.8
    b. 7
    c. 8.1
    d. 12

50. For nearly pure products in a stage operations, the theoretical number of plates may be estimated using the
    a. Rayleigh Equation
    b. Fenske Equation
    c. Tiller-Tour Equation
    d. Murphree Equation

7. GAS ABSORPTION

THEORY AND EQUATIONS

Packed Column



V = total gas flow rate, lb mole/hr
V' = inert gas flow rate, lb mole/hr
L = flow rate of solution, lb mole/hr
L' = flow rate of solvent, lb mole/hr
Y = mole solute/mole inert gas, mole ratio
y = mole fraction of solute in gas
X = mole solute/mole solvent
x = mole fraction of solute in solution

Thus:

$$V' = V(1-y)$$

$$L' = L(1-x)$$

$$L = \frac{L'}{(1-x)}$$

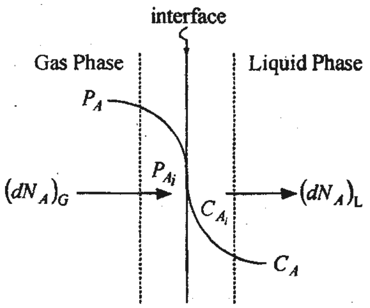
$$V = \frac{V'}{(1-y)}$$

$$X = \frac{x}{1-x}$$

$$Y = \frac{y}{1-y}$$

$$y = \frac{Y}{1+Y}$$

$$x = \frac{X}{1+X}$$



Mass Transfer Equations

Gas Phase

$$(dN_A)_G = k_G(P_A - P_{A_i})dA$$

but $P_A = yP_T$ Let $dA = aSdZ$

$$(dN_A)_G = k_G a P_T (y - y_i) SdZ$$

$$(dN_A)_G = k_y a (y - y_i) SdZ$$

Liquid Phase

$$(dN_A)_L = k_L(C_{A_i} - C_A)dA$$

$$= k_L a \rho_m (x_i - x) SdZ$$

$$(dN_A)_L = k_x a (x_i - x) SdZ$$

Determination of Height of Packed Column

Gas Phase

$$(dN_A)_G = k_y a(y - y_i)SdZ$$

$$Z = \int \frac{(dN_A)_G}{k_y aS(y - y_i)}$$

but $(dN_A)_G = V' dY$

$$dN_A = V(1-y)d\left(\frac{y}{1-y}\right) = \frac{Vdy}{(1-y)}$$

$$Z = \left(\frac{V/S}{k_y a}\right)_{ave} \int_{y_1}^{y_2} \frac{dy}{(1-y)(y_i - y)} = H_G\, N_G$$

where: N_G is evaluated graphically from a plot of the operating line, equilibrium curve and tie-lines.

Liquid Phase

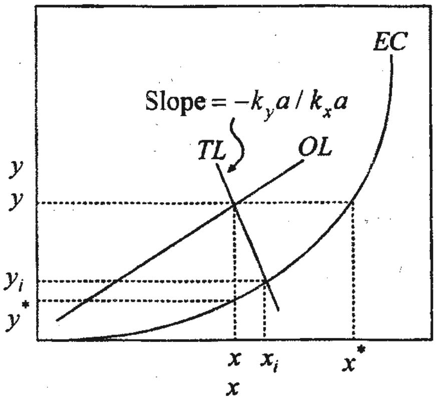
$$(dN_A)_L = k_x a(x_i - x)SdZ$$

$$Z = \int \frac{(dN_A)_L}{k_x aS(x_i - x)}$$

Evaluation of N_G ***or*** N_L

To get values of y vs y_i

1. Plot the Equilibrium Curve.
   Possible sources of equilibrium data:
   a. Solubility data
   b. Based on *Henry's Law*
      (for dilute solutions)
      $p_A = H_A x$
      $y^* = \frac{p_A}{p_T} = \frac{H_A}{p_T} x$
      $y^* = mx$
   c. Based on *Raoult's Law*
      (for ideal solutions)
      $p_A = p^o{}_A\ x \qquad y^* = \frac{p^o{}_A}{p_T} x$



2. Plot the Operating Line. The equation of OL is obtained from a material balance
   $dN_A = V' dY = L' dX$
   $N_A = V'(Y_1 - Y) = L'(X_1 - X)$
   or $V'\left(\frac{y_1}{1-y_1} - \frac{y}{1-y}\right) = L'\left(\frac{x_1}{1-x_1} - \frac{x}{1-x}\right)$

3. Determine the slope of the Tie Line. This slope will relate the actual concentrations x and y with the interfacial equilibrium concentrations x_i and y_i.
Since $(dN_A)_G = (dN_A)_L$

$$\therefore k_y a(y - y_i)SdZ = k_x a(x_i - x)SdZ$$

$$\frac{y - y_i}{x - x_i} = -\frac{k_x a}{k_y a} \quad \therefore \; Slope = -\frac{k_x a}{k_y a}$$

Simplified Equations

a. In terms of the overall MTC, $K_y a$ or $K_x a$

$$(dN_A)_G = K_y a(y - y^*)sdZ$$

$$(dN_A)_L = K_x a(x^* - x)sdZ$$

For case d. : $$Z = \left(\frac{V/S}{K_y a}\right)_{ave} \int \frac{dy}{(1-y)(y-y^*)} = H_{OG} \times N_{OG}$$; Z → height of absorber

For case e. : $$Z = \left(\frac{L/S}{K_x a}\right)_{ave} \int \frac{dx}{(1-x)(x^*-x)} = H_{OL} \times N_{OL}$$

$$\frac{1}{K_y a} = \frac{1}{k_y a} + \frac{m}{k_x a} \quad ; \quad \frac{1}{K_x a} = \frac{1}{k_x a} + \frac{1}{m k_y a}$$; m → slope of E.C.

b. If solution is dilute,

$$Z = \left(\frac{V/S}{K_y a}\right) \int_2^1 \frac{dy}{y - y^*}$$

and if the equilibrium curve is linear,

$$N_{OG} = \frac{y_1 - y_2}{(y - y^*)_{ln}}, \quad \text{where:} \quad (y - y^*)_{ln} = \frac{(y-y^*)_1 - (y-y^*)_2}{\ln \frac{(y-y^*)_1}{(y-y^*)_2}}$$

c. If solution is concentrated and EC and OL are linear within limits,

$$Z = \left(\frac{V/S}{K_y a}\right)_{ave} \frac{1}{(1-y)_{ave}} \cdot \frac{y_1 - y_2}{(y - y^*)_{ln}}$$

d. For very soluble solutes (gas phase resistance is controlling)

Slope of TL $= -\dfrac{k_x a}{k_y a} \to \infty$ since $k_x a >> k_y a$

$$y_i \to y^* \quad ; \quad N_G \to N_{OG} \quad ; \quad k_y a \to K_y a$$

e. For very slightly soluble solutes (liquid phase resistance is controlling)
Slope of TL → 0 since $k_y a >> k_x a$

$$x_i \to x^* \quad ; \quad N_L \to N_{OL} \quad ; \quad k_x a \to K_x a$$

f. Approximate integration of MTE

$$(dN_A)_G = K_G a\left(p - p^*\right)SdZ$$

$$N_A = K_G a\left(p - p^*\right)_{\ln} SZ$$

Plate Column

1. To determine the theoretical number of stages, plot the equilibrium curve (EC) and the operating line (OL). From the point x_2, y_2 draw step up lines between the OL and EC until the point x_1, y_1 is reached. The theoretical number of stages is equivalent to the number of triangles formed.

2. If OL and EC are linear, apply Absorption Factor Method or the Tiller-Tour Equation:

$$N_{theo} = \frac{\log \dfrac{y_1 - y_1^*}{y_2 - y_2^*}}{\log \dfrac{y_1 - y_2}{y_1^* - y_2^*}} \qquad\qquad N_{theo} = \frac{\log \dfrac{x_1 - x_1^*}{x_2 - x_2^*}}{\log \dfrac{x_1 - x_2}{x_1^* - x_2^*}}$$

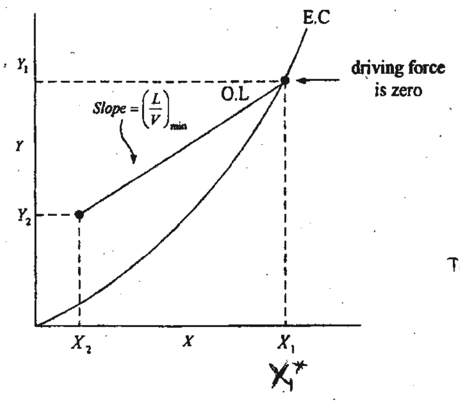
Limiting Flow Rates

a. Based on flooding conditions
For packed column, see Handbook

b. Based on equilibrium conditions

$$\left(\frac{L'}{V'}\right)_{\min} = \frac{Y_1 - Y_2}{X_1^* - X_2}$$

If V' is fixed, L' is min. and if L' is fixed, V' is max.



O.L.

$$V'(Y - Y_2) = L'(X - X_2)$$

$$Y = \underset{\text{slope}}{\frac{L'}{V'}} X + \underbrace{Y_2 - \frac{L'}{V'} X_2}_{\text{y-intercept}}$$

$$y = mx + b$$

To get E.C. :

1.) Solubility data → experimental

2.) Raoult's law $y^* = mx$; $m = \frac{P_A^*}{P_T}$

3.) Henry's Law $y^* = mx$; $m = \frac{H}{P_T}$

$$L'_{actual} = \underset{\uparrow}{(\text{factor})}\, L'_{min}$$

between 1.2 & 1.5 page 14-8

$$A = \frac{\frac{L'}{V'}}{m}$$

↳ absorption factor

REVIEW QUESTIONS AND PROBLEMS

b 1. For moderately soluble gases with relatively little interaction between the gas and liquid molecules, the law which applies most to establish equilibrium relationship is
   a. Raoult's Law
   b. Henry's Law
   c. Dalton's Law
   d. none of these

2. In the choice of solvent for gas absorption, one of the properties to be considered is
   a. solvent should have a low vapor pressure
   b. solvent should have low boiling point
   c. solvent should be highly viscous
   d. solvent should be unusual

a 3. In the case of a straight or concave downward operating line and a straight or concave upward equilibrium line, the minimum liquid rate is that at which
   a. the operating line just touches the equilibrium line at the bottom of the tower
   b. the operating line just touches the equilibrium line on top of the tower
   c. the operating line intersects the equilibrium line at the middle of the tower
   d. the slope of the operating line is smaller than the equilibrium line

4. The use of a liquid rate in gas absorption far above the minimum value will result in
   a. infinite number of plates
   b. small number of plates
   c. minimum number of plates
   d. none of these

5. When dilute solutions are involved in gas absorption, one of the following is not applicable
   a. Henry's Law
   b. $H_L = \dfrac{V}{Sk_y a}$
   c. equilibrium and operating lines are straight
   d. $N_G = \dfrac{\Delta y}{(\Delta y)_{LM}}$ may be used

6. In gas absorption, packings are used
   a. to reinforce the absorption tower due to drag created by the liquid and gas
   b. to disseminate the heat generated to maintain isothermal conditions
   c. to increase the area of contact between the gas and the liquid
   d. to reduce the pressure drop created by the flowing gas

7. When the liquid flow rate is fixed and the composition of the liquid and gas at the bottom of the absorption tower are fixed, the limiting flow rate to give infinitely tall tower becomes
   a. the maximum flooding velocity of the vapor
   b. the minimum loading velocity of the liquid
   c. the maximum flow rate of the vapor
   d. the minimum flow rate of the vapor

8. The rate equation in terms of the gas-phase mass transfer coefficient is used in design calculations instead of that in terms of the liquid phase when
   a. the solubility of the solute in the solvent is very low
   b. the controlling resistance is that of the liquid phase
   c. the controlling resistance is that of the gas phase
   d. the tie line is horizontal

9. It is not very necessary to correct the rate equation for the *phase drift* encountered during gas absorption, since the height calculated will be
   a. slightly over-designed anyway
   b. slightly under designed anyway
   c. based on equimolal counter diffusion anyway
   d. based on the same percentage recovery anyway

10. The overall height of a transfer unit based on the gas phase will equal the gas phase individual HTU, H_y when
    a. the equilibrium curve is linear
    b. the operating line is linear
    c. the gas phase resistance is very small compared with the liquid phase
    d. the liquid-phase resistance is very small compared with the gas phase

11. In mass transfer, a transfer unit means that
    a. a mole of solute is transferred in a unit height
    b. the mass transfer coefficient will approach unity
    c. the average driving force is equal to unity
    d. the concentration range is equal to the average driving force

12. The mole fraction of solute entering a gas absorber is 0.25. If the percentage recovery is 75%, then the mole fraction of the solute leaving the tower will be
    a. 0.0833 b. 0.0625 c. 0.0769 d. 0.157

See Eq. 5-293

13. Assuming that the Penetration Theory applies in an interfacial mass transfer contact, the liquid phase mass transfer coefficient will increase by a factor of _______ if the diffusivity of the solute becomes twice and the contact time becomes one-half.
    a. 2 b. 1 c. ½ d. 4

14. In a stripping or desorption operation, the equilibrium curve is
    a. above the operating line
    b. below the operating line
    c. perpendicular with the tie line
    d. linear

15. Co-current gas-liquid up flow contacting device is highly characterized by
    a. low-gas liquid interaction regime
    b. disperse bubble flow regime
    c. liquid-rich and gas-rich regime
    d. pulsing flow regime

16. Given the individual mass transfer coefficients and equilibrium equation at 25°C, $k_xa = 60$, $k_ya = 15$ mol/hr-ft^3-mole fraction and $x^* = 0.3226\ y$, the over-all MTC K_ya is ______ mol/hr-ft^3-mole fraction.
    a. 8.45 b. 38.62 c. 7.35 d. none of these

17. The total weight of a 13-mm ceramic Raschig rings that can be contained in a cylindrical gas absorption tower 5 m high and 0.55 m in diameter is approximately ______ kg.
    a. 350
    b. 940
    c. 1045
    d. 200

18. Pressure drop is one of the most important parameters in the design of two-phase co-current bed because
    a. pumping cost could be a significant portion of the total operating cost
    b. it may help characterize the hydrodynamics of the system
    c. it may affect the retention of the liquid in the packed bed
    d. all of these

19. Flooding condition is the only consideration that dictates the minimum column diameter that can be used for a specified gas absorption in a packed column.
    a. True
    b. False
    c. can not be determined

20. In gas absorption, if the concentrations are expressed in mole ratio, that is, moles of solute per mole of solute-free medium, it is necessary to assume that the operating line is straight when the coordinates used are X and Y.
    a. True
    b. False

21. In packed columns, the pressure drop for irrigated packings is always greater than the pressure drop for dry packings because
    a. the surface of dry packing is smoother
    b. the flow area of dry packing is greater
    c. the drag friction is lesser than the skin friction for dry packing
    d. none of these

22. For an absorber (mass transfer from gas to liquid) the operating line always
    a. lies below the equilibrium - solubility curve
    b. lies above the equilibrium - solubility curve
    c. coincides with the equilibrium curve
    d. intersects at one-end on the equilibrium curve

23. If the solute-free gas flow rate is 500 kg-mole/hr of 0.10 mole ratio of solute entering the plate absorber at 1 atm, what is the minimum water rate, in kgmole/hr, for a 90% recovery if the vapor pressure of solute is 228 mm Hg
    a. 103
    b. 99
    c. 85
    d. none of these

24. The mechanism of mass transfer in a gas absorber is best described by the
    a. Penetration Theory
    b. Two-Film Theory
    c. Chilton-Colburn Analogy
    d. Surface-Renewal Theory

25. A wetted-wall column is usually used to determine mass transfer coefficient experimentally because ____________ is accurately known.
    a. concentration gradient of A
    b. mass transfer area
    c. thickness of the laminar films adjacent to the interface
    d. the flow rate of gas and liquid

26. The analogy between mass and heat transfer is complete when
    a. the temperature gradient and concentration gradient are equal
    b. no convective flux or phase drift is involved
    c. the resistance to mass and heat transfer are negligible
    d. the momentum transfer rate is negligible

27. In a gas absorption packed tower, the most economical gas velocity is considered to be
    a. equal to
    b. twice
    c. about half
    d. greater than

    the flooding velocity.

28. In gas absorption, when the conditions at the bottom of the tower are fixed and the gas flow rate is given, the limiting flow rate based on equilibrium conditions that will require infinitely tall tower is
    a. minimum liquid flow rate
    b. maximum liquid flow rate
    c. minimum gas flow rate
    d. maximum gas flow rate

29. When the gas flow rate induces flooding in a packed column gas absorber, this is best remedied if the percent recovery of the solute is to be maintained, by
    a. reducing the liquid flow rate
    b. reducing the vapor flow rate
    c. increasing the diameter of the column
    d. increasing the height of the column

    Recovery

30. When the Two-Film Theory is applied to gas absorption, the over-all resistance can be expressed in terms of the individual resistances in the form $1/K_ya = 1/k_ya + m/k_xa$. This is possible because of an important assumption. This assumption is
    a. the operating line is linear
    b. the tie line has a slope between 0 and 1.0
    c. the slope of the equilibrium curve near the tie line is linear
    d. the solute forms an ideal solution with the solvent

31. It has been determined that the equivalent HTU and NTU of a packed absorption tower are 0.85 ft and 15, respectively. If the same separation can be done in a 10-plate absorption tower, then the HETP is ________ ft.
    a. 12.75
    b. 1.275
    c. 0.567
    d. none of these

    $\frac{0.85 \times 15}{10}$

32. In an absorption tower packings are placed inside to
    a. provide a bigger mass transfer area
    b. strengthen the tower
    c. fill up void spaces
    d. reduce pressure drop across the tower

33. In a gas absorption tower, mass transfer occurs primarily
    a. from the liquid phase to the gas phase
    b. from the liquid phase to the packing
    c. from the gas phase to the liquid phase
    d. from the gas phase to the packing

34. It is a unit operation which involves the mass transfer of soluble materials from the liquid phase to the gaseous phase
    a. absorption
    b. drying
    c. desorption
    d. humidification

35. In a gas absorption column, the pressure of the lean gas is expected to be
    a. lower than
    b. higher than
    c. the same as
    d. double
    the pressure of the rich gas entering the column.

36. The method of separating a particular gaseous component from a mixture of gases due to their differences in solubility in a liquid phase is
    a. adsorption
    b. extraction
    c. absorption
    d. distillation

37. The mass transfer rate of a material from one phase to another across an interface is increased by
    a. increasing
    b. decreasing
    c. keeping constant
    d. making zero
    the difference between the bulk concentration and the concentration at the interface between the 2 phases.

38. The pressure drop along a packed tower is $\Delta P = k$ [illegible]
    a. inversely proportional to the mass flow rate
    b. inversely proportional to the square of the mass flow rate
    c. directly proportional to the mass flow rate
    d. directly proportional to the square of the mass flow rate

39. The interfacial concentration Y_i in a gas absorber corresponding to $y = 0.05$ mole fraction is ________ mole fraction. The slope of the operating line is 1.3 with the mole ratios $Y_1 = 0.08$, $Y_2 = 0.03$ and $X_2 = 0$. The equation of the equilibrium curve is $y = 0.8\ x$, the M.T.Cs are $k_xa = 60$ and $k_ya = 15$ lbmoles/hr-ft^3-mole fraction concentration difference.
    a. 0.02
    b. 0.064
    c. 0.046
    d. none of these

40. A 25 mm ID wetted wall column is used to absorb dilute SO_2 m/s. If $D_v = 0.455$ ft^2/hr, the gas film coefficient for the absorption is
    a. 0.0134
    b. 0.0265
    c. 0.0373
    d. none of these

8. HUMIDIFICATION

THEORY AND EQUATIONS

This topic involves the contact of a pure liquid with a gas for the purpose of changing the vapor content of the gas and/or adding or removing heat from the contacting phases for purposes of cooling or heating. The operation may be classified as Humidification, Dehumidification, Air-Conditioning and Water Cooling. The concern of a chemical engineer is to design the various equipment used in the gas-liquid contact operations.

Phase Equilibria

The operation involves two components and two phases. Based on the Gibb's phase rule, the number of degrees of freedom to define equilibrium conditions is two. Thus, if the total pressure is fixed, specifying the temperature fixes the concentration of the vapor in the gas phase. It is important therefore to define the various properties of the gas-vapor system both under equilibrium and non-equilibrium conditions that are used in the analysis and design of the equipment.

Definitions

1. ***Absolute Humidity***, $H \frac{lb.vapor}{lb.d.g}$. This refers to the ratio of the mass of vapor per unit mass of vapor-free gas. This may be determined from the partial pressure exerted by the vapor (A) in the gas (B).

$$H = \frac{p_A}{P_T - p_A} \times \frac{M_A}{M_B}$$

2. ***Saturation Humidity***, H_S. This refers to the maximum amount of vapor that a gas can contain which is in equilibrium with the liquid at a given temperature. The partial pressure of the vapor is in effect equal to the vapor pressure.

$$H_s = \frac{p_A^o}{P_T - p_A^o} \times \frac{M_A}{M_B}$$

3. ***Relative Humidity***, RH or H_R. This refers to the ratio of the partial pressure to the vapor pressure at a specified temperature of the gas-vapor mixture.

$$H_R = \frac{\bar{P}_A}{P_A^o} \times 100$$

4. ***Percentage Saturation or Percentage Humidity***, H_A.

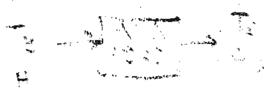
$$H_A = \frac{H}{H_s} \times 100 = H_R \times \frac{P_T - P_A^o}{P_T - \bar{P}_A}$$

5. ***Humid Volume***, v_H, ft^3/lb dry gas. This is the volume occupied by one pound of dry gas plus whatever vapor it contains at a given pressure and temperature.

$$v_H = v_B + v_A = \frac{RT}{P}(n_B + n_A)$$

or $$v_H = \frac{0.73T}{P}\left(\frac{1}{M_B} + \frac{H}{M_A}\right)$$

6. ***Saturated Volume,*** v_S. The specific volume if the gas is saturated with the vapor.
$$v_s = \frac{0.73T}{P}\left(\frac{1}{M_B} + \frac{H_s}{M_A}\right)$$
7. ***Humid Heat,*** c_s BTU/lb-°F. This is the heat needed to raise the temperature of one pound of dry gas and the vapor it contains by 1°F.
For air-water system : $c_s = c_{P_B} + c_{P_A} H$
$$c_s = 0.24 + 0.46H$$
8. ***Enthalpy of Mixture,*** *Hy,* BTU/lb dry gas. This refers to the total enthalpy content of 1 lb of dry gas and its vapor at a given temperature.
$$H_y = H_{y_B} + H_{y_A}$$
If the reference temperature for the gas is taken as T_R and for the liquid as T_R', we get
$$H_y = c_{P_B}(T_y - T_R) + c_{P_A} H (T_y - T_R') + H\lambda_{T_R'}$$
If $T_R' = T_R$
$$H_y = c_s(T_y - T_R) + H\lambda_{TR}$$
9. ***Adiabatic Saturation Temperature,*** T_s. This refers to the steady state temperature attained by a gas-vapor mixture when saturated with vapor by spraying under adiabatic conditions. An Enthalpy Balance around the spray chamber gives



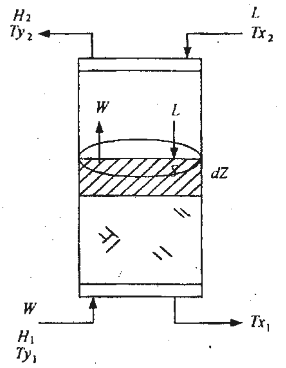
$$\frac{H - H_s}{T_y - T_s} = -\frac{c_s}{\lambda_s}$$ or ASL

The above is known as the equation of the Adiabatic Humidification Line (AHL).
10. ***Wet Bulb Temperature,*** T_w. This refers to the steady state temperature attained by a small mass of liquid immersed in a large body of gas. Application of mass and heat transfer equation around this small mass of liquid yields
$$\frac{H - H_w}{T_y - T_w} = -\frac{\cancel{hc}\,h_c}{k_y M_B \lambda_w}$$ → Psychrometric line

For air-water system: $\frac{hc}{k_y M_B} \approx 0.26$. This is known as the Lewis Relation. Since 0.26 is very near the value of c_s, for air-water system the wet bulb temperature becomes identical with the adiabatic saturation temperature, $T_w = T_s$.
11. ***Dew Point,*** T_d. This is the steady temperature attained when a vapor-gas mixture becomes saturated when cooled at constant humidity, that is $P_A = P_A^o$
12. ***Humidity Chart.*** Many of the above properties for air-water system can be obtained from the humidity chart at 1 atm pressure. Humidity charts for other gas-vapor mixtures are also available.

Design Equations

Consider a gas-liquid contact equipment with the gas and liquid are in counter-current flow with L = as the mass flow rate of the liquid; w = as the mass flow rate of the vapor-free gas; S = free cross-sectional area; and Z = as the height of the contact tower, the following equations may be generated:



Material Balance: $\pm d\varepsilon = wdH = dL$
Enthalpy Balance: $wdH_y = Lc_L dT_x$
Heat Balance: $w\,(c_s dT_y + \lambda dH) = LC_L dT_x$
Mass Transfer Equation (gas phase only): $wdH = K'_y a\,(H - H_i)\,Sd\,Z$
Heat Transfer Equation:

Gas Phase: $wc_s dT_y = h_G a\left(T_y - T_i\right)Sd\,Z$

Liquid Phase: $Lc_L dT_x = h_L a\left(T_i - T_x\right)Sd\,Z$

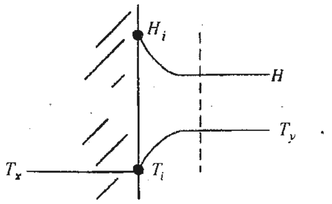
Enthalpy Transfer Equation (air-water system only):

$$w\,dH_y = K'_y a\left(H_y - H_{y_i}\right)Sd\,Z$$

The above equations may be solved and applied to describe the various types of gas-liquid contact operations.

I. *Adiabatic Humidification*

In order for humidification to be considered adiabatic, the following conditions must be met:



1. $T_{x_1} = T_{x_2} = T_x =$ constant
2. $T_{w_1} = T_{w_2} = T_x =$ constant

That is, the temperature of the water is constant and equal to the wet-bulb temperature of the gas which is also constant. This, of course, is a simplification which may not be achieved in reality. Solving the differential design equations for this case, we get

1. *Material Balance.* $\varepsilon = w(H_2 - H_1) = L_2 - L_1$
2. *Heat Balance.* A general heat balance can be derived by an energy accounting around the tower. Let $T_R = T_{y_2}$, then

$$\underbrace{[wc_{s1}(T_{y1} - T_{y2}) + wH_1\ \lambda_{T_{y2}}]}_{air\ inlet} + \underbrace{L_2c_L(T_{x2} - T_{y_2})}_{H_2O\ inlet} =$$

$$\underbrace{[wc_{s_2}(T_{y_2} - T_{y_2}) + wH_2 + \lambda_{T_{y2}}]}_{air\ outlet} + \underbrace{L_1c_L(T_{x1} - T_{y_2})}_{H_2O\ outlet}$$

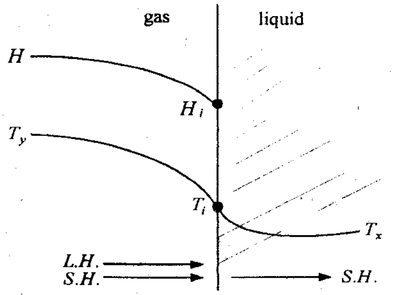
For adiabatic humidification, since: $T_{x_1} = T_{x_2} = T_x$, the above equation may be simplified to the form $\frac{H_2 - H_1}{T_{y2} - T_{y1}} = -\frac{c_{s1}}{\lambda_{T_{y2}}}$

which is similar to the equation of Adiabatic Humidification Line

3. *Mass Transfer Equation.* Since $H_i = H_s =$ constant, integration of the mass transfer equation yields $w(H_2 - H_1) = K'_y a (H_S - H)_{\ln} SZ$
4. *Heat Transfer Equation.* Since the temperature of the liquid is constant only gas phase heat transfer is involved. With $T_x = T_i =$ constant, the heat transfer equation gives $w\bar{cs}(T_{y_1} - T_{y_2}) = h_Ga(T_y - T_x)_{\ln} SZ$

Note that $h_Ga = U_Ga$, the over-all heat transfer coefficient, since there is no resistance to heat transfer in the liquid phase.

II. *Dehumidification or Air-Conditioning*



Integration of the general design equations gives,

1. *Material Balance.* $\pm\varepsilon = L_1 - L_2 = w(H_1 - H_2)$
2. *Enthalpy Balance.* $Lc_L(T_{x1} - T_{x2}) = w(H_{y1} - H_{y2})$

Heat Balance is the same as that derived under adiabatic humidification.

3. *Mass Transfer Equation.* Since the interfacial humidity is not usually known, integration can be approximated by assuming $H_i = H_{T_x}$. Thus,

$$w(H_1 - H_2) = K'_y a (H - H_T)_{\ln} SZ$$

4. *Heat Transfer Equation.* Likewise, since the interfacial temperature is not readily known and since the heat transfer resistance in the liquid phase is small, $T_i \approx T_x$

$$w\bar{c}_S\left(T_{y_1} - T_{y_2}\right) = U_G a\left(T_y - T_x\right)_{\ln} SZ$$

III. ***Water Cooling***

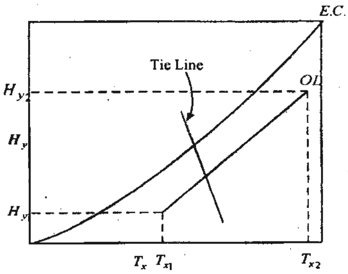
For water cooling, the air undergoes a non-adiabatic humidification process. Thus, the integrated design equations used are similar to that of dehumidification except that the limits are reversed.

More Accurate Design Equations

Due to the approximate nature of the mass and heat transfer equations generated for water cooling and dehumidification, it is necessary to seek for better working design equations. If the system is limited to air-water system, the design can be based on the enthalpy driving force as given by the Merkel's Equation.

Water Cooling

From the enthalpy transfer equation given by



$$wd\,H_y = K'_y a\left(H_{y_i} - H_y\right) SdZ$$

integration yields

$$Z = \frac{w/s}{K'_y a} \int \frac{dH_y}{H_{y_i} - H_y} = H_G \times N_G$$

where H_G is the height of a transfer unit (HTU) and N_G, the number of transfer units (NTU). N_G may be evaluated by graphical integration if the interfacial enthalpy H_{y_i} is known. To get values of H_{y_i} vs H_y, the following steps can be used:

1. Plot the Equilibrium Curve which consists of the enthalpy of air at saturation as a function of the temperature of water: H_{ys} vs. T_x. This may be obtained from the humidity chart.
2. Plot the Operating Line which is generated using the Enthalpy Balance.

$$\frac{L}{w} = \frac{H_{y_2} - H_{y_1}}{T_{x_2} - T_{x_1}} = \text{Slope of O.L.}$$

The ratio $\frac{L}{w}$ is the slope of the operating line.

3. Determine the Slope of the Tie Line obtained by dividing the enthalpy transfer equation by the liquid phase Heat Transfer Equation, that is

$$\frac{H_{y_i} - H_y}{T_i - T_x} = -\frac{h_L a}{K'_y a} = \text{Slope of T.L.}$$

With the slope known, several values of H_{y_i} versus H_y can be generated from the plot which can be used in the graphical integration for N_G.

If the operating line and the equilibrium curve are practically linear within the limits of integration, N_G may be evaluated using the logarithmic mean driving force,

$$N_G = \frac{H_{y2} - H_{y1}}{\left(H_{yi} - H_y\right)_{\ln}}$$

If the resistance to heat transfer in the liquid phase can be neglected, the slope of the tie line becomes infinite, reducing the interfacial conditions to become equal to the equilibrium condition based on the liquid temperature. Usually if $h_L a$ is not known and difficult to evaluate this leads to the assumption that $h_L a >> K_y a$.

Thus, $H_{y_i} \rightarrow H_y^*$ and $N_G \rightarrow N_{OG} = \int \frac{dH_y}{H_y^* - H_y}$

For Dehumidification or Air-Conditioning – equations used are similar to water cooling except that the limits are reversed and the operating line is above the equilibrium curve.

To determine the temperature profile of the air as it flows from bottom to top of the tower may be evaluated graphically using Mickley's Method (see Foust). This involves the finite difference plotting of the differential equation obtained from the enthalpy transfer equation and the gas-phase heat transfer equation

$$\frac{dH_y}{dT_y} = \frac{H_{yi} - H_y}{T_{yi} - T_y}$$

The limiting flow rates of liquid and gas may be determined from the slope of the operating line when it intersects the equilibrium curve in the Enthalpy-Temperature Diagram.

REVIEW QUESTIONS AND PROBLEMS

1. This is the temperature at which a vapor-gas mixture becomes saturated when cooled at constant humidity.
   a. wet-bulb temperature
   b. dew point temperature
   c. saturation temperature
   d. dry-bulb temperature

2. This is the temperature of a vapor-gas mixture as ordinarily determined by immersion of a thermometer in the mixture.
   a. wet-bulb temperature
   b. dew point temperature
   c. saturation temperature
   d. dry-bulb temperature

3. If the partial pressure of the vapor in a gas-vapor mixture is, for any reason, less than the equilibrium vapor pressure of the liquid at the same temperature, the mixture is
   a. saturated
   b. unsaturated
   c. supersaturated
   d. sub-cooled

4. This is a steady-state temperature reached by a small amount of liquid evaporating into a large amount of unsaturated vapor-gas mixture.
   a. wet-bulb temperature
   b. dew point temperature
   c. saturation temperature
   d. dry-bulb temperature

5. For the air-water vapor system, the Lewis relation, h_y/k_yc_s, takes a value of
   a. less than unity
   b. greater than unity
   c. essentially equal to unity
   d. none of these

6. In order for the gas to be dehumidified, as in the water vapor-air mixture, the humidity of the gas must be
   a. greater than the gas-liquid interface
   b. equal with the gas-liquid interface
   c. less than the gas-liquid interface
   d. saturated

7. In dehumidification, where the Lewis Number is equal to one, the operating line on the gas-enthalpy-liquid temperature graph
   a. is below the equilibrium curve
   b. coincides with the equilibrium curve
   c. is above the equilibrium curve
   d. intersects the equilibrium

8. The process which illustrates the principle of adiabatic humidification is
   a. cooling tower
   b. spray chamber
   c. packed tower
   d. heated dryer

9. Fogging is a result of a condition whereby the gas becomes
   a. saturated with vapor
   b. unsaturated with vapor
   c. supersaturated with vapor
   d. liquid due to cooling

10. Air conditioning involves
   a. stripping
   b. humidification
   c. dehumidification
   d. evaporative cooling

11. Air, supplied at the rate of 1200 cfm to a refrigerated coil has a relative humidity of 20% and dry bulb temperature of 150°F. The mass flow rate of dry air entering per minute is
    a. 74.3
    b. 75.0
    c. 78.50
    d. 75.26

12. A sling psychrometer is whirled on a fast spin when measuring the wet bulb temperature of ambient air
    a. since centrifugal force helps in stabilizing the mercury level in the thermometer
    b. to remove excess water in the cloth wrapped around the mercury bulb
    c. to minimize the effect of radiation on the temperature reading
    d. to minimize the effect of convection on the temperature reading

13. In an air-water contact equipment, the individual gas-phase mass transfer coefficient is equal to the over-all mass transfer coefficient since
    a. the mass transfer resistance in the liquid-phase is small
    b. the mass transfer resistance in the gas-phase is small
    c. there is no concentration gradient in the gas-phase
    d. there is no concentration gradient in the liquid-phase

14. The enthalpy transfer equation based on Merkel's procedure of determining the volume of a cooling tower is a convenient way of
    a. eliminating the complications introduced by the effect of sensible and latent heats
    b. eliminating the determination of interfacial temperature and humidity
    c. eliminating the complications of a non-adiabatic dehumidification of air
    d. eliminating the effect of the resistance to heat transfer in the liquid phase

15. In adiabatic humidification, it is possible to maintain the temperature of water constant since
    a. according to the phase-rule, the degrees of freedom is 3
    b. the system can be well insulated from the surroundings
    c. the temperature of the air can also be maintained constant
    d. the increase in the humidity of the air is very small

16. Besides measuring the dry bulb and wet bulb temperatures in determining the humidity of air, another method may be used. This is by
    a. measuring the specific heat of the air
    b. measuring the enthalpy of the air
    c. measuring the dew point of the air
    d. measuring the specific volume of the air

17. In terms of heat transfer, the use of a cooling tower is said to be more efficient and more economical compared to an ordinary heat exchanger since
    a. large volume of air is available and free
    b. temperature profiles of air and water can cross each other
    c. large amount of water can be processed
    d. a cooling tower is much smaller and cheaper than a heat exchanger

18. For an air flow rate of 5000 lb/hr and a water flow rate of 7500 lb/hr, the temperature of the cold water is 80°F using air with temperature of 90°F dry bulb and 70°F wet bulb. The estimated inlet temperature of water for these conditions is (see Figure 12-13 Perry)
    a. 84°F
    b. 98°F
    c. 88°F
    d. none of these

19. Given a forced-draft cooling tower with the following operating data: hot water temperature = 110°F, cooling range = 18°F, wet bulb temperature = 75°F, water flow rate = 500 gal/min. The estimated fan horsepower for this tower is
    a. 2 hp
    b. 5 hp
    c. 8 hp
    d. 10 hp

20. For dehumidification, when the top liquid flow rate is fixed and the top conditions of water temperature and air enthalpy are known, the limiting flow rate is considered to be
    a. minimum air flow rate
    b. maximum air flow rate
    c. minimum water flow rate
    d. none of these

21. The height to diameter ratio of a cooling tower is much less compared to that of a gas absorber because
    a. the liquid flow rate is larger compared to a gas absorber
    b. the liquid flow rate is smaller
    c. the gas flow rate is larger
    d. the gas flow rate is smaller

22. For a cooling tower with a circulating water flow of 5000 gpm, an inlet and outlet water temperatures of 100°F and 80°F, respectively and a 0.5% drift loss, the estimated make-up water is
    a. 85 gpm
    b. 25 gpm
    c. 110 gpm
    d. none of these

23. An air-carbon tetrachloride-vapor mixture at 100°F dry bulb and 60°F wet bulb is heated until the temperature reaches 180°F. The final percentage relative humidity is about
    a. 10%
    b. 5%
    c. 2%
    d. none of these

24. The enthalpy entering and leaving a cooling tower is 52.0 and 75 BTU/lb, respectively. If the inlet and outlet water temperature are 120°F and 100°F, respectively, the estimated overall number of transfer units is approximately
    a. 0.8
    b. 1.2
    c. 2.2
    d. none of these

25. If the air flow rate is 1000 lb/hr, the maximum water rate needed for the tower in Problem *24* is about
    a. 1200 lb/hr
    b. 6000 lb/hr
    c. 3400 lb/hr
    d. none of these

26. If the temperature of the air entering the tower of Problem *24* is 100°F, the exit temperature of the air is estimated to be (use Mickley's graphical method)
    a. 110°F
    b. 115°F
    c. 105°F
    d. none of these

27. The temperature at which the moisture in humid air exerts a partial pressure equal to its vapor pressure is called the
    a. dry bulb temperature
    b. ambient temperature
    c. critical temperature
    d. dew point

28. An indication of the moisture content of ambient air is its
    a. dry-bulb temperature
    b. wet-bulb temperature
    c. ambient pressure
    d. vapor pressure

29. The ratio between partial pressure of water vapor in air and the vapor pressure of the water at the air temperature multiplied by 100 is
    a. absolute humidity
    b. percentage absolute humidity
    c. percentage saturation humidity
    d. percentage relative humidity

30. The relative humidity of air at a given temperature is the
    a. pounds of water vapor in one pound of dry air
    b. the ratio between the actual temperature of the air and its dew point
    c. the ratio between the volume of the water vapor in the air and the humid volume
    d. the ratio of the partial pressure of the water vapor and the vapor pressure of water

31. The dew point of air indicates
    a. the actual temperature of the air
    b. the temperature at which its volume per unit weight of dry air is calculated
    c. the temperature at which its enthalpy is calculated
    d. the temperature at which its water content will start to condense

32. If the mass transfer coefficient, K_{ya} = 230 lbs water/hr-ft^3-atm, then the MTC in lbs water/hr-ft^3-absolute humidity is
    a. 142.8
    b. 7.93
    c. 370.6
    d. 12.8

33. The relative humidity of unsaturated air-water vapor mixture is always
    a. equal
    b. greater than
    c. less than
    d. can not be determined

    compared to the relative or percentage saturation.

34. In an air-water contact operation, when the temperature and humidity of the air both decrease the process is
    a. dehumidification
    b. adiabatic humidification
    c. non-adiabatic humidification
    d. water cooling

35. The enthalpy transfer equation as proposed by Merkel is applicable to air-water system only because the ratio of h_c, convective heat transfer coefficient and the mass transfer coefficient, ky M_B is
    a. constant
    b. equal to humid heat
    c. equal to the enthalpy
    d. equal to unity

36. The tons refrigeration needed to supply air in a room 20 ft by 20 ft by 10 ft charged every 5 min at 70°F dry bulb and 65°F wet bulb by cooling outside air at 120°F db and 100°F wb is
    a. 20.2
    b. 12.2
    c. 50.8
    d. 7.6

37. If 100 lb of dry air at 50°F db and 50°F wb is mixed with 300 lb of dry air at 110°F db and 80°F wb, the resulting mixture will have a dry bulb temperature of
    a. 80°F
    b. 85°F
    c. 90°F
    d. 95°F

38. The wet bulb temperature of the resulting mixture for the mixed air of Problem *37* is
    a. 65°F
    b. 70°F
    c. 75°F
    d. 80°F

39. For a dehumidifier, the slope of the tie line is 2.5 for a liquid to gas ratio of 1.0. Air enters the dehumidifier at 80°F db and 78°F wb while water leaves at 76°F. Estimate the interfacial temperature at a point where the enthalpy of the air is 30 BTU/lb.
    a. 63.5°F
    b. 58.2°F
    c. 70.2°F
    d. 73.5°F

40. For air-benzene vapor mixture at 1 atm, the dry bulb temperature is 100°F and wet bulb temperature of 90°F. The absolute humidity at this condition is
    a. 0.35
    b. 0.26
    c. 0.50
    d. 0.62

9. DRYING

THEORY AND EQUATIONS

Drying involves the removal of moisture, usually water, from a solid by allowing the composite material to come into contact with a drying medium that supplies the heat needed by the moisture to evaporate. Although most of the discussions refer to water and air, the concepts may be applied to other liquid-gas drying operations. The task of the chemical engineer is to be able to design the appropriate dryer that may be used to dry a material, continuously or by batch, to meet the desired throughout and final moisture content. One of the important design parameters that has to be determined is drying time which can be obtained from the rate of drying.

Drying Rate

The rate of drying is defined by

$$R = -\frac{Q}{A}\frac{dW}{d\theta}$$

where R = rate of drying, lb water/hr-ft^2; Q = weight of bone dry solid, lb; A = drying area, ft^2; W = the total moisture content, lb water/lb bone dry solid; and θ = drying time, hr. The units assigned are for convenience only and may be changed to other equivalent units.

The total moisture content W can be broken up into two parts

$$W = X + X^*$$

where X refers to the free moisture content and X^* the equilibrium moisture content. X^* is the moisture that can not be evaporated and is very much dependent on the nature of the solid and the condition of the drying medium. Refer to Perry for the equilibrium moisture contents of various materials.

Drying Time

The drying time may be determined based on the conditions of the drying medium subjecting the solid material. The conditions refer to the temperature, humidity and velocity of the drying medium. The drying conditions may be constant which is typical for batch dryers or variable which usually occurs for continuous dryers operating under low temperature drying.

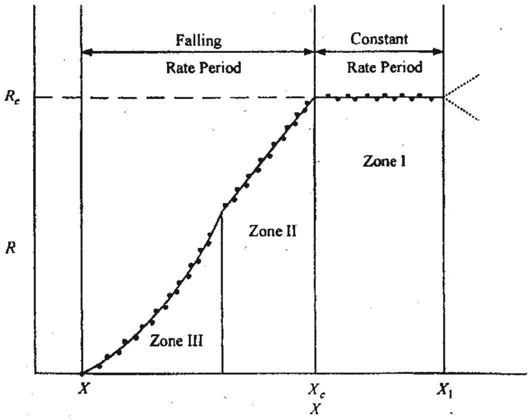
A. ***Constant Drying Conditions***

If the temperature, velocity and humidity of the drying medium are maintained constant, the rate equation may be reduced to

$$R = -\frac{Q}{A}\frac{dX}{d\theta}$$

Solving for the drying time, $$\theta = -\frac{Q}{A}\int_{X_1}^{X_2}\frac{dX}{R}$$

A drying rate curve versus the moisture content of the material may be used to determine the drying time. A typical drying rate curve, usually generated from experimental data is shown



Constant Rate Period, $X > X_c$. The moisture removed is unbound moisture where it is capable of generating a partial pressure equivalent to the vapor pressure at the surface of the solid. The time of drying, θ_c is

$$\theta_c = \frac{Q}{A}\int_{X_c}^{X_1}\frac{dX}{R_c}$$

integrating,
$$\theta_c = \frac{Q}{AR_c}(X_1 - X_c)$$

Falling Rate Period, $X < X_c$. The moisture involved is referred to as bound moisture where the water has to travel to the surface by capillary action or by diffusion or both in order to evaporate. The drying time, θ_F is

$$\theta_F = \frac{Q}{A}\int_{X2}^{X_c}\frac{dX}{R_F}$$

This is evaluated by graphical integration from a set of data of R_F versus X. To simplify the solution, two cases may be considered:

Case 1. Falling Rate Period is linear and passing through the origin

$$R_F = mX = \frac{R_c}{X_c}X$$

substituting in the integral and solving, we get

$$\theta_T = \frac{Q}{AR_c}\left[(X_1 - X_c) + X_c \ln\frac{X_c}{X_2}\right]$$

Case 2. Falling Rate Period is linear but not passing through the origin

$$R_F = \frac{R_c - R_2}{X_c - X_2}X + b$$

substituting in the integral and solving, we get

$$\theta_F = \frac{Q}{A}\frac{X_c - X_2}{R_{\ln}}$$

$$\text{where} \quad R_{\ln} = \frac{R_c - R_2}{\ln \dfrac{R_c}{R_2}}$$

The constant rate of drying, R_c may be evaluated for direct driers by applying simultaneously the mass and heat transfer equations

$$R_c = k'g\left(H_s - H\right)$$

$$R_c = \frac{h_t}{\lambda_s}\left(T_y - T_s\right)$$

where $k'g$ is the mass transfer coefficient and h_t the heat transfer coefficient which is the sum of the heat transfer coefficient due to convection and radiation. That is,

$$h_t = h_c + h_r$$

If conduction and radiation effects can be neglected, the surface temperature of the solids may be taken as equivalent to the wet bulb temperature and

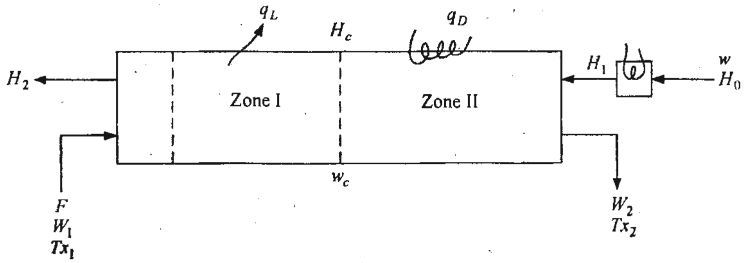
$$k_g' = \frac{h_c}{c_s}$$

The values of h_c, may be evaluated using empirical equations based on the flow rate and the orientation of flow of the drying medium. See Treybal or page 20-20 Perry for typical equations.

B. *Variable Drying Conditions*

For continuous drier such as tunnel driers, rotary driers, belt conveyor driers, the conditions of the drying medium subjecting the solids are changing. Therefore, the varying driving forces will have to be taken into consideration.

Material and Heat Balances



An over-all material balance around the dryer gives

$$\varepsilon = w\left(H_2 - H_1\right) = F\left(W_1 - W_2\right)$$

Heat balance around dryer

$$wC_{s_1}\left(T_{y_1} - T_{y_2}\right) + q_D = Fs\left(T_{x_2} - T_{x_1}\right) + FW_2\left(T_{x2} - T_{x1}\right) + \varepsilon\left[\left(T_{y2} - T_{x1}\right)\right] + \lambda_{T_{y2}} + q_L$$

For adiabatic driers, heat lost and heat added are considered zero and the temperature of the solid and residual moisture is taken as constant. With these conditions, the heat balance is reduced to

$$\frac{H_2 - H_1}{T_{y2} - T_{y1}} = -\frac{C_{s1}}{\lambda_{T_{y2}}}$$

which is similar to the A.H.L. Thus, for adiabatic drying, the wet bulb temperature of the air T_w is constant.

Drying Time for Low Temperature Drying

The drying time is expressed in terms of the total moisture content, W and is given by

$$\theta = \frac{Q}{A}\int_{W_1}^{W_2} \frac{dW}{R}$$

For a counter-current continuous dryer, the drying time may be determined by dividing the dryer into two zones depending on the type of moisture being evaporated so that the expression for R may be determined.

For Zone I. Where unbound moisture is evaporated, $W > W_c$, the rate of drying may be expressed as

$$R_I = k_g'(H_s - H)$$

$$\text{and} \quad R_I = \frac{h_t}{\lambda_s}(T_y - T_s)$$

substituting and solving for the drying time, we get

$$\theta_I = -\frac{Q(W_1 - W_c)}{R_{I\text{ln}}}$$

$$\text{where } R_{I_{\text{ln}}} = k_g'(H_s - H)_{\text{ln}} = \frac{h_t}{\lambda_s}(T_y - T_s)_{\text{ln}}$$

For adiabatic drying H_s and T_s are constant, the equations obtained are

$$\theta_I = \frac{Qw}{AFk_g'}\int_{H_c}^{H_2} \frac{dH}{H_s - H}$$

$$\theta_I = \frac{Qw}{AFk_g'}\ln\frac{H_s - H_c}{H_s - H_2}$$

For Zone II. Where $W_c > W$, bound moisture is evaporated and heating of material occurs. The rate of drying is obtained as

$$R_{II} = m(W - X^*) = \frac{R_c(W - X^*)}{W_c - X^*} = \frac{k_g(H_s - H)(W - X^*)}{W_c - X^*}$$

substituting this in the equation for drying time yields,

$$\theta_{II} = \int \frac{Q}{A}\cdot\frac{dW}{R_{II}} = \frac{Q}{Ak_g'}\int \frac{(W_c - X^*)dW}{(H_s - H)(W - X^*)}$$

This equation can be evaluated by graphical integration or numerical method.

If drying is adiabatic and the equilibrium moisture content is taken as zero or constant, the above equation may be simplified to

$$\theta_{II} = \frac{Qx_c}{Ak_g'}\int_{x_2}^{x_c}\frac{dX}{(H_s - H)X}$$

By material balance, $FdX = wdH$ or $F(x - x_2) = w(H - H_c)$. Thus, integration yields

$$\theta_{II} = \frac{wQX_c}{AFk_g'} \cdot \frac{1}{(H_s - H_2)\frac{w}{F} + X_2} \ln\frac{X_c(H_s - H_2)}{X_2(H_s - H_c)}$$

If drying is not adiabatic but the rate of drying in the falling period R_F can be assumed to be linear and will pass through the origin, i.e., R_F is independent of ΔH, the rate of drying may be simplified to the form

$$R_{II} = m\left(W - X^*\right) = \frac{R_c}{X_c}X$$

which in effect becomes similar to drying constant conditions, the drying time may be evaluated by direct integration. Thus,

$$\theta_{II} = \frac{QX_c}{AR_c}\int\frac{dX}{X} = \frac{QX_c}{AR_c}\ln\frac{X_c}{X_2}$$

Length of Drier

With the total drying time known, the length of the drier may be evaluated by

$$L = \frac{F\theta_T}{Q'} = \frac{FA\theta}{A'Q}$$

where Q' = lbs/ft-drier; A' = drying area/ft and $F\theta_T$ = is the load capacity, lb

REVIEW QUESTIONS AND PROBLEMS

1. When a solid material is said to be 'dry', it means that
   a. the solid does not contain any moisture
   b. the solid still contains very small amount of moisture
   c. the solid contains equilibrium moisture
   d. the weight of the solid is the same as the bone dry weight

2. Under normal operating conditions, when a solid material to be dried is placed inside a batch tray dryer, the material is usually subjected
   a. under constant drying conditions
   b. under variable drying conditions
   c. under high temperature drying
   d. under low temperature drying

3. When a wet granular solid material contained in a metal tray with insulated edges and bottom is placed inside a batch tray drier, the heat transfer mechanism involved in the drying operation is
   a. by convection only
   b. by conduction, convection and radiation
   c. by convection and radiation
   d. by conduction only

4. When a solid material is being dried in a continuous tunnel drier under low temperature drying, the mechanism is considered to be
    a. strictly mass transfer only
    b. simultaneous mass and heat transfer
    c. heat transfer dominated with practically no mass transfer
    d. mass transfer dominated with practically no heat transfer

5. If there is no heat transfer by radiation and conduction from adjoining surfaces, the temperature of the solid subjected to direct drying under constant drying conditions within the constant rate period is usually
    a. greater than the wet bulb temperature of the drying medium
    b. less than the wet bulb temperature of the drying medium
    c. nearly equal to the wet bulb temperature of the drying medium
    d. nearly equal to the dry bulb temperature of the drying medium

6. Given a solid material containing 120% moisture on a dry basis, the equivalent moisture content on a wet basis in percent moisture is
    a. 20 c. 12
    b. 54.5 d. none of these

7. The critical moisture content of a solid depends on the drying history and the thickness of the material. As a result, the critical moisture increases with increased drying rate and with increased thickness of the material being dried. Are these statements true or false?
    a. true b. false c. needs some more conditions

8. When a porous solid is subjected to constant drying conditions starting with bound moisture, the removal of moisture from the solid is initiated by pendular state then followed by funicular state. True or false ?
    a. true b. false

9. The topic of drying and driers is taken up as part of Unit Operations in Chemical Engineering since
    a. it serves as a good cure for those with insomnia
    b. it makes drying clothes more interesting
    c. the quality of the solid products is affected by moisture
    d. the sun drying is no longer popular

10. The portion of water in the wet solid that cannot be removed by the air in direct contact with the solid is called
    a. free moisture c. equilibrium moisture content
    b. final moisture content d. critical moisture content

11. When a wet solid is brought in contact with air, the solid tends to lose moisture if the humidity of the air is
    a. more humid than the solid in contact with it
    b. lower than the humidity corresponding to the moisture content of the solid
    c. equal to the humidity of the moisture content of the solid
    d. none of these

12. This is the moisture in the solid that exerts the equilibrium vapor pressure of pure liquid at the prevailing conditions.
    a. unbound moisture
    b. bound moisture
    c. free moisture
    d. equilibrium moisture

13. When the solid is non-porous
    a. liquid diffusion
    b. capillary action
    c. semi-permeable evaporation
    d. vapor diffusion

    may be used as a model to calculate the time of drying during the falling rate period.

14. This type of drier is used for drying pasty materials such as wet filter cakes and lumpy solids
    a. rotary drier
    b. flash drier
    c. tray drier
    d. continuous drier

15. In
    a. continuous drying
    b. batch drying
    c. direct drying
    d. indirect drying

    the equipment is operated intermittently under unsteady-state conditions.

16. The choice of equipment to be used for drying of solids can be classified according to
    a. nature of the substance to be dried
    b. method of operation, i.e., batch or continuous
    c. method of supplying the heat necessary for evaporation of the moisture
    d. all of these

17. The free-moisture content of the solid does not depend upon
    a. the vapor concentration in the gas
    b. the amount of moisture in the solid
    c. the nature of the solid to be dried
    d. the nature by which heat is supplied

18. In the constant-rate period, the rate of drying is established by
    a. a balance of the heat requirements for evaporation and the rate at which heat reaches the surface
    b. the internal movement of moisture beneath the surface of the solid
    c. air flow perpendicular to the surface of the solid
    d. air flow parallel to the solid surface

19. In the absence of radiation and heat conduction through the solid during the constant drying rate period, the drying surface of the solid will approach the
    a. critical temperature of the gas
    b. absolute temperature of the radiating surface
    c. wet-bulb temperature of the gas
    d. temperature of the tray material

20. The value of constant drying rate, R_c, varies directly with the quantity ($\mathcal{Y}_s - \mathcal{Y}$). Therefore, increasing the humidity
    a. increases the rate of drying
    b. has no effect on the rate of drying
    c. decreases the rate of drying
    d. none of these

21. Unbound moisture in granular and porous solid moves through the interstices of the solid by a mechanism involving
    a. moisture diffusivity
    b. surface renewal
    c. surface tension
    d. desorption

22. The first point of the falling-rate period corresponds to
    a. saturated surface drying
    b. unsaturated surface drying
    c. equilibrium moisture drying
    d. critical-moisture drying

→ first par

23. Drum driers are used for drying
    a. slurries
    b. gases
    c. pharmaceutical products
    d. pastes

24. It is a unit operation which involves the mass transfer of soluble materials from the liquid phase to the gaseous phase.
    a. absorption
    b. drying
    c. desorption
    d. humidification

25. If the rate of drying under constant drying conditions with air at 140°F and absolute humidity of 0.03 lb water per lb dry air of unknown mass of solid is given by

$$R = 0.5 - e^{-60x} \qquad lb\ H_2O / hr - ft^2$$

then the equilibrium moisture content of the material is ____________(d.b.)
    a. 0.034
    b. 0.120
    c. 0.00116
    d. 0.01155

26. The estimated mass transfer coefficient for the above drying conditions is _________ $lb\ H_2O / hr - ft^2 - \Delta H$.
    a. 24.0
    b. 48.1
    c. 96.2
    d. none of these

27. In drying at the falling rate period, the rate at which moisture is removed from the solid material
    a. increases with time
    b. decreases with time
    c. remains constant
    d. no more drying takes place

28. When drying banana chips under the sun, the rate of drying is faster on a
    a. slightly breezy day
    b. cloudy day
    c. calm day
    d. hot and windy day

29. A wet material having a critical moisture content of 15% (d.b.) and an equilibrium moisture content of 3% (d.b.) took 6 hours to dry from 45% (d.b.) to 10% moisture. The time it will take to dry to 15% moisture (d.b.) is
    a. 5 hours
    b. 4 hours
    c. 5.5 hours
    d. none of these

30. Wet solids are to be dried from 36% to 8% moisture in 5 hours under constant drying conditions. X_{Tc} = 14%, X_e = 4%. All moisture contents are on a dry basis. The additional time it will take to dry from 8% to 5.5% moisture under the same drying conditions is
    a. 6.6 hours
    b. 1.6 hours
    c. 1.8 hours
    d. 5 hours

31. Wet solid are to be dried from 40% to 10% in 5 hours under constant drying conditions. The critical moisture content is 20% and the equilibrium moisture content is 7%. All moisture contents are on a dry basis. The time needed to dry from 15% to 5% free moisture under the same drying conditions is
    a. 3.42 hours
    b. 1.846 hours
    c. 0.542 hours
    d. 2.129 hours

32. The driving force in low temperature drying is the difference between
    a. temperature only
    b. humidity only
    c. temperature and humidity
    d. pressure and humidity

33. The rate of drying at constant rate period is 20 lbs/hr. 400 lbs of dry solid containing 300 lbs water enter the drier. If the critical free moisture is 0.5(d.b.) and the equilibrium moisture content is 0.05(d.b.), the drying time to dry the material to 5% moisture (w.b.) is
    a. 67.5 hours
    b. 47.5 hours
    c. 14 hours
    d. 76.5 hours

34. Coffee extract containing 70% water is to be spray dried using air at 420 K in a 6-m diameter by 6-m high chamber with centrifugal disk atomizer. The capacity of the spray drier is ______ lb/hr of feed, if the final product will have a moisture content of 1% (w.b.). See Table 12-36, Perry, 7/e.
    a. 20,500
    b. 35,000
    c. 40,500
    d. 43,200

35. The amount of water to be removed from 2,000 kg/hr of feed to be dried from 110% (d.b.) to 5% (w.b.) is ______ kg/hr.
    a. 998
    b. 1000
    c. 451
    d. 910

36. In an adiabatic drier
    a. the temperature of the drying medium is constant.
    b. no heat is supplied to the drier.
    c. the temperature of the solid is equal to the wet bulb temperature of air.
    d. the drying rate is constant.

b 37. Increasing the absolute humidity of the air, the value of the drying rate constant, R_c
    a. increases
    b. decreases
    c. remains constant
    d. none of these

38. The drying rate is proportional to the moisture content. If half of the moisture content of a material is dried in 2 hours, then three fourths will be dried in 4 hours.
    a. True
    b. False

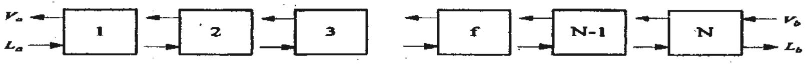
39. One thousand kilograms per hour of a material with 30% moisture content (d.b.) is dried in a belt conveyor drier with a capacity of 50 kg of bone dry solid per meter of drier. The total drying time is 5.3 hours. Estimate the length of the drier.
    a. 74.2 m
    b. 81.5 m
    c. 106 m
    d. 98 m

40. What will be the volumetric flow rate (in ft^3/min) of entering air required to remove 10 lbs of water per hour from rayon, if the air enters at 80°F and 25% humidity and leaves at 170°F and 55% RH? The operating pressure is 14.3 psia.
    a. 12
    b. 8.6
    c. 7.12
    d. 12.7

10. LEACHING (SOLID-LIQUID EXTRACTION)

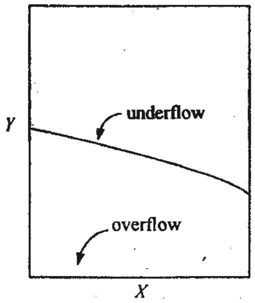
THEORY AND EQUATIONS

Counter-Current Leaching Cascade



A. *Variable Underflow*

Here, L_n or the weight of the retained solution varies from stage to stage. The number of ideal stages may be determined graphically.



1. *Using Rectangular Diagram or Coordinates (McCabe-Smith Method)*

Coordinates chosen are: (b = solids; a = solute; s = solvent)

$Y = \frac{b}{a+s}$, mass ratio of solids to solution

$X = \frac{a}{a+s}$, concentration of solute in solution

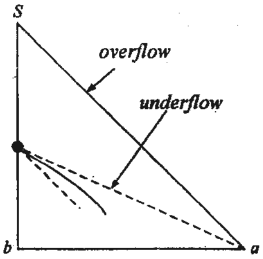
To plot underflow curve, an experimental data of

R vs X must be known where $R = \frac{\text{mass solution retained}}{\text{mass solids}}$ and

X = concentration of solution

Note that $Y = \frac{1}{R}$

2. *Triangular Diagram*



Procedure:

a. Plot X and Y coordinates of known streams, usually, V_b, V_a, L_a

b. Determine J point by setting up over-all balance,

$$V_a + L_b = V_b + L_a = J$$

or $$\frac{L_a}{V_b} = \frac{Y_J - Y_{V_b}}{Y_{L_a} - Y_J}$$

c. Determine point L_b along underflow curve by extending line V_aJ

d. Determine operating point P from a balance around stages (1) to (n):

$$L_a + V_{n+1} = L_n + V_a \qquad \text{or} \qquad V_{n+1} - L_n = V_a - L_a$$

Let $V_{n+1} - L_n = P \qquad \therefore V_a - L_a = P$ and $V_b - L_b = P$

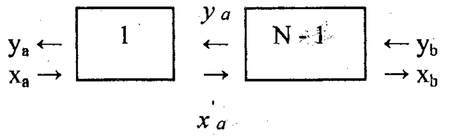
e. Determine Theoretical N following Ponchon-Savarit Method

B. ***Constant Underflow***

Since L_n is constant, the slope of the operating line is constant. With a linear operating line and in leaching, the equilibrium curve is always linear the number of ideal stages may be determined using the ABSORPTION FACTOR METHOD or the TILLER-TOUR Equation.

$$N = \frac{\log \dfrac{y_b - y_b^*}{y_a - y_a^*}}{\log \dfrac{y_b - y_a}{y_b^* - y_a^*}} \qquad \text{where } y_b^* = x_b \text{ and } y_a^* = x_a$$

Since x_a is not known i.e., the fresh feed does not contain any retained solution, to apply the equation, we omit the first stage and just apply it to the (N-1) stages, thus



$$N - 1 = \frac{\log \dfrac{y_b - y_b^*}{y_a' - \left(y_a'\right)^*}}{\log \dfrac{y_b - y_a'}{y_b^* - \left(y_a'\right)^*}}$$

where $\left(y_a'\right)^* = x_a' = y_a$ and y_a' is determined from the performance of stage 1

Case 1. If $\dfrac{\text{solvent}}{\text{solid}}$ ratio is constant, concentrations are expressed in $\dfrac{\text{mass solute}}{\text{mass solvent}}$

Case 2. If $\dfrac{\text{solution}}{\text{solid}}$ ratio is constant, concentrations are expressed in $\dfrac{\text{mass solute}}{\text{mass solution}}$

REVIEW QUESTIONS AND PROBLEMS

1. A unit operation in which a soluble component is removed from an inert solid by a solvent which preferentially dissolves the soluble matter from the mixture is known as
   a. adsorption
   b. solvent extraction
   c. leaching
   d. sedimentation

2. The major problem in leaching is to promote diffusion of the solute out of the solid and into the liquid. The most effective way of doing this is
   a. to reduce the solid to the smallest size feasible
   b. to use counter current operation
   c. to use cross flow operation
   d. none of these

3. There are two underflow-overflow leaching conditions namely ideal and non-ideal. The ideal leaching conditions exist if
   a. the carrier solid is completely inert and is not dissolved or entrained in the solvent
   b. the solute is infinitely soluble in the solvent
   c. sufficient contact time for the solvent to penetrate the solute completely is permitted
   d. all of these

4. In non-ideal leaching conditions, the tie lines slant to the right indicating that the solute is more highly concentrated in the underflow because
   a. of equilibrium solubility or of incomplete leaching
   b. the solvent and solute are completely miscible
   c. of a partially miscible carrier or incomplete settling
   d. all of these

5. In leaching, the particle size influences the extraction rate, the smaller the size,
   a. the greater is the interfacial area between the solid and liquid
   b. the smaller is the distance the solute must diffuse within the solid
   c. both a and b
   d. the lower is the rate of transfer of material

6. Agitation of the liquid influences the rate of extraction. Agitation of solvent is important because
   a. it prevents sedimentation
   b. it increases eddy diffusion
   c. it increases the transfer of material from the surface of the particles to the bulk of solution
   d. both b and c

7. The temperature also affects the rate of extraction. In most cases, the solubility of the material which is being extracted will increase with temperature to
   a. give a higher rate of extraction
   b. increase the diffusion coefficient
   c. prevention of enzyme action
   d. both a and b

8. A slurry of flaked soybeans weighing 100 kg contains 75 kg inert solids and 25 kg of solution 10 weight % oil and 90 weight % solvent hexane. This slurry is contacted with 100 kg pure hexane in a single stage so that the value of retention for the outlet underflow is 1.5 kg of insoluble solid per kg solvent in the adhering solution. The composition of underflow leaving the extraction stage in percent by weight oil is

    a. 1.5 c. 0.3
    b. 2.3 d. 0.8

Problems *9* and *10* are based on the following information:

In a salt recovery plant, rock salt is being leached to produce industrial salt in a continuous counter current system consisting of two (2) ideal stages using water as leaching medium. The average composition of the rock salt is: inerts = 70%, soluble salts = 25%, moisture = 5%, all percentage by weight. The underflow from each stage contains 0.3 kg of solution per kg of inerts. The plant leaches 50 MT of rock salt per day using 50 MT of water.

9. The quantity of soluble salts recovered in MT/day is

    a. 12.1 c. 14
    b. 13.1 d. 11.2

10. The composition of salt in weight percent in the final underflow is

    a. 0.89% c. 0.78%
    b. 0.98% d. 0.68%

Problems *11* and *12* are based on the following information:

Raw gypsum from a fertilizer plant is being leached out of its salt $(NaCl)$ content in a 2 step continuous counter current system using salt-free water as leaching medium. The underflow, $CaSO_4$ slurry is then sent to a drier to obtain the final product. The operating data are as follows;

Raw gypsum feed = 10 MT/day
Salt content of raw gypsum = 1% wt
Water feed rate = 90 m^3/day
Water content of slurry = 0.09 MT H_2O per MT $CaSO_4$

11. The percent of the salt removed in the process is

    a. 89.9% c. 95.9%
    b. 91.9% d. 99.9%

12. The resulting salt content in the overflow in weight percent is

    a. 0.112% c. 0.151%
    b. 0.21% d. .224%

13. Powdered limestone $(CaCO_3)$ containing 10,000 ppm $NaOH$ is to be washed in a two step continuous counter current washing system to remove most of the $NaOH$. Two cells and 100,000 liters of water per 10 MT/day of limestone feed are used. The slurry discharged and removed from the underflow contains 0.091 MT of water per MT $CaCO_3$. Assuming complete mixing and washing, the $NaOH$ content of the washed and dried limestone in ppm is

    a. 0.6 c. 0.8
    b. 0.5 d. 0.4

14. Coconut oil is to be produced from dry copra in two stages. First, through expellers to squeeze out part of the coconut oil and then through a counter current multi-stage solvent extraction process. After expelling, the dry copra cake contains 20% residual oil. In the solvent extraction operation, 90% of the residual oil in the expeller cake is extracted as a solution containing 50% by weights oil. If fresh solvent is used and one kg of solution with every 2 kg of insoluble cake is removed with underflow, the number of ideal stages required is
    a. 4
    b. 6
    c. 7
    d. 5

Problems *15* and *16* are based on the following information:

A counter current multiple contact extraction system is to treat 50 tons per hour of wet sliced sugar beets with fresh water as the solvent. The beets have the following analysis:

Components	*Mass Fraction*
water	0.48
pulp	0.40
sugar	0.12

The strong solution leaving the system is to contain 0.15 mass fraction sugar, and 97% of the sugar in the sliced beets is to be recovered. Determine the number of extraction cells required, assuming equilibrium between the underflow and overflow in each cell.

15. If each ton of dry pulp retains 3 tons of solution is
    a. 16
    b. 14
    c. 15
    d. 10

16. If each ton of dry pulp retains 3 tons of water is
    a. 16
    b. 14
    c. 15
    d. 17

17. A multiple contact extraction system is to treat 1.25 tons (2,500 lbs) per hour of dry black ash containing 40% Na_2CO_3 and 60% insoluble matter with 30 gpm of water. If 5% of the Na_2CO_3 remains unextracted, calculate the number of ideal stages by the absorption factor method. The mass ratio of insoluble matter to solvent in the underflow from the stage is 1:2. The number of ideal stages required is
    a. 3
    b. 2
    c. 4
    d. 5

18. Roasted copper ore containing the copper as $CuSO_4$ is to be extracted in a countercurrent stage extractor. Each hour, a charge consisting of 10 tons gangue, 1.2 tons $CuSO_4$ and 0.5 ton water is to be treated. The strong solution produced is to consist of 90% water and 10% $CuSO_4$ by weight. The recovery of $CuSO_4$ is to be 98% of that in the ore. Pure water is to be used as fresh solvent. After each stage, one ton of inert gangue retained 2 tons of water plus the copper sulfate dissolved in that water. Equilibrium is attained in each stage. The number of stages required is
    a. 12 b. 10 c. 8 d. 14

19. Tung meal containing 55% oil is to be extracted at a rate of 4,000 kg per hour using n-hexane containing 5% wt oil as solvent. A counter current multiple stage extraction system is to be used. The meal retains 2 kg of solvent per kg of oil free meal while the residual charge contains 0.11 kg oil per kg oil free meal while the product is composed of 15 weight percent of oil. The theoretical number of ideal stages is
    a. 4 b. 3 c. 5 d. 6

20. Which of the following operations does not involve leaching?
    a. dissolving gold from ores
    b. dissolving pharmaceutical products from bark or roots
    c. dissolving sugar from the cells of the beet
    d. removing nicotine from its water solution by kerosene

21. Tea percolation employs
    a. liquid-liquid extraction
    b. leaching
    c. absorption
    d. adsorption

22. The rate of leaching increases with increasing
    a. temperature
    b. viscosity of solvent
    c. pressure
    d. size of the solid

23. Stage efficiency in a leaching process depends on the
    a. time of contact between the solid and the solution
    b. rate of diffusion of the solute through the solid and into the liquid
    c. both a and b
    d. vapor pressure of the solution

24. Extraction of coffee from its seed is done by
    a. liquid-liquid extraction
    b. leaching
    c. extractive distillation
    d. steam distillation

25. Leaching of sugar from sugar beets is done using
    a. hot water
    b. hexane
    c. dilute H_2SO_4
    d. lime water

11. LIQUID-LIQUID EXTRACTION

THEORY AND EQUATIONS

Classification: Single Solvent System

A. ***Stagewise Contact***

1. Single Contact (analogous to Equilibrium Distillation)
2. Co-current Multiple Contact or Simple Multi-stage Contact
3. Counter-current Multi-stage or Multiple Contact
   a. Without Reflux
   b. With Reflux (analogous to Fractional Distillation)

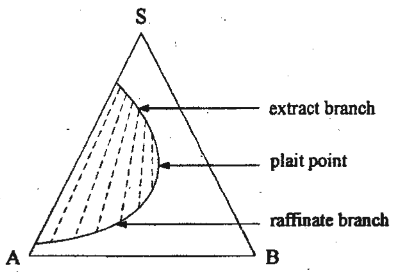
B. ***Continuous Contact (Differential Contact)***

Design Diagrams

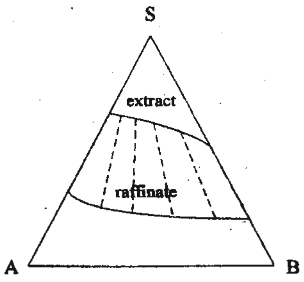
(Diluent and Solvent Partially Miscible)

1. ***Triangular Coordinates ("Equilateral" triangle diagram)***

where
A=feed solvent
B=solute
S=extracting
solvent



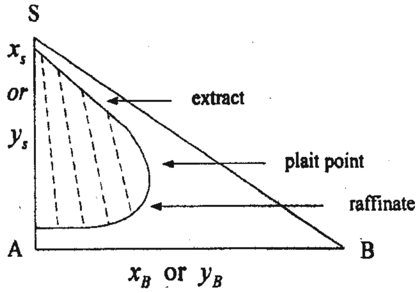
Type I



Type II

2. ***Rectangular Coordinates***

a. *Right Triangle Diagram (weight basis)*



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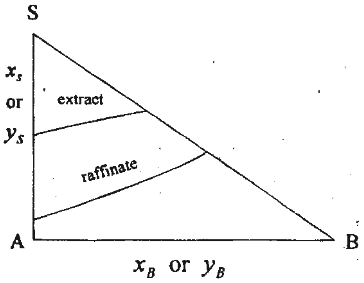
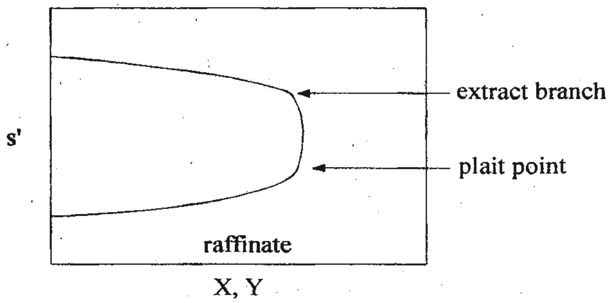


Type II

$$S = \frac{S}{A+B+S}$$

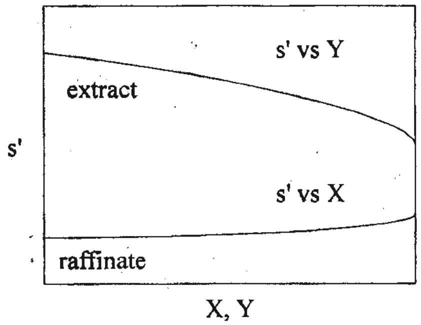
$$X = Y = \frac{B}{A+B+S}$$

b. *Janecke or Ponchon Diagram (weight ratio "solvent-free" basis)*



Type I

$$s' = \frac{S}{A+B}, \quad X = Y = \frac{B}{A+B}$$



Type II

Equilibrium Data for the Acetic Acid-Water-Isopropyl Ether System at 20°C.

Water layer (raffinate)			**Isopropyl ether layer (extract)**		
% Acetic Acid	*% Water*	*% Isopropyl Ether*	*% Acetic Acid*	*% Water*	*% Isopropyl Ether*
0.69	98.1	1.2	0.18	0.5	99.3
1.41	97.1	1.5	0.37	0.7	98.9
2.89	95.5	1.6	0.79	0.8	98.4
6.42	91.7	1.9	1.93	1.0	97.1
13.30	84.4	2.3	4.82	1.9	93.3
25.50	71.1	3.4	11.40	3.9	84.7
36.70	58.9	4.4	21.60	6.9	71.5
44.30	45.1	10.6	31.10	10.8	58.1
46.40	37.1	16.5	36.20	15.1	48.7

REVIEW QUESTIONS AND PROBLEMS

1. To determine the minimum ratio of extraction solvent to feed solvent, one has to know
   a. the distribution coefficient
   b. only the concentration of solute in the feed solvent
   c. only the concentration of solute in the extraction solvent
   d. number of stages in the system

2. In a liquid-liquid extraction process, the extraction solvent has no selectivity when the ratio of the two components in the extraction solvent phase to that in the feed solvent phase is
   a. more than 2.0
   b. 2.0
   c. between 2.0 and 1.0
   d. 1.0

3. In an extraction process the greater the weight of the solute in the raffinate relative to that in the extract ______________ the distribution coefficient.
   a. the same is
   b. the better is
   c. the more is
   d. does not affect

4. The unit operation by which soluble components of a liquid mixture are dissolved in a liquid that is partially immiscible with the other components is
   a. solvent extraction
   b. leaching
   c. adsorption
   d. absorption

5. Liquid-liquid extraction is based on the differences in
   a. solubility
   b. specific volume
   c. partial pressure
   d. viscosity

6. There are 30 kg of solute in 100 liters of H_2O, the weight of solute that will be extracted by 35 liters of ether if the distribution coefficient, k = 4 is
   a. 3 kg b. 2 kg c. 3.45 kg d. 2.45 kg

7. If a 3-stage counter current extraction system is used in Problem *6*, the weight of solute that will remain in the raffinate is
   a. 20 kg b. 10 kg c. 27 kg d. 29 kg

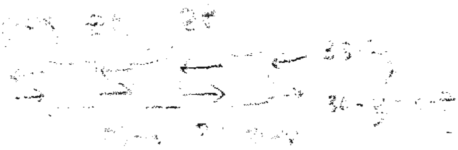
8. A solution of solute (A) in diluent (B) is mixed with a solvent (S). The component (B) is slightly soluble in (S). The resulting extract will be
   a. rich in S, poor in B, poor in A
   b. rich in S, rich in B, rich in A
   c. poor in S, rich in B, poor in A
   d. rich in S, poor in B, rich in A

Problems *9* and *10* are based on the following information:

It is desired to extract benzoic acid from toluene using water as the extracting solvent.

Data:
Analysis of feed :
benzoic acid = 10%
toluene = 90%
Rate of feed = 120 gpm
Rate of solvent = 20 gpm

$\frac{30}{120}$



Assumptions:
1. All flow rates are steady
2. Toluene and water are immiscible
3. Feed concentration remains constant
4. Two streams leaving each stage are in equilibrium with each other and k = 0.125

The % of the acid extracted

9. With a single stage system
   a. 59% b. 69% c. 45% d. 65%

10. With a two stage system
   a. 95% b. 85% c. 79% d. 65%

Problems *11* and *12* are based on the following information:

A solution contains a valuable material M in water. M is recovered from the solution using solvent S. If 9 kg of S is used per kg of solution and the distribution equilibrium is X/Z = 3, where X = kg M/ kg water and Z = kg M/ kg S

The % M that will remain in the solution after solvent extraction using

11. Single batch equilibrium stage is
   a. 30% b. 35% c. 25% d. 40%

12. Two successive batch equilibrium steps using fresh solvent for each step is
    a. 16.6%   b. 17.6%   c. 15.6%   d. 18.6%

Problems *13* to *15* are based on the following information:

Benzoic acid is 9 times more soluble in chloroform than in water. The percent benzoic acid that will remain from a water solution of benzoic acid if

13. Equal quantity of chloroform and water is used is
    a. 10%   b. 20%   c. 15%   d. 30%

14. Twice as much chloroform as water is used is
    a. 2.6%   b. 5.3%   c. 3.5%   d. 6%

15. If extraction as in Problem 13 were followed by an extraction as in Problem 14 is
    a. 0.53%   b. 0.35%   c. 0.63%   d. 0.73%

Problems *16* and *17* are based on the following information:

Acetic acid is to be extracted from an aqueous solution by counter-current extraction with isopropyl ether. The feed is 10,000 kg/hr of 28% acetic acid.

16. The number of equilibrium stages required for a solvent feed rate of 30,000 kg/hr and an extract composition of 8% acetic acid is
    a. 4   b. 5   c. 8   d. 10

17. The minimum solvent to feed ratio which will give the same raffinate composition is
    a. 3.14   b. 4.3   c. 2.4   d. 1.75

18. Heat-sensitive materials with very high latent heat of vaporization may be economically separated using
    a. liquid extraction   c. evaporation
    b. distillation   d. absorption

19. Fractional solvent extraction
    a. employs only one solvent   c. results in low interfacial tension
    b. employs two solvents   d. none of these

20. Choose the best combination or properties for a good solvent for extraction out of the following
    (i) high selectivity
    (ii) low selectivity
    (iii) high viscosity
    (iv) low viscosity
    (v) large distribution coefficient
    (vi) small distribution coefficient
    (vii) high interfacial tension
    (viii) low interfacial tension

    a. (i), (iv), (v), (vii)   c. (i), (iii), (v), (vii)
    b. (i), (iii), (v), (vi)   d. (i), (ii), (iv), (vii)

21. Selectivity of solvent used in extraction should be
    a. 1
    b. < 1
    c. > 1
    d. 0

22. In liquid extraction, if selectivity is unity, then
    a. separation of the constituent is most effective
    b. no separation will occur
    c. amount of solvent required will be minimum
    d. solvent flow rate should be very low

23. When the solvent dissolves very little of the solute then
    a. solvent of low latent heat of vaporization should be used
    b. solvent of low freezing point should be used
    c. large quantity of solvent is required to extract the solute
    d. very small quantity of solute is required

24. Which of the following is the most suitable for extraction in a system having very low density difference?
    a. mixer-settler extractor
    b. centrifugal extractor
    c. pulsed extractor
    d. packed extraction tower

25. In extraction, as the temperature increases, the area of heterogeneity (area covered by binodal curve)
    a. decreases
    b. increases
    c. remains unchanged
    d. none of these

12. CRYSTALLIZATION

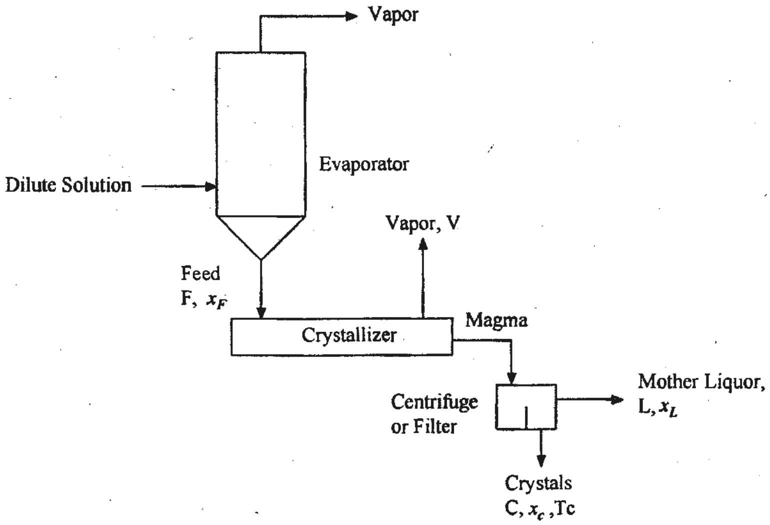
THEORY AND EQUATIONS

Crystallization – process whereby a solution is super saturated so as to cause the formation of crystals.

Methods of Supersaturating a Solution

1. Supersaturation by cooling – Swenson-Walker Crystallizer
2. Supersaturation by evaporation of solvent – "Salting-out" Evaporator, Oslo Crystallizer
3. Adiabatic evaporation with cooling – Vacuum Crystallizer
4. Adding a third component where the solubility of the solute is simply reduced; by seeding
5. Addition of a third component to form precipitates

Principles of Crystallization



A. ***Material Balance***

Over-all Material Balance: $F = C + L + V$

Solute Balance: $Fx_F = Cx_c + Lx_L$

Solvent Balance: $F(1 - x_F) = C(1 - x_c) + L(1 - x_L)$

where x_L is the solubility of the solute at T_L

x_c is the MW of solute/MW of hydrated crystal

For the solubility of some solids, see Figures 18-56 and 18-57, Perry

NOTE: Tie substance method may be applied: (a) If the crystals are anhydrous, water becomes the tie substance between the original solution and the mother liquor, (b) If the crystals are in the form of hydrates, free or excess water is the tie substance.

B. ***Enthalpy Balance***

If Enthalpy-Concentration data are available: $Fh_F = VH_V + Lh_L + Ch_c$

C. ***Heat Balance***

If the specific heats, heat of solution and heat of crystallization are available:

$$q = Fc_F(T_F - T_c) + CH_c$$

For the area of the crystallizer: $q = UA(T - t)_{\ln}$

D. ***Crystallization by Seeding***

Mechanism of crystallization: (a) Nucleation and (b) Crystal Growth
Assumptions in the use of seed crystals:

a. no new nucleation occurs
b. uniform linear growth, i.e., the ΔL or ΔD law applies

ΔL or ΔD law = the rate of linear growth is independent of size

Rate of deposition of crystals: $\dfrac{dW}{dt} = k\,[f(x - x_i)]$

Volume of crystal: $V = aD^3$ or $dV = 3aD^2dD$ also $dW = \rho dV$

substituting, $\dfrac{\rho(3aD^2dD)}{dt} = k\,[f(x - x_i)]$ or $\dfrac{dD}{dt} \approx K\,[f(x - x_i)]$

Relation between seed and product crystals: $D_p = D_s + \Delta D$

For ideal growth, ΔD is the same for all crystals: $W_p = a\rho D_p^3 = a\rho\,(D_s + \Delta D)^3$

but $W_S = a\rho D_S^3$

therefore $W_P = \left(1 + \dfrac{\Delta D}{D_S}\right)^3 W_S$ for a single sized crystal

For an entire range of particle sizes

$$W_P = \int_o^{W_S} \left(1 + \frac{\Delta D}{D_S}\right)^3 dW_S \quad \text{which is solved by trial and error}$$

REVIEW QUESTIONS AND PROBLEMS

1. An equipment that crystallizes a material whose solubility is independent of temperature.
    - a. vacuum crystallizer
    - b. crystallizing evaporator
    - c. vacuum evaporator
    - d. Oslo crystallizer

2. An equipment that crystallizes a material whose solubility increases greatly with temperature.
    - a. Swenson-Walker Crystallizer
    - b. Agitated Batch Crystallizer
    - c. Wolf Bock Crystallizer
    - d. all of these

3. Defined as the separation of components of a binary mixture without addition of solvent.
    - a. melt crystallization
    - b. column crystallization
    - c. solution crystallization
    - d. none of these

4. A diluent is added to the mixture, the solution is then directly or indirectly cooled and/or solvent is evaporated to effect crystallization.
    - a. column crystallization
    - b. melt crystallization
    - c. solution crystallization
    - d. none of these

5. The formation of a new solid phase either on an inert particle in the solution or in the solution itself is called
    - a. crystal growth
    - b. precipitation
    - c. nucleation
    - d. seeding

6. Compounds whose solubility increase with increasing temperature results in
    - a. absorption of heat when the compound dissolves
    - b. no evolution of heat
    - c. evolution of heat when solution occurs
    - d. all of these

7. The solubility of soda ash at 30°C in g/100 g water is
    - a. 9.6
    - b. 21.5
    - c. 11.1
    - d. 38.3

8. The solubility of sal ammoniac at 70°C in g/100 g water is
    - a. 116.8
    - b. 60.2
    - c. 55.2
    - d. 126

9. The solubility of Epsom Salt in equilibrium with the saturated solution at 10°C in g/100 g water is
    - a. 30.90
    - b. 53.23
    - c. 59.5
    - d. 62.9

10. The heat of solution of saltpeter in kg-cal/g mol is
    a. – 5.23
    b. – 6.23
    c. – 8.633
    d. – 4.6

11. The heat of solution of hydroxybenzene in g-cal/gmol is
    a. – 2,605
    b. – 3,960
    c. – 3,705
    d. – 5,210

12. The enthalpy of a saturated $MgSO_4$ at 150°F in BTU/1b solution is
    a. – 25
    b. – 30
    c. – 20
    d. – 40

13. The enthalpy of a 25 %wt of $MgSO_4$ at 82.2°C in BTU/1b solution is
    a. 45
    b. 50
    c. 40
    d. 35

14. The enthalpy of $MgS0_4.7H_20$ at 26.67°C in BTU/1b solution is
    a. – 140
    b. – 150
    c. – 130
    d. – 160

15. In industrial crystallization from a solution, the two phase mixture of mother liquor and crystals of all sizes, which occupies the cystallizer and is withdrawn as product is called
    a. product crystals
    b. mother liquor
    c. invariant crystals
    d. magma

16. Equilibrium in crystallization processes is reached when the solution is
    a. unsaturated
    b. saturated
    c. supersaturated
    d. none of these

17. The latent heat evolved when solid forms from solution which varies with both temperature and concentration is called
    a. heat of dilution
    b. heat of vaporization
    c. heat of crystallization
    d. heat of fusion

18. The concentration difference between that of the supersaturated solution in which the crystal is growing and that of a solution in equilibrium with the crystal is called
    a. supersaturation
    b. saturation
    c. unsaturation
    d. none of these

19. The equation relating the solubility of the substance to its particle size is called
    a. Kelvin
    b. Ostwald
    c. Nucleation Rate
    d. ΔL Law

20. Which of the following solute may be crystallized by cooling without evaporation, evaporation without cooling or a combination of cooling and evaporation?
    a. sodium sulfate
    b. potassium nitrate
    c. sodium sulfite
    d. sodium nitrate

21. How much $CaCl_2 \cdot 6H_2O$ must be dissolved in 100 kg of water at 20°C to form a saturated solution? The solubility of $CaCl_2$ at 20°C is 6.7 gmol anhydrous salt ($CaCl_2$) per kg of water.
    a. 500 kg
    b. 535 kg
    c. 550 kg
    d. 635 kg

22. Crystals of $Na_2CO_3 \cdot 10H_2O$ are dropped into a saturated solution of Na_2CO_3 in water at 100°C. What percent of the Na_2CO_3 in the $Na_2CO_3 \cdot H_2O$ is recovered in the precipitated solid? The precipitated solid is $Na_2CO_3 \cdot H_2O$. Data at 100°C: the saturated solution is 31.2% Na_2CO_3: molecular weight of Na_2CO_3 is 106.
    a. 40%
    b. 30%
    c. 52%
    d. 25%

23. A solution of $MgSO_4$ at 220°F containing 43 g of $MgSO_4$ per 100 g H_2O is fed to a cooling crystallizer operating at 50°F. If the solution leaving the crystallizer is saturated, the rate at which solution must be fed to the crystallizer to produce one ton of $MgSO_4 . 7H_2O$ per hour is
    a. 3.71 tons/h
    b. 4.71 tons/h
    c. 5.71 tons/h
    d. 2.71 tons/h

24. The solubility of sodium bicarbonate in water is 9.6 g/100 g of water at 20°C and 16.4 g/100 g of water at 60°C. If a saturated solution of $NaHCO_3$ at 60°C is cooled to 20°C, the percentage of the dissolved salt that crystallizes out is
    a. 14.5%
    b. 15,4%
    c. 41.5%
    d. 48%

25. A plant produces 30,000 MT of anhydrous sodium sulfate annually by crystallizing process sulfate brine at 0°C. Yields of 95% and 90% in the crystallization and calcination operations are obtained, respectively. The MT of liquor fed to the crystallizer daily for 300 working days/year is
    a. 2387
    b. 3385
    c. 2575
    d. 2170

26. 1200 lb of barium nitrate is dissolved in sufficient water to form a saturated solution at 90°C. Assuming that 5% of the weight of the original solution is lost through evaporation, calculate the crop of crystals obtained when cooled at 20°C. Solubility data for barium nitrate at 90°C is 30.6% wt, and 8.6% wt at 20°C.
    a. 952.4 lbs
    b. 970 lbs
    c. 962.4 lbs
    d. 980 lbs

27. Glaubers salt is made by crystallization from a water solution at 20°C. The aqueous solution at 20°C contains 8.4% sodium sulfate. How many grams of water must be evaporated from a liter of such solution whose specific gravity is 1.077 so that when the residue solution after evaporation is cooled to 20°C, there will be crystallized out 80% of the original sodium sulfate as Glaubers salt. The solubility of sodium sulfate in equilibrium with the decahydrate is 19.4 g Na_2SO_4 per 100 g lb H_2O.
    a. 821.52
    b. 721
    c. 850.52
    d. 801.52

28. A solution of magnesium sulfate containing 43 g solids per 100 g water is to be fed to a vacuum crystallizes at 220°F. The vacuum in the crystallizer corresponds to a water boiling temperature of 43°F. A saturated solution of magnesium sulfate has a BPE of 7°F. The solution that must be fed to produce 1 ton of epsom salt per hour is
    a. 4220 lbs/hour
    b. 3230 lbs/hour
    c. 5325 lbs/hour
    d. 5235 lbs/hour

Problems *29* and *30* are based on the following information:

A Swenson-Walker crystallizer is to be used to produce 1 ton/hr of copperas crystals by cooling a saturated solution which enters the crystallizer at 120°F. The slurry leaving the crystallizer will be at 80°F. Cooling water enters the crystallizer jacket at 60°F and leaves at 70°F. It may be assumed that U for the crystallization is 35 BTU/h-ft°F. There are 3.5 ft^2 of cooling surface per foot of crystallizer length and a crystallization unit is 10 ft length.

Data:

Heat of solution = 4400 cal/gmole copperas
Cp_F = 0.70 BTU/lb/°F
Solubility at 120°F = 140 parts copperas/100 parts excess water
Solubility at 80°F = 74 parts copperas/100 parts excess water

29. The cooling water required is
    a. 52 gpm
    b. 56 gpm
    c. 60 gpm
    d. 45 gpm

30. The number of crystallizer units to be used is
    a. 6
    b. 5
    c. 7
    d. 8

31. One ton of $Na_2S_2O_3.5H_2O$ is to be crystallized per hour by cooling a solution containing 56.5% sodium thiosulfate to 30°C in a Swenson-Walker crystallizer. Evaporation is negligible. The product is to be sized closely to approximately 14-mesh. Seed crystals closely sized to 20-mesh are introduced with the solution as it enters the crystallizer. The pounds of seed crystals required per hour is
    a. 1238.5
    b. 1138.5
    c. 1148.5
    d. 1230.3

32. A Swenson-Walker crystallizer is fed with a saturated solution of magnesium sulfate at 110°F. The solution and its crystalline crop are cooled to 40°F. The inlet solution contains 1g of seed crystals per 100 g of solution. The seeds are 80-mesh. Assuming ideal growth, the mesh size of the crystals leaving with the cooled products, assuming negligible evaporation, is
    a. 35
    b. 28
    c. 32
    d. 20

33. A batch of 1000 kg of KCl is dissolved in sufficient water to make a saturated solution at 363 K, where the solubility is 35 % wt KCl in water. The solution is cooled to 293 K at which temperature the solubility is 25.4 % wt. The weight of the crystals obtained if 5 % of the original water evaporates on cooling is
    a. 400 kg
    b. 238 kg
    c. 200 kg
    d. 480 kg

34. If an aqueous solution of 25 % wt $MgSO_4$ at 140°F is cooled to 30°F, the mother liquor concentration will be _____ % wt $MgSO_4$
    a. 10
    b. 18
    c. 24
    d. 4

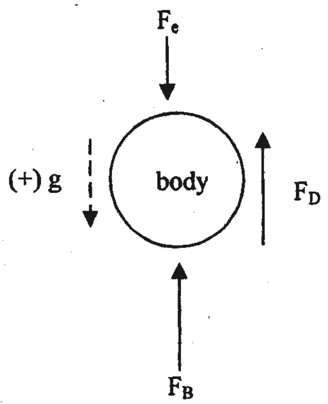
35. Referring to Problem *34*, the type of crystals formed is
    a. $MgSO_4 \bullet 12H_2O$
    b. $MgSO_4 \bullet 2H_2O$
    c. $MgSO_4 \bullet 7H_2O$
    d. $MgSO_4 \bullet 10H_2O$

13. SEDIMENTATION

THEORY AND EQUATIONS

Sedimentation – separation of dilute slurry (solid suspended in fluid) into a clear fluid and dense slurry (higher solid content) by gravity setting.

A. *Mechanism of Particle Motion Through a Fluid*



Newton's Law: $\sum F = Ma$: $F_e - F_b - F_D = \frac{m}{g_c}\frac{du}{dt}$

where External Force, $F_e = \frac{ma_e}{g_c}$; Buoyant Force, $F_b = \frac{m\rho a_e}{g_c}$

Drag Force, $F_D = \frac{C_D u^2 \rho}{2g_c}$

substituting and re-arranging, $\frac{du}{dt} = a_e\left(\frac{\rho_p - \rho}{\rho_p}\right) - \frac{C_D u^2 \rho A_p}{2m}$

If external force is due to gravity, $a_e = g$

If external force is due to centrifugal action: $a_e = r\omega^2$

B. *Terminal Velocity for Free Settling*

When the velocity of the particle attains the maximum (or terminal) velocity,

du/dt = 0, thus $u_t = \left[\frac{2g(\rho_p - \rho)m}{A_p \rho_p \rho C_D}\right]^{1/2} = \omega\left[\frac{2r(\rho_p - \rho)m}{A_p \rho_p \rho C_D}\right]$

For spherical particles: $m = \frac{1}{6}\pi D_p^3 \rho_p$ and $A_p = \frac{1}{4}\pi D_p^2$

$$u_t = \left[\frac{4g\,D_p(\rho_p-\rho)}{3\rho C_D}\right]^{1/2} = \omega\left[\frac{D_p(\rho_p-\rho)}{3\rho C_D}\right]^{1/2}$$

Experimental determination of C_D in terms of $N_{\text{Rep}} = \frac{D_p u_t \rho}{\mu}$ yields a curve that can be reduced to three straight lines which is dependent on the range of N_{Rep}. The general form of the equation is: $C_D = \frac{b_1}{N_{\text{Re,p}}^n}$ and $F_D = \frac{\mu^n b_1 \pi \left(D_p u_t\right)^{2-n} \rho^{1-n}}{8\,g_c}$

RANGE OF MOTION	N_{Rep}	b_1	n
Stoke's Law	< 2	24	1
Intermediate Law	2 to 500	18.5	0.6
Newton's Law	> 500	0.44	0

For Stoke's Law Range: $u_t \frac{g\,D_p^2(\rho_p-\rho)}{18\mu} = \frac{\omega^2 r D_p^2(\rho_p-\rho)}{18\mu}$

To determine the range of motion if N_{Rep} is not known, $K = D_p\left[\frac{a_e\rho(\rho_p-\rho)}{\mu^2}\right]^{1/3}$

If K < 3.3, Stoke's Law applies; 3.3 < K < 44, Intermediate Law; and K > 44, Newton's Law.

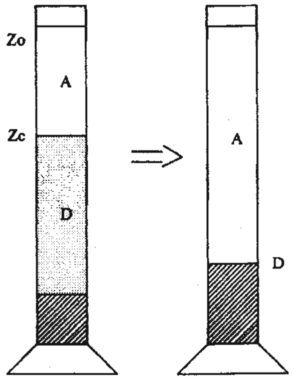
C. *Terminal Velocity for Hindered Settling*

$$u_t = \left[\frac{4\,a_e D_p^{1+n}\varepsilon^{2-n}\left[\varphi(\varepsilon)\right]^n(\rho_p-\rho_m)}{3\,b_1\rho_m^{1-n}\mu^n}\right]^{1/3}$$

where ε = porosity and ρm = density of mixture

For spheres under Stoke's Law range: $\varphi(\varepsilon) = e^{-4.19(1-\varepsilon)}$

D. *Batch Sedimentation*



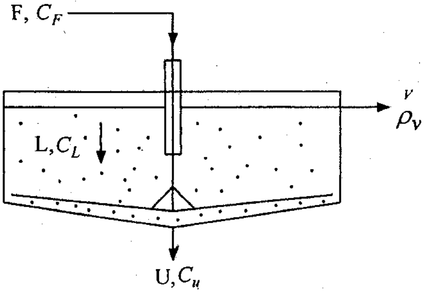
For Free Settling: $\theta_c = \frac{Z_o - Z_c}{u_t}$

For Hindered Settling: $\frac{dZ}{d\theta} = K(Z - Z_\infty)$

integrating, $\int_{\theta_c}^{\theta} K d\theta = \int_{Z_c}^{Z} \frac{dZ}{Z - Z\infty}$

$$\theta = \theta_c + \frac{1}{K}\ln\frac{Z - Z_\infty}{Z_c - Z_\infty}$$

E. *Continuous Sedimentation (Area of a Dorr Thickener)*



Assuming that the concentration of solids is small, $\rho_F = \rho_U = \rho_v = \rho$

Solid Balance: $FC_F = LC_L = UC_u$

Water Balance: $V = L(1 - C_L) - U(1 - C_u)$

Which may be written in the form: $V = LC_L\left(\frac{1}{C_L} - \frac{1}{C_u}\right)$

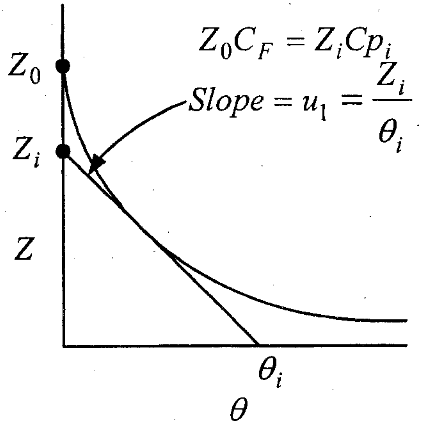
Dividing by the thickener area, A: $\frac{V}{A} = \frac{FC_F}{A}\left(\frac{1}{C_L} - \frac{1}{C_u}\right)$

For the particles to be separated, $\frac{V}{A} < u_t$,

therefore $A = \frac{FC_F}{u_t}\left(\frac{1}{C_L} - \frac{1}{C_U}\right)$

Thus, the minimum thickener area, A, should be the maximum obtained using various values of u_t versus C_L.

To get approximate values of u_t versus C_L from a data of Z vs θ use *Kynch Method* or *Talmadge* and *Fitch Method.*



REVIEW QUESTIONS AND PROBLEMS

1. If the motion of a particle is impeded by other particles, which will happen when the particles are near each other even though they are not actually colliding, the process is called
    a. free settling
    b. unhindered settling
    c. gravity settling
    d. hindered settling

2. The drag coefficient in hindered settling is
    a. greater than
    b. less than
    c. constant
    d. varying

   compared to free settling.

3. The operation by which solids are separated from liquids due to difference in their respective densities is
    a. screening
    b. adsorption
    c. sedimentation
    d. absorption

4. The separation of solid particles into several size fractions based upon the settling velocities in a medium is called
    a. settling
    b. filtration
    c. flotation
    d. classification

5. Device in which a current of air separates particles with different sedimentation velocities.
    a. agitator
    b. air elutriator
    c. classifier
    d. air conveyor

6. The constant velocity with which a body moves relative to the surrounding fluid when the forces acting on it (gravitational, centrifugal, and electrostatic forces) are equal to the friction force acting against the movement.
    a. terminal velocity
    b. settling velocity
    c. maximum velocity
    d. all of these

7. An apparatus in which particles settle in a liquid by gravitational or centrifugal force and are removed as a concentrated slurry.
    a. classifier
    b. thickener
    c. elutriator
    d. agitator

8. Determine the terminal settling velocity of dust particles having a diameter of 60 microns at 294.3K and 101.32 kPa. The dust particles can be considered spherical with a density of 1,280 kg/m^3. For air: $M = 0.01828 \times 10^{-5}\ P_a - S$ and $P = 1.202$ kg/m^3.
    a. 0.18 m/s
    b. 0.14 m/s
    c. 0.2 m/s
    d. 0.09 m/s

9. Solid spherical particles having a diameter of 0.09 mm and a solid density of 2,002 kg/m^3 are settling in a solution of water at 26.7°C. The volume fraction of the solids in the solution is 0.45. The settling velocity is (For H_2O P = 994.7 kg/m^3 and M = 0.861 x 10^{-3} P_a – S)

   a. 5.3 x 10^{-3} m/s
   b. 3.269 x 10^{-3} m/s
   c. 2.369 x 10^{-4} m/s
   d. 3 x 10^{-5} m/s

10. A random handful of silica particles ranging in size from 28 mesh to 200 mesh is thrown to a very deep body of water (without tides or turbulence).

    Data:
    Viscosity of water = 0.01 poise
    Density of silica = 2.65 g/cm^3
    28 mesh: 0.0589 cm
    200 mesh: 0.0074 cm

    The distance between the largest and smallest particle after 10 min is

    a. 4700 cm
    b. 4900 cm
    c. 5000 cm
    d. 4000 cm

11. A gravity settling tank is to be used to clean waste water from an oil refinery. The waste water contains 1% oil by volume as small droplets ranging in size from 100 to 1000 microns which will be removed from the water before the latter is to be discharged into the river. The tank is of rectangular section 2 ft wide by 4 ft deep with provisions for smooth continuous discharge of clean water and skimming off of oil at the surface of the discharge end. If 10,000 gal/min of waste water is to be cleaned of oil droplets, specific gravity of oil 0.87, the length of the settling tank is

    a. 4500 ft
    b. 4850 ft
    c. 5000 ft
    d. 4000 ft

12. A laboratory test on a suspension of a solid in a liquid gave the following information:

Original height of sludge before settling	10 in.
Free settling rate	0.10 in./min
Height of sludge at the end of free-settling period	6.5 in.
Height of the sludge at the end of 120 minutes	4 in.
Height of sludge when settled completely	1.5 in.

    One thousand cubic feet of similar sludge is to be settled in a vertical cylindrical tank, the diameter of which is equal to the depth of the liquid suspension in it. The time it would take for the solid to settle to a height of 20% of the original height of the sludge is

    a. 78.5 hours
    b. 65 hours
    c. 68.5 hours
    d. 85.8 hours

13. Free settling of sludge is 0.25 cm/min. Using an original height of 25 cm, the sludge settled to height of 18 cm after the free-settling period. The sludge was found to settle to a height of 10 cm after 110 min. This particular sludge was found to settle completely to a height of 4 cm. The time to settle to a height of 1/5 of its original height in a cylindrical tank whose diameter is 85% of its depth if it is 85% full and consider 1000 cu ft of sludge in the tank is

    a. 62.4 hours
    b. 54.2 hours
    c. 46.2 hours
    d. 65.4 hours

14. Square mica plates, 1/32 in. thick and 0.01 sq. in area are falling randomly through oil with a density of 55 lb/cu ft and with viscosity of 15 centipoise. The specific gravity of the mica is 3.0, the settling velocity is
    a. 6.2 cm/s
    b. 7.2 cm/s
    c. 5.2 cm/s
    d. 4.2 cm/s

15. In a motion of a particle through fluids, forces act on a particle moving through a fluid. The force which appears whenever there is a relative motion between the particle and the fluid is called
    a. gravitational force
    b. centrifugal force
    c. drag force
    d. buoyant force

16. An intimate mixture of two different ores of densities 2600 kg/m^3 (A) and 5100 kg/m^3 (B) is finely ground and given a screen analysis. The various fractions collected on the screens are then analyzed chemically to determine the amount of each ore in each size fraction, and in this way the following particle size analysis for each component of the original mixture is obtained.

Diameter, microns	15	25	35	45	55	65	75	85	95
% undersize, A	0	22	35	47	59	68	75	81	100
% undersize, B	0	0	21	33.5	46	57.5	67	75	100

The ratio of the heavy ore to the light ore in the mixture was by analysis, 1:5 by weight. If the ores are to be separated from the original mixture by elutriation using water at a velocity of 4.00 x 10^{-3} m/s and a temperature of 18°C, the composition of the bottom product in terms of A is
    a. 33 %
    b. 72 %
    c. 67 %
    d. none of these

17. Referring to Problem *16*, the liquid velocity in m/s required to produce a bottoms product that does not contain any lighter particles is
    a. 2.4 x 10^{-3}
    b. 7.4 x 10^{-3}
    c. 9.4 x 10^{-3}
    d. none of these

18. A continuous thickener is required to concentrate a slurry of calcium carbonate in water from a solids content of 50 kg/m^3 to 130 kg/m^3, and to produce a clear overflow containing no calcium carbonate. The density of the dry calcium carbonate is 2300 kg/m^3. A single batch sedimentation test produced the experimental result below:

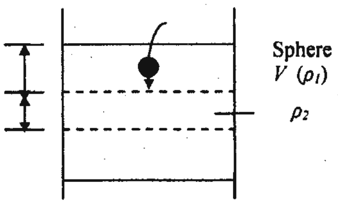
Time, hr	0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Z, m	1.1	0.98	0.82	0.68	0.54	0.42	0.35	0.31	0.28	0.27	0.27

If the thickener is fed with slurry at a rate of 0.06 m^3/s, the minimum thickener area in square meter that is required is
    a. 1005
    b. 505
    c. 1505
    d. none of these

19. The flow rate of clarified water for Problem *18* in m^3/s is
    a. 0.025
    b. 0.062
    c. 0.037
    d. none of these

Problems *20* and *21* are based on the following information and illustration:

In an experiment, a sphere of density ρ_1 and radius r is dropped in a tank of oil of viscosity μ_1 and density ρ_2. The time of descent of the sphere through the first section of height d is recorded as t_1 and through the second section of the same height as t_2, $0 < t_2 - t_1 << 1$.



20. Which of the following is true for the experiment?
    a. The drag force exerted on the sphere increases during its descent through the second section.
    b. The sphere never reaches its terminal velocity while falling through both sections.
    c. The sphere reaches its terminal velocity while falling through the first section.
    d. The drag force exerted on the sphere decreases during the descent through the second section.

21. The drag force exerted on the sphere during its descent through the second section is
    a. $(\rho_1 - \rho_2) g \frac{4}{3} \pi r^3$
    b. $\rho_1 g \frac{4}{3} \pi r^3$
    c. $\frac{4}{3} \pi r^3 \rho_1 g - 6\pi\mu_1 r \left(\frac{d}{t_2}\right)$
    d. $\frac{4}{3} \pi r^3 \rho_1 g + 6\pi\mu_1 r \left(\frac{d}{t_2}\right)$

22. Drag is defined as the force exerted by
    a. the fluid on the solid in a direction opposite to the motion of the solid
    b. the fluid on the solid in the direction of motion of the solid
    c. the solid on the fluid
    d. none of these

23. Drag coefficient for flow past an immersed body is the ratio of
    a. shear stress to the product of velocity head and density
    b. shear force to the product of velocity head and density
    c. average drag per unit projected area to the product of the velocity head and density
    d. none of these

24. Stoke's Law is valid when the particle Reynolds Number is
    a. <1
    b. <5
    c. >1
    d. none of these

25. Drag coefficient C_D is given by the Stoke's Law range
    a. $C_D = \frac{16}{\text{Re},_p}$
    b. $C_D = \frac{18.4}{\text{Re},_p}$
    c. $C_D = \frac{24}{\text{Re},_p}$
    d. $C_D = \frac{0.079}{\text{Re},_p^{0.23}}$

26. At low Reynolds Number
    a. viscous forces are unimportant
    b. viscous forces control
    c. viscous forces control and inertial forces are unimportant
    d. gravity forces control

27. At high Reynolds Number
    a. inertial forces control and viscous forces are unimportant
    b. viscous forces predominate
    c. inertial forces are unimportant and viscous forces control
    d. none of these

28. The ratio of drag force per unit area to the product of fluid density and the velocity head is called
    a. buoyant coefficient
    b. drag coefficient
    c. friction factor
    d. shear coefficient

29. In order for a particle to move through a fluid under the influence of gravity, there must be
    a. velocity difference
    b. pressure difference
    c. density difference
    d. temperature difference

30. In continuous thickeners, separation of solid particles can be achieved if the settling velocity of the solids is _______ compared to the velocity of the displaced liquid
    a. equal
    b. less
    c. greater
    d. none of these

14. CENTRIFUGATION

THEORY AND EQUATIONS

Centrifugation – a mechanical process of separating multi-phase mixture (usually fluid-solid system) via the use of centrifugal force.

A. *Centrifugal Force*

Acceleration due to centrifugal force, $a_e r\omega^2$,

where r = radius and ω = angular velocity, rad/s

Centrifugal Force, $F_c = ma_e mr\omega^2 = \frac{mv^2}{r}$, where v = linear velocity

In terms of the rotation, N in rev/min, $\omega = \frac{2\pi N}{60}$, and $N = \frac{60\omega}{2\pi} = \frac{60v}{2\pi r}$

Force ratio: $\frac{F_c}{F_g} = \frac{mr\omega^2}{mg} = \frac{v^2}{rg} = \frac{r}{g}\left(\frac{2\pi N}{60}\right)^2$

B. *Clarifying Centrifuge*

Settling process (sedimentation) due to the difference in densities of the solid and fluid media. The most common type of equipment used is a Sharples Centrifuge.

Assuming *Stoke's Law* applies: Centrifugal force balance on solid in the fluid media gives

$$u_t = \frac{\omega^2 r\left(\rho_p - \rho\right)D_p^2}{18\mu}$$

$$u_t = \frac{\omega^2 r\left(\rho_p - \rho\right)D_p^2}{18\mu} = \frac{dr}{dt}$$

integrating the above equation for a Sharples centrifuge will give the capacity, q_c given by

$$q_c = \frac{\pi b\omega^2\left(\rho_p - \rho\right)D_{pc}^2}{18\mu}\left[\frac{r_2^2 - r_1^2}{\ln\frac{2r_2}{r_1 + r_2}}\right]$$

where q_c is the capacity or the flow rate of slurry such that particles larger than the cut size D_{pc} can be separated

If the thickness of the fluid in the centrifuge is small, u_t is constant, and the capacity becomes, $q_c = \frac{2\pi b\omega^2\left(\rho_p - \rho\right)D_{pc}^2 r_2^2}{9\mu}$

C. *Centrifugal Filtration*

For filtration, $-\Delta P = \frac{\mu v}{g_c}\left(\frac{m_c a}{A} + R_m\right)$ but $\Delta P = \frac{\rho\omega^2 (r_2^2 - r_1^2)}{2g_c}$ and $v = \frac{q}{A}$

therefore, the capacity of a centrifugal filter becomes,

$$q = \frac{\rho\omega^2\left(r_2^2 - r_1^2\right)}{2\mu\left(\frac{\alpha m_c}{A^2} + \frac{R_m}{A}\right)}$$

If change in area with radius is large,

$$q = \frac{\rho\omega^2\left(r_2^2 - r_1^2\right)}{2\mu\left(\frac{\alpha m_c}{A_L A_a} + \frac{R_m}{A_2}\right)},$$

where $A_a = (r_i + r_2)\pi b$ and $A_L = 2\pi b\,(r_2 - r_i)/\ln(r_2/r_i)$

$A_2 = 2\pi\, r_2\, b$

REVIEW QUESTIONS AND PROBLEMS

1. The capacity in cubic meters per hour of a clarifying centrifuge operating under these conditions is

Diameter of the bowl = 600 mm
Thickness of liquid layer = 75 mm
Depth of bowl = 400mm
Speed = 1200 rpm/min
Specific gravity of liquid = 1.2
Specific gravity of solid = 1.6
Viscosity of liquid = 2 cp
Cut size of particles = 30 μm

a. 200 m^3/h
b. 310 m^3/h
c. 320 m^3/h
d. 210 m^3/h

2. If a centrifuge is 3 ft diameter and rotates at 1,000 rpm, the speed of a laboratory centrifuge of 6 in. diameter be ran if it is to duplicate plant conditions is

a. 2500 rpm
b. 2449 rpm
c. 2469 rpm
d. 2000 rpm

3. The terminal velocity of the 10 micron particles (specific gravity = 1.2) clarified out of water in the laboratory centrifuge in Problem *2* is

a. 560 ft/s
b. 565 ft/s
c. 5564.5 ft/s
d. 556 ft/s

4. In a test conducted using a laboratory centrifuge, it was found that the optimum recovery of protein from coconut oil was achieved with an rpm of 2,500. Industrial size centrifuge comes in 2.5, 3.0, 3.5, 4.0, and 5.0 ft diameter with warranty if the centrifuge is operated not over 1,000 rpm. For optimum commercial operations, the centrifuge size you will recommend is

Data : Laboratory Centrifuge
Height = 9 in.
Diameter = 5 in.
rpm = 2,000 to 3,000

a. 2.5 ft
b. 3.0 ft
c. 3.5 ft
d. 4.0 ft

5. Determine the filtration rate that can be expected from a basket centrifugal filter using the data below :

Basket height = 12 in.
Inside basket diameter = 26 in.
Rotation rate = 2,000 rpm
Material to be filtered:
gypsum slurry, α = 2.52×10^{11} ft/lb
ε = 0.5
Specific gravity of $CaSO_4 \cdot 2H_2O$ = 2.65

Assume that the cake is incompressible, filter medium resistance is negligible and the liquid surface corresponds to the filter cake surface and the thickness of the cake is 1 in.

a. 0.60 gpm
b. 0.95 gpm
c. 0.85 gpm
d. 0.43 gpm

6. A batch centrifugal filter having a bowl diameter of 750 mm and a bowl height of 450 mm is used to filter a suspension having the following properties :

Temperature: liquid, water = 25°C
Porosity of cake = 0.435
Final thickness of cake = 150 mm
Specific cake resistance = 9.5×10^{10} ft/lb
Filter medium resistance = 2.6×10^{10} per ft
Speed of centrifuge = 2,000 rpm
Concentration of solids in feed = 60 g/li
Density of dry solid in cake = 2000 kg/m^3

The final cake is washed with water under such conditions that the radius of the inner surface of the liquid is 200 mm. Assuming that the rate of flow of wash water equals the final rate of flow of filtrate, the rate of washing in m^3/hr ?

a. 0.60
b. 0.40
c. 0.75
d. 0.85

7. The capacity of a Sharples centrifuge is estimated to increase/decrease by _____% if its speed is doubled and the cut size of the particles is reduced by 20%.

a. 20% increase
b. 156% increase
c. 80% decrease
d. none of these

8. A centrifuge with a bowl which is 500 mm long and has an inside radius of 50.5 mm is to be used to separate crystals from a dilute aqueous mother liquor. The optimum speed of rotation for the centrifuge is 60,000 rpm, and the discharge weir is adjusted so that the depth of liquid at the bowl wall is 38.5 mm. The crystals are approximately spherical and none are smaller that 2×10^{-6} m in diameter. The maximum volumetric flow rate in m^3/s of the mother liquor that can be processed by this centrifuge if all the crystals have to be removed is
   a. 0.054
   b. 0.024
   c. 0.154
   d. none of these

9. A centrifuge with a radius of 76.2 mm rotates at a peripheral velocity of 53.34 m/s. The centrifugal force developed compared to gravitational force in the bowl centrifuge is
   a. 2800 g
   b. 3100 g
   c. 3800 g
   d. 4250 g

10. A centrifuge bowl is spinning at a constant speed of 2000 rpm. The radius of bowl in cm needed to create a force of 455 g is
    a. 10.2
    b. 5.8
    c. 12.0
    d. 8.5

11. For the separation of sugar solution from settled out mud, we use
    a. sparkler filter
    b. plate and frame filter
    c. centrifugal filter
    d. rotary drum vacuum filter

12. Moisture can be removed from lubricating oil using
    a. tubular centrifuge
    b. clarifier
    c. sparkler filter
    d. vacuum leaf filter

13. Which of the following can be most effectively used for clarification of tube oil and printing ink?
    a. sparkler filter
    b. precoat filter
    c. disc-bowl centrifuge
    d. sharpless supercentrifuge

14. If the radius of a basket centrifuge is halved and the rpm is doubled, then the
    a. linear speed of the basket is doubled
    b. linear speed of the basket is halved
    c. centrifugal force is doubled
    d. capacity of centrifuge is increased

15. Where the difference in density of the two liquid phases to be separated is very small (as in milk cream separator), the most suitable separator is
    a. disc bond centrifuge
    b. sharpless supercentrifuge
    c. batch basket centrifuge
    d. sparkler filter

MEMBRANE SEPARATION

REVIEW QUESTIONS AND PROBLEMS

1. A membrane separation process where a component from a heated liquid phase permeates through the membrane and is removed under low pressure is
   a. reverse osmosis
   c. dialysis
   b. pervaporation
   d. microfiltration

2. In the removal of a solute from a water phase by liquid extraction using a membrane, it is advantageous to use
   a. a polymer membrane
   c. any porous membrane
   b. a hydrophobic membrane
   d. an asymmetric membrane

3. A solution containing equimolal O_2 and N_2 is passed through a membrane to separate O_2 from N_2. The final product is found to contain 45% O_2 and 55% N_2. Find the percentage O_2 remaining if only 20% of the original solution passed through the membrane.
   a. 51 %
   c. 50 %
   b. 15 %
   d. 45 %

4. In a membrane separation process, an asymmetric membrane refers to
   a. a series of polymer membranes
   b. a composite polymer and porous membrane
   c. a membrane that is not uniform in thickness
   d. a membrane that is not symmetrical in thickness

5. The osmotic pressure of a solution containing a 0.10 g mol NaCl/1000 g water at 25°C is
   a. 2.44 atm b. 1.22 atm c. 4.88 atm d. none of these

6. An experimental hollow fiber membrane (d_o= 500 μm, d_i = 400 μm) inside a tube with an inside diameter of 900 μm is used for desalination of water. Salt water flows at a velocity of 1 cm/s inside the annular space at a pressure of 40 atm while the permeate pressure is 2 atm. The osmotic pressure difference between feed and product may be taken as 5 atm. The dense layer of the membrane is about 0.1 μm with a salt rejection of 99.5%. The water content is about 0.2 gm/cm^3 and the diffusivity of water and salt may be taken as 10^{-6} and 5×10^{-8} cm^2/s, respectively. If the operating temperature is 30°C, the diffusion flux of water in cm/s is
   a. 9.0×10^{-4} b. 4.8×10^{-4} c. 1.2×10^{-4} d. none of these

7. The polarization factor for the process in Problem *6* is
   a. 430 b. 2.8 d. 700 d. none of these

8. The pressure drop expected through the membrane in Problem *6* if the length is one meter and one end is closed is
   a. 2.0 atm b. 12.5 atm c. 4.8 atm d. none of these

9. **If the pressure in the upstream side of a membrane is very much higher** compared to **that in the permeate side, then the concentration** of the feed is __________ if the **selectivity is 8 and the permeate** composition is 0.35 mole fraction.
   a. **0.063** b. 0.20 c. 0.15 d. none of these

10. Referring to Table 17-7, Perry the selectivity of H_2-N_2 in a polychloroprene membrane at 25°C is estimated to be ___________.
    a. 11.7 b. 25.2 c. 38.1 d. none of these

11. The estimated effective diffusivity of CO_2 through a DuPont cellophane 600 P.D. at 300 K is ____________ cm^2/s.
    a. 8.0 x 10-4 b. 1.15 x 10-4 c. 4.35 x 10-4 d. none of these

12. A membrane having a thickness of 2 x 10^{-3} cm, a permeability of A equal to 400 x 10^{-10} cm^3(STP)-cm/(s-cm^2-cm-Hg), and a selectivity of 10 is to be used to separate a gas mixture of A and B. The feed flow rate is 2 x 10^3 cm^3 (STP)/s and its composition is 0.413 mole fraction A. The feed side pressure is 80 cm Hg and the permeate side pressure is 20 cm Hg. The reject composition is to be 0.30 mole fraction A. Using the arithmetic method, calculate the permeate composition.
    a. 0.738 b. 0.262 c. 0.523 d. none of these

13. Referring to Problem *12*, the percent of the feed that permeated is
    a. 25.8% b. 12.5% c. 72% d. none of these

14. The area in square centimeters of the membrane used in Problem *12* is estimated to be
    a. 10^6 b. 6.9 x 10^6 c. 9.8 x 10^6 d. none of these

15. A process where components are separated from each other using a semi-permeable membrane by virtue of their different diffusion rates through the membrane is referred to as
    a. osmosis b. pervaporation c. dialysis d. ultra-filtration

FLOTATION

THEORY AND EQUATIONS

Flotation – includes any operation in which one solid is separated from another by floating one of them on the surface of the fluid.

Flotation Process

It involves chemical treatment of the ore pulp to create conditions favorable for the attachment of certain mineral particles to the air bubbles. The air bubbles carry the selected minerals on the surface of the pulp which is skimmed off while the other minerals submerged at the bottom.

Flotation Reagents Used

1. *Frothers* – added to strengthen temporarily covering film of the air bubbles. It serves to stabilize the froth and holds the minerals until the froth can be scraped off into the concentrate launder.

   Commonly used frothers:
   - a. pine oil
   - b. cresylic acid
   - c. polypropylene glycol ether
   - d. 5 to 8 carbon aliphatic alcohols

   Examples: methyl isobutyl carbinol and methyl amyl alcohol

2. *Promoters* or *collectors* – alter the surface of the mineral in order that it will become air-avid (to cause it to adhere to air bubbles)

   Examples:
   - a. xanthates; dithiophosphates
     - – for flotation of metallic sulfides and native metals
   - b. crude or refined fatty acids and their soaps; petroleum; sulfonates; sulfonated fatty acids
     - – for flotation of fluorspar, phosphate rock, iron ore and other non-metallics
   - c. fatty amines; amine salts
     - – for flotation of quartz, potash and silicate minerals
   - d. fuel oil; kerosene
     - – for coal, graphite, sulfur and molybderite

3. *Activators* – enhance the absorption of a collector by mineral particles

   Examples: copper ion and sodium sulfide

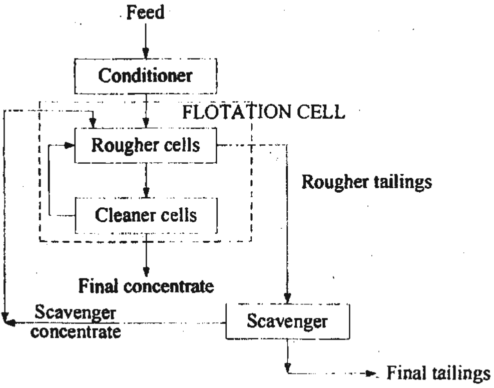
4. *Depressors (or depressants)* – prevent the absorption of a collector by a mineral particle and thereof inhibit the flotation of minerals

   Examples: sodium or calcium cyanide; zinc sulfate; sodium ferrocyanide; lime; quebracho; lignin sulfonates

5. *Regulators (conditioners)* – substances added to maintain the proper *pH.*

   Examples: lime; caustic soda; soda ash; sulfuric acid

Typical Arrangement of a Flotation Unit



Analysis: (By material balance on each unit)

Data:

1. density of minerals
2. L/S, water to solid ratio
3. composition of feed, concentrate and tailings
4. reagents
5. contact time
6. type of flotation cells

REVIEW QUESTIONS AND PROBLEMS

1. Any operation in which one solid is separated from another by floating one of them at or on the surface of a fluid.
   a. coagulation
   b. flotation
   c. centrifugation
   d. sedimentation

2. The flotation agent that prevents coalescence of air bubbles as they travel to the surface of the water is/are
   a. collectors
   b. promoters
   c. frothing agent
   d. modifying agent

3. A flotation plant processes 3,000 tons/day of $CuFeS_2$ (chalcopyrite). It produces 80 tons Cu concentrate assaying 25% Cu. If ore analyzes 0.7% Cu, the percent recovery is
   a. 90.5 %
   b. 98 %
   c. 92.54 %
   d. 95.24 %

4. A flotation modifier which assists in the selectivity (sharpness of separation) or stop unwanted minerals from floating.
   a. depressants
   b. activators
   c. alkalinity regulators
   d. promoters

5. Dispersants are important for the control of slimes which sometimes interfere with the selectivity and increase reagent consumption. Another term for dispersant is
   a. deflocculant
   b. depressants
   c. frothers
   d. regulators

6. An example of a collector for flotation of metallic sulfides and native metals is
   a. xanthates
   b. sodium silicate
   c. sodium sulfide
   d. sphalerite

7. Which of the following is an example of a deflocculant?
   a. sulfuric acid
   b. lignin sulforate
   c. dithiophosphate
   d. molybderite

Problems *8* and *9* are based on the following information :

A flotation section of a mining company is extracting CuS from covellite ores. The ore consists of 5% CuS and 95% gangue, which may be assumed to be SiO_2. The following data are given :

	% CuS	*% SiO_2*
Feed	5	95
Concentrate	85	15
Rougher tailings	1	99
Scavenger concentrate	10	90
Final tailings	0.3	99.7

Laboratory experiments indicated that the water to solids ratio, L/S = 2 and the contact time is 10 min. in the rougher; L/S = 4, contact time = 18 min. in the scavenger. On the basis of 300 tons per day of ore treated.

Data: Density of SiO_2 = 2.65 g/cc
Density of CuS = 4.6 g/cc

8. The volume of the rougher needed is
   a. 179.8 ft^3
   b. 170 ft^3
   c. 175 ft^3
   d. 169.8 ft^3

9. The volume of the scavenger needed is
   a. 525 ft^3
   b. 520 ft^3
   c. 535 ft^3
   d. 435 ft^3

Problems *10* and *11* are based on the following information:

Ground lead ore is to be concentrated by a single flotation process using 1.5 oz of reagent per ton of ore. The feed concentrate and tailings have the following composition by weight on a dry basis:

	Feed %	*Concentrate %*	*Tailings %*
PbS	30	90	0.9
ZnS	25	3	35.6
SiO_2	45	7	63.5

Water is fed to the cell at the rate of 1,000 gallons per ton of wet concentrate with 99% of the water leaving with the tailings and 1% with the concentrate.

10. Mass of wet concentrate produced per hour when ten tons of ore are fed to the cell per 24 hours is
    a. 3.4
    b. 4.3
    c. 14.23
    d. 4.7

11. Total water required in pounds per hour is
    a. 1150
    b. 1200
    c. 1185
    d. 1285.8

12. A typical flotation machine has the following specifications :

Number of cells = 4
Flotation time = 12 min
Cell volume = 60 cu.ft
Hp per cell = 10 Hp

The material treated has the following specifications :
Pulp (mixture of ore and water) = 40% solids
Specific gravity of ore = 3

Equation : $n = \dfrac{\text{T x Cap x d}}{\text{V x 1440}}$

where n = number of cells
V = volume in cu. ft. per cell
Cap = tons of dry ore per 24 hours
d = cu. ft. of pulp (ore and water) containing one ton (2,000 lbs) of solids

The capacity of the machine in tons of dry ore per 24 hours is
    a. 590
    b. 390
    c. 490
    d. 450

13. Froth Flotation is most suitable for treating
    a. iron ores
    b. sulfide ores
    c. quartz
    d. metal ores

14. In Froth Flotation, the chemical agent added to cause air adherence is called
    a. collector
    b. frother
    c. modifier
    d. promoter

15. Pine oil used in forth flotation technique acts as a
    a. collector
    b. modifier
    c. frother
    d. activator

17. ADSORPTION

THEORY AND EQUATIONS

Adsorption – concentration of a substance on the surface of a solid or a liquid.

The substance attracted to a surface is the adsorbed phase, while the substance to which it is attached is the adsorbent.

Adsorption of Gases by Solids

Factors determining the amount of gas adsorbed by a solid

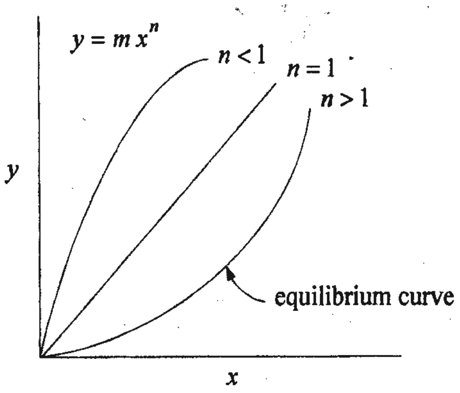
1. Nature of the adsorbent and the gas being adsorbed
2. Area of the adsorbent
3. Temperature of the gas
4. Pressure of the gas

Types of Adsorption

1. ***Physical of Van Der Waal's Adsorption*** – occurs when the intermolecular forces of attraction between the fluid molecules and the solid surface are greater than the attractive forces between molecules of the fluid itself. Fluid molecules adhere to the surface of the solid adsorbent. The forces responsible for the adsorption are of the same find as are involved in the deviation of gases from ideal behavior and in liquefaction, i.e. Van der Waal's forces.
   – characterized by low heats of adsorption.

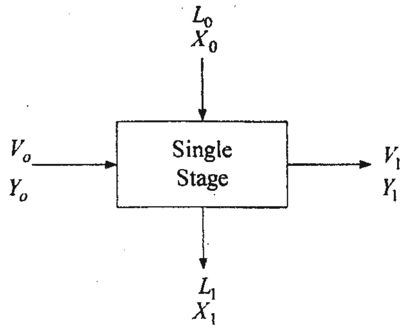
2. ***Chemical or Activated Adsorption*** – involves chemical interaction between the adsorbed fluid and the adsorbent solid. Frequently, the adsorption is irreversible and it is difficult to separate the adsorbate from the adsorbent. Hence, only physical adsorption tends itself to continuous stagewiser operations.

At equilibrium, Freundlich Isotherm,



Adsorption Operations (One Component Adsorption)

I. *Single Stage Operation*



where :

$$x = \frac{\text{mass adsorbate}}{\text{mass adsorbent}}$$

$$y = \frac{\text{mass adsorbate}}{\text{mass solution}}$$

L & V = adsorbent and solution flow streams

Material balance on adsorbate

$$V_oY_o - V_1Y_1 = L_1X_1 - L_oX_o$$

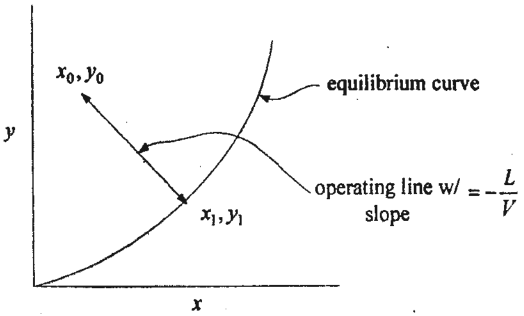
Since $V_o = V_1 = V$ and $L_o = L_1 = L$

$$V(Y_o - Y_1) = L(x_1 - x_0)$$

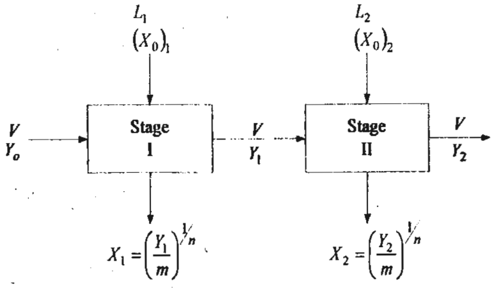
$$\frac{L}{V} = \frac{y_0 - y_1}{x_1 - x_0}$$

$$\frac{L}{V} = \frac{y_0 - y_1}{\left(\frac{y_1}{m}\right)^{1/n} - x_0}$$

$x_0 = 0$ (for pure of fresh adsorbent used)



II. *Two Stage Co-Current Process*



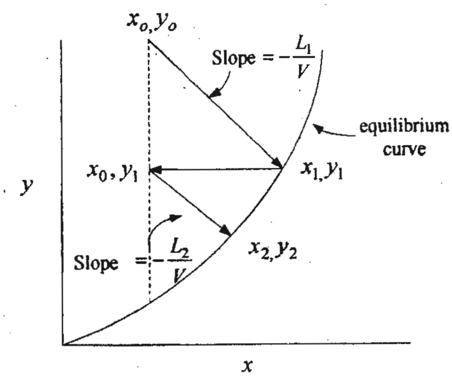
The first stage and second stage operating lines are

$$\frac{L_1}{V} = \frac{y_0 - y_1}{x_1 - (x_0)_1} \quad \text{and} \quad \frac{L_2}{V} = \frac{y_1 - y_2}{x_1 - (x_0)_2}$$

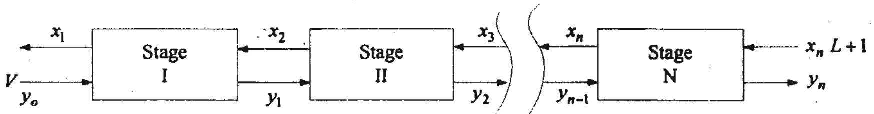
$$\frac{L_t}{V} = \frac{L_1 + L_2}{V} = \frac{y_0 - y_1}{\left(\frac{y_1}{m}\right)^{1/n} - (x_0)_2}$$

$$\frac{d\left(\frac{L_t}{V}\right)}{d\,y_1} = 0 \quad ; \quad (x_0)_1 = (x_0)_2 = 0$$

$$\left(\frac{y_1}{y_2}\right)^{1/n} = \frac{1}{n} \cdot \frac{y_0}{y_1} + \left(1 - \frac{1}{n}\right)$$



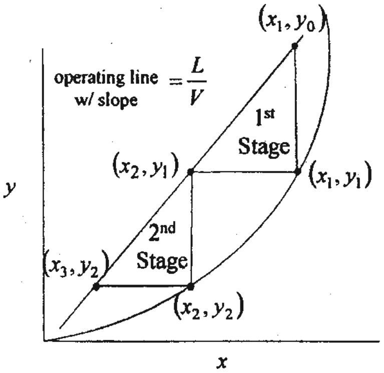
III. *Countercurrent Operation*



$$\frac{L}{V}=\frac{y_0-y_n}{x_1-x_n+1}$$

For 2-stage process:

$$\frac{L}{V}=\frac{y_0-y_2}{x_1-x_3}=\frac{y_1-y_2}{x_2-x_3}$$



REVIEW QUESTIONS AND PROBLEMS

1. A unit operation wherein specific components of a fluid phase (gas or liquid) are preferentially adhered to the surfaces of the solid
   a. adsorption
   b. absorption
   c. chemisorption
   d. leaching

2. The adsorbent used in the purification of hydrocarbon products
   a. alumina
   b. bone char
   c. fuller's earth
   d. silica gel

3. The component adsorbed in adsorption operation is called
   a. adsorbate
   b. adsorbent
   c. absorbed materials
   d. chemisorption

4. A type of adsorption which results in intermolecular forces of attraction between molecules of the solid and the substance adsorbed.
   a. gas-phase adsorption
   b. liquid-phase adsorption
   c. physical adsorption
   d. chemical adsorption

5. Fifty parts of copperas and lime per million parts of dyehouse effluent removes 50% of the color. How much will be required to reduce the color to 5% if n= 8.5 ?
   a. 124.5 ppm
   b. 130 ppm
   c. 120.5 ppm
   d. 126.5 ppm

6. Water contains organic color which is to be extracted with alum and lime. Five parts of alum and lime per million parts of water will reduce the color to 25% of the original color and 10 parts will reduce the color to 3.5%. Estimate how much alum and lime as parts per million are required to reduce the color to 0.5% of the original color.
   a. 16.4
   b. 14.8
   c. 18.5
   d. 15.8

7. In bleaching or removal of coloring substance of material such as coconut oil or sugar, decolorizing agents such as activated carbon is used. Bleaching can be carried out in a single pass, or multipass or other methods. If 80% of the color is removed in a single stage decolorization with 4% activated carbon, the activated carbon that will be needed to remove the same amount of color in a 2-stage counter current decolorization if n = 2 is
   a. 0.025
   b. 0.0223
   c. 0.03
   d. 0.04

Problems *8* and *9* are based on the following information:

It is required to dry natural gas containing 80 lbs of water per 10^6 ft^3 by passing it through a bed of activated alumina gel in two adsorption towers.

Data:

Natural gas to be dried = 1 x 10^6 ft^3/day (24 hrs)
Density of the alumina gel = 50 lb/ft
Economic adsorption factor = 4% water by weight (dry basis)
Critical gas velocity through the tower = 35 fpm
Temperature of natural gas = 50°F
Pressure = 225 psia

Economic adsorption factor refers to the amount of adsorbate per amount of adsorbent used.

8. The height of the tower is
   a. 14.9 ft
   b. 10.8 ft
   c. 15.9 ft
   d. 1.34 ft

9. The weight of the activated alumina gel required is
   - a. 1000 lbs
   - b. 2000 lbs
   - c. 3000 lbs
   - d. 1500 lbs

10. Two identical aqueous solutions containing valuable solute are colored by small amounts of an impurity, to a different extent. The dark solution has a color intensity of 50 units and the light solution has 20 color units, measured on the same arbitrary scale. It is desired to treat an equal amount of light and dark solutions to a color unit of 0.5. The equilibrium adsorption isotherm on activated carbon is given by *Freundlich Equation* $Y = mX^n$ where $n = 1$ and $m = 0.005$ with Y = color units/kg solution and X = color units adsorbed/kg carbon. The color scale is such that colors are additive, i.e., equal weights of solution of color 20 and 50 will give a solution of color (20+50)/2 = 35. In a single stage process, will it be more economical of carbon to first blend the original solutions and to treat the blend, or treat each separately to color 0.5 and to blend the finished products ?
    - a. blend first, treat later
    - b. treat first, blend later
    - c. both a and b
    - d. none of these

11. The following data are for the adsorption of *CO* on wood charcoal at 0°C. The partial pressure *P* of *CO* is in mmHg while *V* is the volume of gas in cc, measured at standard conditions, adsorbed by 2.964 g of charcoal.

P	73	180	309	540	882
V	7.5	16.5	25.1	38.1	52.3

    Determine the constants *m* and *n* of the *Freundlich Equation*. Use units of mmHg, cc, and gram.
    - a. 17, 2.0
    - b. 17, 1.37
    - c. 30, 1.7
    - d. 30, 2.0

12. Physical adsorption is
    - a. an irreversible phenomenon
    - b. a reversible phenomenon
    - c. accompanied by evolution of heat
    - d. both b and c

13. Chemisorption (chemical adsorption) is
    - a. the same as "Van der Waals" adsorption
    - b. characterized by adsorption of heat
    - c. also called activated adsorption
    - d. none of these

14. The rate of adsorption increases as the
    - a. temperature increases
    - b. temperature decreases
    - c. pressure decreases
    - d. size of adsorbent increases

15. When adsorption hysteresis is observed, the desorption equilibrium pressure is
    a. always lower than that obtained by adsorption
    b. always higher than that obtained by adsorption
    c. same as that obtained by adsorption
    d. dependent on the system which can be either lower or higher than that obtained by adsorption

16. Which of the following adsorbents is used to decolorize yellow glycerine?
    a. silica gel
    b. alumina
    c. Fuller's earth
    d. activated carbon

17. Freundlich Equation applies to adsorption of solute from
    a. dilute solutions, over a small concentration range
    b. gaseous solutions at high pressure
    c. concentrated solutions
    d. none of these

18. In case of physical adsorption, the difference between heat of adsorption and heat of normal condensation is
    a. equal to the heat of formation of surface compound
    b. equal to the heat of wetting
    c. zero
    d. called integral heat of adsorption

19. Pick out the wrong statement
    Generally for physical adsorption, a gas of
    a. higher molecular weight is adsorbed in preference to a gas of low molecular weight
    b. high critical temperature is adsorbed in preference to a gas of law critical temperature
    c. low volatility is adsorbed in preference to a gas of high volatility
    d. both b and c

20. The change in enthalpy per unit weight of adsorbed gas when adsorbed on a gas-free or "outgassed" adsorbent to form a definite concentration of adsorbate is called its
    a. integral heat of adsorption
    b. heat of wetting
    c. differential heat of adsorption
    d. heat of normal condensation

21. With an increase in concentration of the adsorbate the integral heat of adsorption
    a. increases
    b. decreases
    c. remains unchanged
    d. may increase or decrease; depends on type of adsorbate

22. The change in enthalpy when a unit quantity of gas is adsorbed by a relatively large quantity of adsorbent (on which a definite concentration of the adsorbed gas already exists) is termed as the
    a. differential heat of adsorption
    b. heat of wetting
    c. integral heat of adsorption
    d. heat of normal condensation

23. As complete saturation of an adsorbent is approached, the differential heat of adsorption approaches
    a. heat of normal condensation
    b. integral heat of adsorption
    c. zero
    d. none of these

24. Ion exchange process is similar to
    a. absorption
    b. extraction
    c. adsorption
    d. leaching

25. CO_2 can be adsorbed by
    a. hot cupric oxide
    b. heated charcoal
    c. cold $Ca(OH)_2$
    d. alumina

18. SCREENING

THEORY AND EQUATIONS

Screening – separates a mixture of various sizes of particles into two or more portions, each of which is more uniform in size of particle than the original mixture.
– passing a material over a surface provided with openings of the desired size.

Dry Screening – the treatment of a material containing a natural amount of moisture or a material that has been dried before screening.

Wet Screening – an operation when water is added to the material being treated for the purpose of washing the fine material through the screen.

Importance of Screening

1. means of preparing a product for sale or for subsequent operation (as in marketing of coal where the size is the basis for its classification for sale)
2. means of analysis, either to control or gauge the effectiveness of another operation such as crushing or grinding (to control the rates of reactions involving solids as in)
3. to determine the value of a product for some specific application

Methods of Indicating Particle Size Distribution

FIRST	SECOND	THIRD
Oversize, $\frac{1}{4}$ in.	$+\frac{1}{4}$ in	$+\frac{1}{4}$ in
Oversize, 20 mesh	+20 mesh	+20 mesh
Through 10 mesh on 20 mesh	-10 + 20	10/20
Through $\frac{1}{4}$ in on $\frac{1}{8}$ in	$-\frac{1}{4}+\frac{1}{8}$	$\frac{1}{4}/\frac{1}{8}$ in
Undersize, 200 mesh	-200	-200

Screen Analyses

Screens – used for control and analytical work. They are constructed of wire mesh cloth, the diameters of the wire and the spacing of the wires are specified
Screen Aperture – clear space between the individual wires of the screen
Mesh – number of apertures per linear inch
Example: A 10-mesh screen will have 10 openings per inch and the aperture will be 0.1 inch minus the diameter of the wire
Screen Interval – relationship between the successive sizes of screen openings in a series

Types of Testing Sieves

1. *Tyler Standard Sieve Series* – series of screens based upon a 200 mesh screen with wire 0.0021 in. thick and with an opening of 0.0029 in (0.0074 cm). The other sizes vary by a fixed ratio of $\sqrt{2}$. The mesh is only up to 400.
2. *United States Sieve Series* – introduced by the National Bureau of Standards differ slightly from the Tyler Series being based on a 1-mm opening (No. 18 mesh) and varying by $\sqrt[4]{2}$.
3. *International Test Sieve Series* – similar to both but the wires have different gauges.

Methods of Reporting Screen Analysis

1. *Differential Screen Analysis or Fractional Plot*

   The data consist of $\lfloor \Delta\phi_n \text{ v.s.} D_{p,n} \rfloor$ or $\lfloor \Delta\phi_n \text{ v.s.} \overline{D}_{p,n} \rfloor$

   where $\Delta\phi_n$ = mass fraction retained by screen, n
   $D_{p,n}$ = particle diameter or mesh opening

   $$\overline{D}_{p,n} = \frac{D_{p,n-1} + D_{p,n}}{2}$$

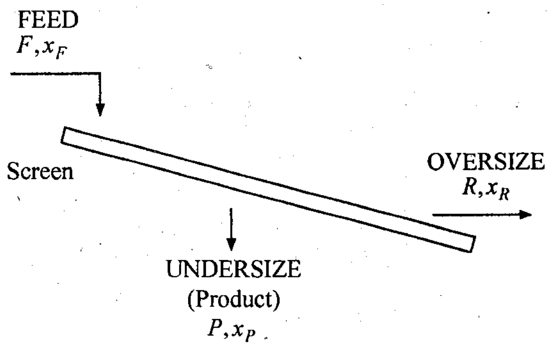
2. *Cumulative Analysis or Cumulative Plot*

   a. The data consist of $\lfloor \phi_n \text{v.s.} D_{p,n} \rfloor$ where $\phi_n = \sum_{n=1}^{N} \Delta\phi_n$

   b. The data consist of $\lfloor (1-\phi_n) \text{v.s.} D_{p,n} \rfloor$ where ϕ_n = fraction larger than $D_{p,n}$
   $1-\phi_n$ = fraction smaller than $D_{p,n}$

   Ordinary rectangular coordinates or logarithmic methods of plotting can be used. However, the logarithmic method is preferred as this spreads the points for the small particles along the dimension scale.

Effectiveness of Screens



Let x = mass fraction of the desired material (in this case the Undersize)

$$\text{Recovery} = \frac{Px_p}{Fx_F}$$

$$\text{Rejection} = 1 - \text{Recovery of Undesired Material} = 1 - \frac{P(1-x_p)}{F(1-x_F)}$$

$$\text{Effectiveness} = (\text{Recovery}) \times (\text{Rejection}),\ E = \frac{Px_p}{Fx_F}\left[1 - \frac{P(1-x_p)}{F(1-x_F)}\right]$$

In terms of mass fraction:

Overall Material Balance: $F = P + R$

Component Material Balance: $Fx_F = Px_p + Rx_R$

$$\frac{P}{F} = \frac{(x_F - x_R)}{x_P - x_R}$$

$$\text{Recovery} = \frac{x_P(x_F - x_R)}{x_F(x_P - x_R)} \qquad \text{Rejection} = 1 - \frac{(1-x_P)(x_F - x_R)}{(1-x_F)(x_P - x_R)}$$

$$\text{Effectiveness} = (\text{Recovery})(\text{Rejection}),\ E = \frac{x_p(x_F - x_R)}{x_F(x_P - x_R)}\left[1 - \frac{(1-x_P)(x_F - x_R)}{(1-x_F)(x_P - x_R)}\right]$$

Industrial Screening Equipment

1. *Grizzlies* – widely used for screening large sizes, particularly of 1 inch and over. The material enters at the top left and works its way downward to the right. The large and oversize particles are discharged over the lower right end and the smaller particles pass through the slots between the bars into the hopper directly below.

2. *Stationary Screens* – made of punched metal plates or woven wire mesh, usually set at an angle with the horizontal up to about 60°. Suitable for small scale operation such as screening sand, gravel or coal.

3. *Vibrated Screens* – used where large tonnages are to be treated. They are particularly useful in the chemical and fertilizer industry. They handle very successfully many light, fine, and dry materials and metal powders. Most of these screens have intense, high speed (1500 to 7200 vibrations/min).

4. *Oscillating Screens* – characterized by low-speed (300 to 400 rpm) oscillations. Screens in this group are usually used from ½ inch to 60 mesh. Silk cloth are often used.

5. *Reciprocating Screens* – used extensively and are standard equipment in many chemical and processing plants for handling fine separations even down to 300 mesh. Used to handle a variety of chemicals, usually dry, light or bulky materials, light metal powders, powdered foods and granular materials.

6. *Trommels or Revolving Screens* – consist of a cylindrical screen rotating about its axis. Revolves at very low speed of 15 to 20 rpm. Efficiency is relatively low.

7. *Gyratory Screens* – box-like machines either round or square with a series of screen cloths nested atop one another.

Testing Sieve Shakers

1. *Ro-Tap Testing Sieve* – equipped with 1 to 13 sieves at a time
2. *End-Strak Testing Sieve Shaker*
3. *Dynamic Sieve Shaker*

Capacity of Screens

The screen capacity indicates how much material a screen can handle.

Expressions of screen capacity:

1. mass of feed $/(time)(area)$: $\frac{MT\ feed}{24\,h - ft^2}$
2. $\frac{\text{mass of feed}}{(time)(area)(aperture)}$: $\frac{MT\ feed}{day - ft^2 - mm}$

REVIEW QUESTIONS AND PROBLEMS

1. The material passing one screening surface and retained on a subsequent surface is called
   a. intermediate material
   b. minus material
   c. plus material
   d. none of these

2. The minimum clear space between the edges of the opening in the screening surface and is usually given in inches or millimeters.
   a. sieve
   b. aperture
   c. mesh number
   d. holes

3. The screen used in making size separation smaller than 4-mesh and larger than 48- mesh.
   a. grizzly screen
   b. gyratory screen
   c. oscillating screen
   d. vibrating screen

4. When the object is to recover an oversize product from the screen, efficiency may be expressed as
   a. ratio of the amount of undersize obtained to the amount of undersize in the feed
   b. using the Taggart Formula, $E = \frac{100(e-v)}{e(100-v)}.100$ where e = percentage of undersize in the feed; v = percentage of undersize in the screen oversize
   c. ratio of the amount of oversize obtained to the amount of true oversize
   d. none of these

5. The wire diameter of a 14-mesh screen (Tyler Standard) is
    a. 0.0235 in.　　c. 0.028 in.
    b. 0.025 in.　　d. 0.03 in.

6. Box-like machines, either round or square with a series of screen clothes nested atop one another.
    a. reciprocating screen　　c. electricity vibrated screen
    b. oscillating screen　　d. gyratory screen

7. The removal of a small amount of oversize from a feed which are predominantly fines is called
    a. scalping　　c. coarse separation
    b. desliming　　d. dewatering

8. Removal of free water from a solids-water mixture and is generally limited to 4 mesh and above.
    a. scalping　　c. trash removal
    b. dewatering　　d. separation

9. Making a size separation smaller than 48-mesh is called
    a. coarse separation　　c. ultrafine separation
    b. fine separation　　d. scalping

10. Another name for revolving screen is
    a. shaking screen　　c. mechanically vibrated screen
    b. vibrating screen　　d. trommel screen

11. The mesh number of a screen denotes
    a. the area of the screen in square inch
    b. the number of opening per linear inch of screen
    c. the number of layers in a screen system
    d. the number of screens needed to obtain the required fines

12. Materials which remain on a screen surface are called
    a. fines　　c. intermediate material
    b. undersize　　d. oversize

13. The wire diameter of a 10-mesh screen whose aperture is 0.065 in. is
    a. 0.045 in.　　c. 0.035 in.
    b. 0.025 in.　　d. 0.050 in.

14. It is desired to separate a mixture of sugar crystals into two fractions, a coarse fraction retained on an 8-mesh screen, and a fine fraction passing through it. Screen analysis of feed, coarse and fine fractions show

    Mass fraction of +8 particles in feed = 0.46
    Mass fraction of +8 particles in coarse fraction = 0.88
    Mass fraction of +8 particles in fine fraction = 0.32

The overall effectiveness of the screen used for the separation purpose per 100 kg of feed is

a. 45% c. 40%
b. 55% d. 47.8%

Problems *15* and *16* are based on the following information:

Limestone is crushed by six units operating in parallel and the products separated by six 35-mesh screens also in parallel, into two fractions. The effective dimensions of each screen is 6' by 20'. The common undersize from the screen comes out at the rate of 50 tons/hour. Assume no losses.

Mesh Size	Feed Size	Oversize	Undersize
6/8	0.075	0.080	0.020
8/10	0.125	0.145	0.055
10/20	0.100	0.170	0.090
20/28	0.125	0.150	0.085
28/35	0.125	0.280	0.100
35/48	0.175	0.175	0.150
48/65	0.225		0.150
65/100	0.050		0.250
100/150			0.100

15. The efficiency of screening operation is
    a. 52.8% c. 48.2%
    b. 56% d. 50%

16. The capacity of each screen in lb/24 hour per sq. ft. is
    a. 5800 c. 5750
    b. 5600 d. 5670

Problems *17* and *18* are based on the following information:

1800 lbs of dolomite per hour is produced by crushing and then screening through a 14-mesh screen. The screen analysis is as follows:

Tyler Mesh	*Feed to Screen*	*Undersize Product*	*Screen Oversize Circulating Load*
4 on	14.3		20
8 on	20.0		28
14 on	20.0		24
28 on	28.5	40	24
48 on	8.6	30	0 through 24 mesh
100 on	5.7	20	
100 through	2.86	10	

17. The total load to the crusher is

a. 6300 lbs/hour
b. 6510 lbs/hour
c. 6400 lbs/hour
d. 6320 lbs/hour

18. The effectiveness of the screen

a. 62.5%
b. 64%
c. 65%
d. 60%

19. Granular feldspar is produced by beneficiation of high alumina river sand. After screening, drying and magnetic separation, the recovery is only 21%. The screen analysis of this product on a dry basis is as shown:

US Standard Sieve	***Percent***
-10 + 20	1.5
-20 + 40	24.0
-40 + 60	30.0
-60 + 80	18.5
-80 + 100	12.5
-100 + 120	8.0
-120	5.5

In a specific application, this product must be reprocessed to remove the grains finer than 100 mesh. Where 2.0 MT reprocessed product is required.

The MT of river sand with 10% moisture that would have to be beneficiated is

a. 13.2 MT
b. 14.2 MT
c. 15.3 MT
d. 12.2 MT

Problems *20* to *22* are based on the following information:

Fine silica is fed at 1500 lbs/hour to a double-deck vibrating screen combination to obtain a 48/65 mesh (Tyler) product. The silica feed is introduced into the upper screen of the 48 mesh and the product is discharged off the surface of the lower screen of 65 mesh. During the screening operation, the ratio of oversize to product to undersize is 2:1½:1

Laboratory analysis of the different fractions:

Screen Mesh	**Feed Mass Fraction**	**Oversize Mass Fraction**	**Product Mass**	**Undersize Mass Fraction**
10/14 to 28/35	0.2821	0.5855	0.3385	0.00453
35/48	0.2580	0.3370	0.3220	0.00360
48/65	0.2810	0.0660	0.5260	0.34400
65/100	0.0910	0.0050	0.0670	0.29900
100/150 to 150/200	0.0870	0.0060	0.0260	0.35300

20. The effectiveness of the screening equipment is
    a. 58.7% c. 68.6%
    b. 48.7% d. 45.6%

21. If the screens measure 5 ft x 8 ft each, the capacity in MT/day-ft^2-mm of the 65 mesh screen on the basis of a perfectly functioning 48 mesh screen is
    a. 0.901 c. 0.801
    b. 1.09 d. 0.75

22. The capacity in MT/day-ft^2-mm on the basis of the actual performance of the 48 mesh screen
    a. 1.09 c. 1.29
    b. .901 d. 1.49

23. If the total percentage of particles larger that the screen opening in the feed, product, and undersize are 36%, 89% and 3%, respectively, the effectiveness of the screen is ______%.
    a. 93.4 c. 95.0
    b. 88.5 d. 64

24. The Tyler Standard screen series is characterized by
    a. square root of two ratio of areas between successive screens
    b. square root of four ratio of linear openings between successive screens
    c. twice the area ratio between successive screens
    d. none of these

25. The ratio of the clear opening corresponding to a mesh size in the Tyler Standard screen series to that of the next smaller screen is
    a. 2 c. 1.5
    b. $\sqrt{2}$ d. none of these

26. The clear opening of a 200-mesh screen in the Tyler Standard screen series is
    a. 0.0074 cm c. 0.0047 cm
    b. 0.0074 mm d. 0.0047 mm

27. The ratio of the area of the opening in one screen (Tyler Series) to the opening of the next smaller screen is
    a. 1.5 c. $\sqrt{2}$
    b. 1 d. none of these

28. The Cumulative Screen Analysis for determining the surface area of particles is more precise than the differential screen analysis because of the
    a. assumption that all particles in a single fraction are equal in size
    b. fact that screening is more effective
    c. assumption that all particles in a single fraction are equal in size is not needed
    d. none of these

29. Increasing the capacity of a screen
    a. decreases the screen effectiveness
    b. increases the screen effectiveness
    c. does not affect the screen effectiveness
    d. none of these

30. The screen efficiency is
    a. recovery + rejection
    b. recovery
    c. rejection
    d. none of these

31. As the particle size is reduced
    a. screening becomes progressively more difficult
    b. screening becomes progressively easier
    c. capacity and effectiveness of the screen is increased
    d. none of these

32. A screen is said to be blinded when
    a. oversize are present in undersize fraction
    b. undersize are retained in oversize fraction
    c. the screen is plugged with solid particles
    d. its capacity is abruptly increased

33. Size measurement of ultrafine particles can be best expressed in terms of
    a. centimeter
    b. screen size
    c. micron
    d. surface area per unit mass

34. Trommels separate a mixture of particles depending on their
    a. size
    b. wettability
    c. screen size
    d. electrical and magazine

35. Screen capacity is expressed in terms of
    a. tons/h
    b. tons/ft^2
    c. both a and b
    d. tons/h-ft^2

19. SIZE REDUCTION

THEORY AND EQUATIONS

Size Reduction – involves the production of smaller mass units from larger mass units of the same material. Application of pressure on the larger solids is required to cause a fracture to take place. Fracture can be caused by compressive loads because of the irregularity of the orientation of crystals of the solid matter. Equipment for size reduction uses compression or shear or both as the disrupting force.

Properties of Particles

1. ***Particle Size and Shape***

   Volume of any particle (any shape), $V_p = aD^3{}_p$

   Surface area of any particle, $S_p = 6b\,D_p{}^2$

   where D_p = arbitrarily chosen characteristic dimension of any particle
   a and b = geometric constants (dependent on the shape of the particle)

   $$\therefore \frac{V_p}{S_p} = \frac{aD_p{}^3}{6bD_p{}^2} = \frac{D_p}{6\lambda}$$

   where λ = shape factor

   $\lambda = \frac{b}{a}$ (independent of size)

   Sphericity, $\Phi_s = \frac{1}{\lambda}$

   For spheres and cubes, $\lambda = 1.0$ and $\Phi_s = 1.0$

2. ***Specific Surface and Number of Particles in a Mixture***

   For uniform particles of mass, m: $volume = \frac{m}{\rho_p}$

   where m = mass of particles
   ρ_p = density of particles

   For a single particle, $V_p = aD_p{}^3$

   For number of particles, $N = \frac{m/p_p}{aD_p^3}$

   Total surface area, $A = NS_p = \left(\frac{m/\rho_p}{aD_p^3}\right)\left(6bD_p{}^2\right)$ $A = \frac{6\lambda m}{\rho_p D_p}$

3. ***Specific Surface of a Mixture,*** Aw, ft²/lb mixture

   a. *Based on Differential Screen Analysis*

$$Aw = \frac{6\lambda}{\rho_p}\left[\frac{\Delta\phi_1}{D_{p1}} + \frac{\Delta\phi_2}{D_{p2}} + \ldots\ldots + \frac{\Delta\phi_n}{D_p n}\right]$$

   b. *Based on Cumulative Screen Analysis*

$$Aw = \frac{6\lambda}{\rho_p}\int_0^1 \frac{d\phi}{D_p}$$

4. ***Number of Particles in a Mixture,*** Nw

   a. *Based on Differential Screen Analysis*

$$Nw = \frac{1}{a\rho_p}\sum_{n-1}^{N}\frac{\Delta\phi_n}{D_p^{\,3}}$$

   b. *Based on Cumulative Screen Analysis*

$$Nw = \frac{1}{a\rho_p}\int_0^1 \frac{d\phi}{D_p^{\,3}}$$

5. ***Average Particle Size***

   a. *Volume-Surface Mean Diameter*

$$\overline{D}_{v_s} = \frac{6\lambda}{Aw\,\rho_p}$$

   b. *Arithmetic Mean Diameter*

$$\overline{D}_N = \frac{\int_0^{Nw} D_p\, dN}{Nw}$$

   c. *Mass-Mean Diameter*

$$\overline{D}_w = \int_0^1 D_p d\phi$$

6. ***Particle Size Distribution in Comminuted Products***

For particles too fine to sieve accurately:

$$-\frac{d\phi}{dD_p} = BD_p^k$$ This equation is used to extrapolate screen analysis data

integrating and simplifying,

$$\log\Delta\phi_n = (k+1)\log D_{p_1}n + \log B' \rightarrow$$ equation of a straight line

1. evaluate the value of (k+1) → m (slope)
2. evaluate the value of B' → y intercept

Power Requirement

1. ***Rittinger's Law*** states that "the work required in crushing is proportional to the new surface created"

$$\frac{P}{T}=\frac{Aw_b - Aw_a}{N}$$

where p = theoretical power
T = flow rate of the feed
Aw_b = specific surface area of product
Aw_a = specific surface area of feed
N = Rittinger's Number – new surface produced per unit of mechanical energy absorbed by the material being crushed

2. ***Bond's Crushing Law*** states that "the work required to form particles of size Dp from very large feed is proportional to the square root of the surface to volume ratio of the product"

$$\frac{P}{T}=K\sqrt{\frac{S_p}{V_p}}=K\sqrt{\frac{6\lambda}{D_p}}$$

where K = constant which depends on type of machine and material

3. ***Kick's Law*** states that "energy required for crushing is proportional to the length of the initial and final diameters"

$$P = k\log\frac{Dp_a}{Dp_b}$$

Stages of Size Reduction

In order to achieve successful size reduction, every lump or particle must be broken down by contact with other particles or with the moving parts of the machine. However, as the average particle size decreases, the number of particles increases therefore requiring more contacts for unit mass. Hence a solid has to undergo stages of size reduction.

A. ***Coarse Size Reduction for Hard Materials***

Size range of feed is 1.5 in. to 96 m. in diameter or larger.

1. *Jaw Crusher* – consists of a swinging jaw which moves back and forth, working against a stationary surface called the anvil jaw, with which it forms a V-shape chamber. It is wide at the top and narrow at the bottom, where the crushing takes place. Jaws are lined with tough abrasion resistant material such as manganese.
– employs a compressive force

a. *Dodge Type Jaw Crusher* – swinging jaw pivoted at the bottom
– made of smaller size
– not widely used because of its tendency to choke

b. *Blake Type Jaw Crusher* – swinging jaw is pivoted at the top
– toggle plates in the driving mechanism is relatively weak so that if any large stress is set up, it will just break
– crushing faces are either manganese steel or chilled cast iron
– more commonly used than the Dodge type

2. *Gyratory Crusher* – employs a crushing head in the frame of truncated core, mounted on a shaft
– employs a compressive force
– the crushing action takes place around the whole of the core
– power consumption is lower
– has a large capacity per unit area of grinding surface
– suitable only where large quantities of material are to be handled because of its high cost

Capacities of Jaw and Gyratory Crushers

– with openings of 4 in. to 2 ft.
– can be determined by the *Taggart Formula*: $T = 0.6\,LS$

where T = capacity (tons/hr)
L = length of feed opening (in)
for: jaw crushers (L) = normal to gape
gyratory (L) = perimeter of the circle
S = greatest width of discharge opening

Power Requirement

About the same, but the gyratory load is somewhat more uniform since its crushing is continuous whereas jaw crusher works intermittently.

Taggart's Rule states that "if the hourly tonnage to be crushed divided by the square of the gape in inches is less than 0.115, use a jaw crusher; otherwise, a gyratory".

B. ***Coarse Size Reduction for Soft Materials***

For soft materials like coal, gypsum, some types of limestone, ice, fire clay and shales.

1. *Bradford Breaker for coal* – combines the two features of breaking and screening
– the coal enters through the chute at the far end is lifted, falls and is broken by the impact as the cylinder with perforations is rotated into the chute below
– rocks and refuse are plowed out

2. *Toothed Roll Crusher* – breaks by pressure of the teeth against the larger lumps of the material

3. *Hammer Mill* – the hammer delivers heavy blows to the feed material while it is in suspension, driving it against a breaker plate until it is fine enough to pass through the openings

4. *Squirrel-Cage Disintegrator* – for fibrous materials such as wood blocks and asbestos
   – two concentric cages rotate in opposite direction
   – the feed is introduced into the inner cage
   – centrifugal force drives the material into the spaces between the rotating cages where it is torn apart

C. ***Intermediate Size Reduction***

This class covers machines that will take indefinitely coarse feeds or produce materials that will pass through a 200-mesh screen.

1. *Crushing Rolls* – two rolls, one in adjustable bearings, rotate in opposite directions. The clearance between them can be adjusted according to the size of feed and the required size of product. The machine is protected by spring loading against damage from very hard material. Materials to be crushed is fed from above and is discharged from beneath the rolls.

2. *Cone Crushers* – consists of a conical crushing head similar to that of the gyratory crusher. Operation is also similar to the latter. However, what is different about the cone crusher is that the outer stationary crushing plate flares outward to provide increasing area of discharge so that the machine can quickly clear itself of the reduced product. This stationary crushing plate is held in position by a nest of heavy helical tension springs so that when tramp iron or other uncrushable objects enter the crushing zone, the plate is lifted preventing fracture of plate and injury to the machine.

3. *Edge Runners* – the only commonly used crusher of this general type is the one in which the pan rotates and the horizontal axis of the grinding wheels is stationary.
   – widely used in the clay industry, but little anywhere else and is usually known as dry pan or wet pan according to whether the clay is crushed with or without the addition of water.
   – not suited for hard rock crushing

D. ***Fine Size Reduction***

Size reduction in the finer ranges is usually termed fine grinding. This is due to the fact that most of the older devices used for reduction in this range consisted of two parts, a stationary surface and a surface rubbed against the stationary surface. Such machines cause size reduction mainly by the application of shear loads. However, more recent devices in fine size reduction, such as ball mills, depend more on impact than on shearing forces.

1. *Pebble Mill* – a steel cylinder lying on its side and rotated about its long axis containing an appropriate grinding medium. The material is introduced through a manhole in the center of the shell length after which the opening is closed hermetically by a cover plate. The discharge is through the same opening after replacing the cover plate with a grate with wide slots to hold back the balls.

2. *Rod Mill* – similar to pebble mills and ball mills except that the grinding media are steel rods rather than balls. The rods are always longer than the diameter of the mills and therefore lie in the mill parallel to the axis. As the mill turns, the rods drop on to lower ones, reducing the charge partly by impact and partly by grinding.

3. *Ball Mill* – consists of a horizontal cylinder whose diameter is roughly equal to its length, lined with heavy liner plates. The feed end consists of a helical feed scoop which lifts feed into the spiral feed liner from which it enters the mill. The load of the balls, the speed of revolution, the size of the balls and the rate of feed are all factors that are controlled so that the discharge leaving the discharge screen and the discharge funnel is of the desired size. The discharge screen is a coarse-mesh screen, not to screen out particles that have not been ground to the correct size but to keep back any of the balls that may have entered the discharge end of the mill. The mill is rotated by the gear. The mill in operation will contain balls of various sizes. They are not put in various sizes; but, since the balls are being continually worn away by attrition, new balls must be supplied from time to time.

Operating Conditions of Ball Mill

The rate of rotation of ball mills should be less than the speed at which the charge is held against the inside surface by centrifugal force, since no size reduction will take place unless the balls fall upon the material to be crushed. At low speeds where the balls simply roll over each other and are not carried up and dropped, only the smallest particles are affected. The critical rate at sea level may be ascertained from the expression:

$$N = \frac{76.65}{\sqrt{D-d}}$$

where N = revolution per minute
D = diameter of the mill (ft)
d = average diameter of the balls

At low speeds where the contents are simply tumbled or rolled over, the power required to drive the mill varies directly with the speed of rotation.

Capacity of Ball Mills

Depends on the reduction ratio as well as on the hardness of the material, and it cannot accurately be calculated. The normal capacity of cylindrical ball mills in tons per 24 hours may be estimated as

Capacity – volume of mill (cu.ft.)/20°C where C varies from 1 to 2

REVIEW QUESTIONS AND PROBLEMS

1. The term applied to all ways in which particles of solids are cut or broken into smaller pieces
   a. size reduction
   b. screening
   c. comminution
   d. crushing

2. The hardness of a mineral is a criterion of its resistance to crushing. Which of the following is an example of a hard material?
   a. talc
   b. calcite
   c. sapphire
   d. feldspar

3. States that the energy required for crushing is proportional to the new surface created.
   a. Rittinger's Law
   b. Kick's Law
   c. Bond Law
   d. Energy Law

4. The critical speed of a ball mill in rpm whose diameter is 12 in. with grinding balls of diameter 1/2 in. is approximately ____ rpm.
   a. 60 b. 50 c. 90 d. 80

5. It is defined as the efficiency of technical grinding compared with that of laboratory crushing experiments.
   a. Grinding Efficiency
   b. Bond Work Index
   c. Practical Energy Efficiency
   d. none of these

6. Work index is defined as the gross energy requirement in kWh/ton of feed needed to reduce very large feed to such a size that 80% of the product passes a 100 microns screen. What is the work index of gypsum rock?
   a. 8.16 b. 25.17 c. 13.11 d. 6.73

7. Shape factors are important in characterizing particles such as those encountered in various unit operations. The specific surface (surface per unit mass of material), in sq.cm./g., for quartz with a diameter of 2 in., density of 165 lb/cu.ft. and a shape factor of 10 is
   a. 45 b. 95 c. 4.47 d. 8.92

8. In crushing a certain ore, the feed is such 80% is less than 50.8 mm in size and the product size is such that 80% is less than 6.35 mm. The power required is 89.5 kW. Use the Bond equation. The power required using the same feed so that 80% is less than 3.18 mm is
   a. 147.6 kW b. 157.6 kW c. 146.7 kW d. 157.7 kW

9. A material is crushed in a Blake Jaw Crusher and the average size of particles reduced from 50 mm to 10 mm with the consumption of energy at the rate of 13 kW/(kg/s). The consumption of energy needed to crush the same material of average size 75 mm to an average size 25 mm assuming Kick's Law applies is
   a. 8.88 kW/(kg/s)
   b. 4.33 kW/(kg/s)
   c. 8.08 kW/(kg/s)
   d. 4.66 kW/(kg/s)

10. A 6,000 lb of a material goes through a crusher and grinder per hour in succession (on the same power drive). Screen analysis from the crusher shows a surface area of product of 500 ft^2 per lb. Screen analysis of the grinder product indicates a surface area of 4,200 ft^2 per lb. The Rittinger number of the material processed is 163 sq. in. per ft-lb_f. The efficiency of the crusher is estimated to be 25% while that of the grinder is 30%. The total power to be delivered to the equipment is
    a. 34.8 hp b. 35.4 hp c. 38.4 hp d. 40.4 hp

11. The average diameter of sphalerite is 1,000 microns, the ratio of specific surfaces is
    a. 4 b. 3 c. 5 d. 3.5

Problems *12* to *14* are based on the following information:

A ball mill is to grind 250 tons/day of calcite having a specific surface of 90.34 sq. cm/g. No recrushing of material is to be done. Overall energy effectiveness of the ball mill is 7.5%.

Mesh	Mass Fraction Product
10/14	0.02
14/20	0.07
20/28	0.18
28/35	0.25
35/48	0.14
48/65	0.11
65/100	0.08
100/150	0.05
150/200	0.04
200/270	~~0.325~~ 0.0325
270/400	0.0275

12. The specific surface of the product is
    a. 179.2 sq cm/g c. 195.2 sq cm/g
    b. 285.2 sq cm/g d. 160.2 sq cm/g

13. The theoretical horse power requirements to grind the calcite is
    a. 2.8 hp b. 0.5 hp c. 1.38 hp d. 2.3 hp

14. Hp required by the ball mill when loaded is
    a. 8 hp b. 5.4 hp c. 9 hp d. 8.4 hp

15. If 20 % of pulverized limestone with a work index of 12.1 is retained by a 150-mesh screen from an original uniform size of 35 mesh, the energy required in kW to process 1 ton/hour is
    a. 10 b. 4.5 c. 6.25 d. 8.5

16. In comminution, the energy requirement is determined theoretically by
    a. the initial and final sizes of the particles
    b. the type of equipment
    c. the change in shape of the particle
    d. none of these

17. Size reduction is important in chemical engineering since
    a. it prevents chemical engineers from becoming overweight
    b. it makes products to become uniform in size
    c. it prepares raw materials of the desired sizes prior to processing
    d. none of these

18. Based on Bond's Crushing Law, the power required to crush a certain material will change by _____% if the diameter of the product is made smaller by 50%.
    a. 50% b. 41% c. 25% d. 75%

19. Shape factor for a cylinder whose length equals its diameter is
    a. 1.5 b. 0.5 c. 1 d. 5

20. Equivalent diameter of a particle is the diameter of the sphere having the same
    a. ratio of surface to volume as the actual volume
    b. ratio of volume to surface as the particle
    c. volume as the particle
    d. none of these

21. For coarse reduction of hard solids, use
    a. impact
    b. attrition
    c. compression
    d. cutting

22. Soft and non-abrasive materials can be made into fines by
    a. attrition
    b. compression
    c. cutting
    d. none of these

23. Crushing efficiency is the ratio of
    a. surface energy created by the crushing to the energy absorbed by the solid
    b. energy absorbed by the solid to that fed to the machine
    c. energy fed to the machine to the surface energy created by the crushing
    d. energy absorbed by the solid to the surface energy created by the crushing

24. Rittinger's Crushing Law states that
    a. work required to form a particle of any size is proportional to the square of the surface to volume ratio of the product
    b. work required to form a particle of a particular size is proportional to the square root of the surface to volume ratio of the product
    c. work required in crushing is proportional to the new surface created
    d. for a given machine and feed, crushing efficiency is dependent on the sizes of feed and product

25. Bond Crushing Law
    a. calls for relatively less energy for the smaller product particle than does the Rittinger Law
    b. less realistic in estimating the power requirements of commercial crushes
    c. states that the work required to form particle of any size from very large feed is proportional to the square root of the volume to surface ratio of the product
    d. states that the work required for the crushing is proportion

26. Work index is defined as the
    a. gross energy (kWh/ton of feed) needed to reduce very large feed to such a size that 80% of the product passes a 100 micron screen
    b. energy needed to crush one ton of feed to 200 microns
    c. energy (kWh/ton of feed) needed to crush small feed to such a size that 80% of product passes a 200-mesh screen
    d. energy needed to crush one ton of feed to 100 microns

27. The operating speed of a ball mill should be
    a. less than the critical speed
    b. much more than the critical speed
    c. at least equal to the critical speed
    d. none of these

28. A fluid energy mill is used for
    a. cutting
    b. grinding
    c. ultragrinding
    d. crushing

29. Wet grinding in a revolving mill
    a. gives less wear on chamber walls than dry grinding
    b. requires more energy than for dry grinding
    c. increases capacity compared to dry grinding
    d. complicates handling of the product compared to dry grinding

30. Cement clinker is reduced to fine size
    a. Roll Crusher
    b. Ball Mill
    c. Tube Mill
    d. Hammer Mill

20. MATERIALS HANDLING

THEORY AND EQUATIONS

Handling of Solids

Handling of Materials – deals with the transfer of materials over relatively short distances.

Unassisted Manpower – short distances not exceeding 10 ft. and only when the quantity does not exceed 4 or 5 tons.

Assisted Manpower – work radius is about 200 ft. portable power driven machines for handling of solids.

Portable Power Driven Machines for Handling of Solids

1. Electric storage battery truck
2. Gasoline powered industrial trucks
3. Trailer
4. Tractors
5. Power Shovels
6. Gantry or Bridge Cranes

Permanent Installations for Handling of Solids

1. Vibrators
2. Mechanical Conveyors
    a. Scraper
    b. Carriers

Scrapers

1. Screw or Helical Flight Conveyors
2. Flight Conveyors
3. Slat or Drag-Conveyors
4. Reddler Conveyor

Capacity of Flight Conveyors (at 80% Efficiency)

$$T = \frac{BDS\rho_b}{6000}$$

T = capacity, tons/hr
B = width of flight, in.
D = depth of flight, in.
S = speed of conveyor, fpm
ρ_b = bulb density of material being handled, lb/ft^3

Horsepower Requirements of Screw Conveyors and all Conveyors Operating with a Scraping Action

$$\text{Horsepower} = \frac{(\text{Coefficient})(\text{Capacity, lb./min})(\text{Length, ft})}{33{,}000\ \frac{\text{ft}-\text{lbf}}{\text{Hp min}}}$$

where Coefficients = 4.0 (ashes)
= 2.5 (coal)
= 1.3 (grain)

Horsepower Required to Drive Flight Conveyors

$$HP = \frac{a(T)(L)+b(W)(L)(S)+10\,L}{1000}$$

where HP = total horsepower of conveyor shaft
T = material handled, tons/hour
L = length of conveyor from center to center of sprocket, ft.
W = total weight of chain and flights per foot of distance between centers (both runs), lb; usually equal to ¼ T max.
S = speed, fpm
a = constant for material
b = constant for conveyor

Note : W = 0.5 lb/in. of width per running foot for 4" x 10" to 6" x 18"
W = 1.0 lb/in. of width per running foot for 8" x 18" to 10" x 24"

Carriers

1. Belt Conveyors
2. Apron Conveyors
3. Peck Carriers
4. Bucket Elevators
   a. Centrifugal discharge type
   b. Positive discharge type
   c. Continuous discharge type

Power Requirement for Belt Conveyors

1. For empty belt conveyor (minimum value).

$$HP_1 = \frac{F(L-Lo)(0.03\,WS)}{990}$$

2. For material (not considering belt) conveyed horizontally.

$$HP_2 = \frac{T\Delta Z}{990}$$

3. For lifting material

$$HP_3 = \frac{T\Delta Z}{990}$$

4. Total horsepower required

$$HP_r = HP_1 + HP_2 + HP_3$$
$$= \frac{F(L+L_o)(T+0.03\,WS)+T\Delta Z}{990}$$

where HP = horsepower required
F = friction factor, 0.05 for plain bearing; 0.03 for anti-friction bearing depending upon the installation maintenance
L = length of conveyor between terminal pulleys, ft.
Lo = 100 for plain bearing; 150 for anti-friction bearing
S = speed of belt, fpm
T = material handled, tons/hour
ΔZ = increase in elevation of material, ft.
W = mass of moving parts, including belt and idlers per foot of distance between center of terminal pulleys (both/runs), lb
W = 1.0 lb/in. of width per running ft.

REVIEW QUESTIONS AND PROBLEMS

1. A solid handling equipment used to handle large volumes over long distance economically is a
   a. pneumatic conveyor
   b. belt conveyor
   c. bucket elevator
   d. screw conveyor

2. A solid handling equipment used for moving powdered or granular materials to and from storage or between reaction vessels as in moving bed catalytic.
   a. bucket elevator
   b. screw conveyor
   c. belt conveyor
   d. pneumatic conveyor

3. Which of the following conveyors for bulk materials is used for handling materials over a combination horizontal and vertical path?
   a. continuous flow
   b. gravity discharge bucket
   c. pivoted bucket
   d. all of these

4. Determine the capacity of a flight conveyor having a flight size and number of strands in mm of 15 x 7 (380 x 180) – 1 specification. See Table 21-10, Perry.
   a. 61 MT/h
   b. 113 MT/h
   c. 71 MT/h
   d. 81 MT/h

5. Determine the maximum horsepower requirement of a screw conveyor with a capacity of 30 tons/h and a speed of 55 rpm.
   a. 14.3 hp
   c. 10
   b. 30.6
   d. 5

6. What is the minimum width of a bolt that can be used for a belt conveyor having a maximum speed of 137m/min, a cross sectional area of load of 0.049 m^2 and a capacity of 645 MT/h?
   a. 90 cm
   c. 75 cm
   b. 60 cm
   d. 70 cm

7. The bulk density of potassium chloride in lb/ft^3 is
   a. 75
   c. 85
   b. 77
   d. 60

8. The bulk density of impure aluminum oxide in lb/ft^3 is
   a. 90
   c. 80
   b. 70
   d. 60

9. The width of an apron conveyor having a capacity of 75 tons/h and a speed of 50 ft/min is
   a. 1220 mm
   c. 1370 mm
   b. 1070 mm
   d. 460 mm

10. A type of pneumatic conveyor system characterized by a material moving in an air stream or pressure less than ambient is
    a. fluidizing
    c. pressure-vacuum
    b. pressure
    d. vacuum

11. A conveyor auxiliary device used to cut out the driving force when a conveyor jams
    a. brake
    c. torque-limiting
    b. holdback
    d. cleaner

12. A bucket elevator used for large lump materials and effective for handling finely pulverized or aerated materials.
    a. continuous
    c. positive discharge
    b. centrifugal discharge
    d. oscillating

13. The supports for a belt conveyor are rollers on shaft supports and permits the belt for a width to carry more material per linear foot without spillage are called
    a. chains
    c. feeders
    b. idlers
    d. scrapers

14. The pipe size of a pneumatic conveyor to convey plastic pellets with bulk density of 30 lb/ft^3 using a blower with a capacity of 600 ft^3/min is approximately ____ inches.
    a. 2
    c. 4
    b. 6
    d. 8

15. The approximate investment cost for the above pneumatic conveyor to handle approximately 50,000 lb/hr is _______US dollars.
    a. 5,000
    b. 50,000
    c. 100,000
    d. 200,000

16. The method used to discharge a belt conveyor depends on whether or not the discharge is from the end of the conveyor or at some intermediate point. Special devices are necessary for discharge at discharge points. Which of the following devices consists of a discharge and return pulleys and are so mounted that the belt is doubled back for a short distance?
    a. scraper
    b. tipping idler
    c. shuttle conveyor
    d. tripper

17. Select from among the four types of conveyors listed below the smallest hp conveyor that can deliver 100 tons per hour of ashes horizontally at a distance of 100 ft. Assume plain bearings. (Use $F = 0.05$, $L_o = 100$, $a = 0.54$, $b = 0.004$)
    a. belt conveyor
    b. screw conveyor
    c. flight conveyor
    d. bucket elevator

18. A belt conveyor is required to deliver crushed lime stone having a bulk of 75 lbs/ft^3 at the rate of 200 tons per hour. The conveyor is to be 200 ft between centers of pulleys with a rise of 25 ft. The largest lumps are in 4 in. and constitute 15% of the total. The conveyor will discharge over the end. For the belt speed of 200 fpm, the horsepower for the drive motor is (Use $F = 0.03$ and $L_o = 150$)
    a. 11 hp
    b. 25 hp
    c. 8 hp
    d. 20 hp

19. The capacity of the flight conveyor of 12 by 24 inches traveling at 100 fpm and handling the crushed limestone of Problem *18* is ?
    a. 300 tons/h
    b. 360 tons/h
    c. 400 tons/h
    d. 350 tons/h

20. A screw conveyor is to be installed to convey 800 bushels (a bushel is 1.224 ft^3) of wheat per hour over a distance of 80 ft., the horsepower requirements for the installation is (for wheat coefficient = 1.3)
    a. 4
    b. 3
    c. 2.5
    d. 3.5

21. Which is most suitable for transportation of sticky material?
    a. apron conveyor
    b. screw conveyor
    c. belt conveyor
    d. pneumatic conveyor

22. Which of the following cannot be recommended for transportation of abrasive materials?
    a. belt conveyor
    b. flight conveyor
    c. apron conveyor
    d. chain conveyor

23. For transporting pastry material, one will use

a. apron conveyor	c. belt conveyor
b. screw conveyor	d. bucket elevator

24. The capacity of a belt conveyor depends upon two factors. If one is the cross section of the load, the other is the

a. speed of the belt	c. thickness of the belt
b. length of the belt	d. material to be transported

25. Dry powdery solid materials are transported by a

a. belt conveyor	c. bucket elevator
b. screw conveyor	d. all of these

21. DIMENSIONAL ANALYSIS

THEORY AND EQUATIONS

Dimensions – names given to physical quantities. Some examples of dimensions are length (L), time (t), mass (M), force (F), volume (V), velocity (v), and Temperature (T).

Unit – a definite standard or measure of a dimension. Examples are foot, meter, and Angstrom which are all different units of length; pound and kilogram are standard units of mass, °C and kelvin (K) are units of temperature, etc.

Four Systems of International Units:
1. *International System (SI)* – meter (m), second (s), kilogram (kg), Newton (N)
2. *English Engineering System* – feet (ft), second (s), pound mass (lb_m), pound force (lb_f)
3. *Absolute Engineering System* – ft, s, lb_f, slug
4. *Absolute Metric System* – centimeter (cm), gram (gm), second (s), dyne

For detailed listing of variables, properties and derived physical parameters see Units and Conversions at the end of this book.

Force and mass are related by Newton's Second Law of Motion

$$F = Ma \quad or \quad F = MLt^{-2}$$

Variables Expressed In Terms of Primary Dimensions M, L, t, T

VARIABLE	SYMBOL	DIMENSION
Mass	M	M
Length	L	L
Time	t	T
Velocity	v	Lt^{-1}
Temperature	T	T
Gravitational Acceleration	g	Lt^{-2}
Force	F	MLt^{-2}
Pressure	P	MLt^{-2}
Density	ρ	ML^{-3}
Viscosity	μ	$ML^{-1}t^{-1}$
Surface Tension	σ	Mt^{-2}
Thermal Conductivity	k	$MLt^{-3}T^{-1}$
Thermal Diffusivity	α	L^2t^{-1}
Heat Transfer Coefficient	hc	$Mt^{-3}T^{-1}$
Mass Transfer Coefficient	kc	$Mt^{-1}L^{-2}$

Dimensional Analysis – a procedure of grouping variables into meaningful dimensionless groups for the purpose of reducing the number of parameters involved in the experimental investigation of a physical phenomenon.

Methods of Dimensional Analysis

Method 1. Direct or Rayleigh's Method

Example : Establish the Reynolds Number relation by dimensional analysis.

Solution : Consider the Reynolds Number of a fluid flowing in a closed circular conduit to be a function of fluid density, fluid viscosity, velocity and diameter.

$$N_{Re} = f(\rho, \mu, v, D)$$

$$N_{Re} = K\rho^a \mu^b v^c D^d$$

In terms of primary dimensions of force (*F*), length (*L*), time (*T*)

$$\rho \equiv \frac{M}{L^3} = \frac{FT^2L^{-1}}{L^3} = FT^2L^{-4}$$

$$\mu = \frac{FT}{L^2} = FTL^{-2}$$

$$v = \frac{L}{T} = LT^{-1}$$

$$D = L$$

substituting,

$$N_{Re} = \left(FT^2L^{-4}\right)^a \left(FTL^{-2}\right)^b \left(LT^{-1}\right)^c (L)^d$$
$$= F^{a+b} T^{2a+b-c} L^{-4a-2b+c+d}$$

Since we want N_{Re} to be dimensionless, the exponents must all be zero, i.e.,

$$a + b = 0$$
$$2a + b - c = 0$$
$$-4a - 2b + c + d = 0$$

Solving in terms of *b*

$$\therefore a = -b; \quad a = -b; \quad d = -b; \quad c = -b$$

substituting,

$$N_{Re} = K\rho^{-b}\mu^b v^{-b} D^{-b}$$
$$= K\left(\frac{\mu}{Dv\rho}\right)^b$$

or appropriately,

$$N_{\mathrm{Re}} = K\left(\frac{Dv\rho}{\mu}\right)^{-b}$$

From experiment, $K = 1$ and $b = -1$

Method 2. Buckingham Pi Theorem

Example : An incompressible fluid is flowing inside a circular tube of inside diameter, D. The significant variables are pressure drop Δp, velocity v, diameter D, tube length L, viscosity μ and density ρ.

Solution:

Variables	***Units***	***In Terms of MLt***
Pressure drop, Δp	N/m^2	$ML^{-1}t^{-2}$
Velocity, v	m/s	Lt^{-1}
Diameter, D	m	L
Tube length, L	m	L
Viscosity, μ	kg/m-s	$ML^{-1}t^{-1}$
Density, ρ	kg/m^3	ML^{-3}

Total number of variables, $Q = 6$

Number of dimensions, $S = 3$

Number of dimensionless groups or π 's is $N = Q - S = 6 - 3 = 3$

Thus, $\pi_1 = f(\pi_2, \pi_3)$

Select a core group of 3 variables to appear in each π group. The variables must contain all fundamental dimensions and no two variables must have the same dimensions.

Δp is isolated since we would like to determine the effect of the other variables on Δp. Only one of L or D can be chosen. We choose D, v, and ρ.

$$\therefore \pi_1 = D^a v^b \rho^c \Delta p^1$$

$$\pi_2 = D^d v^e \rho^f L^1$$

$$\pi_3 = D^g v^h \rho^i \mu^1$$

Consider the π_1 group,

$$\pi_1 = L^a\left(Lt^{-1}\right)^b\left(ML^{-3}\right)^c\left(ML^{-1}t^{-2}\right)$$

exponent of L : $a + b - 3c - 1 = 0$

M : $c + 1 = 0$

t : $-b - 2 = 0$

Solving, $a=0$, $b=-2$, $c=-1$

$$\therefore \pi_1 = D^0 v^{-2} \rho^{-1} \Delta p = \frac{\Delta p}{v^2 \rho}$$

Consider the π_2 group,

$$\pi_2 = L^d \left(Lt^{-1}\right)^e \left(ML^{-3}\right)^f L^1$$

exponent of $M: \; f = 0$

$L: \; d + e - 3f + 1 = 0$

$t: \; -e = 0$

Solving, $d=-1$, $e=0$, $f=0$

$$\therefore \pi_2 = D^{-1} v^0 \rho^0 L \qquad \pi_2 = \left(\frac{L}{D}\right)$$

repeating the procedure for π_3, $\pi_3 = \dfrac{Dv\rho}{\mu}$

substituting, $\dfrac{\Delta p}{v^2 \rho} = f\left(\dfrac{L}{D}, \dfrac{Dv\rho}{\mu}\right)$

which is a form of the *Fanning-Darcy Equation* for straight conduits.

Selected Dimensionless Groups

DIMENSIONLESS GROUP	DEFINING EXPRESSION	MEANING OR APPLICATION
Biot Number, Bi	$\dfrac{hL}{k_s}$	Ratio of the solid's internal thermal resistance to the fluid's thermal resistance
Bond Number, Bo	$\dfrac{g(\rho_f - \rho_v)L^2}{\sigma}$	Ratio of gravitational and surface tension forces
Euler Number, Eu	$\dfrac{p/\rho L}{v^2/L} = \dfrac{p}{\rho v^2}$	Ratio of pressure force to inertia force
Friction Factor, f	$\dfrac{\Delta P}{(L/D)(\rho V^2/2)}$	Dimensionless pressure drop for internal flow
Froude Number, Fr	$\dfrac{v^2}{gL}$	Ratio of inertia force to the gravity force
Grashof Number, Gr	$\dfrac{g\beta(T_s - T_\infty)L^3}{v^2}$	Ratio of buoyancy to viscous forces
Jacob Number, Ja	$\dfrac{C_p(T_s - T_{sat})}{h_{fg}}$	Ratio of sensible to latent heat absorbed during evaporation or condensation
Lewis Number, Le	$\dfrac{\alpha}{D_{AB}}$	Ratio of thermal and mass diffusivities

Mach Number, Ma	$\frac{V}{c}$	Ratio of the speed of fluid flowing and that of sound measured at the same conditions
Nusselt Number, Nu	$\frac{hL}{k_f}$	Dimensionless temperature gradient at the surface
Peclet Number, Pe	$\frac{vL}{\alpha} = \text{Re}_L \text{Pr}$	Dimensionless independent heat transfer parameter
Prandtl Number, Pr	$\frac{C_p \mu}{k} = \frac{v}{\alpha}$	Ratio of momentum and thermal diffusivities
Reynolds Number, Re	$\frac{DV\rho}{\mu}, \frac{VL}{v}$	Ratio of inertia and viscous forces
Schmidt Number, Sc	$\frac{v}{D_{AB}}$	Ratio of momentum and mass diffusivities
Sherwood Number, Sh	$\frac{kL}{D_{AB}}$	Dimensionless concentration gradient at the surface
Stanton Number, St	$\frac{h}{\rho V c_p} = \frac{Nu_L}{\text{Re}_L \text{Pr}}$	Modified Nusselt Number
Weber Number, We	$\frac{\rho V^2 L}{\sigma}$	Ratio of inertia to surface tension forces

REVIEW QUESTIONS AND PROBLEMS

1. The repeating variables in a dimensional analysis should
    a. include the dependent variable
    b. have two variables with the same dimensions if possible
    c. exclude one of the dimensions from each variable if possible
    d. satisfy none of these

2. The Reynolds Number may be defined as the ratio of
    a. inertial forces to viscous forces
    b. viscous forces to gravity forces
    c. gravity forces to inertial forces
    d. none of these

3. Assuming that the efficiency of mixing of a rotary drum mixer is dependent on the diameter of the drum, the speed of rotation, the density and viscosity of the liquid, determine the speed of an actual mixer to mix SAE oil (density = 917 kg/m^3, viscosity = 0.29 kg/m-s) efficiently. A laboratory prototype one-fourth the size of the actual mixer required ½ rpm to mix ethyl alcohol (density = 789 kg/m^3, viscosity = 1.2 x 10^{-3} kg/m-s) efficiently.
    a. 13 rpm
    b. 6.5 rpm
    c. 20 rpm
    d. 1770 rpm

4. The Brinkman Number is often used in the analysis of organic liquid flows. This dimensionless number is proportional to viscosity, μ. Derive the Brinkman number if it depends on the viscosity, velocity of flow, V, thermal conductivity, k, and fluid temperature, T.
   a. $\mu k/VT$
   b. $\mu V^2/kT$
   c. $kT/\mu V^2$
   d. $TV^2/\mu K$

5. A pendulum bob of weight W is connected to a weightless string of length L. If the weight of the bob is doubled and the length of the string is cut to one-half, the period or time of a complete swing becomes ______ the original period.
   a. ½
   b. twice
   c. 0.707 times
   d. 1.41 times

6. It is a measure of inertial forces to gravitational forces.
   a. Froude Number
   b. Reynolds Number
   c. Grashof Number
   d. Rayleigh Number

7. It is essentially the ratio of buoyancy forces to viscous forces.
   a. Nusselt Number
   b. Peclet Number
   c. Prandtl Number
   d. Grashof Number

8. The dimensionless drag coefficient on a sphere is dependent in the Reynolds Number for the fluid and is expressed as follows:

$$C_D = \frac{F_D}{\frac{1}{2}\rho v^2 A} = f\left(\rho \frac{VD}{\mu}\right)$$

   where ρ is the density and μ is the viscosity. If the drag coefficient for a sphere, which has a diameter that is $^1/_{10}$ the length of the diameter of the sphere of interest, is found to have the same drag coefficient as the sphere of interest, then what is the ratio of the speed of the smaller sphere to the larger sphere?
   a. 10:1
   b. 1:10
   c. 100:1
   d. 1:100

9. Which of the following is the dimensional formula for the volumetric quantity of water flowing in unit time?
   a. Mt
   b. L^3t
   c. M^3t^{-1}
   d. L^3t^{-1}

10. A liquid flows in a circular tube at constant temperature with a Reynolds Number of 1,000. In a dynamically similar situation, the same liquid flows through a tube whose radius is twice as long as the radius of the first tube. If ν is the kinematic viscosity of the fluid at that particular temperature, then the product of the velocity of fluid and the tube radius in the second tube is
   a. 1000
   b. 500
   c. 1000
   d. 2000

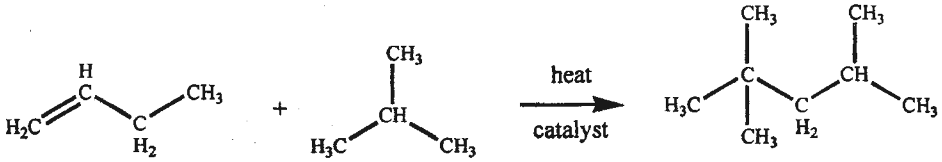
E. CHEMICAL PROCESS INDUSTRIES

Outline of Unit Processes

Unit Process — **Typical Industry Using Process**

1. Alkylation — Petroleum; Organic chemicals

Addition of alkyl radical (– CH_3) with side chain final product



1-butylene — isobutane — 2,2,4-trimethylpentane or isooctane

2. Amination by Ammonolysis — Dyestuffs; Synthetic fibers; Organic chemicals

$$\underset{\text{ethylene dichloride}}{Cl\cdot CH_2\cdot CH_2\cdot Cl} + 4NH_3 \longrightarrow \underset{\text{ethylene diamine}}{NH_2\cdot CH_2\cdot CH_2\cdot NH_2}$$

$$\underset{\text{adipic acid}}{HO_2C\,(CH_2)_4CO_2H} + 2NH_3 \longrightarrow \underset{\text{adiponitrite}}{NC\cdot (CH_2)_4CN}$$

3. Amination by Reduction — Dyestuffs; Organic chemicals

$$\underset{\text{2-nitroparaffin}}{CH_3\cdot CH\cdot NO_2\cdot CH_3} + 3H_2 \longrightarrow \underset{\text{isopropylamine}}{CH_3\cdot CH\cdot NH_2\cdot CH_3}$$

4. Ammonoxidation — Plastics; Synthetic fibers

$$\underset{\text{propylene}}{CH_3 : CH_2\cdot CH_3} + \underset{\text{ammonia}}{NH_3} + \underset{\text{air}}{1.5O_2} \longrightarrow \underset{\text{acrylonitrile}}{CH_2 : CH\cdot CN} + H_2O$$

5. Calcination

Cement

$$\underset{\text{limestone}}{CaCO_3} + \text{heat} \longrightarrow \underset{\text{lime}}{CaO} + CO_2$$

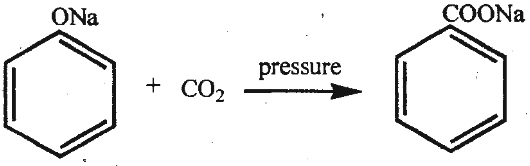
6. Carbonylation

Organic chemicals

$$\underset{\text{methanol}}{CH_3OH} + \underset{\text{carbon monoxide}}{CO} \longrightarrow \underset{\text{acetic acid}}{CH_3COOH}$$

7. Carboxylation

Organic chemicals



8. Combustion

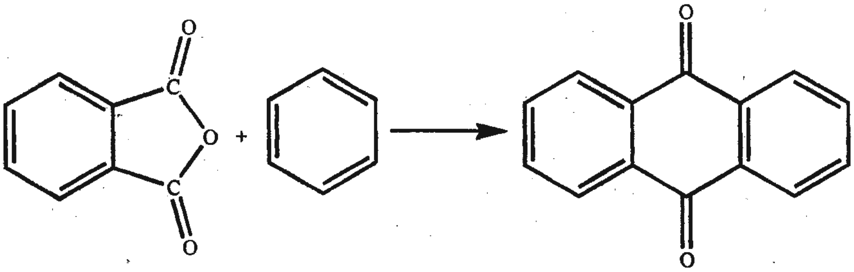
Process heating

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

9. Condensation

Synthetic perfumes

$$\underset{\text{benzaldehyde}}{C_6H_5CHO} + \underset{\text{acetaldehyde}}{CH_3CHO} \xrightarrow{NaOH} \underset{\text{cinnamaldehyde}}{C_6H_5CH:CHCHO} + H_2O$$



phthalic anhydride

anthroquinone

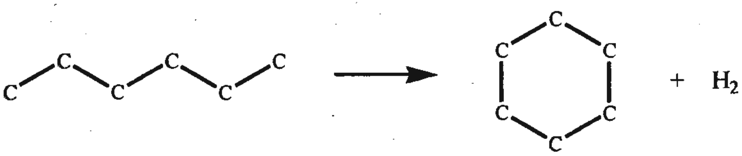
10. Cracking or Pyrolysis — Destruction distillation Petroleum

of coal

11. Cyanidation or Cyanation — Organic chemicals

$HC:CH + HCN \longrightarrow CH_2:CH\cdot CN$
acetylene → acrylonitrile

12. Cyclization — Petroleum



13. Dehydration — Organic chemicals

$CH_3CH_2OH \longrightarrow H_2C:CH_2 + H_2O$
ethyl alcohol → ethylene

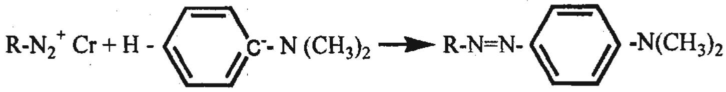
$Ca(OH)_2 \longrightarrow CaO + H_2O$
calcium hydroxide → calcium oxide

14. Dehydrogenation — Synthetic rubbers

$CH_3\cdot CH_2\cdot CH:CH_2 \longrightarrow CH_2:CH\,CH:CH_2 + H_2$
1-butene → 1, 3-butadiene

15. Diazotization and Coupling — Dyestuffs

a. $R-NH_2 + HCl + HNO_2 \longrightarrow R-N_2Cl + 2H_2O$

b. 

16. Disproportionation

Organic chemicals

$$\underset{\text{propylene}}{2CH_2:CHCH_3} \longrightarrow \underset{\text{ethylene}}{H_2C:CH_2} + \underset{\text{butylene}}{CH_3CH_2CH=CH_2}$$

17. Double Decomposition (metathesis)

Inorganic chemicals

$$Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4 + 2H_2O$$

18. Esterification

Oils and fats
Soaps
Organic chemicals

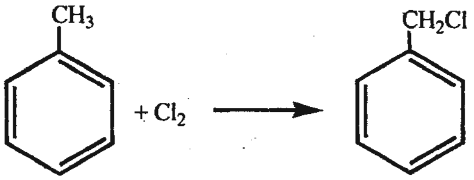
Alcohol + Acid

$$ROH + R'COOH \longrightarrow R'COOR + H_2O$$
$$ROH + H_2SO_4 \longrightarrow RHSO_4 + H_2O$$

19. Halogenation

Organic chemicals

$$\underset{\text{ethylene}}{CH_2=CH_2} + Cl_2 \longrightarrow \underset{\text{ethylene dichloride}}{ClCH_2 \cdot CH_2Cl}$$



toluene

benzyl chloride

20. Hydration

Organic chemicals
Inorganic chemicals

$$H_2C:CH_2 + H_2O \longrightarrow CH_3CH_2OH$$

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

21. Hydroformylation

Organic chemicals

Olefin ⟶ aldehyde with additional C

$$RCH = CH_2 + CO + H_2 \longrightarrow R(CH_2)_2 - CHO$$

22. Hydrogenation

Fats and waxes
Coal hydrogenation
Petroleum

$$R = R' + H_2 \longrightarrow RH - HR'$$

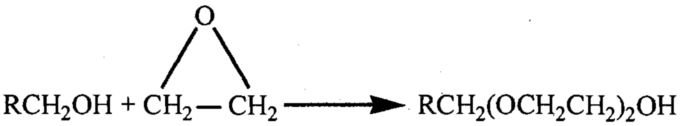
23. Hydrolysis

Organic chemicals

$$\underset{\text{chlorobenzene}}{C_6H_5Cl} + H_2O \longrightarrow \underset{\text{phenol}}{C_6H_5OH} + HCl$$

24. Hydroxylation

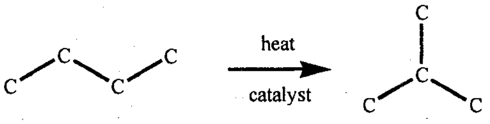
Detergent



ethylene oxide

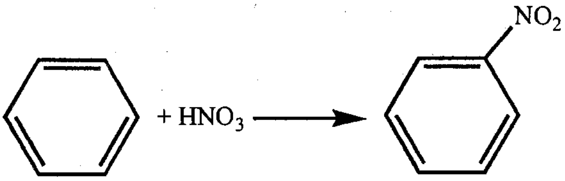
25. Isomerization

Petroleum



26. Nitration

Explosives
Dyestuffs



nitrobenzene

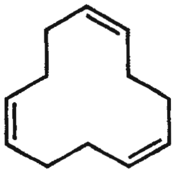
$CH_3 \cdot CH_2 \cdot CH_3 + HNO_3 \longrightarrow$

$CH_3 \cdot CH_2 \cdot CH_2 \cdot NO_2$
$CH_3 \cdot CHNO_2\,CH_3$
$CH_3 \cdot CH_2 \cdot NO_2$
$CH_3 \cdot NO_2$
nitroparaffins

27. Oligomerization — Organic chemicals

$$3\ CH_2{:}CH{:}CH{:}CH_2$$

1, 3-butadiene



1, 5, 9-cyclododecatriene

28. Oxidation — Organic chemicals

$$RCH_2OH + O_2 \longrightarrow RCHO + RCOOH$$

$$CH_3 \cdot CH_2 \cdot CH_2 \cdot CH_3 + O_2 \longrightarrow 2CH_3COOH + \text{By-products}$$

$$2CH_4 + 3/2O_2 \longrightarrow HC : CH + 3H_2O$$

29. Polymerization

Petroleum
Plastics
Elastomers
Synthetic fibers

a. *Addition polymerization*

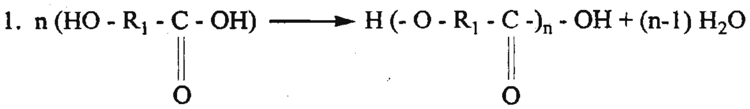
$$\underset{\substack{\text{ethylene}\\ \text{monomer}}}{H_2C=CH_2 + H_2C=CH_2} \longrightarrow \underset{\text{dimer}}{-CH_2-CH_2-CH_2-CH_2-}$$

$$\xrightarrow{C_2H_4} \text{etc.} \longrightarrow \underset{\text{polyethylene}}{(CH_2)_n}$$

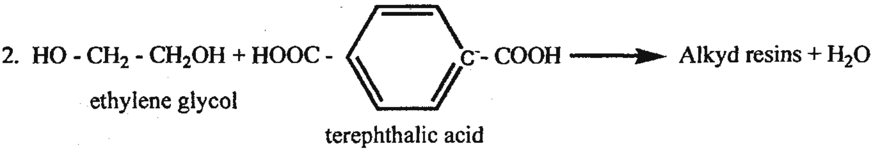
$$\underset{\text{polyvinyl monomer}}{H_2C=CHX + H_2C=CHX} \longrightarrow H_3C-CHX-CH=CHX$$

$$\xrightarrow[X = \text{ chloride, acetate}]{H_2C=CHX} \text{etc.} \longrightarrow (C_2H_3X)_n$$

b. *Condensation polymerization*
– splitting off of small molecules such as H_2O, NH_3, CH_2O, NaCl

1.


$$n\,(HO - R_1 - \underset{\underset{O}{\|}}{C} - OH) \longrightarrow H(- O - R_1 - \underset{\underset{O}{\|}}{C} -)_n - OH + (n-1)\,H_2O$$

2.


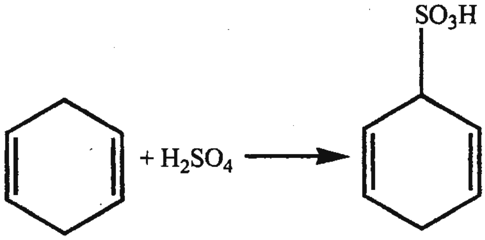
30. Reduction

Polymer catalyst manufacture

$$3\,TiCl_4 + Al \longrightarrow 3TiCl_3 + AlCl_3$$

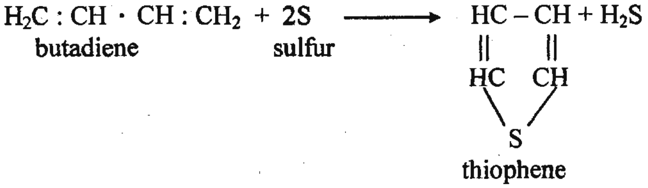
31. Sulfonation

Dyestuffs
Surface active agents



32. Thionation

Organic chemicals



$$CH_3OH + H_2S \longrightarrow CH_3SH + H_2O$$

MISCELLANEOUS PROCESSES

1. **Kraft Process** – manufacture of paper from pulp employing the Foudrinier machine.

2. **Bosch Process** – method of recovering hydrogen from water gas; carbon monoxide is reacted with steam at 500°C in the presence of catalyst to form carbon monoxide and hydrogen.

3. **Hoepener Process** – recovering copper from its sulfide ores by leaching with cupric and sodium or calcium chloride solution and electrolyzing the resulting cuprous chloride liquor in cells with impure copper anodes protected by diaphragms; the electrolytic by product, cupric chloride, is returned for further leaching.

4. **Holloway Process** – copper or iron sulfides fused and blown with air to burn out the sulfur content.

5. **Barff Process** – formation a rust resistant coating on iron; base metal by oxidation with superheated steam

6. **Carinthian Process** – process for reduction of lead ores; small charge is roasted slowly at a low temperature, the lead being collected outside the furnace by means of a heat

7. **Cyanidation Process** – method of recovering gold and silver from their ores into a soluble from by treatment with cyanides.

8. **Babbyry Process** – rubber reclaiming process in vulcanized scraps are introduced into a mixer (Banbury) where in the presence of air it is worked under pressure and at high temperature for a very short time.

9. **Dennis Bull Process** – sulfonation and extraction process in the manufacture of phenol.

10. **Solvay Process** – soda ash manufacture

11. **Haber-Bosch Process** – production of ammonia by direct combination of nitrogen and hydrogen at 600°C and under 200-300 atmospheric pressure in the presence of catalyst.

12. **Frasch Process** – process of recovering sulfur from the buried porous cap rock of a salt dome and delivering it above ground as a product of suitable purity and condition for use.

13. **Hall's Process** – extraction of aluminum from bauxite

REVIEW QUESTIONS AND PROBLEMS

1. Catalysts used in the manufacture of sulfuric acid by chamber and contact processes are respectively
   a. V_2O_5 and Cr_2O_3
   b. Oxides of nitrogen and Cr_2O_3
   c. V_2O_5 on a porous carrier and oxides of nitrogen
   d. oxides of nitrogen and V_2O_5 on a porous carrier

2. In contact process, SO_3 is absorbed in 97% H_2SO_4 and not in water because
   a. SO_3 gas is sparingly soluble in water
   b. water forms an acid mist which is difficult to absorb
   c. the purity of acid is affected
   d. scale formation in absorber is to be avoided

3. Contact process
   a. yields acid of higher concentration than chamber process
   b. yields acids of lower concentration than chamber process
   c. is obsolete
   d. eliminates absorber

4. 20% Oleum means that in 100 lb., there are 20 lb. of
   a. SO_3 and 80 lb of H_2SO_4
   b. H_2SO_4 and 80 lb SO_3
   c. SO_3 for each 100 lb of H_2SO_4
   d. H2SO4 and 80 lb SO3

5. Producer gas consists mainly of
   a. CO, CO_2, N_2, H_2
   b. CO, H_2
   c. H_2, CH_4
   d. C_2H_2, CO_2, H_2

6. Oxygen is produced by fraction of air using
   a. Linde's process
   b. Claude's process
   c. both Linde's and Claude's process
   d. Bayer's process

7. Raw materials for 'Solvay Process' for manufacture of the soda ash are
   a. salt, limestone ,ammonia and coke oven gas
   b. ammonia, salt and limestone
   c. ammonia, limestone and coke
   d. ammonia and coke oven gas

8. Economics of 'Solvay Process" depends upon the efficiency of
   a. carbonating tower
   b. ammonia recovery
   c. ammonia recovery and size of plant
   d. ammoniation of salt solution

9. Cement mainly contains
   a. CaO, SiO_2, Al_2O_3
   b. MgO, SiO_2, K_2O
   c. Al_2O_3, MgO, Fe_2O_3
   d. CaO, MgO, K_2O

10. Gypsum is
    a. calcium chloride
    b. potassium sulfate
    c. sodium sulfate
    d. calcium sulfate

11. Glauber's salt is
    a. calcium sulfate
    b. potassium sulfate
    c. potassium chlorate
    d. sodium sulfate decahydrate

12. Permanent hardness of water is due to the presence of calcium and magnesium
    a. bi-carbonates
    b. sulfates and chlorides
    c. carbonate
    d. chlorides

13. Widely used method for conditioning of boiler feed water is
    a. cold lime process
    b. coagulation
    c. hot-lime soda process
    d. sequestration

14. Hydrazine is largely used
    a. as a starting material for 'hypo'
    b. in photographic industry
    c. as rocket fuel
    d. in printing industry

15. Trinitro-toluene is
    a. used in glycerin manufacture
    b. an explosive
    c. used in dye manufacture
    d. used in paint manufacture

16. Oil is
    a. a mixture of glycerides
    b. a mixture of glycerides of fatty acids
    c. solid at normal temperature
    d. ester of alcohols other than glycerin

17. Wax is
    a. a mixture of glycerides
    b. a mixture of esters of polyhydric alcohols except glycerin
    c. liquid at room temperature
    d. a mixture of glycerides of fatty acids

18. Unsaturated oils compared to saturated oils have
    a. lower melting point and higher reactivity to oxygen
    b. higher melting point and higher reactivity to oxygen
    c. lower melting point and lower reactivity to oxygen
    d. higher melting point and lower reactivity to oxygen

19. Rancidity of oil can be reduced by
    a. decoloration
    b. hydrogenation
    c. oxidation
    d. purification

20. Solvent used for extraction of oil is
    a. hexane
    b. methyl ethyl ketone
    c. furfural
    d. benzene

21. Catalyst used in hydrogenation of oil is
    a. Nickel
    b. platinum
    c. iron
    d. alumina

22. Metallic soap is
    a. sodium salt of fatty acids
    b. potassium salt of fatty acids
    c. both sodium and potassium salt of fatty acids
    d. aluminum or calcium salt of fatty acids

23. Fat splitting catalyst is
    a. $CaCO_3$
    b. ZnO
    c. alumina
    d. iron

24. Free alkali in toilet soap is
    a. less than that in a laundry soap
    b. more than that in a laundry soap
    c. same as that in a laundry soap
    d. not present in laundry soap

25. Soap cannot be used with hard water because
    a. hard water contains sulfate
    b. they form insoluble calcium soaps which precipitate
    c. they attract back the removed dirt
    d. they increase the surface tension

26. Builders are added in soap to
    a. boost cleaning power
    b. act as anti-redeposition agent
    c. act as corrosion inhibitor
    d. acts as fabric brightener

27. Bio-degradable detergents
    a. can be readily oxidized
    b. pose problem in sewerage plant
    c. have an isoparaffinic structure
    d. should not be used as it spoils the cloth

28. Which of the following is a detergent?
    a. fatty alcohol
    b. alkyl benzene sulfonate
    c. fatty acids
    d. methyl chloride

9. Cement mainly contains
   a. CaO, SiO_2, Al_2O_3
   b. MgO, SiO_2, K_2O
   c. Al_2O_3, MgO, Fe_2O_3
   d. CaO, MgO, K_2O

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   a. lower melting point and higher reactivity to oxygen
   b. higher melting point and higher reactivity to oxygen
   c. lower melting point and lower reactivity to oxygen
   d. higher melting point and lower reactivity to oxygen

29. Yellow glycerin is made into white, using
    a. activated carbon c. bauxite
    b. diatomaceous earth d. bentonite

30. An analysis of the gases entering the converter of an ammonia oxidation nitric acid plant indicates that the gases contain 0.066 lb of NH_3 and 0.934 lb of air per pound of gas. A sample of the gases leaving the converter is absorbed in hydrogen peroxide and titrated with NaOH. The results indicate that 1 lb of the gas leaving the converter contains 0.00361 lbmol of NO (assume no NO_2 is formed). The percent of NH_3 converted to NO in the converter is
    a. 83% b. 93% c. 90% d. 88%

31. 90% of the NH_3 entering an NH_3-oxidation unit is converted to HNO_3 and 10% loss of NH_3 is due to conversion losses, NO in the stack gases and miscellaneous losses. The kg of NH_3 necessary to produce 60,000 kg of 62 wt % HNO_3 is
    a. 11,150 b. 12,000 c. 12,150 d. 11,000

32. The eletrolytic reaction for the production of aluminum may be written as $Al_2O_3 + 3/2\ C \rightarrow 2Al + 3/2\ CO_2$, 235,000 cal of energy (in the form of electricity) is consumed for the production of 2 gmol of Al. Some CO is also formed in a reaction requiring more energy. On the basis of the reaction evolving CO_2, the current efficiency may be taken as 35%. This means that only 35% of the current passing through the cell is available at a cost of 1 centavo per kWh, the amount to be paid for electrical power per lb of Al produced is
    a. ₱ 0.08/lb Al c. ₱ 0.088/lb Al
    b. ₱ 0.09/lb Al d. ₱ 0.066/lb Al

33. A water solution of molasses contains 10% by weight sucrose ($C_{12}H_{22}O_{11}$). The CO_2 formed in the reaction can be considered having a negligible solubility in the solution and the last 10% of the sugar can be assumed as unchanged. The weight percent of ethyl alcohol in the solution after 90% of the sucrose has been converted to ethyl alcohol by fermentation is
    a. 6.5% b. 5.6% c. 5.1% d. 6%

34. At a plant which produces H_2SO_4 by the contact process, a large storage tank currently holds 100,000 kg of 20% oleum, where 20% oleum means that in 100 kg of material there is 20 kg of SO_3 dissolved in 80 kg of pure H_2SO_4. The tank has a total capacity when filled of 130,000 kg. If water is added to the tank to fill it just to its capacity, the weight percent H_2SO_4 in the final mixture in the tank is
    a. 80.4 % c. 70.6 %
    b. 85 % d. 78%

35. Essential oils are usually obtained using
    a. steam distillation c. solvent extraction
    b. extractive distillation d. leaching

36. Plasticizers are added to paints to
    a. make it corrosion resistant
    b. make glossy surface
    c. give elasticity and prevent cracking of the film
    d. increase atmospheric oxidation

37. Which oil is preferred for paint manufacture?
    a. drying oil c. semi-drying oil
    b. non-drying oil d. saturated oil

38. Function of thinner in a paint is to
    a. accelerate the oxidation of oil
    b. prevent gelling of the paint
    c. suspend pigments and dissolve film-forming materials
    d. form a protective film

39. Varnish does not contain
    a. pigment c. dryer
    b. thinner d. anti-skinning agent

40. Enamels
    a. give good glossy finish c. are prepared from non-drying oil
    b. are same as varnish d. do not contain pigment

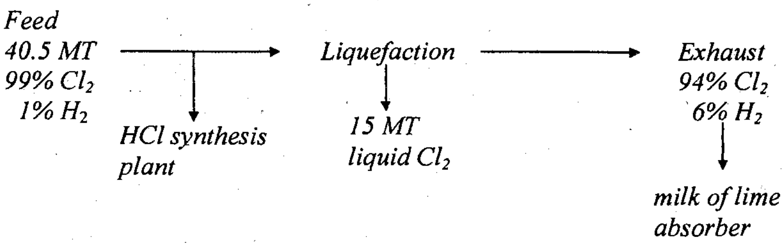
41. A 20% aqueous solution of Na_2CO_3 and 25% aqueous solution of $Ca(OH)_2$ were reacted to produce caustic soda solution. The precipitate which formed was analyzed to contain 5% H_2O, 1% NaOH, 94% $CaCO_3$. The concentration of NaOH solution produced is
    a. 98.67% c. 20.97%
    b. 15.68% d. 10.97%

42. A plant near Maria Cristina Falls is to manufacture NH_3 by using a stoichiometric mixture of N_2 and H_2. Electrolytic H_2 is to be reacted with air to produce NH_3. The moles of H_2 present in the mixture when 100 moles of pure electrolytic H_2 is used is
    a. 15.053 moles c. 84.95 moles
    b. 25.05 moles d. 74.95 moles

43. SO_2 is bubbled through hot sugar-cane juice to
    a. act as an acidifying agent c. increase the amount of molasses
    b. increase its concentration d. increase the crystal size

44. In the lime soda process for caustic soda manufacture, lime is made to react with water and then with soda ash. Composition of raw materials are: Lime: 54% CaO, 1.5% MgO and inerts; soda ash: 50% Na_2O and inerts. The metric tons of lime that will be needed to produce 100 MT of 25% liquid NaOH is
    a. 38.75 MT c. 33.12 MT
    b. 30.1 MT d. 31.21 MT

45. In a liquid Cl_2 plant, chlorine gas with some H_2 gas is liquified, with part of the Cl_2 made to form HCl, according to the following diagram.



The Cl_2 sent to HCl synthesis plant in MT is
a. 22.7
b. 2.82
c. 23.3
d. 6.04

46. The MT of $CaCO_3$ needed to produce 100 MT of soda ash daily by the solvay process is
a. 32.08
b. 110.1
c. 94.34
d. 84.34

47. Using the data given below, the metric tons of rock phosphate [$CaFCa_4(PO_4)_3$] needed to produce 6000 MT of 90% purity superphosphate is
Rock phosphate = 90% purity
Overall reaction efficiency = 90%
Sulfuric acid = 60°Be
60° Be Sulfuric acid is 77.67% H_2SO_4
Reactions:

$$CaFCa_4(PO_4)_3 + 5H_2SO_4 + 10H_2O \rightarrow 3H_3PO_4 + 5CaSO_4 2H_2O + HF$$

$$CaFCa_4(PO_4)_3 + 7H_3PO_4 \rightarrow 5CaH_4(PO_4)_2 + HF$$

a. 5920
b. 9530
c. 5254
d. 2536

48. A cement company uses 3000 MT of gypsum a month. If 40 MT of this gypsum are needed for every 1000 MT of clinker to produce Portland cement, the MT of clinker produced monthly by the cement plant is
a. 75,000
b. 85,000
c. 70,000
d. 90,000

49. A cement clinker with the following analysis:
CaO = 64%
Fe_2O_3 = 6.5%
SiO_2 = 21%
Al_2O_3 = 7.5%

is produced at a rate of 2000 MT per day. The materials used are limestone ($CaCO_3$ and inert materials) containing 97% CaO; iron oxide (Fe_2O_3 and inert materials) containing 85% Fe_2O_3; Shale (SiO_2, Al_2O_3 and inerts) containing 60% SiO_2 and 25% Al_2O_3 and silica with 90% SiO_2 and 10% inerts.

The MT of silica required for a 300-day operation per year is

a. 20,000
c. 25,000
b. 30,000
d. 35,000

50. Bauxite containing 61% Al_2O_3 and 8% SiO_2 is roasted and dissolved in caustic soda to form a solution from which iron present is precipitated and filtered out. By suitable treatment, hydrated Al_2O_3 is precipitated in very pure form with a recovery of 80% of the original Al_2O_3. The SiO_2 remains behind as Na_2SiO_3. The precipitated hydrated Al_2O_3 is dehydrated and forms the charge to an aluminum furnace. If liquid caustic soda (50% NaOH) costs ₱2,300 per MT, what will be the cost of the caustic soda needed for producing 1000 kg of pure Al_2O_3 assuming 10% more than the theoretical amount of NaOH needed is used ?

Reactions:

$$Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$$

$$SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$$

a. ₱ 6065
c. ₱ 6030
b. ₱ 5035
d. ₱ 6080

F1. PLANT and EQUIPMENT DESIGN

THEORY AND EQUATIONS

Pressure Riveted Vessel

A. ***Longitudinal Joint***

$$ts = \frac{PD}{2SE}$$

where P = internal pressure of vessel
D = inside diameter of vessel
S = unit tensile stress of material
E = efficiency of the joint
ts = shell thickness

B. ***Circumferential Joint***

$$ts = \frac{PD}{4Se}$$

Welded Pressure Vessel ASME Welding Code

1. Single butt joint : $E = 0.70$ ts = 1/16" to 1/8"
2. Double butt joint : $E = 0.80$ ts = 1/8" to ¼"
3. Single V-butt joint : $E = 0.70$ ts = ¼" to $\frac{5}{8}$"
4. Single V-butt joint with backing strip : $E = 0.80$ ts = $\frac{5}{8}$" to $1\frac{1}{4}$"
5. Double V-butt joint : $E = 0.90$ ts = > $\frac{5}{8}$" to any thickness

Design Equation

$$ts = \frac{PD}{2SwE - P} + C$$

where ts = thickness of the shell, P = internal pressure, D = inside diameter, E = efficiency of the joint, Sw = working stress

$Sw = Su * Fm * Fa * Fs * Fr$
Fm : 1.0 - for grade A or fire box grade
0.97 - for grade B or flange grades
0.98 - for structural design
Fa : 1.12 - radiographing factor
Fr : 1.06 - stress relieving factor
Fs : Factor of safety = 0.25 for temperature less than 600°F

NOTE: Fa and Fr will only be used when all the main joints of the vessel are radiographed. If relieving nor radiographing is not employed, the values of Fr and Fa are taken as unity.

Stress Relieving and Radiographing is mandatory if

(Use Fa = 1.12, Fr = 1.06)

a. $t > 1\frac{1}{4}''$

b. $t > \frac{D+50}{120}$

where D = inside diameter (for values of D less than 20 inches D is assumed to be 20.0)

$$t_{\min} = \frac{D+100}{1000}$$

Head Selection and Design

1. ***Standard Ellipsoidal*** $t = \frac{PD}{2SE}$

2. ***Standard Dished*** $T = \frac{PLW}{2SE}$

where L = crown radius in inches = Do - 6
k_r = knuckle radius = 0.06 Do

VALUES OF W FOR DISHED HEADS

k_r/L	W
0.06	1.80
0.07	1.70
0.08	1.65
0.09	1.60
0.10	1.55
0.11	1.50
0.12	1.47
0.13	1.44
0.14	1.41
0.15	1.40
0.16	1.38
0.17	1.37
0.18	1.35
0.19	1.32
0.20	1.30
0.25	1.25
0.50	1.12
1.00	1.00

3. ***Conical*** $t = \frac{PM}{2(\cos A)SE}$

r must be at least $3t$ and $0.06 \times (D + 2t)$, L must not exceed $D + 2t$

$$t = \frac{PLM}{2SE - 0.2P} \qquad P = \frac{2SEt}{LM + 0.2t}$$

where t = shell or head thickness
P = pressure
S = allowable stress
R = inside radius
E = joint efficiency, dimensionless
D = inside diameter of head skirt or inside length of major axis of an ellipsoidal head
h = inside depth of an ellipsoidal head
r = inside knuckle radius of a torispherical head
L = inside radius of hemispherical head or inside crown radius of a torispherical

REVIEW QUESTIONS AND PROBLEMS

1. The only strength of stress grade lumber that can be precisely determined without breaking the piece is
   a. rigidity
   b. factor of safety
   c. modulus of rupture
   d. stiffness

2. The chief difference between exterior grade plywood and interior grade plywood is
   a. that different types of glue are used
   b. in the number of laminations used
   c. in the weight per square foot
   d. in the size of knotholes permitted

3. Warp, wane and checks are all factors that help determine the quality of
   a. concrete
   b. stress grade lumber
   c. structural glass
   d. brick masonry

4. The Brinell Number of a material is a measure of
   a. specific gravity
   b. specific heat
   c. density
   d. hardness

5. A major classification group of stainless steels 6% to 22% nickel in addition to 16% to 26% chromium. This group differs from the other two major groupings in that its steels
   a. are non-magnetic
   b. have their iron in the ferritic form
   c. have their iron in the martensitic form
   d. have a coefficient of linear expansion almost zero

6. The ultimate strength divided by the allowable stress is
   a. yield point
   b. percentage of elongation
   c. working stress
   d. factor of safety

where M = arithmetic mean diameter of cone
A = ½ the included angle of cone

4. ***Hemispherical*** $t = \dfrac{PD}{4\,SE}$

Vessel Design Formulas for Internal Pressure

1. ***Cylindrical Shell*** $t = \dfrac{PR}{SE - 06P}$ $P = \dfrac{SEt}{R + 0.6\,t}$

   Circumferential stress (longitudinal joints) when t does not exceed 0.5 R or P does not exceed 0.385 SE

2. ***Spherical Shell*** $t = \dfrac{PR}{2\,SE - 0.2\,P}$ $P = \dfrac{2\,SEt}{R + 0.2\,t}$

   when t does not exceed 0.356 R or P does not exceed 0.665 SE

3. ***Hemispherical Head*** $t = \dfrac{PL}{2\,SE - 0.2\,P}$ $P = \dfrac{2SEt}{L + 0.2\,t}$

   when t does not exceed 0.356 L or P does not exceed 0.665 SE, L = inside radius

4. ***Ellipsoidal Head (semi ellipsoidal)***

   for semi ellipsoidal head in which $h = D/4$

   $t = \dfrac{PD}{2\,SE - 0.2\,P}$ $P = \dfrac{2\,SEt}{D + 0.2\,t}$

   for values of D/h from 2 to 6 $K = \dfrac{1}{6}\left(2 + \left(\dfrac{D}{2h}\right)^2\right)$

   $t = \dfrac{PDK}{2\,SE - 0.2\,P}$ $P = \dfrac{SEt}{DK + 0.2t}$

5. ***Torispherical Head (spherically dished)***

   For standard ASME head in which minimum knuckle radius = 6% of inside crown radius but is not less than $3t$, L must not exceed $D + 2t$

   $t = \dfrac{0.885\,PL}{SE - 0.1\,P}$ $P = \dfrac{SEt}{0.885L + 0.1\,t}$

   for values of L/r from 1 to 16 $2/3$

   $$M = \frac{1}{4}\left(3 + \sqrt{L/r}\right)$$

7. If an engineering structure is to be designed against rupture of any of its members under steady load, the factor of safety is a ratio based on working stress and
   a. elastic strength
   b. ultimate strength
   c. toughness
   d. endurance limit

8. The unit lateral deformation of a body under stress divided by the unit longitudinal deformation is known as
   a. Poisson's Ratio
   b. Hooke's Law
   c. Euler's Ratio
   d. Mohr's Modulus

9. A thin wire is subject to a tensile stress. If the temperature is constant, the electric resistance of the stressed wire with respect to the electric resistance of the unstressed wire will
   a. increase
   b. decrease
   c. remain the same
   d. any of these, depending on the material

10. The offset method is used to find a property of metals that do not have a well-defined stress-strain curve such as steel. This property is called the
    a. yield point
    b. modulus of elasticity
    c. proportional limit
    d. moment of inertia

11. The stress in an elastic material is
    a. inversely proportional to the material's yield strength
    b. inversely proportional to the force acting
    c. proportional to the displacement of the material acted on by the force
    d. inversely proportional to the strain

12. Normally the diameter of a rivet is 1/16 in. less than that of the hole in which it is to fit. This is to insure easy entrance of a hot rivet. In boiler calculations, the rivet is assumed to
    a. fill the hole after driving
    b. remain the same size after driving
    c. attain a size found by tables
    d. shrink an additional 1/16 in. on cooling

13. The intermittent welds generally used to hold material in place temporarily are called
    a. double vee
    b. tack
    c. fillet
    d. butt

14. In the construction of a vinegar container tank, one of these metals of construction is not recommended
    a. aluminum
    b. stainless steel
    c. brass
    d. monel

15. A chemical engineer was commissioned to design vertical cylindrical tank with a flat bottom and a conical roof. The tank must be able to hold a maximum of 4,500 m^3 of water for firefighting purposes. Ease of climbing the tank and bearing capacity allows a maximum height of 16.5 m from the bottom of the tank up to the rim of the tank cylinder. Normal working practice dictates that the maximum working capacity of the tank is 90% of the total tank volume. The tank roof has a 10% incline. Suitable steel plates available for constructing the tank come in size 4' x 8' sheets. The number of sheets needed is
    a. 540
    b. 575
    c. 610
    d. 525

16. Circular cylindrical cans of volume V_0 are to be manufactured with both ends closed. The ratio of the diameter and height that will require the minimum amount of metal to make in each can is
    a. $\frac{d}{h}=0.16$
    b. $\frac{d}{h}=0.8$
    c. $\frac{d}{h}=1.0$
    d. $\frac{d}{h}=1.2$

17. Four inch (4.0 inch) schedule 40 steel pipes are to be used to transport high pressure steam. The pipe joints are to be butt-welded. The safe working fiber stress for butt welded pipes is 457.1 kg/cm^2. The maximum steam pressure, in kg/cm^2, the pipes can handle is
    a. $\frac{50.8\,kg}{cm^2}$
    b. $\frac{18.28\,kg}{cm^2}$
    c. $\frac{25\,kg}{cm^2}$
    d. $\frac{55\,kg}{cm^2}$

18. A spherical carbon steel storage tank for ammonia has an inside diameter of 30 ft. All joints are butt welded with backing strip. If the tank is to be used at a working pressure of 50 psig and a temperature of 80°F, estimate the necessary wall thickness. Assume no corrosion is necessary, efficiency is 80% and allowable tensile strength is 13,700 psi.
    a. 1/2 in.
    b. 1/4 in.
    c. 7/16 in.
    d. 5/16 in.

Problems *19* and *20* are based on the following information:

A reactor will operate at 300 psi and 600°F. Height = 12 ft; crown radius = 66 in; diameter = 6 ft; double welded butt joint, efficiency = 80%. Allowable tensile strength of material is 12,000 psi.

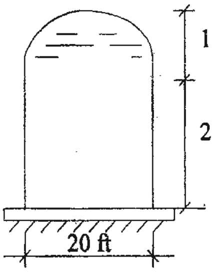
19. The thickness of the shell is
    a. 1-3/16"
    b. 1-1/16"
    c. 2'
    d. 1-1/4"

20. The thickness of the head is
    a. 5/2"
    b. 1/2"
    c. 3/4"
    d. 3/2"

21. A horizontal cylindrical tank is used for the storage of motor gasoline in the bulk plant of an oil company in Pandacan. The tank has an inside diameter of 3m and an inside length of 10m. The suction line of the tank is located 30 cm from the tank bottom to avoid sucking out sludge. To prevent overfilling, the maximum height of liquid in the tank is not made to exceed 90% of the vertical height of the tank. The working capacity of the tank in kiloliters is
    a. 36.23　　c. 45.23
    b. 63.32　　d. 68.32

22. A water tank 30 ft. in diameter has a thickest steel plate available of 3/8 inch thick. Assume the allowable stress of steel is 15,000 psi and a joint efficiency of 80%. Provide a corrosion allowance of 1/16 inch. The maximum height of the water tank is
    a. 84.3 ft.　　c. 68.05 ft.
    b. 43.6 ft.　　d. 48.03 ft.

23. A cylindrical water tank with a hemispherical dome has the dimensions shown below.



The tank is full. The total force, in lbf, exerted by the water on the base of the tank is most nearly
    a. 500,000　　c. 550,000
    b. 520,000　　d. 590,000

24. Bracket supports are most suitable for
    a. thick walled vertical vessels　　c. thin spherical vessels
    b. horizontal vessels　　d. tall vertical vessels

25. Skirt support is most suitable for
    a. small horizontal vessel　　c. tall horizontal vessel
    b. large horizontal vessel　　d. thick walled small vertical vessel

F2. UNIT OPERATIONS ECONOMICS

Optimum Economic Design – based on the condition giving the least cost per unit of time or the maximum profit per unit of production.

Economic Balance – the design of equipment or the selection of operating conditions whereby the increasing costs are balanced by the decreasing costs to give the greatest economic return. It is concerned with design, operation and yield.

General Procedure for Determining Optimum Conditions

1. Determine the factor to be optimized.
2. Develop a relationship showing how the different variables involved affect the factor chosen.
3. Combine these relationships analytically or graphically to give the desired optimum condition.

REVIEW QUESTIONS AND PROBLEMS

1. A design based on conditions giving the least cost per unit time and maximum profit per unit production.
   a. battery limit
   b. break-even point
   c. optimum economic design
   d. plant design

2. A flow diagram, indicating the flow of materials, unit operations involved, equipment necessary and special information on operating temperature and pressure is a
   a. schematic diagram
   b. qualitative flow diagram
   c. combined-detail flow diagram
   d. quantitative flow diagram

3. In a plant design implementation, soil testing is done to determine
   a. pH
   b. load bearing capacity
   c. porosity
   d. viscosity

4. This involves all engineering aspects in the development of either a new, modified or expanded industrial plant
   a. plant design
   b. optimum design
   c. process design
   d. engineering design

5. A chemical engineer specializing in the economic aspects of design is called
   a. plant engineer
   b. cost engineer
   c. design engineer
   d. process engineer

6. This refers to the actual design of the equipment and facilities necessary for carrying out the process.
   a. process engineering
   b. plant design
   c. process design
   d. optimum design

7. The final step before developing construction plans for the plant and includes complete specifications for all components of the plant and accurate costs based on quoted prices.
   a. preliminary design
   b. quick estimate design
   c. firm process design
   d. detailed design estimate

8. A thorough and systematic analysis of all factors that affect the possibility of success of a proposed undertaking usually dealing with the market, technical, financial, socio-economic and management aspects is called
   a. project feasibility study
   b. plant design
   c. project development and research
   d. product development

9. Discusses the nature of the product line, the technology necessary for production, its availability, the proper mix of production resources and the optimum production volume.
   a. market feasibility
   b. socio-economic feasibility
   c. technical feasibility
   d. management feasibility

10. Discusses the nature of the unsatisfied demand which the project seeks to meet, its growth and the manner in which it is to be met.
    a. financial feasibility
    b. management feasibility
    c. market feasibility
    d. technical feasibility

11. A multiple effect evaporator produces 10,000 kg of salt from a 20% brine solution per day. One kg of steam evaporates 0.7 N kg of water in N effects at a cost of ₱25 per 1000 kg of steam. The cost of the first effect is ₱450,000 and the additional effects at ₱300,000 each. The life of the evaporator is 10 years with no salvage value. The annual average cost of repair and maintenance is 10% and taxes and insurance is 5%. Assume 300 operating days per year. The optimum number of effects for minimum annual cost is
    a. 3 effects
    b. 5 effects
    c. 4 effects
    d. 2 effects

12. A process requires 20,000 lb/hr of saturated steam at 115 psig. This is purchased from a neighboring plant at ₱18.00 per short ton and the total energy content rate (mechanical) in the steam may be valued at ₱7.5 x 10^{-6} per BTU. Hours of operation per year are 7200. The friction loss in the line is given by the following equation:

$$F = \frac{187.5\, Lq^{1.8} mc^{0.20}}{d^{0.20} Di^{4.8}}, \text{ in ft-lbf/lbm}$$

$$C_f = 1.44\, Di^{1.5} L, \text{ in P/yr}$$

where L = length of straight pipe, ft.
q = steam flow rate, cu.ft. per sec.
mc = steam viscosity, cP
d = steam density, lb per ft^3
Di = inside diameter of pipe, in.

The optimum pipe diameter that should be used for transporting the above steam is

a. 6 in.
b. 4 in.
c. 3 in.
d. 5 in.

13. A smelting furnace operating at 2,400°F is to be insulated on the outside to reduce heat losses and save on energy. The furnace wall consists of a ½ inch steel plate and 4-inch thick refractory inner lining. During operation without outer insulation, the outer surface of the steel plate exposed to air has a temperature of 300°F. Ambient air temperature is at 90°F. Operation is 300 days per year. Thermal conductivities in BTU per hr-ft °F are: steel plate = 26; refractory = 0.1; insulation to be installed = 0.025. The combined radiation and convection loss to air irrespective of material exposed is 3 BTU per hr–ft^2 –°F, annual fixed charge is 20% of the initial insulation cost. If heat energy is ₱5.00 per 10,000 BTU and installed cost of insulation is ₱100 per inch ft^2 of area, the optimum thickness of the outer insulation that should be installed is

    a. 8 in.
    b. 12 in.
    c. 10 in.
    d. 6 in.

14. An organic chemical is produced by a batch process. In this process chemicals X and Y react to form Z. Since the reaction rate is very high, the total time required per batch has been found to be independent of the amount of materials and each batch requires 2 hours, including time for charging, heating and dumping. The following equation shows the relation between the pound of Z produced (lbz) and the pound of X (lbx) and Y (lby) supplied:

$$lbz = 1.5\left(1.1\,lbx\,lbz + 1.3\,lby\,lbz - lbx\,lby\right)^{0.5}$$

    Chemical X costs ₱0.09 per pound, chemical Y costs ₱0.04 per pound and chemical Z sells for ₱0.8 per pound. If half of the selling price for chemical Z is due to cost other than raw materials, the maximum profit obtainable per pound of chemical Z is

    a. ₱0.3 per lbs
    b. ₱0.5 per lbs
    c. ₱0.12 per lbs
    d. ₱0.25 per lbs

15. One hundred gram moles of R are to be produced hourly from a feed consisting of a saturated solution of A (C_{a0} = 0.1 g mole per liter). The reaction is A→R with rate r_a = (0.2/hr) C_a. Cost of reactant at C_{a0} = 0.1 gram mol per liter is ₱3.75/ g-mole A; cost of backmix reactor, installed complete with auxiliary equipment, instrumentation, overhead, labor depreciation, etc. is ₱0.075 per hr-liter. The % conversion of A that should be used for optimum operation is

    a. 45%
    b. 60%
    c. 50%
    d. 40%

16. One hundred lb moles of reactant A at a concentration of 0.01 lb mole per cu ft. is to be reacted with reactant B to produce R and S. The reaction follows the aqueous phase elementary reaction: $A + B \rightarrow R + S$ where k = 500 cu. ft./lb mole-hour
The amount of R required is 95 lb moles/hour
Data:
    1. In extracting R from the reacted mixture, A and B are destroyed
    2. B costs ₱15 per lb mole in crystalline form, and is very soluble in aqueous solutions such that even when present in large amount does not effect A in solution
    3. Capital and operating cost for backmix reactor is ₱ 0.10 per cu. ft.-hr

    The optimum backmix reactor size is
    a. 23,900 ft^3
    b. 24,200 ft^3
    c. 25,900 ft^3
    d. 23,500 ft^3

17. Optimum economic pipe diameter for fluid flow is determined by the
    a. viscosity of the fluid
    b. density of the fluid
    c. total cost considerations (pumping cost plus fixed cost of the pipe)
    d. viscosity and density of the fluid

18. For turbulent flow $(N_{Re} > 2100)$ of low viscosity fluid $(\mu < 20\,cp)$ in steel pipes, the optimum inside pipe diameter is given by
    a. $Di_{opt} = 3.9\,q_f^{0.45}\rho^{0.13}$
    b. $Di_{opt} = 3.9\,q_f^{0.45}\mu_c^{0.95}$
    c. $Di_{opt} = 3.9\,q_f^{0.49}\rho^{0.14}$
    d. $Di_{opt} = 3.9\,q_f^{0.36}\mu_c^{0.18}$

    where q_f = fluid flow rate, ft^3/sec; μ_c = fluid viscosity, centipoises; ρ = fluid density, lb/ft^3; Di_{opt} = optimum inside pipe diameter, inches

19. For laminar flow $(N_{se} < 2100)$ in steel pipe, the optimum inside pipe diameter is given by
    a. $Di_{opt} = 3.6\,q_f^{0.45}\mu_c^{0.28}$
    b. $Di_{opt} = 3\,q_f^{0.36}\mu_c^{0.18}$
    c. $Di_{opt} = q_f^{0.487}\mu_c^{0.025}$
    d. $Di_{opt} = q_f^{0.364}\mu_c^{0.182}$

    where q_f = fluid flow rate, ft^3/sec; ρ = fluid density, lb/ft^3; μ_c = fluid viscosity, centipoises; Di_{opt} = optimum inside pipe diameter, inches

20. For a non-washing plate and frame filter press operated at constant pressure, the maximum capacity in terms of the volume of filtrate collected per cycle is obtained when the filtration time is______ the dumping and cleaning time.
    a. greater than b. equal to c. less than d. can not be determined

G. INSTRUMENTATION AND PROCESS CONTROL

REVIEW QUESTIONS AND PROBLEMS

1. The simplest mode of control which is characteristic of a two-position control commonly utilized in a thermostat for controlling the temperature of heaters, air-conditioners, refrigerators, etc.
   a. proportional control
   b. derivative control
   c. on-off control
   d. programmable logic control

2. It is a control system in which the control action is independent of the output.
   a. closed-loop system
   b. feedback control system
   c. open-loop system
   d. cascade control system

3. An arrangement of physical components connected or related in such a manner as to command, direct or regulate itself or another system.
   a. stimulus
   b. unit process
   c. control system
   d. unit operation

4. It is the actual response obtained from the control system. It may or may not be equal to the specified response implied by the input
   a. input b. output c. answer d. result

5. The response of two tanks in series is
   a. overdamped
   b. underdamped
   c. critically damped
   d. oscillating

6. A control system in which the control action is somehow dependent on the output.
   a. closed-loop control system
   b. open-loop control system
   c. feedforward control system
   d. deadtime compensator

7. A property of a closed-loop system which permits the output (or some other controlled variable) to be compared with the input to the system (or the input to some other internally situated component or subsystem) so that the appropriate control action may be formed as some fraction of the output and input.
   a. feedback control system
   b. control system
   c. continuous time
   d. bandwidth

8. A frequency response measure of how well the system responds to variations in the input signal.
   a. feedback
   b. control system
   c. continuous time
   d. bandwidth

9. A signal dependent on continuum of values of the independent variable.
   a. continuous time signal
   b. discrete time signal
   c. AM signal
   d. SOS signal

10. A signal defined at, or of interest at, only discrete (distinct) instants of the variable (upon which it depends).
    a. analog signal
    b. continuum time signal
    c. a digital signal
    d. SOS signal

11. A device that converts an analog or continuous signal into a discrete or digital signal.
    a. analog-to digital (A/D) converter
    b. digital-to analog (D/A) device
    c. pressure to voltage converter
    d. discrete to continuous converter

12. It is used to convert one signal or energy form into another.
    a. transducer
    b. amplifier
    c. detector
    d. resistor

13. The part of the deviation of the response which approaches zero as time approaches infinity.
    a. steady state response
    b. output
    c. transient response
    d. frequency response

14. The integral of a unit step function is also known as
    a. unit ramp function
    b. sinusoidal function
    c. unit impulse function
    d. transcendental function

15. When the total number of variables in a process is greater than the number of independent equations that can be set-up, the process is said to be
    a. over specified
    b. under specified
    c. the degrees of freedom is zero
    d. the degrees of freedom is less than zero

16. A control structure with two feedback controllers with the output of the primary controller changing the set-point of the secondary controller whose output goes to the final controller.
    a. feedforward control
    b. ratio control
    c. cascade control
    d. override control

17. A type of advanced control system that identifies continuously online the parameters of the process as they change and returns the controller appropriately.
    a. linear control
    b. adaptive control
    c. cascade control
    d. override control

18. A pneumatic proportional controller is used to control the temperature within the range of 60 to 100°F. The controller is adjusted so that the output pressure goes from 3 psi, with the valve fully open, to 15 psi, with the valve fully closed, as the measured temperature goes from 71 to 75°F with the set point held constant. The gain of the control element in psi/°F is
    a. 6
    b. 3
    c. 1/3
    d. 10

19. The proportional band of the above controller is
    a. 20%
    b. 15%
    c. 10%
    d. 40%

20. A sensor usually made of a semiconductor that utilizes the effect of temperature on the resistance to current is called a
    a. thermocouple b. thermistor c. resistor d. capacitor

21. A thermometer with a time constant of 0.2 min is placed in a temperature bath, and after the thermometer comes to equilibrium with the bath, the temperature of the bath is increased linearly with time at a rate of 1 degree per min. The difference between the indicated temperature and the bath temperature after 1.0 min is
    a. 0.075° b. 1.0° c. 0.20° d. none of these

22. Given the characteristic equation of a closed loop transfer function,
    $$2s^3 + 4s^2 + 4s + 12 = 0$$
    The system is
    a. stable b. unstable c. cannot be determined

23. Consider the characteristic equation of a certain closed-loop control system
    $$S^3 + 3Ks^2 + (K + 2)s + 4 = 0$$
    The range of K so that the system is stable is
    a. $-2.75<K<0.528$ b. $K>0.528$ c. $K< -2.75$ d. none of these

24. A system has poles at -1, -5, and zeroes at 1 and -2. Is the system stable or not?
    a. stable b. unstable c. cannot be determined

25. If a step function is applied to the input of a system and the output is of the form Y = t, is the system stable or unstable?
    a. stable b. unstable c. cannot be determined

26. If a step function is applied to the input of a system and the output remains below a certain level for all time, is the system necessarily stable?
    a. true b. false c. cannot be determined

27. The Routh Stability Criteria can be applied to systems which contain time delays.
    a. true b. false c. cannot be determined

28. Write the transfer function of a system with a gain factor of 2, poles at 0, -3 and at $-1\pm 2j$ and zeroes at $-2 \pm j$.
    a. $2(s^2+4s+5)/s(s+3)(s^2+2s+5)$ b. $2s(s+3)(s^2+2s+5)/(s^2+4s+5)$
    c. none of these

29. The amplitude ratio for the transfer function $2/(s + 2)$ for $\omega = 2$ is
    a. 2 b. 0.707 c. 1.41 d. 0.35

30. The phase angle for the transfer function given in Problem *29* is ______degrees
    a. 45 b. –90 c. –45 d. –60

31. A sinusoidal input $X = 2 \sin 2t$ is applied to a system with the transfer function $G(s) = 2/s\,(s + 2)$. The steady state output as a function of t is
    a. $Y = 2 \sin (2t - 135)$ c. $Y = 0.707 \sin 2t$
    b. $Y = 0.707 \sin (2t - 135)$ d. $Y = 1.41 \sin (2t - 45)$

32. Is the system with a transfer function $Y(s) = (s-1)/(s+2)(s^2+4)$ stable or unstable?
a. stable b. unstable c. cannot be determined

33. The gain margin of a system with a transfer function of $1/(s + 1)^3$ is
a. 1 b. 4 c. 8 d. 1/4

34. The phase margin of the system in Problem *33* is ________ degrees.
a. 90 b. –180 c. –90 d. –45

35. The angle of $GH(s) = 16(s + 1)/s(s + 2)(s + 4)$ at the point $s = -2 + 2j$ is________ degree
a. –153 b. –90 c. 0 d. 90

36. The magnitude of the transfer function given in Problem *35* at the same point is
a. 5 b. 2.23 c. 1.5 c. 0.321

37. The range of value of K for a system with characteristic equation given by $s^4 + 6s^3 + 11s^2 + 6s + K = 0$ is
a. K> 0 b. K<10 c. K>10 d. 0<K<10

38. A proportional controller exhibits a large offset. This offset can be eliminated without altering the proportional constant K_c by
a. adding another proportional control c. adding an integral control
b. adding an on-off control d. adding a derivative control

39. If a step function is applied to the input of a process system and the output is of the form $Y = e^t \sin t$, the system is
a. stable b. unstable c. cannot be determined

40. A spring motion is described by the differential equation $x''(t) + 5x(t) + 6x(t) = 0$. The motion of the spring is
a. overdamped c. critically damped
b. underdamped d. undamped

41. A PI controller of a first order process is subjected to a unit step input. If the integral constant is fixed, decreasing the proportional gain will
a. increase the overshoot c. decrease the overshoot
b. increase the oscillation d. decrease the offset

42. This is an advanced control system which basically involves a multiple input process in which the inputs can be measured.
a. ratio control c. derivative control
b. integral control d. automatic control

43. In the control of pressure in a distillation column, there is no need to include
a. proportional control c. derivative control
b. integral control d. automatic control

44. A control scheme that is based on the model of a process that is first order with dead time is
    a. Cohen-Coon Control
    b. Internal Model Control
    c. Smith-Predictor Control
    d. Foxboro Control

45. The integral of a Dirac function is a
    a. ramp function
    b. step function
    c. impulse function
    d. pulse function

46. A PID controlled process has a highly oscillating response. The process can be stabilized by
    a. increasing proportional gain
    b. decreasing proportional gain
    c. increasing derivative time constant
    d. decreasing derivative time constant

47. A PI controller of a first order process is subjected to a unit step input. If the integral constant is fixed, increasing the proportional gain will
    a. increase the overshoot
    b. increase the oscillation
    c. decrease the offset
    d. decrease the overshoot

48. It is a graph of the process systems' magnitude of GH(ω) and arg [GH(ω)] in a rectangular coordinate with ω as a parameter
    a. Nichols plot
    b. Bode plot
    c. Nyquist plot
    d. Root locus plot

49. A 2-in diameter spherical ball with a thermal conductivity of 30 BTU/hr-ft-°F is immersed in a fluid whose heat transfer coefficient is 9 BTU/hr-ft^2-°F. The temperature response of the solid may be determined by considering it as
    a. distributed parameter system
    b. heat transfer system
    c. lumped parameter system
    d. open-loop system

50. A controller tuning procedure based on the error-integral criteria for the first order system with transport lag model is
    a. C – C Method
    b. Z – N Method
    c. L – M – S Method
    d. P – R – C Method

Part III

GENERAL ENGINEERING

A. MATHEMATICS

REVIEW QUESTIONS AND PROBLEMS

1. Solve for X, Y and Z.
   a. $(X\text{-}2)\,(Y\text{-}3) = 5$
   b. $(Y\text{-}3)\,(Z\text{-}1) = 1$
   c. $(Z\text{-}1)\,(X\text{-}2) = 5$

   a. $x = 7,\ y = 4,\ z = 2$
   b. $x = -3,\ y = 2,\ z = 0$
   c. all of these
   d. none of these

2. A Chemical Engineer mixed 40 ml of 8% hydrochloric acid with 60 ml of 12% hydrochloric acid solution. He used a portion of this solution and replaced it with distilled water. If the new solution tested 5.2% hydrochloric acid, how much of the original mixture did he use?
   a. 60 ml
   b. 50 ml
   c. 40 ml
   d. 80 ml

3. How many pounds of cream containing 12% butterfat must be added to 1800 lbs. of milk containing 2% butterfat to obtain milk having 3% butterfat?
   a. 150 lbs of cream
   b. 200 lbs of milk
   c. 150 lbs of milk
   d. 200 lbs of cream

d 4. A housewife adds 5 cups of water for every 4 cups of uncooked rice. How many cups of water are added to make 10 cups of cooked rice assuming each cup of uncooked rice results to 2 cups of cooked rice ?
   a. 6
   c. 8
   d. 6-1/4
   e. none of these

a 5. A wine maker has 2 casks of wine having a capacity of 38 gallons and 68 gallons, respectively. He drew a certain quantity from each cask and finds that the quantities left have a ratio of 4 to 7. He then added 3 gallons to the smaller casks and 4 gallons into the bigger casks, and the quantities they contain have now a ratio of 7 to 12. How many gallons were drawn from each cask?
   a. smaller cask = 6 gallons ; bigger cask = 12 gallons
   b. smaller cask = 12 gallons ; bigger cask = 18 gallons
   c. smaller cask = 10 gallons ; bigger cask = 20 gallons
   d. smaller cask = 8 gallons ; bigger cask = 16 gallons

b 6. A man bought 24 boxes of screws for ₱2,200. There were three types of screw bought. Screw *A* costs ₱300.00 per box, Screw *B* costs ₱150.00 per box and Screw *C* costs ₱50.00 per box. How many boxes of each screw did he buy?
   a. *A* = 3 boxes; *B* = 4 boxes; *C* = 17 boxes
   b. *A* = 2 boxes; *B* = 5 boxes; *C* = 17 boxes
   c. *A* = 5 boxes; *B* = 6 boxes; *C* = 13 boxes
   d. *A* = 4 boxes; *B* = 10 boxes; *C* = 10 boxes

A. MATHEMATICS

REVIEW QUESTIONS AND PROBLEMS

1. Solve for *X*, *Y* and *Z*.
   a. $(X-2)(Y-3) = 5$
   b. $(Y-3)(Z-1) = 1$
   c. $(Z-I)(X-2) = 5$

   a. $x = 7,\ y = 4,\ z = 2$
   b. $x = -3,\ y = 2,\ z = 0$
   c. all of these
   d. none of these

2. A Chemical Engineer mixed 40 ml of 8% hydrochloric acid with 60 ml of 12% hydrochloric acid solution. He used a portion of this solution and replaced it with distilled water. If the new solution tested 5.2% hydrochloric acid, how much of the original mixture did he use?
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   d. 80 ml

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   e. none of these

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   a. *A* = 3 boxes; *B* = 4 boxes; *C* = 17 boxes
   b. *A* = 2 boxes; *B* = 5 boxes; *C* = 17 boxes
   c. *A* = 5 boxes; *B* = 6 boxes; *C* = 13 boxes
   d. *A* = 4 boxes; *B* = 10 boxes; *C* = 10 boxes

18. A flagpole 20 m high stands on top of a tower which is 100 m high. At what distance from the base of the tower will the flagpole subtended an angle of 42°? The height of instrument is 4 meters.
    a. 46.48 m b. 50.32 m c. 83.1 m d. 66.75 m

19. What part of 90% alcohol must be removed and replaced by an equal amount of pure alcohol to make a 95% alcohol solution?
    a. 5% or less c. between 5% and 10%
    b. 5% d. 50%

20. How many triangles are determined by 8 points, no three of which are collinear?
    a. 56 b. 81 c. 42 d. 72

21. How many diagonals does a 10 sided convex polygon has?
    a. 45 b. 40 c. 35 d. 30

22. The sides of the triangle are in the ratio 2:3:4, if its area is 11.619, find its perimeter.
    a. 14 b. 16 c. 15 d. 18

23. Find the length of the altitude to the longest side of the triangle whose sides are 4, 5 and 6 units respectively.
    a. 3.3 b. 2.1 c. 4.5 d. 5.6

24. The lengths of the sides of a triangle are 12, 15 and 18. A circle tangent to the longest and shortest side has its center on the remaining side. Find the distance from the center of the circle to the midpoint of the side where the center of the circle lies.
    a. 2.3 b. 1.5 c. 3.4 d. 4.6

25. A regular octagon has an apothem of 1 unit. The area of the inscribed circle is
    a. π b. 2π c. 3π d. 4π

26. Find the area of the triangle whose vertices lie at the points (4,1), (6,2) and (2,5)
    a. 4 b. 6 c. 5 d. 7

27. The major and minor axes of an ellipse measure 10 and 8 units respectively, the distance between the foci is
    a. 3 b. 6 c. 5 d. 7

28. Find the area in sq. cm. of the largest square which can be cut from a circle of radius 5 cm.
    a. 50 b. 55 c. 60 d. 65

29. The sum of the interior angles of a polygon is 2700°. How many sides are there?
    a. 15 b. 16 c. 17 d. 18

30. A gasoline tank consists of a horizontal cylinder 30 cm in diameter and 1.5 m long. Determine the number of liters in the tank when the gauge rod in the plane of the vertical diameter shows a depth of 10 cm in the tank ($1\ m^3 = 1000$ liters).
    a. 31.5 b. 48.2 c. 63.6 d. 85.7

31. The vertex of the parabola, $x^2+2x-y+3=0$
    a. (2, 1) b. (2,-1) c. (-1, 2) d. (1, 2)

32. The volume of the sphere is increasing at the rate of 6 cm^3/hr. At what rate is its surface area increasing when the radius is 40 cm?
    a. 0.5cm $^2/hr$ b. 0.4 cm $^2/hr$ c. 0.3 cm $^2/hr$ d. 0.2 cm $^2/hr$

33. Two posts 10 m high and the other 15 m high stands 30 m apart. They are to be stayed by transmission wire attached to a single stake at ground level, the wires running to the tops of the posts. Where should the stake be placed to use the least amount of wire?
    a. 12 m from shorter post c. 18 m from shorter post
    b. 16 m from shorter post d. 10 m from shorter post

34. An open box is to be made of a piece of cardboard 10 cm x 16 cm cutting equal shares out of the corners and turning up the edges to form sides. Determine the maximum capacity of the box.
    a. 186 cu. cm. b. 100 cu. cm. c. 200 cu. cm. d. 144 cu. cm.

35. A solution is passing through a conical filter 24 cm deep and 16 cm across the top into a cylindrical vessel at diameter 12 cm. At what rate is the level of the solution in the cylinder rising when the depth of the solution in the filter is 12 cm? Its level is falling at the rate of one cm/sec.
    a. 0.555 cm/sec b. 0.777 cm/sec c. 0.444 cm/sec d. 0.333 cm/sec

36. A rectangular box with a square base is to have a capacity of 27 cu. in. Determine the least amount of material required.
    a. 16 b. 54 c. 32 d. 72

37. The volume of a gas in isothermal expansion is given by $V= {}^k/_P$. Find the approximate percentage change in *V* due to a 2% increase in P, *k* being constant.
    a. 6% decrease b. 4% increase c. 2% decrease d. 6% increase

38. Find the seventh derivative of the function: $y = x^6 - 7x^5 + 2x^4 - x^3 + x^2$
    a. 720 b. $x - 840$ c. 0 d. 1

39. A statue 5 ft tall stands on a pedestal 9 ft high. If an observer's eye is 5 ft above the ground, how far from the pedestal should he stand so that the angle subtended in his eye by the statue will be maximum.
    a. 36 b. 6 c. 9 d. 49

40. What positive number when raised to a power equal to itself will give a minimum value?
    a. e b. ln e c. $\frac{1}{e}$ d. $\ln \frac{1}{e}$

41. The depth of a conical vessel containing water is equal to the radius of its top. If the water leaks through a hole at the vertex of the vessel at the rate of π cu. ft/min, how fast is the surface of the water falling when the depth is 2 ft?
    a. 5 in/min b. 6 ft/s c. 3 in/min d. 5 ft/s

42. The height of a right circular cylinder is fixed at 6 cm. How fast is the volume changing at the instant when r = 3 cm, if the radius increases?
    a. $20\pi\frac{cm^3}{cm}$ b. $36\pi\frac{cm^3}{cm}$ c. $2\pi\frac{cm^3}{cm}$ d. $12\pi\frac{cm^3}{cm}$

43. If $s = t^2 - t^3$, the velocity when the acceleration is zero.
    a. $v = 1/3$ b. $v = 1/2$ c. $v = 1/5$ d. $v = 1/6$

44. The area of an isosceles triangle decreases at a rate of 12 m^2/s. If the base is always twice the altitude, how fast is the altitude changing with time when the base is 3 m.
    a. – 4 m/s b. 8 m/s c. – 3 m/s d. – 5 m/s

45. Find the area of the largest rectangle that can be inscribed in circle of radius ***a*** cm.
    a. $\sqrt{2}\,a^2$ b. $2a^2$ c. a^2 d. $\sqrt{2}\,a$

46. A lot has the form of a right triangle with perpendicular sides 60 ft and 80 ft. Find the length and the width of the largest rectangular building that can be erected facing the hypotenuse of the triangle
    a. 36 x 75 b. 45 x 60 c. 50 x 24 d. 50 x 100

47. Two vertical poles, respectively, 1 m and 9 m high are 6 m apart. How far from the foot of the shorter pole is the point where the line segment joining the tops of the poles subtends the greatest angles?
    a. 3 b. 9 c. 6 d. 5

48. Two factors are considered essentially the same if
    a. both of them are positive
    b. one is exactly the same as the other
    c. both of them are negative
    d. one is merely the negative of the other

49. The curve represented by the equation r = 6 is
    a. a circle c. an ellipse
    b. a parabola d. a line

50. The plane rectangular coordinate system is divided into four parts which are known as
    a. octants c. coordinates
    b. quadrants d. axis

51. The sum of the squares of two numbers is 58 and the difference of their squares is 40. Find the larger no.
    a. 7 b. – 7 c. –3 d. 3

52. Find the area of a circle whose equation is $x^2 + y^2 + 4x + 6y - 23 = 0$
    a. 36 π b. 30 π c. 40 π d. 45 π

a.

53. Super ferry allowed A kg of baggages for free with additional charge for baggage in excess of the limit. The combined weight of the baggages of two passengers on one particular trip was 105 kg. One passenger paid ₱100 extra while the other paid ₱150 extra. A third passenger in the same trip has 105 kg baggage and was charged ₱650 extra. Find A in kg.
    a. 40 b. 50 c. 60 d. 70

54. Which of the following is not factorable?
    a. $2m^2 + 5mn + 3n^2$ c. $s^{12} - 1$
    b. $-x^2 - x + 12$ d. $t^2 + 5$

55. What is the value of x for which $y = 2x^3 - 3x^3 - 36x + 25$ will have an inflection point?
    a. 1/3 b. 1/4 c. 1/2 d. 1/5

56. Find the area in the first quadrant bounded by the parabola $y^2 = 4x$, $x = 1$ and $x = 3$.
    a. 5.595 b. 5.955 c. 9.555 d. 9.955

57. The difference of the squares of two numbers is 95 and the sum of their squares is 193. Find the smaller number.
    a. 7 b. –7 c. –12 d. 12

58. A number has 2 digits whose sum is 9. The difference between the original number and the number resulting from an interchange of the digit is 27. What is the original number?
    a. 63 b. 36 c. 54 d. 45

59. A father is now 4 times as old as his son. In 6 years, the father will be 6 times as old as the son was, 2 years ago. How old is the father?
    a. 9 b. 36 c. 20 d. 5

60. An angle is 30 less than thrice its complement. What are the angles?
    a. 40°, 50° b. 10°, 80° c. 20°, 70° d. 30°, 60°

61. If the length and the width of a rectangle were each increased by 2 cm, the area would increase by 14 cm^2. If the length is increased by 1 cm and the width is decreased by 1 cm, the area will be decreased by 2 cm^2. Find the length of the original rectangle.
    a. 2 b. 4 c. 5 d. 3

62. The perimeter of a right triangle is 80 cm and its hypotenuse is 34 cm. Find the length of its shortest side.
    a. 30 b. 16 c. 15 d. 27

63. The area of a rectangular piece of metal sheet is 400 cm^2. An open box is formed by cutting a square 1 cm wide on each side from each of the corners and folding up the sides. The volume of the box formed is 322 cm^3. Find the length of the metal sheet.
    a. 12 b. 16 c. 20 d. 25

64. A pipe can fill the tank alone in 15 minutes and another pipe in only 3 minutes. How long would it take both pipes to fill the tub?
    a. 2.50 mins b. 3.75 mins c. 7.50 mins d. 4.25 mins

65. A marine vessel travels at 25 kph between two ports of distance 60 km. If it takes an hour less time when going with the low tide current than against it, what is the rate of the current?
    a. 2.5 kph b. 3.0 kph c. 5.0 kph d. 5.5 kph

a 66. Simplify : $4(5^{x+1}) + 5(5^x) - 5^{x+2} - 25(5^{x-2})$
    a. -5^x b. 5^x c. -5^{x+1} d. 5^{x-1}

67. Which of the following is true?
    a. $\sqrt{-6} \times \sqrt{-2} = 12$
    b. $24 = 4(\sqrt{6})$
    c. $\sqrt{10} = \sqrt{5} + \sqrt{2}$
    d. $4^4 + 4^4 + 4^4 + 4^4 = 4^5$

68. Find the 1265th digit in the decimal expansion of 263/999.
    a. 6 b. 3 c. 2 d. 9

c 69. Evaluate $\log_3 6$
    a. 1.12 b. 0.50 c. 1.63 d. 0.61

70. Find a quadratic equation whose roots are $3-\sqrt{2}$ and $3+\sqrt{2}$.
    a. $x^2 + 6x + 7 = 0$
    b. $x^2 + 6x - 7 = 0$
    c. $x^2 - 6x + 7 = 0$
    d. $x^2 - 6x - 7 = 0$

71. Find the 21st term of the expansion of $\left(\frac{1-2a^3}{2a^2}\right)^{25}$
    a. $\frac{26565}{16}a^{10}$
    b. $\frac{26655}{16}a^{10}$
    c. $\frac{26565}{32}a^{10}$
    d. $\frac{26655}{32}a^{10}$

72. Find the middle term in the expansion of $\left(a^2 - \frac{1}{2b}\right)^8$
    a. $\frac{35}{8}\left(\frac{a^5}{b^3}\right)$
    b. $\frac{35}{18}\left(\frac{a^8}{b^4}\right)$
    c. $\frac{35}{8}\left(\frac{a^4}{b^8}\right)$
    d. $\frac{35}{8}\left(\frac{a^8}{b^4}\right)$

73. In the complex number $3 - 4i$, the absolute value is
    a. –5 b. 25 c. 5 d. –25

74. Simplify : $i^{2002} + i^{2003}$

a. $-i - 1$ b. 1 c. $-1 + 1$ d. 0

75. Evaluate : $\sqrt{-10} \times \sqrt{-7}$

a. $i\sqrt{70}$ b. $-\sqrt{70}$ c. $\sqrt{10}$ d. $\sqrt{70}$

76. If the roots of an equation are zero, then they are classified as

a. trivial solns c. conditional solns
b. extraneous solns d. hypergolic solns

77. The logarithm of 1 is

a. 0 b. 1 c. $-\infty$ d. $+\infty$

78. The polynomial $2x^3+4x^2-3x+8$ is divided by $x+2$, the remainder is

a. 10 b. 14 c. 5 d. 7

79. Which of the following is not a factor of $x^4-x^3-3x^2+x+2=0$?

a. –1 b. –2 c. 1 d. 2

80. Given: tan A = 8/15, determine the value of 1 – sin A.

a. 0.08 b. 0.28 c. 0.47 d. 0.61

81. Find the minimum value of $\dfrac{2+\sin A}{3+\cos B}$

a. 5/8 b. 1/4 c. 1/2 d. 5/3

82. Simplify: $\dfrac{2\tan x}{1+\tan^2 x}$

a. sin 2θ b. sec 2θ c. cos 2θ d. tan 2θ

83. Simplify cos (60°– θ) + cos (60° + θ) as a function of θ only.

a. sin θ b. sec θ c. tan θ d. cos θ

84. What is the value of (log 4 to the base 2) + (log 6 to the base 3)?

a. 7.39 b. 3.63 c. 3.97 d. 9.37

85. Find the area of the triangle with vertices (2,1), (–1, 4) and (–2,1).

a. 6 b. 8 c. 10 d. 12

86. What is the increase in the area of triangle if one side is decreased by 10%?

a. 9% b. 18% c. 19% d. 21%

87. The distance between the points (5, 2) and (2, y) is 5. What is the value of y?

a. 5 and –3 b. 1 and –7 c. 3 and –5 d. 6 and –2

88. Find the distance from the point (–1, –3) to the line $3x–4y = 1$.
    a. 1.6 b. 2.5 c. 3.2 d. 4.7

89. The collection of all points in the plane equidistant from two fixed points is
    a. ellipse b. parabola c. line d. circle

90. Find $\lim\limits_{x\to 2^+} \dfrac{\sqrt{x\text{-}2}-1}{x\text{-}3}$
    a. 0 b. 1 c. –½ d. infinite

91. If $a + b = 9$, find the maximum value of ab^2
    a. 0 b. 64 c. 98 d. 108

92. Find a point on the curve $y = 2e^{-2x}$ whose tangent line is perpendicular to the line $2x – 4y = 1$.
    a. (0,1) b. $(\ln\sqrt{2}, 1)$ c. (ln 2, 4) d. $(1, e^2)$

93. Find the derivative of $y = x^x$.
    a. x^x b. $x^x (lnx)$ c. $x^x(1 + lnx)$ d. none of these

94. A hot air balloon leaves at a rate of 5 m/sec as seen by an observer 15 m away. How fast is the angle of elevation of the line of sight increasing after 4 sec?
    a. 0.12 rad/s b. 0.08 rad/s c. 0.03 rad/s d. 0.06 rad/s

95. Water is flowing into a conical container at a rate of 24 cm^3/sec. The vessel is 18 cm deep with a radius of 6 cm. At what rate is the level of liquid rising when the water in the vessel is 3 cm deep?
    a. 6.28 b. 2.55 c. 4.57 d. 5.73

96. The function, $y = \dfrac{x-1}{x^2+x-2}$
    a. 2 b. 1 c. –1 d. –2

97. Evaluate $\int_0^3 \sqrt{9-x^2}\,dx$
    a. 1.75π b. 2.25π c. 3.50π d. 4.25π

98. Evaluate $\int_{-1}^{3} (3x^2 + 4x - 9)\, dx$
    a. 8 b. 4 c. 2 d. 6

99. Find the area of the region bounded by the lines $x + y = 0$, $x + 2 = 0$; $y = 1/x^2$.
    a. 1 b. 2 c. 3 d. 0.5

100. Find the volume generated by rotating the region bounded by $x = 2y$, $x - 4 = 0$ and $y^2 = 4x$, about the x-axis.
   a. 19 b. 31 c. 52 d. 84

DIFFERENTIAL EQUATIONS

1. The differential equation $\frac{d^2y}{dx^2} + 3\frac{dy}{dx} + 2y = \cos 2x$ can be classified as
   a. exact
   b. variable separable
   c. linear and homogeneous
   d. linear but not homogenous

2. The general solution of the ordinary differential equation $\frac{dy}{dx} = x - 2xy$ with c = constant is
   a. $\ln(1-2y) = x^2 + c$
   b. $-\ln(1-2y) = \frac{x^2}{2} + c$
   c. $2y = 1 + ce^{-x^2}$
   d. $+\ln(1-2y) = \frac{x^2}{2} + c$

3. The order of the differential equation $\left[\frac{d^2y}{dx^2}\right]^{1/3} = k\left[1 + \frac{dy}{dx}\right]^{3/2}$ is
   a. 1 b. 3 c. 2 d. 4

4. The degree of the differential equation $\left[\frac{dy}{dx}\right]^3 = 1 + \left(\frac{d^2y}{dx^2}\right)^2$
   a. 6 b. 3 c. 2 d. 4

5. Solve the differential equation $\frac{dy}{dx} = 6x^2\sqrt{y}$ subject to $y = 9$ when $x = -2$
   a. $y = (x^3 + 11)^2$ b. $y = (2x^3 - 5)$ c. $y = (2x^3 + 11)^2$ d. $y = (x^3 + 5)^2$

6. Solve $x\frac{dy}{dx} - 6y = x$
   a. $y = -x^6 + cx^5$ b. $y = x^5 + cx^6$ c. $y = -x^5 + cx^6$ d. $y = x^6 + cx^5$

7. Solve the homogenous equation $(x^2 + y^2)dx + 2xydy = 0$
   a. $x(x^2 + 3y^2) = c$
   b. $x^2(x^2 + 3y^2) = c$
   c. $x^2(x^2 + 3y^2) = c$
   d. $x(x^2 + 2y^2) = c$

8. Solve $(6x + y^2)\,dx + y(2x - 3y)\,dy = 0$
   a. $3x^2 + 2xy^2 - y^3 = 0$
   b. $3x^2 + xy^2 + y^3 = c$
   c. $3x^2 + xy^2 - y^3 = c$
   d. $3x^2y + y^2 + 3y = c$

9. $(9+2x\sin y)\,dx - x^2\cos y\,dy = 0$
   a. $x+2x^2\sin y = c$
   b. $\sin y = cx^3 - 3$
   c. $x - x^2\sin y = c$
   d. $x\sin y = cx^3 - 3$

10. Solve the equation $\frac{d^2y}{dx^2}+8\frac{dy}{dx}+15y=0$
    a. $y=c_1e^{5x}+c_2e^{3x}$
    b. $y=c_1e^{-5x}+c_2e^{-3x}$
    c. $y=(c_1x+c_2)e^{3x}$
    d. $y=(c_1x+c_2)e^{-5x}$

11. Solve the equation $y''+6y'+9y=0$ subject to the conditions $y(0)=-4$ and $y'(0)=5$.
    a. $y=(-7x-4)e^{3x}$
    b. $y=(-7x-4)e^{-3x}$
    c. $y=(11x-4)e^{-3x}$
    d. $y=(11x-4)e^{3x}$

12. Solve the equation $\frac{d^2y}{dx^2}+2\frac{dy}{dx}-15y=-2\cos x$
    a. $y=c_1e^{-5x}+c_2e^{3x}+\frac{1}{65}\cos x+\frac{8}{65}\sin x$
    b. $y=c_1e^{-5x}+c_2e^{3x}-\frac{1}{65}\cos x+\frac{8}{65}\sin x$
    c. $y=c_1e^{-5x}+c_2e^{3x}+\frac{8}{65}\cos x-\frac{1}{65}\sin x$
    d. $y=c_1e^{-5x}+c_2e^{3x}+\frac{8}{65}\cos x+\frac{1}{65}\sin x$

13. Find the particular solution of $\frac{d^2y}{dx^2}+\frac{dy}{dx}-2=4e^x$
    a. $y_p=-4xe^x$
    b. $y_p=\frac{-xe^x}{4}$
    c. $y_p=\frac{-4xe^x}{4}$
    d. $y_p=\frac{-3xe^x}{4}$

14. Find a particular solution of $\frac{d^2y}{dx^2}-5\frac{dy}{dx}=4e^{-3x}+\sin x$
    a. $y_p=6e^{-3x}+\frac{1}{26}\sin x+\frac{5}{26}\cos x$
    b. $y_p=6e^{-3x}-\frac{1}{26}\sin x-\frac{5}{26}\cos x$
    c. $y_p=6e^{-3x}+\frac{1}{6}\sin x-\frac{5}{26}\cos x$
    d. $y_p=\frac{1}{6}e^{-3x}-\frac{1}{26}\sin x+\frac{5}{26}\cos x$

15. The differential equation $dv=(y^2-3vy)\,dy$ is said to be
    a. linear in y
    b. non-linear in x
    c. non-linear in v
    d. linear in v

16. The differential equation $y''+3y'-4y=2x$ is
    a. first order linear differential equation
    b. second order homogenous linear differential equation
    c. second order non-homogenous linear differential equation
    d. linear differential equation of higher order and with variable coefficient

17. The differential equation $\left(x^2+4xy+y^2\right)dx-xydy=0$ is
    a. variable separable
    b. homogenous
    c. exact
    d. linear differential equation

18. Which of the following is a linear differential equation?
    a. $\left(1+y^2\right)dx-2x^2ydy=0$
    b. $\left(x^2+y^2\right)dx-xydy=0$
    c. $(2xy-\tan y)dx+\left(x^2-\sec^2 y\right)dy=0$
    d. $dv-(y-3v)dy=0$

19. A certain radioactive substance decomposes at a rate proportional to the amount present. Suppose that in 25 years approximately 1.2% of the substance will disintegrate, how many percent will remain after 100 years?
    a. 4.72%
    b. 98.8%
    c. 95.28%
    d. 25%

20. The body of a murder victim was discovered at 11 PM. At 11:30 PM the victim's body temperature was measured to be 94.6°F. After 1 hour, the body temperature was 93.4°F. The room where the body was found was at a constant temperature of 70°F. Assuming that Newton's Law of cooling is applicable and assuming that the normal human body temperature is 37°C, the time of death was approximately
    a. 2:30 PM
    b. 8:30 PM
    c. 9:30 PM
    d. 11:00 PM

21. A tank was initially filled with 100 gal of salt solution containing 1 lb of salt per gallon. Fresh brine containing 2 lbs of salt/gal runs into the tank at the rate of 5 gal/min, and the mixture, assumed uniform, runs out at the same rate. At what time will the concentration of the salt in the tank becomes ?
    a. 14 min
    b. 28 min
    c. 32 min
    d. 55 min

22. The Laplace transform of t is
    a. $1/s$
    b. $2/s^2$
    c. $1/s^2$
    d. $1/(s-1)$

23. The Laplace transform of e^t is
    a. $1/s$
    b. $1/(s+1)$
    c. $1/(s-1)$
    d. $1/(s-1)^2$

24. The rate of decay of radioactivity elements is usually assumed to be proportional to the number of atoms that have not decayed, where λ is the proportionality constant. If at time $t=0$ there are X_o atoms of a given element, the expression for the number of atoms, X, that have not decayed (as a function of time, t, λ, and X_o) is
    a. $X_o(1-\lambda t)$
    b. $X_o e\,(1-e^{-\lambda t})$
    c. $X_o e^{-\lambda t}$
    d. $X_o/(1+\lambda t)$

25. A 1000 ft^3 storage tank is filled with natural gas at 80°F and 1 atm pressure. The tank is flushed out with nitrogen gas at 80°F and 1 atm pressure, at a constant rate of 300 cfm. The flushing process is carried out at constant temperature and pressure, under conditions of perfect mixing in the tank at all times. The time required to reach a gas composition of 95 vol. % nitrogen in the tank is nearest to
    a. 3 min
    b. 7 min
    c. 5 min
    d. 10 min

26. Which of the following is a differential equation of the first order and of degree one?
    a. $(y'')^3 + 2y' = -3$
    b. $dy/dx + (9-x)/x = y^3$
    c. $\partial^2 Q/\partial x^2 - \partial Q/\partial y = 0$
    d. $(dy/dx)^2 = -y + x$

27. How can the differential equation $A(t)\dfrac{d^2x}{dt^2} + B(t)\dfrac{dx}{dt} + C = D(t)$ best be described?
    a. linear, homogenous and first order
    b. homogenous and first order
    c. linear, second order and non-homogenous
    d. second order and non-homogenous

28. The differential equation given is correctly described by which one of the following choices: $d^2y/dx^2 + dy/dx + bxy = f(x)$
    a. linear, second order, homogenous
    b. non-linear, second order, homogenous
    c. linear, second order, non-homogenous
    d. non-linear, second order, non-homogenous

29. What is the Laplace transform of $e^{-2t} \sin 3t$?
    a. $\dfrac{3}{s^2 + 4s + 13}$
    b. $\dfrac{3}{s^2 + 4s + 15}$
    c. $\dfrac{3}{s^2 + 9}$
    d. $\dfrac{s}{s^2 + 4s + 13}$

30. A low radioactive material is used in biochemical process to induce biological mutation. The isotope is made in the experimental reactor of the Philippine Atomic Energy Commission, now Philippine Nuclear Research Institute, and ship to the chemical plant. It has a half life of 8.06 days. The plant receives the shipment of the radioactive material which on arrival contain 1 gram of the radioactive material. The plant uses the material at the rate of 0.1 gram per week. The time it will take for the radioactivity to last is
    a. 3.24 weeks
    b. 4.34 weeks
    c. 5.4 weeks
    d. 4.74 weeks

31. A tank and its contents weigh 100 lbs. The average heat capacity of the system is 0.5 BTU/lb°F. The liquid in the tank is heated by an immersion heater which delivers 100 BTU/min. Heat is lost from the system at a rate proportional to the difference between the temperature of the system (assumed uniform throughout at any instant) and the temperature of the surrounding air, the proportionality constant being 2 BTU/min°F. If the air temperature remains constant at 70°F and if the initial temperature of the tank and its contents is 55°F, the temperature of the tank as a function of time is
   a. $T = 120+65e^{t\ 25}$
   b. $T = 120 - 65e^{-t/25}$
   c. $T = -120+65e^{-t/25}$
   d. $T = 12\text{-}6.5e^{-t/25}$

32. A spherical tank whose inner diameter is 2 meters is filled with water (density=1 g/cc). If a tank has a hole 1 cm in diameter at the bottom, the time the tank will be totally empty is
   a. 4.21 hours
   b. 3.61 hours
   c. 2.41 hours
   d. 6.31 hours

33. A cylindrical tank is 12 ft in diameter and 9 ft high. Water flows into the tank at the rate of $\frac{\pi}{10}$ cu. ft./sec. It has a hole of radius ½ inch at the bottom. The time the tank will be full if initially it is empty is
   a. 65 min
   b. 56 min
   c. 76 min
   d. 50 min

34. A water container whose circular cross section is 6 ft in diameter and whose height is 8 ft is filled with water. It has a hole at the bottom of radius 1 inch. The time it will take if the tank rests on support so that its 8 ft height is in a horizontal direction and the hole in its bottom is
   a. 24.95 min
   b. 25.46 min
   c. 29.4 min
   d. 28.95 min

35. The rate at which a solid substance dissolves varies directly as the amount of undissolved solid present in the solvent and as the difference between the saturation concentration of the substance and the instantaneous concentration of the solution. Five grams of A are placed in 100 cc of solvent B. The solution when saturated will hold 10 grams of A. If 2 grams of A dissolves in 1 hour, how many grams of A will be in solution in 2 hours?
   a. 4 g b. 3 g c. 5 g d. 7 g

36. A 50 lb iron ball is heated to 200°F and then plunged immediately into a vessel containing 100b lbs of water whose temperature is 40°F. The specific heat of iron is 0.11 BTU/lb °F. The common temperature, approached by the iron and water as time approaches infinity is
   a. 48.34°F b. 38.43°F c. 58.4°F d. 68.5°F

37. A new water pump has a capacity of 60 m^3/day. If its capacity goes down by 15% every year, in how many years will the capacity go down to 20 m^3/day?
    a. 3.72 years b. 4.72 years c. 7.32 years d. 8.6 years

38. A mothball loses mass by evaporation at rate that is proportional to the surface area. If half the mass is lost in 100 days, how long will it take the radius to decrease to half its initial value?
    a. 243 days b. 255 days c. 234 days d. 275 days

39. Calculate the time in hours that it will take to reach the fatal conc. of 40% methane in a kitchen measuring 15 ft x 12.5 ft x 8 ft for a leaking stove. The rate of leak is 15 cu ft of 100% methane/hour. Assume no fresh air is coming in. The gas rate is measured at the rate conditions prevailing in the kitchen.
    a. 50 hours c. 30 hours
    b. 40 hours d. 45 hours

40. A substance containing 10 lbs of moisture is placed in a sealed room whose volume is 2000 cu ft and which when saturated can hold 0.015 lb moisture/cu ft. Initially the air contains 30% of the moisture which it can hold when saturated. If the substance loses 4 lbs of moisture in 1 hour, how much time is needed for the substance to lose 80% of its moisture content? Assume the substance loses moisture content at a rate that is proportional to the moisture content and the difference between the moisture content of the saturated air and the moisture content of the air.
    a. 3.8 hours c. 8.3 hours
    b. 4.76 hours d. 5.6 hours

PROBABILITY AND STATISTICS

Statistics – mathematical science that involves the collection, presentation, analysis and interpretation of data and the methods utilized therein.

Two Major Areas of Statistics

1. *Descriptive Statistics* – comprises statistical methods dealing with collection, tabulation and summarization of data so as to present meaningful information.
2. *Inferential Statistics* – comprises those methods concerned with the analysis of a subset of data leading to predictions or inferences about the entire set of data.

Population and Samples

Population – totality of the observations with which a statistician is concerned.

Sample – subset of a population.

Statistical Measures of Data

Parameters and Statistics

A parameter is a numerical quantity that describes some characteristics of a population.

A statistic is a quantitative value that is calculated from the observations in a sample.

Measures of Central Tendency

Statistical measures of tendency are numerical values that are indicative of the central point or the greatest frequency concerning a set of data. The most common measures of central tendency are the *mean*, *median* and *mode*.

Mean

The average of the measurements in a set of data.

Given the set of data values x_1, x_2,....x_N from a finite size of population N. Population mean (μ) is given by

$$\mu = \frac{1}{N}\sum_{t=0}^{N} xt$$

Given the set of data values x_1,x_2....x_n from a sample of size n, the sample mean $\bar{x}$ is given by: $\bar{x} = \frac{1}{n}\sum_{t=0}^{n} xt$

Median

The median of a set of observations is the value that when the observations are arranged in an ascending or descending order satisfies the following conditions:

1. If the number of observations is odd, the median is the middle value.
2. If the number of observations is even, the median is the average of the two middle values.

Mode

The mode of a set of observations is the specific value that occurs with the greatest frequency. There may be more than one mode in a set of observations, if there are several values that occur with the greatest frequency. If the observations occur with the same frequency, there is no mode.

Midrange

The midrange is the average of the smallest and the largest values in the set of data.

Weighted Mean

The formula is given by: $\bar{X} = \frac{\sum_{t=1}^{n} W_t W_t}{N}$ where w_t = the weight of each item

Combined Mean

Suppose that k finite population N_1, N_2, N_3 . . . . .N_{10} measurements respectively have means μ_1, μ_2, μ_3....μ_k. The combined mean μ_c is given by:

$$\mu_c = \frac{\sum_{t=1}^{k} N_t \mu_k}{\sum_{t=1}^{k} N_t}$$

Geometric Mean

The geometric mean G of k positive integers x_1, x_2,, x_3.... x_k is the k^{th} root of their product.

$$G = \sqrt[k]{x_1 \cdot x_2 \cdot x_3 \ldots\ldots x_k}$$

Harmonic Mean

The harmonic mean of k numbers x_1, x_2....x_k is the number k divided by the sum of the reciprocals of the k numbers.

$$H = \frac{k}{\sum_{t=1}^{k} \frac{1}{k_t}}$$

Statistical Measures of Variation

The statistical measures of variation are the *range*, *variance* and *standard distribution.*

Range

The range of the set of observations is the absolute value of the difference between the largest and the smallest values in the set.

Variance and Standard Distribution

The variance of the set of data is a cumulative measure of the square of the difference of all the data value from the mean. It is calculated as follows:

Given a set of data values x_1, x_2, x_3.....x_n from a finite population of size N, the population variance (σ^2) is given by:

$$\sigma^2 = \frac{1}{N} \sum_{t=0}^{N} (x - \mu)^2$$

Given the set of data values x_1, x_2,....x_n from a sample of size n, the sample variance (s^2) is given by:

$$S^2 = \frac{1}{n-1} \sum_{t=0}^{n} \left(x_t - \bar{x}\right)^2$$

The standard deviation of a set of data is the positive square root of the variance.

The Z score

The *z* score of an observation x_i taken from a population with mean μ and standard deviation σ is denoted by z and is given by:

$$z = \frac{x_1 - \mu}{\sigma}$$

The *z* score is a measure of the number of standard deviations that an observation is above or below the mean. A positive *z* score indicates that the observation is above the mean and a negative *z* score means that an observation is below the mean.

The Mean Deviation

The mean deviation of a sample of *n* observations is given by:

$$\text{mean deviation} = \frac{\Sigma\,|\,\bar{x} - x_t\,|}{n}$$

Coefficient of Variation

The coefficient of variation is given by:

$$V = \frac{s}{\bar{x}} \cdot 100\% \qquad \text{for sample}$$

$$V = \frac{\sigma}{\mu} \cdot 100\% \qquad \text{for population}$$

It expresses the standard deviation as a percentage of the mean.

Symmetry and Skewness

A set of observations is symmetrically distributed if its graphical representation (histogram, bar chart) is symmetric with respect to a vertical axis passing through the mean. *For a symmetrically distributed population or sample, the mean, median and mode have the same value.*

A set of observations that is not symmetrically distributed is said to be skewed. It is positively skewed if a greater proportion of the observations are less than or equal to the mean. This indicates that the mean is larger than the median. The histogram of a positively skewed distribution will generally have a long right tail. This distribution is also known as being skewed to the right.

On the other hand, a negatively skewed distribution has more observations that are greater than or equal to the mean. Such a distribution has a mean that is less than the median. The histogram of a negatively skewed distribution will generally have a long left tail. The distribution is also known as *skewed to the right.*

Pearson's Coefficient of Skewness (SK)

This coefficient provides a numerical measure of the skewness of a distribution. S.K. is given by:

$$SK = 3\frac{(\mu - \bar{x})}{\sigma} \quad \text{for population} \qquad\qquad SK = 3\frac{(\bar{x} - \bar{x})}{s} \quad \text{for a sample}$$

For a perfectly symmetric distribution, the mean and the median will have the same value and SK = 0. A distribution that is skewed to the right will have a mean that is larger than the median and SK > 0. A distribution that is skewed to the left will have a mean that is less than the median and so SK < 0. In general, the values of SK will vary from –3 to +3.

Techniques of Counting

Theorem. If an operation can be performed in n_1 ways and if for each of these a second operation can be performed in n_2 ways, then the two operations can be performed together in $n_1 \, x \, n_2$ ways.

Factorial Notation

The product of the positive integers from 1 to *n* inclusive is denoted by the symbol n! read as n factorial.

$$n! = 1 \times 2 \times 3 \; .... \; (n \times n_2) \times (n - 1)\,(n) \qquad \text{where } 0! = 1$$

In general: $N! = n \times (n\text{-}1)!$

REVIEW QUESTIONS AND PROBLEMS

1. How many permutations can be made from the letters A, B, C if all letters are taken at a time ?
   a. 8 b. 6 c. 12 d. 10

2. In a group of 10 boys and 15 girls. How many selections of 6 students are possible ?
   a. 177,100 c. 356,733
   b. 21.252×10^6 d. 67.835×10^6

3. How much will you spend if you will bet all the combinations in a Lotto Lottery Draw ?
   a. ₱ 75,357,200 c. ₱ 50,375
   b. ₱ 52,457,860 d. ₱ 58,372,500

4. In how many ways can you line up 5 persons to get up a bus when persons A and B will not follow each other ?
   a. 120 ways b. 90 ways c. 60 ways d. 72 ways

5. In a group of 10 boys and 15 girls, how many selections of students are possible if it is composed of 2 boys and 4 girls ?
   a. 45 ways b. 61,425 ways c. 1,365 ways d. 177,100 ways

6. What is the average for a student who receives grades of 85, 76 and 82 on 3 tests and a 79 on the final examination in a certain course of the final examination which counts 3 times as much as the 3 tests ?
   a. 80 b. 78 c. 82 d. 76

7. On a vacation trip, a family bought 21.5 liters of gasoline at 39.9 cents per liter, 18.7 liters at 42.9 cents per liter and 23.5 liters at 10.9 cents per liter. Find the mean price paid per liter.
   a. 41.75 cents/liter c. 45.11 cents/liter
   b. 38.15 cents/liter d. 30.08 cents/liter

8. In a group of 40 executives 27 prefer to drink San Miguel Beer while 25 prefer to drink Beer na Beer. How many of them prefer to drink both?
   a. 10 b. 11 c. 12 d. 13

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The product of the positive integers from 1 to *n* inclusive is denoted by the symbol n! read as n factorial.

$n! = 1 \times 2 \times 3 \ldots. (n \times n_2) \times (n-1)(n)$ where $0! = 1$

In general: $N! = n \times (n-1)!$

REVIEW QUESTIONS AND PROBLEMS

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   a. 10 b. 11 c. 12 d. 13

9. Three sections of a statistics class containing 28.32 and 35 students average 83.80 and 76 respectively on the same final examination. What is the combined population mean for all 3 sections?
   a. 97.4 b. 79.4 c. 74.9 d. 47.9

10. A survey of a random sample of people leaving an amusement park showed an average expenditure of ₱103 for the evening. The average expenditure for the 20 girls in the sample was ₱97 and for the boys it was 111. How many boys are there in the sample?
   a. 15 b. 12 c. 18 d. 16

11. Over a period of 4 consecutive years an employee has received 7.2, 8.6, 6.9, and 9.8% annual increases. The ratios therefore of each new salary to the previous salary are 1.072, 1.086, 1.069, 1.098. Find the geometric mean of these 4 ratios and then determine the average percent increase for this employee over the 4-year period.
   a. 1.23 , 8.044 c. 1.32 , 8.44
   b. 1.23 , 8.140 d. 1.32 , 8.91

12. On a vacation trip, a family travels 500 km each day. If the trip lasts 3 days and the family averages 80 km per hour the first day, 93 km per hour on the second day and 87 km per hour the third day, find the average speed of the entire trip.
   a. 68.3 km/hour c. 86.3 km/hour
   b. 38.6 km/hour d. 83.6 km/hour

13. The grade point average of 20 college seniors selected at random from the graduating class are as follows:

3.2	1.9	2.7	2.4
2.8	2.9	3.8	3.0
2.5	3.3	1.8	2.5
3.7	2.8	2.0	3.2
2.3	2.1	2.5	1.9

   Calculate the standard deviation.
   a. 0.585 b. 0.855 c. 0.558 d. 0.638

14. A man works in a company whose employees had an average income this past year for 280,000 pesos with a standard deviation of ₱ 30,000. How much did the man earn this past year if his z score was – 0.8 ?
   a. 256,000 b. 265,000 c. 562,000 d. 652,000

15. In how many different ways can a true or false test consisting of 9 questions be answered ?
   a. 512 ways b. 362 ways c. 181 ways d. 481 ways

16. In how many ways can 4 boys and 5 girls sit in a row if the boys and girls must alternate ?
   a. 8,280 ways c. 2,088 ways
   b. 8,802 ways d. 2,880 ways

17. In how many ways can 5 different trees be planted in a circle ?
    a. 36 ways b. 30 ways c. 24 ways d. 42 ways

18. How many different permutations can be made from the word "infinity" ?
    a. 3,360 ways b. 3,630 ways c. 6,330 ways d. 6,033 ways

b 19. A college plays 12 basketball games during a season. In how many ways can a team end the season with 7 wins, 3 losses, and 2 ties ?
    a. 8920 ways b. 7920 ways c. 9720 ways d. 7290 ways

20. How many ways are there to select 3 candidates from 8 equally qualified recent graduates for openings in an engineering firm ?
    a. 65 ways b. 56 ways c. 45 ways d. 54 ways

21. a) Find the number of ways in which 4 boys and 4 girls can be seated in a row if the boys and girls are to have alternate seats.
    a. 1,152 b. 504 c. 648 d. 763

a b) Find the number of ways if they sit alternately and if one boy and one girl are to sit in adjacent seats.
    a. 504 b. 648 c. 1,152 d. 763

c) Find the number of ways if they sit alternately and one boy and one girl must not sit in adjacent seats.
    a. 648 b. 1,152 c. 504 d. 763

22. Two cards are drawn in succession from a deck without replacement. What is the probability that both cards are greater than 2 and less than 8 ?
    a. 98/663 b. 89/663 c. 36/896 d. 66/893

23. In a game of Yahtzee, where 5 dice are tossed simultaneously, find the probability of getting
    a) two pairs
    a. 52/108 b. 52/1,296 c. 25/108 d. 25/1,296

    b) 4 of a kind
    a. 52/108 b. 52/1,296 c. 25/108 d. 25/1,296

24. In how many ways can 4 boys and 4 girls be seated at a round table if each girl is to sit between the boys.
    a. 12 b. 144 c. 64 d. 96

25. A class contains 10 men and 20 women of which half the men and half the women have brown eyes. Find the probability that a person chosen at random is a man or has brown eyes.
    a. 1/3 b. 2/3 c. 1/4 d. 3/4

17. In how many ways can 5 different trees be planted in a circle ?
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25. A class contains 10 men and 20 women of which half the men and half the women have brown eyes. Find the probability that a person chosen at random is a man or has brown eyes.
    a. 1/3 b. 2/3 c. 1/4 d. 3/4

38. There are 2 defectives per 100 items of a product in a long run. What is the probability that there is one and only one defective in a random lot of 100 ?
    a. 0.0027 b. 0.0067 c. 0.0096 d. 0.0079

39. The graphical representation of the cumulative frequency distribution in a set of statistical data is called
    a. Mean
    b. Histogram
    c. Frequency Polyhedron
    d. Mass Diagram

40. A cosmetic shop sells 10 different brands of shampoo; each for men and women variety, each either anti-dandruff or for dry hair, and each blond or black hair. How many different kinds of shoes does he sell?
    a. 64 b. 80 c. 72 d. 92

41. In a game consisting of 6 cards, what is the probability of holding 2 kings and 2 queens?
    a. 6!/52!
    b. 6/52
    c. 4257/2544815
    d. 1264/45685

42. In how many ways can a PIChE Chapter with 15 directors choose a president, a vice president, a secretary, a treasurer and an auditor, if no member can hold more than one position.
    a. 630630 b. 3300 c. 360360 d. 3003

43. A two-digit number is chosen randomly. What is the probability that it is divisible by 7?
    a. 7/50 b. 13/50 c. 1/7 d. 5/7

44. In raw data, the term that occurs most frequently is known as
    a. mean b. median c. mode d. quartile

45. In probability theory, the set of possible outcomes of an experiment is termed as
    a. sample space
    b. set of random counts
    c. a set of random variables
    d. a fuzzy set

B. PHYSICS

REVIEW QUESTIONS AND PROBLEMS

1. What fraction of an iceberg is immersed in sea-water?
   Hint: density of iceberg = 0.92 g/cc density of sea-water = 1.03 g/cc
   a. 36.7 % c. 52.8%
   b. 47.2 % d. none of these

2. Sound wave does not travel in
   a. hot air c. soft
   b. compressed air d. vacuum

3. The resultant of force A(8 lb) and force B(13 lb) is 5 lb. What is the angle between A and B?
   a. 0° b. 90° c. 180° d. 45°

4. Two cars A and B are moving in opposite directions at a velocity of 100 kph and 80 kph respectively. What is the final velocity of the wreckage when the cars collided head-on?
   a. 10 kph at the direction of A c. 20 kph at the direction of B
   b. 20 kph at the direction of A d. 10 kph at the direction of B

5. Two cars leave the same point at 9 AM. One car headed west at 60 kph while the other car headed south at 80 kph. What is the distance between the two cars at 10 AM of the same day?
   a. 80 km b. 90 km c. 100 km d. none of these

6. An aircraft begins its take-off run with an acceleration of 4m/s^2, which then decreases to zero in 15 seconds, at which time the craft becomes airborne. What is the take-off speed in m/s ?
   a. 30 m/s b. 40 m/s c. 50 m/s d. 60 m/s

7. Find the density and specific gravity of gasoline if 51 g occupies 75 cm^3.
   a. 0.77 b. 0.80 c. 0.86 d. 0.68

8. What volume does 300 g of mercury occupy ? The density of mercury is 13,600 kg/m^3.
   a. 22.1 cm^3 b. 33.1 cm^3 c. 21.3 cm^3 d. 31.2 cm^3

9. A mass of oxygen occupies 0.0200 m^3 at atmospheric pressure, 101 kPa, and 5°C. Determine its volume if its pressure is increased to 108 kPa while its temperature is changed to 30°C.
   a. 0.0204 m^3 b. 0.2004 m^3 c. 0.0024 m^3 d. 0.0402 m^3

10. An iron plate 2 cm thick has a cross section of 5000 cm^2. One side is at 150°C and the other side is at 140°C. How much heat passes through the plate each second? For iron, *k* is 0.115 cal/s · cm ·°C.
    a. 3000 b. 2560 c. 2880 d. 2186

11. A metal plate 4 mm thick has a temperature difference at 32°C between its faces. It transmits 200 kcal/h through an area of 5 cm^2. Calculate the thermal conductivity k = of this metal in W/m · K.
a. 63.7 b. 85.5 c. 58.5 d. 55.8

12. The resultant of two perpendicular forces is 5N. If the magnitude of one force is 4N, the magnitude of the other is
a. 1N b. 2N c. 3N d. 7N

13. Train covers a 110-m straight track with an initial speed of 6m/s and a constant acceleration of 1m/s^2. The train covers the given distance in
a. 10s b. 12s c. 15s d. 18s

14. Journey decelerates from a speed of 20m/s and stops in 19 secs. The distance it covered is
a. 70 m b. 90 m c. 100 m d. 120 m

15. A juggler tosses a ball upward. It reaches its highest point in 25 secs. What is the initial speed of the ball?
a. 4.9 m/s b. 9.8 m/s c. 19.6 m/s d. 25 m/s

16. A ball is dropped from a 98 m tall building. The ball reaches the ground in
a. $\sqrt{5}s$ b. $\sqrt{10}s$ c. $\sqrt{15}s$ d. $\sqrt{20}s$

17. A shell is fired at an angle of 15° with the horizontal. It lands on the same level after covering a range of 100 m. Its initial speed is
a. $\sqrt{800}m/s$ b. $\sqrt{1850}m/s$ c. $\sqrt{1960}m/s$ d. $\sqrt{2110}m/s$

18. What is the horizontal component of the shell's velocity just before touching the ground?
a. $\dfrac{\sqrt{1800}\sin 15°}{9.8}$ S c. $\dfrac{\sqrt{1960}\sin 15°}{9.8}$ S
b. $\dfrac{\sqrt{1850}\sin 30°}{9.8}$ S d. $\dfrac{\sqrt{2110}\sin 30°}{9.8}$ S

19. At a certain point above the surface of the earth, the weight of an object is 1/9 that of his weight on the surface of the earth. The distance of this point from the surface of the earth is
a. 2 R_E b. 3 R_E c. 4 R_E d. 5 R_E

20. When the separation distance between two bodies is doubled, the gravitational force between them is
a. 4 times b. 2 times c. ½ times d. ¼ times
the original gravitational force between them.

21. A 10 kg body in uniform circular motion rotates with an angular speed of a 10 rad/s in a circle of radius 1 m. Its centripetal acceleration is
a. 100 m/s^2 b. 200 m/s^2 c. 300 m/s^2 d. 350 m/s^2

22. A 50 kg person on a skateboard rolls down a short hill inclined at 30° with the horizontal. Calculate the person's acceleration if friction is ignored.
    a. 4.4 m/s b. 4.9 m/s c. 5.4 m/s d. 5.9 m/s

23. A falling coconut has a mass of 2 kg and the upward force of air resistance is 10 N. Its acceleration is
    a. 9.6 m/s^2 up c. 4.9 m/s^2 up
    b. 4.9 m/s^2 down d. 9.8 m/s^2 down

24. The kinetic energy of a 20 kg body is 1,000 J. What is the momentum?
    a. 100 kg m/s c. 400 kg m/s
    b. 200 kg m/s d. 500 kg m/s

25. Two bodies undergo a perfectly elastic collision. Which of the following is true?
    a. Their kinetic energy increases and they separate afterwards
    b. Their kinetic energy decreases and they separate afterwards
    c. Their kinetic energy does not change and they separate afterwards
    d. Their kinetic energy does not change and they won't separate afterwards

26. A 10,000 kg car moving at 20 m/s collides with a 50,000 kg truck moving at 10 m/s in the same direction. If the collision is perfectly inelastic, the common velocity after coupling is
    a. 20 m/s b. 10 m/s c. 15 m/s d. 25 m/s

27. A 40 g bullet is fired with a velocity of 500 m/s at a stationary 10 kg body. It exits with a velocity of 200 m/s. The velocity of the block after being hit is
    a. 0.5 m/s b. 0.9 m/s c. 1.2 m/s d. 1.5 m/s

28. The heat of condensation of steam is used to melt 5400 g of ice at – 40°C to liquid water at 0°C. How many grams of steam are required?
    L_{vap} = 540 cal/g C_{ice} = 0.5 cal/g°C
    C_{liq} H_2O = 1.0 cal/g°C L_{fusion} = 80 cal/g
    a. 100 g b. 110 g c. 120 g d. 140 g

29. A 100-cm rod at 20°C changes length by 0.05 cm at 70°C. Its coefficient of expansion is
    a. 1.0 (10^{-5}) /°C c. 2.0 (10^{-5})/°C
    b. 1.5 (10^{-5}) /°C d. 2.5 (10^{-5})/°C

30. A parallel plate capacitor has capacitance C_o. What is the new capacitance if the area of its plates and the separation distance are simultaneously doubled?
    a. 2 C_o b. 4 C_o c. ½ C_o d. C_o

31. A wire has resistance, Re. What is the new resistance if both its length and diameter are halved?
    a. ¼ Re b. ½ Re c. Re d. 2 Re

32. A ray of light strikes a slab of glass (n = 1.5) with an angle of incidence of 30°. The angle of refraction is
    a. 19.5° b. 30° c. 35° d. 40°

33. What is the speed of light in a transparent material with n = 1.2?
    a. 1.5 (10^8) m/s
    c. 2.0 (10^8) m/s
    b. 1.8 (10^8) m/s
    d. 2.5 (10^8) m/s

34. An object 5 cm high is 40 cm from a concave mirror whose radius of curvature is 16 cm. Which of the following characterizes the image?
    a. the image is 10 cm high, real and erect
    b. the image is 10 cm high, virtual and erect
    c. the image is 1.25 cm high, real and inverted
    d. the image is 2.5 cm high, virtual and erect

35. An object 1 cm tall placed 12 cm from a spherical mirror gives a virtual image 4 cm tall. Which of the following is true?
    a. the mirror is concave with f = +16 cm
    b. the mirror is concave with f = +48 cm
    c. the mirror is convex with f = –24 cm
    d. the mirror is convex with f = –16 cm

36. A sound wave propagating at a frequency of 100 MHz has a wave length of 2m. What is its velocity of propagation ?
    a. 200 m/s b. 220 m/s c. 250 m/s d. 280 m/s

37. Sound travels in air with a speed V_o at 27°C. What is its speed at 77°C ?
    a. $\sqrt{7/6}\ Vo$ b. $\sqrt{2/3}\ Vo$ c. $\sqrt{3/2}\ Vo$ d. $\sqrt{3/4}\ Vo$

38. A 1 m long string has a mass of 10 g. If the tension in the string is 1 N, the velocity of a propagation wave is
    a. 5 m/s b. 8 m/s c. 10 m/s d. 12 m/s

39. A 2 m long string stretched between two ends vibrates with a frequency in the fourth harmonic. Its wave length is
    a. 1/4 m b. 1/2 m c. 1 m d. 2 m

40. A 100 li closed tank contains moles of ideal gas at 27°C. What is its pressure?
    a. 2.46 atm b. 3.56 atm c. 3.92 atm d. 4.54 atm

41. A lamp is suspended from a high ceiling with a cord 4 m long. Find its period of oscillation.
    a. 1 s b. 2 s c. 3 s d. 4 s

42. A SHM traveling wave of period 3.0 seconds and wavelength of 30 m moves to the right in a long cord. The maximum transverse velocity in the cord is 2.5 cm/s. Find the amplitude of the wave in meter.
    a. 0.01 b. 0.012 c. 0.015 d. 0.02

43. An object is 12 cm from a concave mirror whose focal length is 4 cm. Where will the image be formed?
    a. 6 cm b. –6 cm c. 3 cm d. –3 cm

44. A small object lies 4 cm to the left of the vertex of a concave mirror of radius of curvature 12 cm. Find the magnification of the image.
    a. 6 b. –6 c. 3 d. –3

45. Find the fundamental frequency of a pipe with length 1.85 m.
    a. 45.9 Hz b. 91.7 Hz c. 136.8 Hz d. 183.2 Hz

46. A man standing 3360 ft from a high cliff hits a tree stump with an axe, and hears the faint echo 6.4 s later. What is the velocity of sound in the air that day?
    a. 1050 fps b. 1100 fps c. 1150 fps d. 1200 fps

47. A man standing somewhere between two walls of a wide canyon shout "hello". If the first echo arrived after an interval of 1.2 s, while the second arrived 0.6 s later. How wide is the canyon?
    a. 127.5 m b. 255 m c. 510 m d. 1020 m

48. A train traveling at 40 m/s has a horn that vibrates at a frequency of 200 Hz. Calculate the frequency of the horn's sound heard by a bicycle rider traveling at 10 m/s in the same direction as the train when the bike is ahead of the train.
    a. 184 Hz b. 200 Hz c. 220 Hz d. 240 Hz

49. Assume that the auditory canal of the outer ear is a 3.0 cm long pipe closed by one end by the eardrum. Calculate the fundamental frequency of this pipe when in air at 7°C ?
    a. 2800 Hz b. 3000 Hz c. 3200 Hz d. 3400 Hz

50. What is the velocity of a jet plane traveling at Mach Number 2?
    a. 600 m/s b. 680 m/s c. 760 m/s d. 840 m/s

51. How fast does light travel in glass of refractive index 1.5?
    a. 2×10^8 m/s b. 3×10^8 m/s c. 3.75×10^8 m/s d. 4.5×10^8 m/s

52. Light is incident from air to glass (n = 1.51). If the angle of incidence is 37°, what is the angle of reflection?
    a. 23.5° b. 30° c. 37° d. 45°

53. A beam of light enters a lake at an angle of incidence of 40°. Find the angle of refraction if the index of refraction of water is 1.33.
    a. 27° b. 29° c. 31° d. 33°

54. A flat bottom swimming pool is 8 ft deep. How deep does it appear to be when filled with water whose index of refraction is 4/3?
    a. 4 ft b. 5 ft c. 6 ft d. 8 ft

55. An object is 4 cm from a diverging lens whose focal length is 12 cm. Where will the image be?
    a. 3 cm b. 6 cm c. –3 cm d. –6 cm

56. Find the focal length of a magnifying glass that produces an erect image magnified 3 times of an object 1.5 cm away.
    a. 2.25 cm b. 4.5 cm c. –2.25 cm d. –4.5 cm

57. A meniscus lens has one concave and one convex surface, The concave surface of a particular meniscus lens has a radius of curvature of 30 cm, and its convex surface has a radius of curvature of 50 cm. The index of refraction of the glass used is 1.5. Find the focal length of the lens.
    a. 150 cm b. 100 cm c. –150 cm d. –100 cm

58. How much oil at 200°C must be added to 50 g of the same oil at 20°C to heat it to 70°C?
    a. 12.39 g b. 19.23 g c. 23.91 g d. 29.12 g

59. The critical angle for total internal refraction from a liquid to air media is 48°. If n is the index of refraction of the liquid, which of the following is true?
    a. n = sin 48° c. n = 1/tan 48°
    b. n = 1/sin 48° d. n = sec 48°

60. A tank in the form of a closed upright cylinder 220 cm in diameter and 10 m long is full of gasoline (specific gravity = 0.7). What is the gauge pressure at the bottom?
    a. 68.6 Pa b. 68.6 kPa c. 85.4 kPa d. 95.3 kPa

61. A 15 resistor is connected in series with a parallel combination of 3 resistors each with a resistance of 30. The equivalent resistance of the circuit is
    a. 5 Ω b. 8 Ω c. 10 Ω d. 25 Ω

62. A 100 W motor runs for 1 hour. The energy expended is
    a. 1 kWh b. 0.1 kWh c. 2 kWh d. 0.2 kWh

63. What is the power required to transfer 97,000 coulombs of charge through a potential rise of 50 volts in one hour?
    a. 0.5 kW b. 0.9 kW c. 1.3 kW d. 2.8 kW

64. Three capacitors are connected in series 20 μF, 40 μF, 80 μF. The total potential difference across the capacitors is 70 V. The potential difference across the 80 μF capacitor is
    a. 5 V b. 10 V c. 15 V d. 20 V

65. A rope of 0.60 m length, and a mass of 160 g is under a tension of 200 N. Assume that both ends are nodes, find the fundamental frequency.
    a. 22.8 Hz b. 45.6 Hz c. 68.4 Hz d. 91.2 Hz

C. ENGINEERING MECHANICS

REVIEW QUESTIONS AND PROBLEMS

1. A car jumps across a 10-ft wide ditch from a 2° incline with a constant velocity V_o, the ditch is 6 in. lower on the far side. What is the minimum velocity (in miles per hour) that will keep the car from falling into the ditch?
   a. 42.3 miles/hour
   b. 37.4 miles/hour
   c. 50.3 miles/hour
   d. 29.7 miles/hour

2. The center of gravity of a log 10 ft long and weighing 100 lbs is 4 ft from one end of the log. It is to be carried by two men. If one is at the heavy end, how far from the other end does the second man have to hold the log if each is to carry 50 lbs?
   a. at the end
   b. 2 ft
   c. 4 ft
   d. 5 ft

3. In a problem involving rolling friction, the value of it would be given as
   a. an angle Ø
   b. μ_s, the tangent F_s/N of an angle Ø (F_s = static friction)
   c. μ_k, the tangent F_k/N of an angle Ø (F_k = kinetic friction)
   d. b, deformation, as linear dimension

4. The formula $I = \int y^2 dA$ represents the
   a. product of inertia
   b. section modulus
   c. area of cross section
   d. moment of inertia

5. A pebble was dropped in a well, and it was found that 4.25 sec elapsed after release of the pebble before the splash was heard. If the velocity of sound in the well is 1030 ft/sec, the depth to the water surface is most nearly
   a. 230 ft b. 260 ft c. 290 ft d. 450 ft

6. A body moves so that the *x* component of acceleration is given by the equation 6 – t and the *y* component of acceleration is given by 6 + t. If the initial *x* and *y* components of velocity are both 2, the speed of the body at the end of 2 sec is closest to
   a. 12 b. 14 c. 16 d. 20

7. A river flows north with a speed of 3 miles/hr. A man rows a boat across the river. His speed relative to the water is 4 miles/hr. What is his velocity relative to the earth?
   a. 4 miles/hour
   b. 3 miles/hour
   c. 5 miles/hour
   d. 1 miles/hour

8. A batted baseball leaves the bat at an angle of 30° above the horizontal and is caught by an outfielder 400 ft from home plate. Assume the ball's height when hit is the same as when caught and that air resistance is negligible. The initial velocity of the ball is closest to
   a. 125 ft/sec
   b. 175 ft/sec
   c. 150 ft/sec
   d. 200 ft/sec

9. A satellite travels in a perfectly circular orbit around the earth at an altitude of 1000 miles. Assume the earth is a perfect sphere with a radius of 4000 miles and that the force of the earth's gravity, g at the height of the satellite is 20.6 ft/sec^2. The speed of the satellite is nearest to
   a. 10,000 miles/hour
   b. 12,000 miles/hour
   c. 14,000 miles/hour
   d. 16,000 miles/hour

10. A traveling crane lifts a 1000-lb load on a 20-ft hoisting cable. The maximum horizontal acceleration that the crane may have without producing a deviation of the cable of more than 30° from the vertical is closest to
    a. 19 ft/sec^2
    b. 25 ft/sec^2
    c. 32 ft/sec^2
    d. 43 ft/sec^2

11. An elevator, which with its load weighs 70,000 N (newtons), descending at a speed of 4.5 m/sec. If the load on the cable must not exceed 125,000 N, the shortest distance in which the elevator should be stopped is most nearly
    a. 0.6 m b. 1.0 m c. 1.3 m d. 2.0 m

12. Two 3-N weights are connected by a string of negligible mass hanging over a smooth frictionless peg. If a third weight of 3 N is added to one of the weights and the system is released, the amount of the increased force on the peg is most nearly
    a. 0 N b. 1.5 N c. 2 N d. 3 N

13. A locomotive weighing 120 tons is coupled to, and pulls, a car weighing 40 tons. The resistances to motion on a level track are $^1/_{100}$th of its weight for the locomotive and $^1/_{60}$th of its weight for the car. The tractive force exerted by the locomotive is 8000 lb. The tension T in the coupling is nearest to
    a. 1775 lb b. 2225 lb c. 4500 lb d. 5100 lb

14. A 150-lb man stands at the rear of a 250-lb boat. The distance from the man to the pier is 30 ft, and the length of the boat is 16 ft. Assume no friction between the boat and the water. The distance of the man from the pier after he walks to the front of the boat at a velocity of 3 miles/hr is most nearly
    a. 14 ft b. 16 ft c. 20 ft d. 24 ft

15. An unbalanced flywheel has its center of mass 4.00 in. from the axis of rotation. The radius of gyration of the flywheel with respect to an axis through the center of mass parallel to the axis of rotation is 16.00 in. The flywheel, which weighs 145.0 lb, is rotating clockwise about its axis at an angular speed of 3600 rpm when a counterclockwise torque $T=18.0\ t^2$ is applied, where T is in pound-feet and t is in seconds. Neglecting friction, the angular speed in revolutions per minute of the flywheel when t is 10.00 sec is closest to
    a. 1500 rpm clockwise
    b. 2900 rpm clockwise
    c. 3100 rpm counterclockwise
    d. 16,600 rpm counterclockwise

16. A simple spring-mass system possesses a certain natural frequency. If the mass is quadrupled in value, the ratio of the new period of oscillation to the original value is closest to which of the following?
    a. 4 b. 1/4 c. 2 d. 1/2

17. A 5-kg block of metal is totally immersed in water by suspending it from a light string. If the tension in the rope is 30 N, the buoyant force exerted by the water on the block is
    a. 79 N b. 69 N c. 98 N d. 89 N

18. A 10-kg block lies stationary on a plane inclined at 30°. It impends to move downward. Its normal force is
    a. 60 N b. 67 N c. 74 N d. 85 N

19. A student lifts up a book with a force of 20 N a vertical distance of 1 m in 2 secs. The work done by the student is
    a. 10 J b. 15 J c. 25 J d. 30 J

20. Two forces of magnitude 100 N each act in the following directions 30° N of E and 30° S of E. The magnitude of the net force is
    a. 100 N b. 70 N c. 120 N d. 170 N

21. A car accelerates from rest at a constant rate of 2 m/s^2 from 10 secs. It then decelerates and stops 20 secs after decelerating. The magnitude of its deceleration is
    a. 1.5 m/s^2 b. 2 m/s^2 c. 1 m/s^2 d. 3 m/s^2

22. Three forces of magnitude 100 N each act on a body: 30°W of E, 60°S of E and 30°N of E. The direction of the net force is
    a. 30°W of E b. 60°S of E c. 45°S of E d. 30°N of E

23. A sprinter runs with a constant velocity of 2 m/s. After recovering 20 m, he starts to decelerate at a constant rate of 1/8 m/s until he stops. What is his total time of travel?
    a. 16 s b. 20 s c. 26 s d. 30 s

24. A 10-kg body is suspended from a spring stretched by 10 cm. What weight will stretch it by 14 cm?
    a. 98 N b. 120 N c. 137 N d. 145 N

25. A 4-kg metal block at 495°C is immersed in 2 kg of water at 15°C. At thermal equilibrium, the temperature of the system is 95°C. The specific heat of the metal is
    a. 0.01 cal/g°C c. 0.15 cal/g°C
    b. 0.1 cal/g°C d. 0.03 cal/g°C

D. STRENGTH OF MATERIALS

REVIEW QUESTIONS AND PROBLEMS

1. What load must be applied to a 25 mm round steel bar 3 m long if its elongation is limited to 1.3 mm ?
   a. 36.12 kN
   b. 42.54 kN
   c. 58.2 kN
   d. 66.3 kN

2. A steel rod 2.5 m long is secured between two walls. If the load on the rod is zero at 20°C, compute the stress when the temperature drops to -20°C. The cross-sectional area of the rod is $1200 mm^2$, $\propto = 11.7$ µm/m.°C, assuming that the walls spring together a total distance of 0.500 mm as the temperature drops.
   a. 93.6 MPa C
   b. 93.6 MPa T
   c. 53.6 MPa C
   d. 53.6 MPa T

3. A solid steel shaft 5 m long is stressed to 60 MPa when twisted through 4°. Using G = 83 GPa, compute the shaft diameter. What power can be transmitted by the shaft at 20 r/s ?
   a. 18.7 MW
   b. 1.64 MW
   c. 2.11 MW
   d. 3.22 MW

4. A helical spring of 75 mm radius made of 20 turns of 12 mm diameter wire is loaded with 120 N load. Determine the maximum shearing stress required using R.A.M. Wahl Formula.
   a. 22.65 MPa
   b. 18.73 MPa
   c. 29.56 MPa
   d. 33.61 MPa

5. A simple beam 5 m long is supported at its ends. The beam carries a uniform load of 10 kN/m for the first 3 m and 6 kN/m for the second 2m. What will be the shear at a point 4m from the heavy end?
   a. –12.6 kN
   b. 15.2 kN
   c. 10.8 kN
   d. 13.7 kN

6. A body having the same elastic properties in all directions is
   a. isotropic
   b. homogeneous
   c. isothermal
   d. orthotropic

7. The coefficient of thermal expansion of steel is approximately what percent of the coefficient of thermal expansion of concrete?
   a. 50%
   b. 75%
   c. 100%
   d. 125%

8. The rails of a tramway are welded together at +50°F. Assume the coefficient of linear expansion of rails is 70×10^{-7} in/in°F and the modulus of elasticity is 30×10^{6} lb/in^2. The stress produced in the rails when heated by the sun to +100°F is nearest to
   a. 0 psi
   b. 10,500 psi
   c. 32,000 psi
   d. 35,000 psi

9. A ½-in diameter steel tie rod 18 ft in length is joined to two rigid walls in such a way that an axial tensile stress of 20,000 psi is induced in the rod. Assume a Poisson's ratio of 0.25 and E = 30 x 10^6 psi. The change in the diameter of the rod caused by the application of this tensile load is closest to
   a. 6.66 x 10^{-4}
   b. 1.66 x 10^{-4}
   c. 8.33 x 10^{-5}
   d. 6.50 x 10^{-6}

10. What load must be applied to a 1-in round steel bar 8 ft long (E = 30,000,000 psi) to stretch the bar 0.05 in.?
    a. 7,200 lb
    b. 9,850 lb
    c. 8,600 lb
    d. 12,250 lb

11. A steel bar having a 1-in^2 cross section is 150 in. long when lying on a horizontal surface. Assume E = 30 x 10^6 psi and W = 0.283 lb/in^3. The increase in the length of the bar when it is suspended vertically from one end is nearest to
    a. 1 x 10^{-5} in.
    b. 1 x 10^{-4} in.
    c. 1 x 10^{-2} in.
    d. 1 x 10^{-1} in.

12. The maximum shear stress in a solid round shaft subjected only to torsion occurs
    a. on principal planes
    b. on planes containing the axis of the shaft
    c. on the surface of the shaft
    d. only on planes perpendicular to the axis of the shaft

13. In an I-beam subjected to simple bending, the maximum bending stress occurs
    a. at the neutral axis
    b. in the web above the neutral axis
    c. in the web below the neutral axis
    d. at the top and bottom surfaces of the beam

14. The bending moment of a beam
    a. depends on the modulus of elasticity of the beam
    b. is minimum where the shear is zero
    c. is the maximum at the free end of a cantiliver
    d. may be determined from the area of the shear diagram

15. The moment curve for a simple beam with a concentrated load at midspan takes the shape of a
    a. triangle
    b. semicircle
    c. parabola
    d. rectangle

16. The moment diagram for a beam uniformly loaded with a concentrated load in the center is the sum of
    a. two triangles
    b. a rectangle and a triangle
    c. a parabola and a triangle
    d. a rectangle and a trapezoid

17. A helical spring has a natural length of 6 in. It requires a force of 20 lb to hold it extended to a length of 12 in. Assume the spring does not exceed its elastic limit. The work done in inch-pounds to stretch the spring from a total length of 9 in. to 11 in. is nearest to
    a. 5 in-lb
    b. 10 in-lb
    c. 15 in-lb
    d. 25 in-lb

18. A 3-inch diameter solid steel shaft 10 ft long is subjected to a constant torque of 100,000 in-lb at each end, together with an axial tensile load of 70,000 lb also applied at each end. For a circular cross section the polar moment of inertia $J = \pi d^4/32$. The maximum compressive stress in the shaft under this loading is nearest to
    a. 0 psi
    b. 10,000 psi
    c. 15,000 psi
    d. 18,800 psi

19. The least radius of gyration is required in the design of
    a. shaft couplings
    b. columns
    c. cantilevered beams
    d. riveted joints

20. A rectangular shape has a cross section 30 cm wide and 60 cm in height. The least radius of gyration for this shape is closest to
    a. 10 cm
    b. 15 cm
    c. 20 cm
    d. 25 cm

21. A beam has a cross-sectional area of 72 cm^2 and a radius of gyration of 3 cm. The corresponding value of the moment of inertia for the beam is nearest to
    a. 24
    b. 216
    c. 650
    d. 1300

22. A cantilivered beam 20 in. long and of square cross section, 1 in. on a side, is loaded at its end through the centroid of the cross section by a vertical force of magnitude 150 lb. The magnitude of the maximum bending stress is nearest to which value?
    a. 3000 psi
    b. 6000 psi
    c. 12,000 psi
    d. 18,000 psi

23. The maximum unit fiber stress at any vertical section in a beam is obtained by dividing the moment at that section by
    a. the section modulus
    b. the cross-sectional area
    c. one-half the distance to the point where the shear is zero
    d. the radius of gyration

24. Stirrups in a reinforced concrete beam are designed primarily to resist stresses caused by
    a. diagonal tension
    b. axial tension
    c. axial compression
    d. web crippling

25. The ratio of the uniform trixial stress to the change in volume at equal stress in all direction is
    a. Modulus of flexure
    b. Modulus of rupture
    c. Coefficient of restitution
    d. Bulk of modulus of elasticity

26. The maximum stress to which a material may be subjected without the occurrence of permanent strain remaining upon the complete release to stress.
    a. ultimate strength
    b. rupture point
    c. resilience point
    d. elastic limit

27. The measure of the strength of the agent that is causing the deformation.
    a. bulk modulus
    b. stress
    c. Young's modulus
    d. strain

28. A mild steel column is hollow and circular in cross section with an external diameter of 350 mm and internal diameter of 300 mm. It carries a compressive axial load of 2000 kN. What is the corresponding strain of the column? Modulus of elasticity = 200 GPa.
    a. 0.000392 b. 0.00392 c. 0.0392 d. 0.392

29. The stress is a 90 cm diameter pipe having a wall thickness of 9.5 cm and under a static head of 70 m of water is
    a. 32.5 kPa b. 325 kPa c. 3.25 kPa d. 32.5 kPa

30. A bar of circular cross section is 2.5 m long. For the 2 m of its length, its diameter is 200 mm while for the remaining 0.5 m, its diameter is 100 mm. The bar is firmly supported at its end and subjected to a torque of 50 kN-m applied at its change of section. What is the shearing stress of the 200 mm bar section?
    a. 12.23 MPa b. 25.46 MPa c. 50.93 MPa d. 75.34 MPa

E. ENGINEERING ECONOMICS

THEORY AND EQUATIONS

Interest

1. ***Simple Interest***

$$F = P(1 + ni)$$

   a. ordinary simple interest : one interest period = 360 days
   b. exact simple interest : one interest period = 365 days
   = 366 days

2. ***Compound Interest***

$$F = P\left(F/_P, i, n\right) = P(1+i)^n$$
$$P = F\left(P/_F, i, n\right) = F(1+i)^{-n}$$

$$\left(F/_P, i, n\right) = (1+i)^n \text{ = single payment compound amount factor}$$
$$\left(P/_F, i, n\right) = (1+i)^{-n} \text{ = single payment present worth factor}$$

where P = principal (present worth), F = accumulated amount (future worth),
i = rate of interest per interest period, n = number of interest periods

3. ***Continuous Interest***

$$F = Pe^{rn} \qquad P = Fe^{-rn}$$

where r = rate of interest, n = number of years

Rates of Interest

1. nominal rate of interest – specifies the rate of interest and the number of interest periods in a year
2. effective rate of interest $i_{eff} = (1 + i)^n - 1$
   where n = number of interest periods in a year
   If compounded continuously... $i_{eff} = e^r - 1$

Annuity

1. ***Ordinary Annuity***

$$P = A\left(P/_A, i, n\right) = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = A\left[\frac{1-(1+i)^{-n}}{i}\right]$$

$$F = A\left(F/_A, i, n\right) = A\left[\frac{(1+i)^n - 1}{i}\right]$$

$$\text{uniform series present worth factor} = \left(P/_A, i, n\right) = \frac{1-(1+i)^{-n}}{i} = \frac{(1+i)^n - 1}{i(1+i)^n}$$

Annuity Due: $P = A + A\left[\frac{1-(1+i)^{-n}}{i}\right]$
Payment is made at the beggining of period

capital recovery factor = $\left(A/_P, i, n\right) = \dfrac{i}{1-(1+i)^{-n}} = \dfrac{i(1+i)^n}{(1+i)^n - 1}$

uniform series compound amount factor = $\left(F/_A, i, n\right) = \dfrac{(1+i)^n - 1}{i}$

sinking fund factor = $\left(A/_F, i, n\right) = \dfrac{i}{(1+i)^n - 1}$

2. ***Deferred Annuity***

$$P = A\left(P/_A, i, n\right)\left(P/_F, i, m\right)$$

$$P = A\left[\frac{1-(1+i)^{-n}}{i}\right](1+i)^{-m}$$

3. ***Perpetuity*** $P = \dfrac{A}{i}$

4. ***Uniform Arithmetic Gradient***

$$P = G\left[\frac{(l+i)^n - 1 - in}{i^2(l+i)^n}\right]$$

$$F = \frac{G}{i}\left[\frac{(l+i)^n - 1}{i} - n\right]$$

$G < 0$, decreasing arithmetic gradient
$G > 0$, increasing arithmetic gradient

5. ***Geometric Gradient***

g = percentage change in payment from one payment to the next
g is (+) if increasing
g is (−) if decreasing

$$P = A_1\left[\frac{1-(1+i)^{-n}(1+g)^n}{i-g}\right], i \neq g$$

$$P = \frac{nA_1}{1+i}, i = g$$

$$F = A_1\left[\frac{(1+i)^n - (1+g)^n}{i-g}\right], i \neq g$$

$$F = nA_1(1+i)^{n-1}, \cancel{i \neq g}\ i = g$$

Depreciation

I. ***Uniform Methods***

1. *Straight Line*

$$d = \frac{V - V_s}{n}$$

$$D_a = ad = \frac{a}{n}\left(V - V_s\right)$$

$$V_a = V - D_a$$

2. *Sinking Fund*

$$d = \frac{(V - Vs)i}{(1+i)^n - 1}$$

$$Da = (V - Vs)\left[\frac{(1+i)^a - 1}{(1+i)^n - 1}\right]$$

$$Va = V - Da$$

II. *Non Uniform Methods*

1. *Declining Balance*

$$da = V(1-f)^{a-1}.f$$

$$Va = V(1-f)^a$$

$$f = 1 - \sqrt[n]{\frac{Vs}{V}}$$

2. *Double Declining Balance*

$$da = V\left(1 - \tfrac{2}{n}\right)^{a-1}.\frac{2}{n}$$

$$Va = V\left(1 - \tfrac{2}{n}\right)^a$$

3. *Sum of the Years Digit*

$$da = \left[\frac{n - a + 1}{\frac{n}{2}(n+1)}\right](V - Vs)$$

$$Va = V - Da = V - (d_1 + d_2 + ... + da)$$

4. *Output Method*

$$da = \frac{Q_a}{Q_T}(V - Vs)$$

5. *Working Hours Method*

$$da = \frac{H_a}{H_T}(V - Vs)$$

where d = annual depreciation, V = original cost, Vs = salvage value, N = economic life, a = number of years in actual use, Da = accumulated depreciation, Va = asset value, f = fixed percentage, Qa = number of units a machine can produce for period a, Q_T = number of units a machine can produce during its economic life, H_a = number of hours a machine is utilized for period a, H_T = number of hours a machine is utilized during its economic life

recovery [illegible]

[illegible] $= V - Da = V - (d_1 + d_2 ...$ [illegible]

Recovery Period vs [illegible]

$Va = V - D$ [illegible]

Evaluation of Economic Alternatives

1. Rate of Return on Investment
2. Annual Worth
3. Present Worth
4. Future Worth
5. Internal Rate of Return

6. Capitalized Cost
7. Payout Period
8. Benefit-Cost Method

Break Even Analysis involves investment of capital wherein at a certain level of production the total income of the company would just be equal to total expenses, thus resulting in no loss nor profit.

REVIEW QUESTIONS AND PROBLEMS

1. What is an annuity?
    a. the future worth of a present amount
    b. an annual repayment of a loan
    c. a series of uniform amounts over a period of time
    d. a lump sum at the end of the year

2. Additional cost which results from increasing the output of a system by one or more units is
    a. incremental cost c. fixed cost
    b. variable cost d. direct cost

3. Costs that are repetitive and occur when an organization produces similar goods or service on a continuing basis.
    a. direct cost c. non-recurring cost
    b. recurring cost d. indirect cost

4. How is the capital recovery factor $(A/P, i, n)$ related to the uniform series sinking fund factor $(A/F, i, n)$? i is the effective annual rate of return and n is in years.
    a. $(A/P, i, n) = (A/F, i, n) + i$ c. $(A/P, i, n) = (A/F, i, n) - i$
    b. $(A/P, i, n) = (A/F, i, n) - i$ d. $(A/P, i, n) = [(A/F, i, n) + i]/n$

5. Costs that are difficult to attribute or allocate to a specific output or with activity is
    a. direct cost c. fixed cost
    b. variable cost d. indirect cost

6. Which of the following expressions is incorrect?
    a. $(A/F, i, n) \times (P/A, i, n) = (P/F\ i, n)$ c. $(P/A, i, n) = 1/(A/P, i, n)$
    b. $(A/F, i, n) - i = (A/P, i, n)$ d. $(F/P, i, n) = 1/(P/F, i, n)$

7. When using net present worth calculation to compare two projects, which of the following could invalidate calculation?
    a. differences in the magnitude of the project
    b. evaluation over different time periods
    c. mutually exclusive projects
    d. non-conventional cash flows

8. The uniform annual end of year payment to repay a debt in years, with an interest rate *i*, is determined by multiplying the capital recovery factor by the
    a. average debt
    b. initial debt plus total interest
    c. average debt plus interest
    d. initial debt

9. What must two investments with the same present worth and unequal lives have?
    a. identical salvage values
    b. identical equivalent uniform annual cash flow
    c. different salvage values
    d. different equivalent uniform annual cash flow

10. If two investors are considering the same project, the payback period will be longer for the investor with the higher minimum attractive rate of return (MARR). Is the statement true or false?
    a. true
    b. false

11. A bridge will collect tolls from vehicles that cross it. In benefit cost analysis, the toll revenue is a
    a. benefit
    b. cost
    c. neither

12. Capital means
    a. money, except those consumed in the public section
    b. savings
    c. that which is invested
    d. money, except those which is owned

13. Compound interest calculations serve to
    a. render differently time cash flows commensurable
    b. compute fair repayment patterns and amounts for loans
    c. relate money to time in a consistent manner
    d. all of these

14. For economic decision making process in the private sector, economic calculations are made to maximize net benefits to
    a. those who invest in the enterprise and assume the risk
    b. the public
    c. those who work as part of the enterprise
    d. the creditors of the enterprise

15. You have determined the profitability of a planned project by finding the present value of all cash flows from that project. Which of the following would cause the project to look less appealing, that is, have a lower present value?
    a. the discount rate decreases
    b. the cash flows are extended over a longer period of time
    c. the discount rate increases
    d. b and c are both correct

16. What is work-in process classified as?
    a. an asset
    b. an expense
    c. a liability
    d. a revenue

17. Which of the following is true regarding the minimum attractive rate of return used in judging proposed investments?
    a. it is the same for every organization
    b. it is larger than the interest rate used to discount expected cash flow for investments
    c. it is frequently a policy decision made by an organization's management
    d. it is not relevant in engineering economy studies

18. What is the formula for a straight line depreciation rate?
    a. $\frac{\text{100\% - \% net salvage value}}{\text{estimated service life}}$
    b. $\frac{\text{\% net salvage value}}{\text{estimated service life}}$
    c. $\frac{\text{100 \% net salvage value}}{\text{estimated service life}}$
    d. $\frac{\text{average net salvage value}}{\text{estimated service life}}$

19. The power of a good service to satisfy human wants
    a. producer goods
    b. value
    c. consumer goods
    d. utility

20. The group of costs involved in a going activity whose total cost will remain relatively constant throughout the range of operational activity.
    a. variable cost
    b. first cost
    c. fixed cost
    d. direct cost

21. Costs that have been incurred at some past date
    a. sunk costs
    b. fixed costs
    c. maintenance costs
    d. operation costs

22. Funds to finance public activities are obtained through
    a. the assessment of taxes and borrowing
    b. charges for services
    c. both a and b
    d. revenues to be operated by project being financed

23. The annual depreciation charge equals capital recovery with return for an interest rate of
    a. 100%
    b. zero
    c. greater than zero
    d. greater than one

24. Depreciation resulting not from a deterioration in the assets ability to serve its intended purpose but from a change in the demand for the services it can render.
    a. physical
    b. functional
    c. depletion
    d. none of these

25. A set of projects are _________ if at most one of them may be accepted. It is thus a question of picking the single economically best project (or if rejecting them all)
    a. mutually exclusive
    b. independent projects
    c. financially interdependent
    d. contingent

26. How much do you need to invest in equal annual amounts for the next 10 years if you want to withdraw ₱5,000 at the end of the eleventh year and increase the annual withdrawal by ₱1,000 each year thereafter until year 25? The interest rate is 6% compounded annually.
    a. ₱ 20,000
    b. ₱106,117
    c. ₱8,054
    d. ₱5,000

27. Your R & D group has developed and tested computer software that assists engineers in controlling a proper chemical mix for the tire-manufacturing industry. If you decide to market the software, your first year operating net cash flow is estimated to be ₱1,000,000. Because of market completion, your product life will be about 4 years and its market share will decrease by 25% each year over the previous years. You have been approached by a big software house who wants to purchase the right to manufacture and distribute the product. Assuming that your interest rate is 15%, for what minimum price would you be willing to sell the software?
    a. ₱2,507,621
    b. ₱2,887,776
    c. ₱2,766,344
    d. ₱2,047,734

28. What is the capitalized equivalent amount at 10% of annual interest for a series of annual receipts of ₱400 for the first 10 years, which will increase to ₱500 per year after 10 years and remains constant thereafter?
    a. ₱4,621
    b. ₱4,386
    c. ₱4,452
    d. ₱9,954

29. Consider the following two mutually exclusive projects:

	Net Cash Flow	
End of Year	Project A	Project B
0	–₱ 1,000	–₱ 2,000
1	475	915
2	475	915
3	475	915

At an interest rate of 12%, what do you recommend?
    a. Project A
    b. Project B
    c. either one
    d. neither

30. A manufacturing company is considering two types of industrial projects which require the same level of initial investment but provide different levels of operating cash flows over the project life. The in-house engineer has compiled the following financial data related to both projects, including the internal rate of return (IRR) figures. The company has been using the internal rate of return as a justification tool, and these projects will be evaluated based on the principle of rate of return. The firms minimum rate of return is 12%. Which project should you select?

	Net Cash Flow	
n	Project A	Project B
0	–₱ 18,000	–₱ 18,000
1	960	11,600
2	7,400	6,500
3	13,100	4,000
4	7,560	3,122
IRR	18%	20%

a. Project A
b. Project B
c. either one
d. neither

31. Consider the following two mutually exclusive service projects with individual lives of 3 years and 2 years, respectively. (Mutually exclusive service projects will have identical revenues for each year of service). The interest rate is known to be 6%.

	Net Cash Flow	
End of year	Project A	Project B
0	–₱ 1,000	–₱ 2,000
1	– 400	–150
2	– 400	–150 + 0 (salvage)
3	– 400 + 200 (salvage)	

If the required service period is indefinite (infinite) and both projects can be repeated with the given costs, which project is the better choice?

a. Project A
b. Project B
c. indifferent
d. neither

32. Two options are available for painting your house: (1) oil-based painting which costs ₱5,000 and (2) water-based painting which costs ₱3,000. The estimated lives are 10 years and 5 years respectively. For either option, there is no salvage value at the end of respective service life. Assume that you will keep and maintain the house for 10 years. If your personal interest rate is 10% per year, which of the following statements is correct?

a. On annual basis, Option 1 will cost about ₱850.00.
b. On annual basis, Option 2 is about ₱22.00 cheaper than Option 1.
c. On annual basis, both options cost about the same.
d. On annual basis, Option 2 will cost about ₱820.00.

33. A drill press machine can be purchased at ₱100,000 and is expected to have a constant salvage value of ₱20,000 regardless of its age. The operating cost for the first year is expected to be ₱40,000 and it will then increase ₱20,000 per year, as a result of degrading efficiency. If the interest rate is 10%, determine the economic service life of the drill press machine. (Assume that all cost figures and salvage value are given on an after-tax basis).
    a. 2 years c. 4 years
    b. 3 years d. 5 years

34. If a certain fund earns an interest of 12% compounded quarterly, what is the effective rate of interest?
    a. 12% c. 12.55%
    b. 3% d. 12.68%

35. What will be the future worth after 18 months if a sum of ₱1,000.00 is invested at a simple interest of 10% per year?
    a. ₱1,161.10 c. ₱1,150.00
    b. ₱1,600.00 d. ₱1,500.00

36. The sum of ₱1,000.00 was deposited in a fund at the end of each year for eight consecutive years and earned an interest of 6%. What amount will be in the fund immediately after the last deposit was made?
    a. ₱8,800.25 c. ₱9,500.00
    b. ₱9,897.47 d. ₱8,000.00

37. What annual expenditure for 10 years is equivalent to spending ₱1,000.00 at the end of the second year, ₱2,000.00 at the end of fifth year and ₱6,000.00 at the end of eight year, if the interest is 8% per year?
    a. ₱813.72 c. ₱900.00
    b. ₱872.13 d. ₱825.23

38. The sum of ₱2,600.00 was deposited in a fund that earns interest of 8% per annum compounded quarterly. What would be the principal in the fund at the end of 3 years?
    a. ₱3,275.25 c. ₱2,759.14
    b. ₱3,297.42 d. ₱3,000.00

39. What sum must be deposited to provide annual payments of ₱10,000.00 that are to continue indefinitely if the endowment fund earns an interest of 4% semi-annually?
    a. ₱250,000.00 c. ₱247,524.75
    b. ₱275,312.65 d. ₱500,000.00

40. An enterprising engineer purchased a fleet of trucks for ₱780,000.00. Payments were made by an immediate cash payment of ₱50,000.00 and twelve month-end payments of ₱64,860.00 each. Another deal referred to finance the purchase at an interest rate of 3/4 % per month on the unpaid balance. Which offer should the engineer have accepted?
    a. the first offer
    c. the second offer
    b. either of the two offers
    d. neither of the two offers

41. A company purchased a machine for ₱30,000.00 used it for 5 years and then sold it for ₱10,000.00. If the capital is worth 8%, determine the annual cost of depreciation and interest using straight line depreciation plus average interest.
    a. ₱5,760.00
    c. ₱3,560.00
    b. ₱8,760.00
    d. ₱5,000.00

42. A mine will have a net annual income of ₱400,000.00 annually for 15 years. Determine its value if the annual dividend rate is to be 12% payable annually, and sinking fund is to accumulate at 7% annually.
    a. ₱2,503,213.11
    c. ₱2,609,500.35
    b. ₱3,456,789.00
    d. ₱456,789.90

43. A man buys a house and lot worth ₱1.5 M if paid in cash. On the installment basis, he pays ₱500,000.00 downpayment; ₱300,000.00 at the end of the first year; ₱400,000.00 at the end of the second year; and the final payment at the end of the fourth year. What is the final payment if interest is 35%?
    a. ₱1,854,393.70
    c. ₱3,782,259.40
    b. ₱300,000.00
    d. ₱1,584,383.70

44. A new boiler was installed at a cost of ₱1.5 M and projected to have zero salvage value at the end of its 10-year life. What is the capitalized cost if interest is 10% per year?
    a. ₱2.44 M
    c. ₱3.42 M
    b. ₱6.02 M
    d. ₱1.02 M

45. The value of the property at the end of its economic life is called
    a. book value
    c. market value
    b. scrap value
    d. salvage value

46. Mr. Y borrowed ₱50,000.00 from GSIS in the form of calamity loan with interest at 8% compounded quarterly payable in equal quarterly payments for 10 years. What is the quarterly payment?
    a. ₱1,537.35
    c. ₱1,827.80
    b. ₱1,850.00
    d. ₱2,000.00

47. A welding machine costs ₱45,000.00 with an estimated life of 5 years. Salvage value is ₱2,500.00. What is the depreciation during the third year if straight line method is used?
    a. ₱9,000.00
    b. ₱8,500.00
    c. ₱8,250.00
    d. ₱8,000.00

48. A pump costs ₱50,000.00 estimated to have an economic life of 5 years with a negligible salvage value. What is the capital recovery cost if interest is 12% per annum?
    a. ₱7,870.50
    b. ₱6,000.00
    c. ₱13,870.50
    d. ₱15,385.00

49. How long will it take for ₱10,000.00 invested in a bank savings account to double in value if interest is 6% compounded semi-annually. The answer is nearest to
    a. 8 years
    b. 12 years
    c. 16 years
    d. 24 years

50. If ₱100,000.00 is invested at 12% compounded monthly, the annual interest is nearest to
    a. ₱1,000.00
    b. ₱12,350.00
    c. ₱12,000.00
    d. ₱12,700.00

51. The installed cost of a refrigeration unit is ₱250,000.00. It has a salvage value of ₱20,000.00 after an economic life of 10 years. Using straight line depreciation method, what is the book value at the end of 5 years?
    a. ₱135,000.00
    b. ₱125,000.00
    c. ₱200,000.00
    d. ₱130,000.00

Problems *52* to *60* are based on the following information:

Two machines are being compared.

	MACHINE X	MACHINE Y
Initial cost	₱50,000.00	₱120,000.00
Uniform annual maintenance	4,000.00	2,000.00
Useful life	10 years	20 years
Salvage value	10,000.00	negligible
Interest rate = 8%		

52. Based on the declining balance method of depreciation, the book value after 3 years of machine X is closest to
    a. ₱20,000.00
    b. ₱28,000.00
    c. ₱26,000.00
    d. ₱30,000.00

53. The SYD depreciation for the fourth year of machine X is closest to
    a. ₱2,000.00 c. ₱5,000.00
    b. ₱7,000.00 d. ₱10,000.00

54. The annual straight line depreciation for machine X is nearest to
    a. ₱4,000.00 c. ₱5,000.00
    b. ₱8,000.00 d. ₱10,000.00

55. The uniform annual production benefits from installing machine Y are estimated at ₱12,460.00 per year. If installed, machine Y would have a rate of return nearest to
    a. 4% c. 6%
    b. 5% d. 8%

56. To provide a 10% before tax rate of return, machine Y must have annual benefits nearest to
    a. ₱8,000.00 c. ₱10,000.00
    b. ₱14,000.00 d. ₱16,000.00

57. To have sufficient money to replace machine X with an identical replacement at the end of 10 years, annual end of year deposits will be made into a sinking fund. If the fund earns 8% interest, the annual deposit is nearest to
    a. ₱2,800.00 c. ₱3,500.00
    b. ₱12,200.00 d. ₱18,500.00

58. The present worth of cost for 20 years of machine Y is nearest to
    a. ₱8,000.00 c. ₱12,000.00
    b. ₱140,000.00 d. ₱160,000.00

59. The capitalized cost of machine X is nearest to
    a. ₱50,000.00 c. ₱65,000.00
    b. ₱135,000.00 d. ₱80,000.00

60. At the end of 10 years, the original machine X will be replaced by another machine X with identical initial cost, annual maintenance, useful life and salvage value. The equivalent uniform annual cost for the 20-year period is closest to
    a. 4,000.00 c. ₱10,800.00
    b. ₱7,000.00 d. ₱11,500.00

F. LAWS, CONTRACTS AND ETHICS

DEFINITION OF TERMS

Code of Ethics – guides for actions of a professional in relation to his employer, his fellow professionals and the public that he serves.

R.A. 9297 (Chemical Engineering Law of 2004) – an act regulating the practice of Chemical Engineering in the Philippines and for other purposes. This Act repeals R.A. 318, otherwise known as "The Chemical Engineering Law".

Chemical Engineering – the study, development and application of unit operations and unit processes in the transformation of raw materials into finished product.

Chemical Engineer – a professional who conceptualizes, develops, designs, improves and applies safe, healthy, ethical and economic ways of utilizing materials and energy in unit processes and operations for the benefit of society and environment through the knowledge of mathematics, chemistry, biology, information technology and other natural, applied and social sciences, gained by study, research and practice. *(CHED – TPETA)*

Contract – meeting of minds between two persons whereby one binds himself with respect to the other to give something or to render service.

Obligation – a juridical necessity to give, to do, or not to do.

Consent – agreement of the will of one contracting party with that of another or others, upon the object and terms of the contract.

Partnership – form of business organization composed of two or more members in order to conduct a business. Each member is called a partner.

Offer – initial step in the formation of a contract. It contains items and conditions, which if accepted, may give rise to a contract.

Corporation – a group of people organized for the purpose of business or industrial transaction which is incorporated under the laws of the Philippines.

R.A. 165 (Patent Law of the Philippines) – an act creating a patent office, prescribing its powers and duties, regulating the issuance of patents, and appropriating funds therefor.

Patent – an exclusive right given to an inventor over his invention for a limited time. It serves to protect him from uncontrolled competition from parties who had no part to that invention.

Invention – any new and useful machine, process, manufactured product or substance or an improvement of the three mentioned.

Infringement – the act of making, using, or selling by any person of a patented invention without the expressed authorization of the patentee.

R.A. 166 – an act to provide for the registration and protection of trademarks, tradenames, and service marks, defining unfair competition and false marking and providing remedies against the same.

Trade Name – includes names and surnames, first names and trade names, devices or words used by manufacturers, industrialists, merchants, agriculturists to identify their business, vocations or occupations: names and titles lawfully adopted and used by natural and juridical persons: unions and any manufacturing industrial, commercial, agricultural organizations engaged in trade or commerce.

Service Mark – mark used in the sale and advertising of services to identify the services of one person and distinguish them from the services of others.

Trade Mark – includes any word, name or symbol, emblem, sign or device or any combination adopted and used by a manufacturer or merchant to identify his goods and distinguish them from those manufactured or sold by others.

False Marking – any activity or affixture, annexing, or using in connection with any goods, a false designation of origin, or false description or representation including words or other symbols tending falsely to words or represent the same and shall cause such goods and services into commerce.

R.A. 2067 (Science Act of 1958) – an act to integrate, coordinate, and intensify scientific and technological research and development and to foster invention to provide funds therefor.

R.A. 1655 (Food and Drugs Act) – an act to provide standards for foods and drugs and to provide penalties for violations of the same.

Foods – all articles whether simple, mixed or compounded, which are used for food, drink, confectionery, or condiment by man or other animals.

Drugs – include all medicines and preparations recognized in the USP or National Formulatory for internal or external use. Any substance or mixture intended to ensure mitigation, or prevention of disease of either man or animal.

R.A. 5186 (Investment Incentives Act) – an act prescribing incentives and guarantees to investment in the Philippines creating the Board of Investment, appropriating funds therefor and for other purposes.

Registered Enterprise – a corporation organized and existing under Philippine laws of which at least 60% of the capital stock outstanding and entitled to vote is owned and held by Philippines nationals, at least 60% of the members of the board of directors are citizens of the Philippines engaged in a preferred area of investment and duly registered with the BOI.

Preferred Area of Investment – economic activities that the Board shall have declared as such.

Pioneer Enterprise – a registered business engaged in the manufacture, processing, or production and not merely in the assembly or packing of goods, products, commodities or raw materials that have not been or are not being produced in the Philippines on a commercial scale. Also, that which uses a design, formula, scheme, method, process, or system of production of any element, substance or raw material into another material, a finished good which is new and untried in the Philippines provided that the final product is of substantial use and processing uses domestic raw materials.

Investment Priorities Plan – plan prepared by the BOI which shall contain the analysis, synthesis, and projections of data collected by the Board from public or private sectors regarding activities in the agricultural, mining, and manufacturing sectors.

R.A. 5455 (Foreign Business Regulation Act) – an act which amended some portions of R.A. 5186.

Measured Capacity – the estimated additional volume of production which the BOI determines to be desirable in each preferred and pioneer area of investment in order to supply the needs of the economy at reasonable prices, taking into account the export potential of the area.

R.A. 6136 (Export Incentives Act of 1970) – an act to invigorate the economic growth by grabbing certain incentives and exemptions to registered export producers, export traders, and service exporters.

R.A. 6124 – an act providing for the fixing of maximum selling price of essential articles or commodities and creating the Price Control Council (PCC). This aims to stabilize the price of prime commodities so as to reach the needs of the consuming public.
P.D. 223 – a presidential decree creating the Professional Regulation Commission and prescribing its powers and functions.

REVIEW QUESTIONS AND PROBLEMS

1. Organization of chemical engineers duly accredited by the Professional Regulation Commission.
   a. PICHES b. AICHE c. PIChE d. JSCHE

2. The Professional Regulation Commission has supervisory powers over the Board of Chemical Engineering.
   a. True b. False

3. If the grades obtained by a ChE examinee are 55% in Chemical Engineering; 50% in Physical and Chemical Principles and 98% in General Engineering, he will
   a. pass the exam b. get a conditional grade c. fail the exam

4. No one can practice chemical engineering in the country unless licensed by the Board of Chemical Engineering.
   a. True b. False

5. One of the requirements to qualify as member of the Board of Chemical Engineering is 10 years of actual practice in the profession.
   a. True b. False

6. It is provided in the Chemical Engineering Law that holders of a doctorate degree in Chemical Engineering can secure license without examination.
   a. True b. False

7. A patent protects the inventor from the illegal use of his invention.
   a. True b. False

8. The BOI submits to NEDA proposals for the granting of incentives to pioneer, non-pioneer and preferred industries.
   a. True b. False

9. Foreigners who on the date of the approval of R.A. 6511 had been practicing chemical engineering are exempt from registration.
   a. True b. False

10. Industrial plants are those in which unit operation and unit process are involved.
    a. True b. False

11. A chemical engineer who designed and built a new type of reactor and for three years sold many units to the public can still patent his reactor.
    a. True b. False

12. DOTC is the government department responsible for pollution control and environmental concerns.
    a. True b. False

13. A chemical engineer can review the work of another chemical engineer without his permission for the same client.
    a. True b. False

14. Code of Ethics is a guide for a chemical engineer's actions.
    a. True b. False

15. Big advertisements of one's expertise is permitted in the Code of Ethics.
    a. True b. False

16. A chemical engineer can be a consultant of two or more firms that produce similar products.
    a. True b. False

17. It is right to compete with another chemical engineer provided inadequate compensation is made.
    a. True b. False

18. Exchange of information among chemical engineers are allowed except for confidential information.
    a. True b. False

19. Patent is a contract of the inventor with the public.
    a. True b. False

20. The chemical engineering profession can only work on unit operations.
    a. True b. False

21. Chemical engineers are guided at present, by
    a. R.A. 389 b. R.A. 9297 c. R.A. 318

22. Professional Regulation Commission was created under
    a. P.D. 223 b. P.D. 232 c. P.D. 233

23. A foreign chemical engineer can practice chemical engineering in the Philippines provided he is given an exemption by
    a. PRC b. DTI c. DOST

24. The life of a patent is
    a. 18 years b. 17 years c. 19 years

25. A chemical engineer can practice his profession by signing papers at the age of
    a. 20 years b. 18 years c. 21 years old

26. The Bureau of Patents, Trademarks and Technology Transfer is under the supervision of the Department of
    a. Trade and Industry
    b. Science and Technology
    c. Public Works and Highways

27. A chemical engineer may be suspended in practicing his profession for not more than
    a. one year b. one and a half years c. two years

28. The important function of regulating food standards is the responsibility of the
    a. Department of Trade and Industry
    b. Department of Health
    c. Department of Science and Technology

29. The office responsible for quality and standards of products is the
    a. Bureau of Trade
    b. Bureau of Product Standards
    c. Bureau of Small and Medium Industries

30. Ethics is a norm of conduct.
    a. True b. False

31. One cannot under price his/her professional fee just to get a contract.
    a. True b. False

32. It is not necessary to have the consent of both parties for a contract to be valid.
    a. True b. False

33. An underage examinee cannot be allowed to take his/her oath even after passing the board examination.
    a. True b. False

34. To be a chemical engineer board examiner, one must be at least 30 years of age.
    a. True b. False

35. As a general rule, a foreign chemical engineer can practice his profession in the Philippines.
    a. True b. False

36. According to R.A. 9297, the term of duty of a Board of Examiner for Chemical Engineering is three years only, with reappointment.
    a. True b. False

37. The Professional Regulation Commission is the agency that formulates the licensure examination questions.
    a. True b. False

38. A utility model is the same as an invention.
    a. True b. False

39. Changing the process of a patented invention without the inventor's permission is an act of infringement.
    a. True b. False

40. The President of the Philippines appoints the members of the Board of Examiners.
    a. True b. False

41. A Board of Examiner should not be connected with a school where he has a pecuniary interest.
    a. True b. False

42. It is unethical to undervalue ones professional services compared with others just to get a given contract.
    a. True b. False

43. An invention that is for public good could be developed even without the permission of the inventor especially if he refuses to license the invention for a reasonable royalty.
    a. True b. False

44. Two countries can allow their professionals to practice even without a license provided there is a reciprocity agreement.
    a. True b. False

45. A chemical engineer can do the work of a chemist.
    a. True b. False

46. It is the 1976 decree on Pollution Control.
    a. P.D. 894 c. P.D. 349
    b. P.D. 984 d. P.D. 232

47. The Commissioner of the Professional Regulation Commission must have executive or managerial experience of at least _____ years.
    a. 10 c. 6
    b. 8 d. 5

48. The act regulating the practice of chemical engineering in the Philippines is
    a. R.A. 9297 c. R.A. 813
    b. R.A. 9792 d. R.A. 318

49. The intangible, incorporeal right to literary, scholarly, scientific or artistic production is a
    a. patent c. copyright
    b. monopoly d. registered trade mark

50. An agreement between or among two or more persons is a/an
    a. obligation c. writ
    b. charter d. contract

51. It is the law creating the Patent Office.
    a. R.A. 156 c. R.A. 615
    b. R.A. 165 d. R.A. 516

52. A chemical engineer must be guided in his profession and relationship with others by
    a. the remuneration he receives
    b. his seniority and rank
    c. personal interest
    d. the highest standard of honor and integrity

53. A person who has passed the Chemical Engineering Licensure Examination can take his/her oath as a chemical engineer if his/her age is not less than ________ years.
    a. 19 b. 21 c. 23 d. 25

54. Specification means __________.
    a. the act or process of making specific through supplying particular details
    b. a statement of requirements
    c. a tool for obtaining equipment, goods or services in accordance with an engineer's requirements
    d. all of these

55. The chemical engineering law was signed by President Gloria Macapagal-Arroyo on May 10, 2004.
    a. True b. False

56. Compulsory licensing of inventions can be done by the Bureau of Patents, Trademarks and Technology Transfer.
    a. True b. False

57. To publicly criticize the work of another chemical engineer is allowed or ethical.
    a. True b. False

58. An employee can claim exclusive ownership of an invention produced during his employment in a company.
    a. True b. False

59. A foreign chemical engineer is allowed to practice in the Philippines if requested by the Philippine Government.
    a. True b. False

60. The Chemical Engineering Board of Examiners is composed of three (3) members.
    a. True b. False

61. A chemical plant should be operated by a chemical engineer.
    a. True b. False

62. __________ is the condition where a third person becomes a new debtor without the knowledge of or against the will of the debtor but always with the consent of the creditor.
    a. subrogation
    b. delegation
    c. rescission
    d. expromission

63. The Code of Ethics for chemical engineers was approved by the Board of Chemical Engineering in
    a. 1948 b. 1985 c. 1939 d. 1990

64. The "Chemical Engineering Law of 2004" was approved in the Senate during the 3rd and last reading at 4:05pm on February 6, 2004. This act is known as Senate Bill Number
    a. 46 b. 2526 c. 9297 d. 2685

65. For admission to the chemical engineering board examination, the age of the applicant should at least be
    a. 16 b. 18 c. 21 d. 25

66. A professional license must be renewed once every three years on the
    a. first day of the year
    b. last day of the year
    c. birthdate of the applicant
    d. date prescribed by PRC

67. The Board of Chemical Engineering may inspect the facilities, faculty, equipment and other aspects related to chemical engineering program of educational institutions in coordination with
    a. DOST b. DOE c. DECS d. CHED

68. A chemical engineer who violates the provisions of the ChE Law, upon conviction, shall be sentenced to a fine or imprisonment, upon the discretion of the court, of not more than
    a. 5 years b. 6 months c. 10 years d. 20 years

69. The chemical engineer shall report any infraction of any rules of professional conduct to the
    a. Supreme Court
    b. PRC
    c. Office of the President of the Philippines
    d. PIChE

70. Which of the following topics is included in the Chemical Engineering Board Examination?
    a. Process Control
    b. Engineering Management
    c. Transport Phenomena
    d. Computer Fundamentals

71. The New Intellectual Property Code is
    a. R.A. 165 b. R.A. 8293 c. P.D. 1856 d. E.O. 192

72. The New Intellectual Property Code took effect on
    a. January 1, 1958
    b. January 1, 1972
    c. January 1, 1997
    d. January 1, 1998

73. The New Intellectual Property Code follows the
    a. first to invent system
    b. first to file system
    c. either a or b
    d. neither a nor b

74. Compositions or forms giving distinct appearance pattern in a product can be protected as
    a. invention
    b. utility model
    c. industrial design
    d. trademark

75. Which of the following is not a requirement for utility model registration?
    a. inventive step
    b. novelty
    c. industrial applicability
    d. a technical solution to problem

76. "TIDE ULTRA" is an example of a
    a. trademark
    b. service mark
    c. collective mark
    d. tradename

77. The Board of Chemical Engineering is mandated by the ChE Law to report the rating of examinees not more than _____days after it has completed the correction of examination papers.
    a. 20 b. 10 c. 4 d. 30

78. Revising DENR Administrative Order No. 21 series of 1992 to further strengthen the implementation of the Environmental Impact Statement (EIS) System is
    a. DAO 96 – 37
    b. DAO 90 – 23
    c. DAO 29
    d. PD 984

79. Copyright works are protected during the life of the author and ___________ after his death
    a. 20 years b. 30 years c. 50 years d. 70 years

80. According to the "Chemical Engineering Law of 2004" at least one chemical engineer shall be included in the personnel of
    a. a chemical plant
    b. waste treatment facilities
    c. transport and distribution of chemicals
    d. all of these

81. The first principle for specification contents states that ___________.
    a. If something is not specified, it will not be provided
    b. Every requirement increases price
    c. The shorter the specification, the less time it takes to prepare it
    d. The specification is equally binding on both purchases and vendors

82. DENR Administrative Order formulating the implementation of Toxic Substances and Hazardous Nuclear Wastes Control Act
    a. DAO 29 b. DAO 34 c. DAO 56 d. DAO 62

83. "MEGALINK" is an example of a
    a. trademark c. collective mark
    b. service mark d. tradename

84. A section of the patent application containing detailed descriptions of the benefits obtained from using the invention is called the
    a. disclosure b. abstract c. request d. claims

85. Approved patents are published in
    a. IPO gazette c. major newspaper
    b. DTI journal d. technical reviews

86. An abstract of a patent application must not be more than
    a. 50 words c. 150 words
    b. 100 words d. 200 words

87. Establishment of Environmental Impact Statement and other environmental related measures
    a. P.D. 1151 c. R.A. 6969
    b. P.D. 1586 d. E.O. 192

88. Toxic Substances and Hazardous Nuclear Wastes Control Act of 1990 is known as
    a. P.D. 1151 b. P.D. 1152 c. R.A. 6969 d. E.O. 192

89. The National Pollution Control Commission (NPCC) has been abolished and replaced by the Environmental Management Bureau under
    a. P.D. 1151 b. P.D. 1152 c. R.A. 6969 d. E.O. 192

90. A document issued by the DENR secretary indicating that the proposed project will not cause significant negative environmental impact.
    a. Environmental Compliance Certificate
    b. Environmental Impact Statement
    c. Environmental Impact Assessment
    d. Environmental Critical Project

91. The cause in which the consideration is pure liberality on the part of the benefactor.
    a. onerous contracts c. gratuitous contracts
    b. remuneratory contracts d. none of these

92. It is the meeting of the mind between two persons whereby one binds himself with respect to the other to give something or render some services.
    a. contract　　c. real
    b. consensual　　d. implied

93. It is a juridical necessity to give, to do or not to do.
    a. contract　　c. obligation
    b. law　　d. none of these

94. Which of the following is not an essential element of a contract?
    a. consent of the contracting parties　　c. cause and consideration
    b. declaration of the third party　　d. subject of the contract

95. Which of the following is not a cause of inexistence and nullity of contracts?
    a. Those which contemplates an impossible service.
    b. Those whose cause and action did not exist at the beginning.
    c. Those which are previously ratified by the contracting parties.
    d. Those which are absolutely fictitious.

96. _______ is a contract whereby the debtor's property is given as a security for his debt.
    a. Usufructuary　b. Mortgage　c. Possession　d. Lease

97. According to the Chemical Engineering Code of Ethics, in how many days the Code shall take effect following its publication in the Official Gazette?
    a. 20　b. 10　c. 15　d. 25

98. A legally binding agreement on promise to exchange goods or services.
    a. contract　b. barter　c. memorandum　d. pro-forma

99. Under the Code of Ethics, the engineer should recognize __________ as one of the major resources of our country.
    a. labor　b. people　c. machine　d. technology

100. Republic Act No. 8749, known as the Clean Air Act of 1999, bans the use of leaded gasoline which contain toxic component called
    a. methylated lead　　c. tetraethyl lead
    b. Pb^{2+}　　d. lead oxide

101. The PRC Modernization Act of 2000 is also known as
    a. R.A. 8749　b. R.A. 8189　c. R.A. 8981　d. R.A. 8974

102. This regulation sets guidelines and targets of solid waste avoidance volume reduction through source reduction and waste minimization measures including composting, recycling, re-use, recovery, green charcoal process and others before collection, treatment and disposal in appropriate and environmentally sound solid waste management facilities.
    a. R.A. 8749　b. P.D. 984　c. R.A. 9003　d. R.A. 6969

103. It serves as a collective recognition by members of a profession of its responsibilities.
a. professional organization
b. code of ethics
c. foundation
d. corporation

104. Which of the following is unethical for a chemical engineer to do?
a. protect the interest of his client as his obligation
b. be associated with good character
c. compete with another engineer unfairly
d. encourage and provide opportunity for professional development

105. What is true about Code of Ethics?
a. self-interpreting
b. rules are stated in specific terms
c. provides ready made solutions to moral problems
d. some parts conflict with the others

106. What is the difference between law and engineering?
a. line of profession
b. there's always an available defender for a criminal while the worst project cannot have an available engineer
c. engineers can refuse, lawyers cannot
d. lawyers are after the number of cases, while engineers are after the number of projects

107. Why should we support the code of ethics?
a. it is our obligation
b. for respectability of profession
c. it hinders engineers to do wrong
d. all of these

108. Republic Act 386 is known as
a. Civil Code of the Philippines
b. Chemical Engineering Law
c. Civil Engineering Law
d. Patent Law

109. What will the chemical engineer do when his company has a contract with another company in which the operating plant causes danger to the public?
a. The chemical engineer should make contract despite that fact.
b. The chemical engineer and company should ignore the welfare of the public and continue doing business.
c. The chemical engineer and company shall avoid being associated with the other company which is not doing good for the public.
d. The chemical engineer and company shall make a contract because they are not the one doing harm to the public.

110. When there's an engineer's conference and an engineer was asked to give additional information and suggestions, what is the right thing to do?
a. He should voice out his knowledge about the topic and make suggestion.
b. He should not tell his knowledge about the topic.
c. He should not voice out for fear that his suggestion might be wrong.
d. He should be quiet at all times and listen only to them.

CHEMICAL ENGINEERING LICENSURE EXAMINATION REVISED SYLLABI (2002)

SCOPE: THE EXAMINEES KNOWLEDGE AND UNDERSTANDING OF THE CONCEPTS, PRINCIPLES, TERMINOLOGY, AND THE APPLICATION OF THESE CONCEPTS AND PRINCIPLES IN THE SOLUTION OF PROBLEMS ENCOUNTERED IN EACH PARTICULAR SUBJECT GIVEN IN THE LICENSURE EXAMINATIONS.

SUBJECTS:

I. PHYSICAL AND CHEMICAL PRINCIPLES (30%)

A. ***General Inorganic Chemistry***: Matter and energy, theory of atoms and molecules, chemical periodicity, calculation principles in chemical changes, chemical bonding, solutions, chemical equilibrium, chemical kinetics, and nuclear chemistry.

B. ***Organic Chemistry***: Structural characteristics and reaction mechanism of different organic compounds: aliphatic, aromatics, arenes, alcohols, aldehydes, ketones, carboxylic, acids, carbohydrates, amino acids, proteins, others.

C. ***Analytical Chemistry***: Theory and practice of gravimetric and volumetric methods of analysis and their application methods in the analysis of acids, bases, salts, and minerals.

D. ***Physical Chemistry***: Properties of gases, liquids, solids and solutions; introduction to first and second laws of thermodynamics; thermochemistry; homogenous and heterogenous equilibria; transference and conductance of ionized solutions; and electrochemistry.

E. ***Biochemical Engineering***: Aspects of biological sciences, primarily microbiology and biochemistry, which are applicable to process industries.

F. ***Environmental Engineering***: Types of pollutants; physical, chemical and biological processes applicable to pollution control and abatement.

II. CHEMICAL ENGINEERING PRINCIPLES (40%)

A. ***Chemical Engineering Calculations***: Mass and energy balances (stoichiometry); principles of equilibrium applicable to unit operations and processes; material and energy balances applicable to industrial processes, e.g. gaseous, liquid and solid fuels, sulfur nitrogen compound, etc.

B. ***Chemical Engineering Thermodynamics***: First and second laws of thermodynamics, P-V-T relationships of fluids, heat effects, thermodynamics of flow processes, power and refrigeration cycles, phase equilibria, and chemical reaction equilibrium.

C. ***Reaction Kinetics***: Principles and applications of chemical kinetics to the design of chemical reactors.

D. ***Unit Operations***: Principles of fluid mechanics; heat, mass and momentum transfer; separation processes; stage-wise operations.

E. ***Chemical Process Industries***: Unit operations and processes involved in the inorganic and organic chemical industries.

F. ***Plant Design***: Application of physical and chemical principles in the design of industrial plants or parts thereof involving preparation of process flow sheets, mass and energy balances, and equipment design.

G. ***Instrumentation and Process Control***: Principles and operations of a wide variety of process instruments and the proper selection thereof for practical industrial application.

III. GENERAL ENGINEERING, ETHICS AND CONTRACTS (30%)

A. ***Mathematics***: Algebra, Trigonometry, Analytic Geometry, Differential Calculus, Integral Calculus, Differential Equation, Statistics, Probability Theory.

B. ***Physics***: Mechanics, waves, sound, heat, electricity, magnetism, light, semi-conductors, and optics.

C. ***Engineering Mechanics***: Statistics and dynamics; free body concepts; equilibrium of coplanar and non-coplanar systems; analysis of frames and trusses; friction; centroids and moments of inertia; motion of particles and rigid bodies; mass, force and acceleration; work and energy; impulse and momentum.

D. ***Strength of Materials (Material Science):*** Types of material, classification, properties and characteristics: polymers, rigid and composite structures and other engineering materials. Axial stress and strain, stresses in torsion and bending, combined stresses, beam deflections, indeterminate beams, and elastic instability including thermal expansion.

E. ***Engineering Economics***: Introductory financial accounting; financial mathematics; time value of money; break-even analysis; capital investment and decision criteria; engineering-oriented applications; value engineering and optimization.

F. ***Laws, Contracts and Ethics***: Legal and ethical issues related to the practice of chemical engineering, including intellectual property and environmental laws.

ANSWERS TO REVIEW QUESTIONS AND PROBLEMS

PART I. PHYSICAL AND CHEMICAL PRINCIPLES

A. **General Inorganic Chemistry**: 1-b, 2-b, 3-a, 4-d, 5-b, 6-c, 7-a, 8-c, 9-b, 10-c, 11-d, 12-c, 13-a, 14-d, 15-c, 16-b, 17-a, 18-d, 19-c, 20-a, 21-a, 22-c, 23-d, 24-d, 25-b, 26-a, 27-c, 28-c, 29-b, 30-c, 31-d, 32-a, 33-d, 34-b, 35-c, 36-a, 37-c, 38-d, 39-b, 40-c, 41-b, 42-b, 43-a, 44-d, 45-b, 46-b, 47-d, 48-c, 49-a, 50-b

B. **Organic Chemistry**: 1-c, 2-a, 3-c, 4-d, 5-a, 6-b, 7-b, 8-c, 9-d, 10-b, 11-a, 12-c, 13-b, 14-c, 15-d, 16-a, 17-c, 18-b, 19-d, 20-c, 21-d, 22-a, 23-b, 24-c, 25-a, 26-d, 27-a, 28-b, 29-d, 30-c, 31-a, 32-c, 33-b, 34-d, 35-a, 36-b, 37-b, 38-b, 39-d, 40-a, 41-a, 42-c, 43-a, 44-d, 45-c, 46-b, 47-c, 48-d, 49-c, 50-d, 51-c, 52-a, 53-b, 54-c, 55-a, 56-c, 57-a, 58-b, 59-c, 60-b

C. **Analytical Chemistry**: 1-d, 2-b, 3-a, 4-c, 5-a, 6-c, 7-c, 8-b, 9-d, 10-a, 11-b, 12-c, 13-c, 14-a, 15-d, 16-b, 17-b, 18-b, 19-c, 20-d, 21-a, 22-c, 23-d, 24-a, 25-d, 26-b, 27-c, 28-a, 29-d, 30-b, 31-d, 32-a, 33-b, 34-c, 35-a, 36-b, 37-c, 38-a, 39-b, 40-d, 41-c, 42-b, 43-a, 44-c, 45-d, 46-a, 47-b, 48-c, 49-c, 50-a

D. **Physical Chemistry**: 1-b, 2-b, 3-b, 4-a, 5-c, 6-d, 7-d, 8-a, 9-a, 10-d, 11-c, 12-b, 13-a, 14-b, 15-a, 16-b, 17-a, 18-b, 19-d, 20-b, 21-a, 22-c, 23-c, 24-b, 25-b, 26-c, 27-a, 28-b, 29-a, 30-b, 31-b, 32-a, 33-a, 34-c, 35-c, 36-c, 37-b, 38-c, 39-a, 40-b

E. **Biochemical Engineering**: 1-c, 2-b, 3-a, 4-d, 5-a, 6-b, 7-b, 8-a, 9-d, 10-d, 11-c, 12-d, 13-a, 14-c, 15-a, 16-b, 17-d, 18-b, 19-d, 20-a, 21-b, 22-c, 23-a, 24-b, 25-c, 26-b, 27-d, 28-a, 29-b, 30-d, 31-d, 32-b, 33-b, 34-b, 35-b, 36-b, 37-c, 38-a, 39-c, 40-d, 41-a, 42-c, 43-c, 44-c, 45-b, 46-c, 47-b, 48-a, 49-b, 50-a

F. **Environmental Engineering**: 1-d, 2-a, 3-c, 4-d, 5-b, 6-a, 7-c, 8-b, 9-b, 10-d, 11-a, 12-a, 13-d, 14-c, 15-b, 16-a, 17-b, 18-a, 19-c, 20-c, 21-b, 22-a, 23-b, 24-a, 25-d, 26-c, 27-c, 28-d, 29-d, 30-b, 31-d, 32-c, 33-a, 34-a, 35-a, 36-b, 37-a, 38-c, 39-b, 40-b

PART II. CHEMICAL ENGINEERING PRINCIPLES

A. **Chemical Engineering Calculations**: 1-c, 2-d, 3-a, 4-a, 5-b, 6-a, 7-d, 8-a, 9-b, 10-c, 11-a, 12-c, 13-b, 14-c, 15-a, 16-b, 17-c, 18-d, 19-a, 20-d, 21-b, 22-a, 23-d, 24-c, 25-c, 26-c, 27-b, 28-a, 29-a, 30-b

B. **Chemical Engineering Thermodynamics**:1-d, 2-a, 3-c, 4-a, 5-a, 6-b, 7-a, 8-c, 9-c, 10-d, 11-a, 12-d, 13-b, 14-a, 15-c, 16-b, 17-b, 18-c, 19-b, 20-c, 21-b, 22-d, 23-a, 24-c, 25-c, 26-a, 27-b, 28-b, 29-a, 30-a, 31-b, 32-b, 33-b, 34-d, 35-c, 36-b, 37-a, 38-b, 39-b, 40-a

C. **Reaction Kinetics**: 1-a, 2-a, 3-a, 4-c, 5-c, 6-d, 7-c, 8-a, 9-d, 10-c, 11-b, 12-c, 13-a, 14-d, 15-c, 16-c, 17-a, 18-c, 19-d, 20-a, 21-b, 22-a, 23-b, 24-c, 25-b, 26-a, 27-a, 28-d, 29-d, 30-d, 31-a, 32-c, 33-c, 34-d, 35-b, 36-a, 37-c, 38-a, 39A-a, 39B-c, 40-b

D. **Unit Operations**
   1. **Flow of Fluids**: 1-b, 2-d, 3-a, 4-b, 5-b, 6-d, 7-b, 8-c, 9-b, 10-c, 11-d, 12-d, 13-c, 14-d, 15-c, 16-d, 17-c, 18-c, 19-a, 20-a, 21-d, 22-d, 23-b, 24-a, 25-b, 26-d, 27-c, 28-b, 29-a, 30-b, 31-b, 32-b, 33-a, 34-b, 35-d, 36-b, 37-c, 38-c, 39-c, 40-b, 41-a, 42-b, 43-a, 44-c, 45-b, 46-c, 47-c, 48-b, 49-a, 50-c

2. **Flow of Heat**: 1-d, 2-b, 3-b, 4-c, 5-c, 6-b, 7-b, 8-b, 9-c, 10-c, 11-a, 12-c, 13-c, 14-b, 15-a, 16-b, 17-c, 18-b, 19-b, 20-c, 21-b, 22-b, 23-b, 24-c, 25-b, 26-a, 27-c, 28-c, 29-b, 30-c, 31-c, 32-a, 33-b, 34-a, 35-d
3. **Evaporation**: 1-c, 2-a, 3-b, 4-c, 5-b, 6-b, 7-a, 8-b, 9-a, 10-c, 11-a, 12-c, 13-b, 14-b, 15-a, 16-b, 17-c, 18-b, 19-a, 20-c
4. **Filtration**: 1-b, 2-c, 3-b, 4-c, 5-c, 6-b, 7-b, 8-b, 9-c, 10-b, 11-b, 12-b, 13-b, 14-d, 15-b, 16-b, 17-c, 18-c, 19-b, 20-c, 21-b, 22-d, 23-a, 24-c, 25-c
5. **Diffusion**: 1-b, 2-d, 3-d, 4-c, 5-b, 6-a, 7-d, 8-c, 9-c, 10-d, 11-a, 12-d, 13-c, 14-b, 15-a, 16-b, 17-b, 18-b, 19-b, 20-b, 21-a, 22-b, 23-a, 24-c, 25-a, 26-c, 27-a, 28-d, 29-c, 30-a, 31-a, 32-a, 33-b, 34-d, 35-c
6. **Distillation:** 1-b, 2-a, 3-c, 4-b, 5-b, 6-b, 7-a, 8-d, 9-a, 10-b, 11-c, 12-c, 13-b, 14-a, 15-b, 16-b, 17-d, 18-c, 19-a, 20-b, 21-b, 22-b, 23-a, 24-b, 25-b, 26-d, 27-b, 28-b, 29-d, 30-d,31-b, 32-c, 33-c, 34-a, 35-c, 36-a, 37-c, 38-a, 39-c, 40-c, 41-c, 42-b, 43-a, 44-a, 45-a, 46-b, 47-d, 48-d, 49-c, 50-c
7. **Gas Absorption**: 1-b, 2-a, 3-a, 4-b, 5-b, 6-c, 7-d, 8-c, 9-a, 10-d, 11-d, 12-c, 13-a, 14-a, 15-b, 16-a, 17-c, 18-d, 19-b, 20-b, 21-b, 22-b, 23-a, 24-b, 25-b, 26-b, 27-c, 28-b, 29-c, 30-c, 31-b, 32-a, 33-c, 34-c, 35-a, 36-c, 37-a, 38-d, 39-a, 40-c
8. **Humidification**: 1-b, 2-d, 3-b, 4-a, 5-c, 6-a, 7-c, 8-b, 9-c, 10-c, 11-a, 12-c, 13-a, 14-b, 15-b, 16-c, 17-b, 18-c, 19-b, 20-b, 21-c, 22-c, 23-b, 24-a, 25-c, 26-c, 27-d, 28-b, 29-d, 30-d, 31-d, 32-c, 33-b, 34-a, 35-b, 36-b, 37-d, 38-c, 39-a, 40-c
9. **Drying**: 1-b, 2-a, 3-c, 4-b, 5-c, 6-b, 7-a, 8-b, 9-c, 10-c, 11-b, 12-a, 13-a, 14-c, 15-b, 16-d, 17-d, 18-a, 19-c, 20-c, 21-a, 22-d, 23-d, 24-c, 25-d, 26-b, 27-b, 28-d, 29-a, 30-b, 31-b, 32-c, 33-c, 34-d, 35-a, 36-c, 37-b, 38-a, 39-b, 40-d
10. **Leaching**: 1-c, 2-a, 3-d, 4-a, 5-c, 6-d, 7-d, 8-d, 9-a, 10-a, 11-d, 12-a, 13-c, 14-d, 15-a, 16-d, 17-b, 18-b, 19-a, 20-d, 21-b, 22-a, 23-c, 24-b, 25-a
11. **Liquid-liquid Extraction**: 1-a, 2-d, 3-c, 4-a, 5-a, 6-d, 7-c, 8-d, 9-a, 10-c, 11-c, 12-a, 13-a, 14-b, 15-b, 16-c, 17-d, 18-a, 19-b, 20-a, 21-c, 22-b, 23-c, 24-b, 25-a
12. **Crystallization**: 1-b, 2-d, 3-a, 4-c, 5-c, 6-a, 7-d, 8-b, 9-a, 10-c, 11-a, 12-a, 13-c, 14-b, 15-d, 16-b, 17-c, 18-a, 19-a, 20-d, 21-b, 22-d, 23-a, 24-c, 25-a, 26-c, 27-d, 28-d, 29-a, 30-c, 31-b, 32-b, 33-a, 34-b, 35-a.
13. **Sedimentation**: 1-d, 2-a, 3-c, 4-d, 5-b, 6-a, 7-b, 8-b, 9-c, 10-a, 11-b, 12-c, 13-a, 14-b, 15-c, 16-c, 17-b, 18-a, 19-c, 20-d, 21-a, 22-b, 23-c, 24-b, 25-c, 27-a, 28-b, 29-c, 30-c.
14. **Centrifugation**: 1-d, 2-b, 3-d, 4-b, 5-a, 6-a, 7-b, 8-a, 9-c, 10-a, 11-c, 12-a, 13-d, 14-c, 15-a.
15. **Membrane Separation**: 1-a, 2-b, 3-a, 4-b, 5-c, 6-b, 7-a, 8-c, 9-a, 10-a, 11-c, 12-a, 13-a, 14-b, 15-c
16. **Flotation**: 1-b, 2-c, 3-d, 4-a, 5-a, 6-a, 7-b, 8-d, 9-c, 10-a, 11-c, 12-c, 13-c, 14-a, 15-c
17. **Adsorption**: 1-a, 2-d, 3-a, 4-c, 5-a, 6-d, 7-b, 8-a, 9-b, 10-c, 11-b, 12-d, 13-c, 14-b, 15-a, 16-d, 17-a, 18-b, 19-d, 20-a, 21-b, 22-a, 23-a, 24-c, 25-b
18. **Screening**: 1-a, 2-b, 3-d, 4-c, 5-b, 6-d, 7-a, 8-b, 9-c, 10-d, 11-b, 12-d, 13-c, 14-a, 15-a, 16-c, 17-d, 18-a, 19-d, 20-b, 21-a, 22-a, 23-b, 24-c, 25-b, 26-a, 27-d, 28-c, 29-a, 30-d, 31-a, 32-c, 33-d, 34-a, 35-d
19. **Size Reduction**: 1-a, 2-c, 3-a, 4-d, 5-c, 6-d, 7-c, 8-c, 9-a, 10-c, 11-b, 12-a, 13-b, 14-b, 15-c, 16-a, 17-c, 18-b, 19-a, 20-a, 21-c, 22-a, 23-a, 24-c, 25-a, 26-a, 27-a, 28-c, 29-c, 30-c

20. **Materials Handling**: 1-b, 2-a, 3-d, 4-d, 5-a, 6-c, 7-b, 8-c, 9-a, 10-d, 11-d, 12-a, 13-b, 14-b, 15-c, 16-d, 17-a, 18-c, 19-a, 20-d, 21-b, 22-b, 23-b, 24-a, 25-b

21. **Dimensional Analysis**: 1-d, 2-a, 3-b, 4-b, 5-d, 6-a, 7-d, 8-a, 9-d, 10-b

E. **Chemical Process Industries**: 1-d, 2-b, 3-a, 4-a, 5-a, 6-c, 7-a, 8-c, 9-a, 10-d, 11-d, 12-b, 13-c, 14-c, 15-b, 16-b, 17-b, 18-a, 19-b, 20-b, 21-a, 22-d, 23-b, 24-a, 25-b, 26-a, 27-a, 28-b, 29-a, 30-b, 31-b, 32-d, 33-c, 34-a, 35-a, 36-c, 37-a, 38-c, 39-a, 40-a, 41-d, 42-c, 43-a, 44-d, 45-a, 46-c, 47-b, 48-a, 49-a, 50-a

F. **Plant and Equipment Design**: 1-d, 2-a, 3-b, 4-d, 5-a, 6-d, 7-b, 8-a, 9-a, 10-a, 11-c, 12-a, 13-a, 14-c, 15-a, 16-c, 17-b, 18-c, 19-a, 20-d, 21-b, 22-d, 23-d, 24-a, 25-c.

Unit Operations Economics: 1-c, 2-b, 3-b, 4-a, 5-b, 6-c, 7-c, 8-a, 9-c, 10-c, 11-d, 12-a, 13-c, 14-c, 15-c, 16-a, 17-c, 18-a, 19-a, 20-b

G. **Instrumentation and Process Control**: 1-c, 2-c, 3-c, 4-b, 5-a, 6-a, 7-a, 8-d, 9-a, 10-c, 11-a, 12-a, 13-a, 14-a, 15-b, 16-c, 17-b, 18-b, 19-c, 20-b, 21-c, 22-b, 23-b, 24-a, 25-b, 26-b, 27-b, 28-a, 29-b, 30-c, 31-b, 32-a, 33-c, 34-b, 35-a, 36-b, 37-d, 38-c, 39-b, 40-a, 41-a, 42-c, 43-c, 44-c, 45-b, 46-b, 47-d, 48-b, 49-c, 50-c

PART III. GENERAL ENGINEERING

A. **Mathematics**

Algebra, Trigonometry, Analytic Geometry, Calculus: 1-c, 2-b, 3-d, 4-a, 5-a, 6-d, 7-b, 8-a, 9-b, 10-c, 11-a, 12-a, 13-a, 14-b, 15-c, 16-a, 17-a, 18-b, 19-b, 20-a, 21-b, 22-c, 23-d, 24-a, 25-a, 26-c, 27-b, 28-a, 29-c, 30-a, 31-c, 32-c, 33-a, 34-d, 35-c, 36-b, 37-c, 38-c, 39-b, 40-c, 41-c, 42-a, 43-a, 44-a, 45-b, 46-c, 47-a, 48-d, 49-a, 50-b, 51-d, 52-a, 53-a, 54-d, 55-c, 56-a, 57-c, 58-a, 59-b, 60-a, 61-d, 62-b, 63-d, 64-a, 65-c, 66-a, 67-d, 68-a, 69-c, 70-c, 71-a, 72-d, 73-c, 74-a, 75-b, 76-a, 77-a, 78-b, 79-b, 80-c, 81-c, 82-a, 83-d, 84-b, 85-a, 86-c, 87-d, 88-a, 89-c, 90-b, 91-d, 92-b, 93-c, 94-a, 95-b, 96-d, 97-b, 98-a, 99-a, 100-d

Differential Equations: 1-d, 2-c, 3-c, 4-c, 5-a, 6-c, 7-a, 8-c, 9-d, 10-b, 11-b, 12-c, 13-c, 14-d, 15-d, 16-c, 17-b, 18-d, 19-c, 20-b, 21-b, 22-c, 23-c, 24-c, 25-d, 26-b, 27-c, 28-c, 29-a, 30-a, 31-b, 32-d, 33-a, 34-a, 35-b, 36-a, 37-c, 38-a, 39-b, 40-a

Probability and Statistics: 1-b, 2-a, 3-b, 4-d, 5-b, 6-a, 7-d, 8-c, 9-b, 10-a, 11-b, 12-c, 13-a, 14-a, 15-a, 16-d, 17-c, 18-a, 19-b, 20-b, 21A-a, 21B-a, 21C-a, 22-a, 23A-c, 23B-d, 24-c, 25-b, 26-c, 27-a, 28-b, 29-c, 30-d, 31-a, 32-a, 33-d, 34-c, 35-a, 36-a, 37-c, 38-a, 39-b, 40-b, 41-c, 42-c, 43-b, 44-c, 45-c

B. **Physics**: 1-b, 2-d, 3-c, 4-a, 5-c, 6-d, 7-d, 8-a, 9-a, 10-c, 11-c, 12-c, 13-a, 14-c, 15-c, 16-c, 17-c, 18-c, 19-a, 20-d, 21-a, 22-b, 23-b, 24-b, 25-c, 26-b, 27-c, 28-a, 29-a, 30-d, 31-d, 32-a, 33-d, 34-c, 35-a, 36-a, 37-a, 38-c, 39-c, 40-a, 41-d, 42-b, 43-a, 44-c, 45-b, 46-a, 47-c, 48 -c, 49-a, 50-b, 51-a, 52-c, 53-b, 54-c, 55-c, 56-a, 57-c, 58-b, 59-a, 60-c, 61-d, 62-c, 63-c, 64-a, 65-a

C. **Engineering Mechanics**: 1-d, 2-b, 3-d, 4-d, 5-b, 6-d, 7-c, 8-a, 9-c, 10-d, 11-c, 12-c, 13-a, 14-c, 15-a, 16-d, 17-d, 18-c, 19-b, 20-a, 21-c, 22-d, 23-a, 24-a, 25-c

D. **Strength of Materials**: 1-b, 2-c, 3-b, 4-c, 5-a, 6-a, 7-c, 8-b, 9-c, 10-d, 11-b, 12-c, 13-d, 14-d, 15-a, 16-c, 17-d, 18-c, 19-b, 20-a, 21-c, 22-d, 23-a, 24-a, 25-d, 26-d, 27-b, 28-a, 29-c, 30-b

E. **Engineering Economics**: 1-c, 2-a, 3-b, 4-a, 5-d, 6-b, 7-b, 8-d, 9-d, 10-b, 11-c, 12-c, 13-a, 14-a, 15-d, 16-a, 17-c, 18-a, 19-d, 20-c, 21-a, 22-c, 23-b, 24-b, 25-a, 26-c, 27-d, 28-b, 29-b, 30-a, 31-a, 32-b, 33-b, 34-c, 35-c, 36-b, 37-a, 38-b, 39-b, 40-c, 41-a, 42-a, 43-a, 44-c, 45-a, 46-c, 47-b, 48-c, 49-b, 50-d, 51-a, 52-d, 53-c, 54-a, 55-c, 56-d, 57-a, 58-b, 59-b, 60-c

F. **Laws, Contracts and Ethics**: 1-c, 2-a, 3-c, 4-a, 5-a, 6-b, 7-a, 8-b, 9-b, 10-a, 11-a, 12-b, 13-b, 14-a, 15-b, 16-b, 17-b, 18-a, 19-a, 20-b, 21-b, 22-a, 23-a, 24-b, 25-c, 26-a, 27-a, 28-b, 29-b, 30-a, 31-a, 32-b, 33-a, 34-a, 35-b, 36-a, 37-a, 38-b, 39-b, 40-a, 41-a, 42-a, 43-b, 44-a, 45-a, 46-a, 47-d, 48-a, 49-c, 50-d, 51-b, 52-d, 53-b, 54-d, 55-b, 56-a, 57-b, 58-b, 59-a, 60-a, 61-b, 62-a, 63-b, 64-d, 65-c, 66-c, 67-d, 68-a, 69-b, 70-a, 71-b, 72-d, 73-b, 74-c, 75-b, 76-d, 77-d, 78-a, 79-c, 80-d, 81-a, 82-a, 83-a, 84-d, 85-a, 86-c, 87-b, 88-c, 89-d, 90-c, 91-c, 92-a, 93-c, 94-b, 95-c, 96-b, 97-c, 98-b, 99-a, 100-c, 101-c, 102-c, 103-b, 104-c, 105-d, 106-b, 107-d, 108-d, 109-c, 110-a

PRACTICE PROBLEMS

I. Physical and Chemical Principles

II. Chemical Engineering Principles

III. General Engineering

PRACTICE PROBLEMS

PHYSICAL AND CHEMICAL PRINCIPLES

1. Arrange the following acids in order of increasing strength:
H_3O^+, H_2O, H_2, $CCl_3\ CO_2\ H$, HSO_4^- and HF
   - a. $H_2O < HF < H_2 < H_3O^+ < HSO_4^- < CCl_3\ CO_2H$
   - b. $HF < H_2O < H_2 < HSO_4^- < CCl_3\ CO_2 H < H_3O^+$
   - c. $H_2 < HF < H_2O < CCl_3\ CO_2\ H < H_2O < HSO_4^-$
   - d. $H_2 < H_2O < HF < HSO_4^- < CCl_3\ CO_2\ H < H_3O^+$

2. A 0.1 M solution of sodium bicarbonate has a pH value of
a. 13.0 b. 7.0 c. 8.4 d. 5.6

3. Which of the following would be the most probable electronic configuration of an element with atomic number 28 ?
a. 2-8-18 b. 2-8-14-4 c. 2-8-16-2 d. 2-8-12-2

4. If the solution X has a pH of 6.0 and a solution Y has a hydronium ion concentration twice that of solution X, the approximate pH of solution Y is
a. 12 b. 3 c. 5.7 d. 9

5. Eight grams of O_2 gas at 27°C and 10 atm expands adiabatically and reversibly to a final pressure of 1 atm. Find the work done in the process if $C_p = 7/2\ R$.
a. 822. 5 g b. 751.5 J c. 786.2 J d. 624.6 J

6. Phenolphthalein is useful as an indicator in the titration of
   - a. acetic acid with ammonia
   - b. acetic acid with NaOH
   - c. ammonia with HCl
   - d. Na_2CO_3 with HCl

7. The following data were taken in measuring the MW of a certain gas by the Regnault Method:
wt of evacuated bulb = 42.5050 g
wt of bulb + gas = 43.3412 g
wt of bulb + water = 365.31 g
T = 25°C
P = 745 mm Hg

The MW of the gas is
a. 64.6 g/mol b. 72.4 g/mol c. 32.4 g/mol d. cannot be determined

8. A central power plant rated at 800,000 kW generates steam at 585 °K and discards heat to a river at 295°K. If the thermal efficiency of the plant is 70% of the maximum value how much heat is discarded to the river at the rated power?
a. 1.5×10^6 kW b. 8.1×10^5 kW c. 3.4×10^5 kW d. 2.0×10^6 kW

9. A cell containing $CuSO_4$ with Cu electrode is connected in series with a cell containing dilute NaOH and inert electrodes. A uniform current was passed through these cells for 25 minutes. The weight of Cu deposited was 0.1680 g. The volume of gas measured at 30°C and 750 mmHg formed at the anode is
a. 20.5 cc b. 35.0 cc c. 33.3 cc d. 25.4 cc

10. What was the average current used in Problem 9 ?
    a. 0.50 amp   b. 0.34 amp   c. 0.25 amp   d. 0.22 amp

11. If 50 ml of a sample of water required 6.4 ml of EDTA solution for titration and each ml of the EDTA solution is equivalent to 0.40 mg Ca_{12}, the ppm $CaCO_3$ hardness is? Molar Weights: Ca = 40; $CaCO_3$ = 100
    a. 320   b. 220   c. 360   d. none of these

12. The following pairs are metallic ions and their corresponding precipitating agent for gravimetric analysis except:
    a. Ca^{+2} ………… $(NH_4)_2C_2O_4$ c. Ag^{+1} ………… HCl
    b. Fe^{+3} ………… NH_4OH d. Mg^{+2} ………… H_2S

13. A steel casting (C_p = 0.5 kJ/kg°C) weighing 40 kg at a temperature of 450°C is quenched in 150 kg of oil (C_p = 2.5 kJ/kg °C) at 25°C. The total entropy change for the process is
    a. −16.33 kJ/K   b. 26.15 kJ/K   c. 9.8 kJ/K   d. − 32.8 kJ/K

14. A given element has an atomic number of 15. It is therefore
    a. a metal with a valence of +1   c. a non-metal with a valence of −1
    b. a metal with a valence of +3   d. a non-metal with a valence of − 3

15. Which of the following aqueous solutions of equal molality has the lowest freezing point?
    a. calcium nitrate   c. sodium hydroxide
    b. sodium chloride   d. sulfurous acid

16. The variation of a vapor pressure with temperature is expressed mathematically by
    a. Gay-Lussac's Law   c. Raoult's Law
    b. Van der Waal's Equation   d. Clausius-Clapeyron Equation

17. The industrial process of Chlorine gas manufacture is called
    a. Haber's Process   c. Contact Process
    b. Deacon Process   d. Kraft Process

18. A 10 N aqueous H_2SO_4 solution (30°Tw) is made to react with a 55% aqueous NaOH solution (64°Be – heavier than H_2O) to form 1350 g of Na_2SO_4 per liter of NaOH solution. If the volume ratio of acid solution to the base solution is 2:1, determine the limiting reactant.
    a. H_2SO_4 b. NaOH   c. Na_2SO_4 d. cannot be determined

19. The density of a gas mixture of O_2 and N_2 is 1.1705 g/L at 27°C, 750 mm. The % of N_2 in the mixture is
    a. 70%   b. 68%   c. 30%   d. 32%

20. Ortho and para-orienting subtituents enhance the rate of electrophilic substitution reactions except in the case of
    a. isoprophyl group   d. phenyl group
    b. hydroxyl group   c. acetamide group

10. What was the average current used in Problem 9 ?
    a. 0.50 amp b. 0.34 amp c. 0.25 amp d. 0.22 amp

11. If 50 ml of a sample of water required 6.4 ml of EDTA solution for titration and each ml of the EDTA solution is equivalent to 0.40 mg Ca_{12}, the ppm $CaCO_3$ hardness is? Molar Weights: Ca = 40; $CaCO_3$ = 100
    a. 320 b. 220 c. 360 d. none of these

12. The following pairs are metallic ions and their corresponding precipitating agent for gravimetric analysis except:
    a. Ca^{+2} .... $(NH_4)_2C_2O_4$ c. Ag^{+1} .... HCl
    b. Fe^{+3} .... NH_4OH d. Mg^{+2} .... H_2S

13. A steel casting (C_p = 0.5 kJ/kg°C) weighing 40 kg at a temperature of 450°C is quenched in 150 kg of oil (C_p = 2.5 kJ/kg °C) at 25°C. The total entropy change for the process is
    a. –16.33 kJ/K b. 26.15 kJ/K c. 9.8 kJ/K d. – 32.8 kJ/K

14. A given element has an atomic number of 15. It is therefore
    a. a metal with a valence of +1 c. a non-metal with a valence of –1
    b. a metal with a valence of +3 d. a non-metal with a valence of – 3

15. Which of the following aqueous solutions of equal molality has the lowest freezing point?
    a. calcium nitrate c. sodium hydroxide
    b. sodium chloride d. sulfurous acid

16. The variation of a vapor pressure with temperature is expressed mathematically by
    a. Gay-Lussac's Law c. Raoult's Law
    b. Van der Waal's Equation d. Clausius-Clapeyron Equation

17. The industrial process of Chlorine gas manufacture is called
    a. Haber's Process c. Contact Process
    b. Deacon Process d. Kraft Process

18. A 10 N aqueous H_2SO_4 solution (30°Tw) is made to react with a 55% aqueous NaOH solution (64°Be – heavier than H_2O) to form 1350 g of Na_2SO_4 per liter of NaOH solution. If the volume ratio of acid solution to the base solution is 2:1, determine the limiting reactant.
    a. H_2SO_4 b. NaOH c. Na_2SO_4 d. cannot be determined

19. The density of a gas mixture of O_2 and N_2 is 1.1705 g/L at 27°C, 750 mm. The % of N_2 in the mixture is
    a. 70% b. 68% c. 30% d. 32%

20. Ortho and para-orienting subtituents enhance the rate of electrophilic substitution reactions except in the case of
    a. isoprophyl group d. phenyl group
    b. hydroxyl group c. acetamide group

PRACTICE PROBLEMS

PHYSICAL AND CHEMICAL PRINCIPLES

1. Arrange the following acids in order of increasing strength:
   H_3O^+, H_2O, H_2, $CCl_3\ CO_2\ H$, HSO_4^- and HF
   a. $H_2O < HF < H_2 < H_3O^+ < HSO_4^- < CCl_3\ CO_2H$
   b. $HF < H_2O < H_2 < HSO_4^- < CCl_3\ CO_2\ H < H_3O^+$
   c. $H_2 < HF < H_2O < CCl_3\ CO_2\ H < H_2O < HSO_4^-$
   d. $H_2 < H_2O < HF < HSO_4^- < CCl_3\ CO_2\ H < H_3O^+$

2. A 0.1 M solution of sodium bicarbonate has a pH value of
   a. 13.0 b. 7.0 c. 8.4 d. 5.6

3. Which of the following would be the most probable electronic configuration of an element with atomic number 28 ?
   a. 2-8-18 b. 2-8-14-4 c. 2-8-16-2 d. 2-8-12-2

4. If the solution X has a pH of 6.0 and a solution Y has a hydronium ion concentration twice that of solution X, the approximate pH of solution Y is
   a. 12 b. 3 c. 5.7 d. 9

5. Eight grams of O_2 gas at 27°C and 10 atm expands adiabatically and reversibly to a final pressure of 1 atm. Find the work done in the process if $C_p = 7/2\ R$.
   a. 822. 5 g b. 751.5 J c. 786.2 J d. 624.6 J

6. Phenolphthalein is useful as an indicator in the titration of
   a. acetic acid with ammonia
   b. acetic acid with NaOH
   c. ammonia with HCl
   d. Na_2CO_3 with HCl

7. The following data were taken in measuring the MW of a certain gas by the Regnault Method:
   wt of evacuated bulb = 42.5050 g
   wt of bulb + gas = 43.3412 g
   wt of bulb + water = 365.31 g
   T = 25°C
   P = 745 mm Hg

   The MW of the gas is
   a. 64.6 g/mol b. 72.4 g/mol c. 32.4 g/mol d. cannot be determined

8. A central power plant rated at 800,000 kW generates steam at 585 °K and discards heat to a river at 295°K. If the thermal efficiency of the plant is 70% of the maximum value how much heat is discarded to the river at the rated power?
   a. 1.5×10^6 kW b. 8.1×10^5 kW c. 3.4×10^5 kW d. 2.0×10^6 kW

9. A cell containing $CuSO_4$ with Cu electrode is connected in series with a cell containing dilute NaOH and inert electrodes. A uniform current was passed through these cells for 25 minutes. The weight of Cu deposited was 0.1680 g. The volume of gas measured at 30°C and 750 mmHg formed at the anode is
   a. 20.5 cc b. 35.0 cc c. 33.3 cc d. 25.4 cc

CHEMICAL ENGINEERING PRINCIPLES

1. A filtration operation in which the pressure drop is held constant and the flow rate is allowed to fall with time.
a. constant rate filtration
b. constant rate filtration followed by constant pressure filtration
c. constant pressure filtration
d. centrifugal filtration

2. In a long pipeline where water is pumped from a horizontal source, the pump is usually installed near the source in order to
a. save on pipe c. avoid cavitation
b. save on energy d. draw more liquid

3. The equivalent diameter of a concentric annular space where 1-in OD pipe is located inside a 2-in ID pipe is
a. 1 in b. 1.5 in c. $\pi/4$ in d. 2 in

4. A 6-inch standard horizontal pipe delivers water at a velocity of 10 ft/s to a 1000 m^3 pond from a river. The equivalent length of the pipe is 1000 ft. If the water temperature is 80°F, the flow is
a. laminar b. turbulent c. transition d. plug flow

5. The theoretical horsepower of the pump used in Problem 4 is
a. 6 b. 18 c. 12 d. none of these

6. The type of pump that may be installed in the system of Problem 4 is
a. axial flow c. single stage centrifugal pump
b. two stage centrifugal pump d. reciprocating pump

7. The primary reason why close steam is used in an open batch steam distillation is to
a. increase the number of degrees of freedom
b. supply heat needed by vaporizing liquid
c. increase the operating temperature
d. increase the operating pressure

8. A 2-4 shell and tube heat exchanger is used to heat 2.52 kg/s of water from 21.1°C to 54.4°C by using hot water under pressure entering at 115.6°C and leaving at 48.9°C. The outside surface area of the tubes in the exchanger is 9.30 m^2. The corrected log mean temperature difference is
a. 31.3 K b. 39.8 K c. 42.3 K d. 41.8 K

9. The concentration of fruit juices in an evaporator requires low temperature operation because they are heat sensitive materials. Hence a fruit juice concentration plant usually employs a
a. crystallizer c. single-effect evaporation unit
b. double-effect evaporation unit d. high pressure evaporation unit

10. The BPR of a 50% NaOH solution at an evaporator pressure of 4.7 psia is
    a. 73 °F
    b. 173 °F
    c. 233 °F
    d. 297 °F

11. Glycerine is to be concentrated from 12% to 72% in a single-effect evaporator. The inlet steam used is at 25 psig and comes out at 170°F. The vapor space in the evaporator has 25 inches Hg vacuum. Ten metric tons of glycerine per hour are fed at 85°F. The concentrated product is at 125°F. The amount of water evaporated (E) in kg/hr is
    a. 7580
    b. 8333
    c. 1667
    d. 3333

12. Which of the following is not true?
    a. Reactions that proceed at a fast rate have low activation energies.
    b. Reactions that proceed at a slow rate have high activation energies.
    c. All collisions of molecules result to a chemical reaction.
    d. Generally, the rate of reaction increases with increase in temperature.

13. The half-life for the decomposition of nitrogen pentoxide at 25°C is 5.7 hours, and is independent of the initial pressure. The specific rate constant for this reaction is
    a. ln 2
    b. 0.122/hour
    c. 0.122 hour
    d. (1/5.7)/hour

14. A solution of Na_2SO_4 in water is saturated at 50°C. When a saturated solution of Na_2SO_4 is cooled, crystals of $Na_2SO_4.10H_2O$ separate from the solution.

Temperature, °C	**Solubility of Na_2SO_4 (g/100 g water)**
50	46.7
10	9

If 1000 kg of this solution is cooled to 10°C, the percentage yield obtained is nearly
    a. 91 b. 90 c. 100 d. 80

15. Ten kg of a solid containing 45% of soluble material were treated with 15 kg of a solvent containing the same solute at 2% concentration in a vessel under constant agitation. After a long time the solution and the solid were separated by pressing. The solid analyzed 0.8 kg of solvent per kg of inert solid. The extract quantity obtained in kg was therefore
    a. 14.8 b. 15.1 c. 13.7 d. 14.8

16. In a determination of the solution retention data, the mass fraction of the solute in the extract was determined to be 0.6. The corresponding underflow analysis showed a retention of 0.6 kg solvent per kg of the inert solid. The mass fraction of solute in the underflow is most likely
    a. 0.6 b. 0.225 c. 0.36 d. 0.375

17. The following tie line data were obtained for a ternary system of solute A, extract solvent S and raffinate solvent B at a temperature of 25°C

Raffinate Layer % wt		**Extract Layer % wt**
A	25	42.5
B	67.5	24.6
C	7.5	32.9

The selectivity at this line is very nearly
a. 1.7 b. 4.67 c. 0.39 d. 1.0

18. The distribution coefficient of solute *A* between solvents *B* and *S* is given by $Y = 2.5X$ where Y = mass of *A*/mass of *S* in extract and X = mass of *A*/mass of *B* in raffinate. *S* and *B* are mutually immiscible. A solution containing 25% *A* in *B* is to be extracted in a single stage contact with a recovery of 80%. The amount of *S* in kg required per 100 kg of solution is nearly
a. 100 b. 150 c. 120 d. 200

19. The distribution coefficient of solute *A* between solvents *B* and *S* is given by $Y = 3X$ where Y and X are mass ratios of *A* to solvent in extract and in raffinate, respectively. *B* and *S* are mutually insoluble to each other. One hundred kg of a 30% solution of *A* and *B* is to be successively treated in two batch contacts with 60 kg of solvent each time. The overall percent recovery of *A* is very nearly
a. 89.9 b. 92.16 c. 96.5 d. 100

20. Lime slurry from a water treatment plant is sent to a rectangular settling canal where the supernatant clear liquid is discharged over the weir at the far end of the canal. The settled lime sludge is pumped out through a bottom hopper at the end of the canal. Experiments show that the settling velocity of the lime sludge is 1.0 cm/min, with the slurry flowing along the canal at a linear velocity of 1.0 m/min. If the average depth of the flow area is 1.0 m., considering a 1.0 m sludge depth, and the slurry discharge to the canal is 200 cu.m./h, the width of the settling canal is
a. 100 m b. 1.0 m c. 3.67 m d. 3.33 m

21. ________ is the ratio of the average diameter of the feed to the average diameter of the product
a. Reduction ratio
b. Tyler Standard screen size
c. Relative roughness
d. Settling ratio

22. A limestone ore is to be ground in a conventional ball mill to minus 200 mesh. The Bond grindability of the ore for a mesh-of-grind of 200 mesh (75 μm) is determined by laboratory test to be 2.73 g per revolution. The 8% passing size of the feed to the test is 1970 μm; the 80% passing size of the product from it is 44 μm. Employ the formula below that yields work index directly

$$Wi = \frac{44.5}{P_1^{0.23} G^{0.82}\left(\frac{10}{P^{0.5}} - \frac{10}{F^{0.5}}\right)}$$

where *Wi* = work index, in kWh/ton
G = grindability, in g/revolution
P = 80% passing size of the product of the grindability test in microns
F = 80% passing size of the feed to the grindability test in microns
P_I = size of the mesh-of-grind of the grindability test in microns

The work index, *Wi*, for the material at this mesh-of-grind is
a. 5.64 kWh/ton b. 6.54 kWh/ton c. 4.64 kWh/ton d. 5.0 kWh/ton

23. The Bond work index for a mesh-of-grind of 200 mesh for a rock consisting mainly of quartz is 17.5 kWh/ton. Employ the formula below based on the Bond Third Theory of Comminution.

where *W* = power required, kwh/ton
$W = 10\ W_i (P^{-0.5} - F^{-0.5})$
Wi = work index, kwh/ton
P = 80% passing size of product in microns
F = 80% passing size of feed in microns

The power needed to reduce the material in a wet grinding ball mill from an 80% passing size of 1100 μm to an 80% passing size of 80 μm
a. 9.34 kWh/ton
b. 41.3 kWh/ton
c. 34.1 kWh/ton
d. 14.3 kWh/ton

24. A taconite ore is to be ground wet in a ball mill. The mill has an internal diameter of 3.96 m and runs at 68% of critical speed. The work index of the ore is 12.2 kWh/ton and its specific gravity is 3.3. The 80% passing size of the ore is 5600 μm. Employ the empirical formula below that yields the maximum size directly

$$M = \left(\frac{F}{K}\right)^{1/2}\left(\frac{SWi}{100\,CsD^{1/2}}\right)^{1/3}$$

where *M* = maximum size of balls in inches
F = 80% passing size of feed to the mill in microns
S = specific gravity of the ore
Wi = work index of the ore, kWh/ton
D = inside diameter of the ball mill in feet
Cs = fraction of critical speed of the mill
K = constant (35 for wet grinding or 330 for dry grinding)

The maximum size of grinding media (maximum diameter of balls) to be used for the operation is
a. 2.19 in b. 1.29 in c. 9.12 in d. 2.91 in

Problems *25 to 34* are based on the following information:

A mixture of ethanol vapor and nitrogen has a dry-bulb temperature of 122°F and wet-bulb temperature of 68°F at standard atmospheric pressure. Specific heats of nitrogen and ethanol are 0.25 and 0.38 BTU/lb°F, respectively. Latent heat of evaporation for alcohol is 16,910 BTU/lb-mol. Diffusivity of alcohol in nitrogen = 0.44 ft^2/h. Vapor pressures of alcohol = 43.6 mm Hg at 20°C and 229 mm Hg at 122°F.

$$\text{Viscosity of air} = 0.018 \text{ cP}, \ \frac{h_G}{k_y} = 0.379 \text{ BTU/lb°F}$$

25. Wet-bulb absolute saturation in units of lb/lb dry air is
a. 0.09 b. 0.1 c. 0.12 d. 0.05

26. The value of the Schmidt Number is very nearly
a. 1.0 b. 1.36 c. 1.32 d. 0.565

27. The dry-bulb absolute saturation lb alcohol/lb nitrogen is very nearly
a. 0.0443 b. 0.100 c. 0.5 d. 0.056

28. Saturated absolute saturation in lb alcohol/lb nitrogen is very nearly
a. 0.80 b. 0.709 c. 0.75 d. 0.045

29. The percentage saturation for the mixture is very nearly
a. 6.25 b. 7.09 c. 10 d. 8.9

30. The percent relative saturation of the mixture is very nearly
a. 4.9 b. 8.7 c. 5.5 d. 6.4

31. Humid volume of the mixture in ft^3/lb is very nearly
a. 14.13 b. 13.17 c. 12.82 d. 17.3

32. The humid heat of the mixture in BTU/lb dry nitrogen is very nearly
a. 0.294 b. 0.267 c. 0.25 d. 0.38

33. The value of Lewis Number for the mixture is very nearly
a. 2.1 b. 1.315 c. 1.92 d. 2.6

34. Heat in BTU/hr needed to heat 1000 ft^3/min of the mixture from 122 to 220°F is very nearly
a. 111108 b. 10000 c. 22000 d. 11100

35. A wet solid slab weighing 200 kg with a drying surface of 1 m^2/75 kg is to be dried from 40 to 20% moisture. Drying tests have shown that this drying takes place at constant rate and that the critical moisture of the solid is 20%. The constant drying rate is 3×10^{-2} kg/m^2 min. The drying time (min) is closest to
a. 1500 b. 2000 c. 1050 d. 500

36. The air in a dryer is at 150°F and has a relative humidity of 25%. It is flowing at a velocity of 5 ft/s. The mass transfer coefficient is given by

$$k_Y = (22.4 + 0.049\,t)G^{0.8}$$

where G = mass velocity, lb/hr-ft^2
t = dry air temperature, °F
k_Y = lb/(h)(ft^2)(unit H)
G = lb wet air/s ft^2

The rate of evaporation (lb/hr) is closest to
a. 0.2 b. 0.4 c. 0.5 d. 0.12

37. An insoluble crystalline solid is placed in a 2 ft x 3 ft x 1 in. deep drying pan. The pan is made of 304 stainless steel, 0.32 in. thick. It is placed in an air stream at 150°F and humidity of 0.01 lb/lb dry air, flowing parallel to upper and lower surfaces at a mass velocity of 2300 lb/hr-ft^2. The clearance between the surface of the pan and an insulated pipe coil above is 4". If the pan is thoroughly insulated and radiation effect is negligible, the drying rate (lb/hr) is closest to
a. 0.976 b. 0.244 c. 3.8 d. 1.3

38. One hundred pounds of a wet solid were loaded in a tray drier at a moisture content of 60% wet basis. The overall drying rate was constant for 4 hours at 11 lb/hr. After that, the rate decreased linearly with moisture content of the dry solid. The equilibrium moisture content of the solid is 4%. The total moisture content in percent on wet basis 3 hours after the rate started declining is very nearly
a. 30.6 b. 40.0 c. 23.4 d. 20.0

39. An insulated hot air countercurrent drier is to be designed to dry 200 kg/h of a product containing 30% moisture to a product containing 0.2% moisture (wet basis). Air will have a dry-bulb temperature of 110°C and a wet-bulb temperature of 38°C. Air leaving the drier will be at 46°C and 95% saturated. The solids will enter the drier at 30°C and will leave the drier at 60°C. The allowable dry air velocity is 4.5 kg/min-m^2 of drier cross section. The dry air rate required is very nearly
a. 15.9 kg/min-m^2 b. 15.9 kg/min c. 953 kg/h d. 953 kg/h-m^2

40. A liquid mixture of three components, A, B and C having different relative volatilities are to be separated by ordinary distillation only into three pure components (sharp separation). What is the least number of theoretically possible sequences for this separation?
a. 2 b. 1 c. 3 d. 4

41. Under normal operating conditions, when a solid material to be dried is placed inside a batch tray drier, the material is usually subjected under
a. constant drying conditions c. high temperature drying
b. variable drying conditions d. low temperature drying

42. When a wet granular solid material is placed in a metal tray with insulated edges and bottom in a batch tray drier, the heat transfer mechanism involved in the drying operation is by
a. convection only
b. convection and radiation
c. conduction, convection and radiation
d. conduction only

43. When a solid material is being dried in a continuous tunnel drier under low temperature drying, the mechanism is considered to be
a. strictly mass transfer only
b. simultaneous mass and heat transfer
c. heat transfer dominated with practically no mass transfer
d. mass transfer dominated with practically no heat transfer

44. If there is no heat transfer by radiation and conduction from adjoining surfaces, the temperature of the solid subjected to direct drying under constant drying conditions within the constant rate period is usually
a. greater than the wet-bulb temperature of the drying medium
b. less than the wet-bulb temperature of the drying medium
c. nearly equal to the wet-bulb temperature of the drying medium
d. nearly equal to the dry-bulb temperature of the drying medium

45. A liquid feed of pure A (1 mole/liter) is treated in two reactors of 2-liter volume each and reacts with a rate of $r_A = 0.05\ C_A^2$, mole/liter-sec. Find what feed rate in liters/min that will give a final outlet concentration of $C_A = 0.50$ mole/liter if two CSTRs in series are used.
a. 12 b. 8.46 c. 10.23 d. 10.67

46. If two CSTRs in parallel are used in Problem *45*, the total feed rate, in liters/min is
a. 6 b. 3 c. 9 d. 8

47. If two plug flow reactors are used in Problem *45*, the total feed rate, in liters/min is
a. 6 b. 9 c. 12 d. 8

48. If two plug flow reactors in series are used in Problem *45,* the total feed rate, in liters/min is
a. 6 b. 9 c. 12 d. 8

49. If a CSTR and a plug flow reactor hooked up in parallel are used in Problem *45,* the total feed rate in liters/min is
a. 6 b. 9 c. 12 d. 8

50. For an identical conversion and throughput, which of the reactors will have a larger volume if the reaction is a second order reaction?
a. backmix reactor
b. plug flow reactor
c. either of the two (d or b)
d. cannot be determined

51. Shape factors are important in characterizing particulate solids such as those encountered in size reduction, screening, etc. What is the specific surface (surface area per unit mass of material) in cm^2/g for quartz with a characteristic diameter of 2 inches, a density of 165 lb/ft^3 and a shape factor of 10?
a. 45 b. 4.47 c. 95 d. 8.92

52. The capacity of a Sharples centrifuge is estimated to increase/decrease by _____% if its speed is doubled and the cut size of the product is reduced by 20%.
a. 50 b. 20 c. 100 d. 156

53. A plate and frame filter press is used to filter a compressible sludge (s = 0.45) at 50 psi for 2 hours. Washing is done at 30 psi with wash water equal to 10% of the filtrate volume collected. The washing time is ______ min.
a. 96 b. 127 c. 100 d. none of these

54. A mixture of silica particles ranging in size from 65 mesh to 150 mesh is thrown into a very deep body of fresh water (without tides or turbulence). How far will the largest particles be, in feet, from the smallest particle after 5 min? The specific gravity of silica is 2.65 and the temperature of water is 30°C.
a. 29 b. 120 c. 50 d. none of these

55. Water contains organic color which is to be extracted with alum and lime. Five parts of alum and lime per million parts of water will reduce the color to 25% of the original color and 10 ppm will reduce the color to 3.5%. Estimate how much adsorbent in ppm are required to reduce the color to 0.5% of the original color.
a. 20 b. 16 c. 30 d. none of these

56. Referring to the appropriate nomograph in the Chemical Engineer's Handbook, determine the volumetric flow rate of air needed to convey oxalic acid crystals in a 5-inch diameter pneumatic conveyor in cfm.
a. 500 b. 850 c. 950 d. 1020

57. The horsepower requirement for the pneumatic conveyor in Problem *56* if the pressure loss in the system is estimated to be 5 psig is
a. 10 hp b. 20 hp c. 30 hp d. 50 hp

58. The estimated capacity of an 8-mesh screen with dimension of 6 ft by 10 ft to classify crushed stone with a bulk density of 100 lb/ft^3 is approximately ______ tons/hr.
a. 10,500 b. 9,800 c. 5,000 d. none of these

59. The effective diffusivity of CO_2 at 300K through a DuPont cellophane with a pore diameter of 33 Angstrom, a porosity of 0.51 and a tortuosity of 4.9 is ________ cm^2/s.
a. 8.70×10^{-4} b. 2.21×10^{-4} c. 4.35×10^{-4} d. none of these

60. High speed vibrating sieves are commonly used for particle sizes ranging from ______mesh to _______ mesh.
a. 325 to 4 b. 10 to 4 c. 100 to 4 d. 28 to 4

61. Based on Bond's Crushing Law, the power required to crush a certain material will change by ________ % if the diameter of the product is made smaller by 50%.
a. 41.4 b. 50.5 c. 20.2 d. none of these

62. The critical speed of a ball mill in rpm whose diameter is 12 inches with grinding balls of ½ in. is approximately
a. 100 b. 92 c. 78 d. 61

63. If the total percentage of particles larger than the screen opening in the feed, oversize, undersize are 36%, 89%, and 3%, respectively, the effectiveness of the screen if the undersize of the product is
a. 65% b. 98% c. 76% d. 89%

64. Referring to the appropriate information given in the Chemical Engineer's Handbook, the width of an apron conveyor having a capacity of 75 tons/hour at a speed of 50 ft/min is ______ mm.
a. 610 b. 1220 c. 305 d. 2400

65. The capacity of a rotary vacuum filter will change by a factor of ______ if the submerged area is increased by 20% with the speed remaining the same.
a. 2 b. 1.1 c. 1.5 d. 1.2

66. Referring to the appropriate characteristic curve found in the Chemical Engineer's Handbook, determine the rated capacity in gpm of a regenerative pump delivering a head of 50 ft.
a. 106 b. 66 c. 76 d. 96

67. The NPSH of a single suction centrifugal hot water pump at a speed of 3550 rpm operating at a pressure of 600 psi and a capacity of 450 gpm is ______ ft.
a. 10 b. 20 c. 30 d. 50

68. The power requirement of a fan in kW in order to supply air at a rate of 1000 m^3/hr at a total discharge pressure of 0.5 psia is ______ kW.
a. 2 b. 1 c. 3 d. 4

69. What is the entrance length in a 1-inch Sch 40 pipe if the Reynolds number is 500?
a. 2.4 ft b. 3.5 ft c. 4.8 ft d. 8.0 ft

70. If the adiabatic head of a compressor becomes three times, the capacity increases by a factor of ______ if the speed is maintained constant.
a. 3.03 b. 2.08 c. 4 d. 1.8

71. What is produced when a carbonate is calcined?
    a. the free metal and sodium carbonate
    b. the metal oxide and carbon dioxide
    c. the free metal and sulfur dioxide
    d. water and the metal hydride

72. During roasting, the metal reacts with
    a. oxygen
    b. carbon monoxide
    c. sulfur
    d. the furnace atmosphere

73. Why is either pure oxygen or oxygen diluted with argon used in a converter instead of air?
    a. the carbon dioxide in air will cause the iron to oxidize and form rust
    b. the oxygen concentration is too low to function efficiently at removing impurities
    c. the carbon monoxide in air reacts with the iron to form a volatile, and toxic, iron carbonyl
    d. the nitrogen in air will react with iron to form iron nitride that will make the iron brittic

74. What happens to the silicon that is contaminant in crude iron in a converter ?
    a. it is converted to the tetrafluoride that bubbles out as a gas
    b. it is precipitated as sodium silicate
    c. it is converted to silicon dioxide and becomes part of the slag
    d. it is precipitated as the carbide

75. Roasting of the monosulfide of zinc (an active metal) in O_2 produces which products?
    a. $Zn_{(s)}$ and $SO_{2(g)}$
    b. $Zn_{(s)}$ and $SO_{3(g)}$
    c. $ZnO_{(s)}$ and $SO_{2(g)}$
    d. $ZnO_{2(s)}$ and $SO_{2(g)}$

76. A basic slag is needed in steel making to
    a. remove SiO_2 as silicates
    b. reduce any nitrogen containing compounds to N_2
    c. react with any Bronsted-Lowry acids present
    d. provide CaO to remove phosphorous oxides as $Ca_3(PO_4)_2$

77. Which of the following are the products of calcining limestone, $CaCO_3$?
    a. $Ca_{(s)}$ and $CO_{3(g)}$
    b. $Ca_{(s)}$ and $CO_{2(g)}$
    c. $CaO_{(s)}$ and $CO_{3(g)}$
    d. $CaO_{(s)}$ and $CO_{2(g)}$

78. It is selectively dissolving a metal-containing compound from an ore.
    a. leaching
    b. sol formation
    c. oxidation
    d. refining

79. Which of the following is false concerning the Bayer Process?
    a. It is hydrometallurgical process.
    b. It involves treatment of baute with cold, dilute hydroxide solution.
    c. In the process, aluminum is converted to a soluble aluminate ion.
    d. It results in the separation of aluminum from iron and silicon.

80. The flotation process is used to separate
    a. magnetic minerals from nonmagnetic gangue
    b. cyanide-complexing elements from gangue
    c. high-melting and low-melting metal oxides
    d. minerals whose surfaces are hydrophobic gangue

81. It is the undesirable material that is separated from an ore during the concentration process.
    a. gangue b. leachate c. slag d. flocculent

82. The hydrometallurgical process used in refining gold ore entails converting metallic gold to water-soluble $Au(CN)_2$. What must happen to the metallic gold to allow it to complex with CN to form $Au(CN)_2$ removable in liquid form from the gangue?
    a. It is reduced with a metal hydride
    b. It is reduced with $CO_{(g)}$ to form $Au(CO)_4^{2-}$
    c. It is oxidized in the presence of O_2 to Au(I)
    d. It is oxidized with $CO_{(g)}$ to form $Au(CO)_4^{+}$

83. A major by-product in the Hall electrometallurgical process for refining aluminum is
    a. $O_{2(g)}$ from oxidation of H_2O at the anode
    b. $CO_{2(g)}$ from oxidation of the graphite anode
    c. $H_{2(g)}$ from oxidation of H_2O at the cathode
    d. $Fe_{(s)}$ from impurities present in bauxite ore

84. Which of the following unit processes is essential in the manufacture of commercial explosives and military high explosive?
    a. controlled oxidation b. electrolysis c. nitration d. dehydration

85. It is the process of joining together many molecules to form very large molecules.
    a. monomerization b. dimerization c. polymerization d. hydroxylation

86. It states that if two models are geometrically, kinematically and dynamically similar, all velocities and forces are in constant relationship at counterpart positions.
    a. scale model c. dimensional theory
    b. model theory d. transport model

87. This exists in a geometrically similar system of models of different sizes if all velocities at counterpart positions bear a constant ratio.
a. geometric similarity c. kinematic similarity
b. dynamic similarity d. dimensional analysis

88. Which of the following unit processes is employed in the production of chemicals for warfare, insecticides, intermediates for dyes, chemicals like chloro-benzene, benzal chloride and carbon tetrachloride?
a. chlorination b. bromination c. halogenation d. iodination

89. A unit process where heat is employed to decompose a compound and takes place at low temperatures and in the presence of solvents.
a. polymerization b. pyrolysis c. neutralization d. ion exchange

90. Heating a material at a temperature below its melting point can cause the loss of moisture or other volatile compounds. The material can also be oxidized or reduced. This unit process is referred to as
a. calcination b. combustion c. dehydration d. alcoholysis

91. Saponification of oils and fats, starch conversion, sugar inversion and breaking down of proteins are examples of what unit process?
a. halogenation b. hydrolysis c. neutralization d. nitration

92. A unit process which deals with the use of micro-organisms like yeast and bacteria, to convert one substance into another.
a. alkylation b. alcoholysis c. halogenation d. fermentation

93. A steel test specimen is 5/8 in. diameter at the root of the thread. It is to be stressed to 50,000 psi tension. What load must be applied?
a. 12,790 lb b. 15,340 lb c. 16,320 lb d. 25,600 lb

94. In designing a cylindrical pressure tank 3 feet in diameter, a factor of safety of 2.5 is used. The cylinder is made of steel (σ_{yield} = 30 Ksi) and will contain pressures up to 1,000 psi. What is the required wall thickness, t, based on circumferential stress condition?
a. 0.75 in. b. 1.5 in. c. 3 in. d. 3.75 in.

95. A water solution of molasses contains 10% by weight sucrose ($C_{12}H_{22}O_{11}$). Determine the weight percent of ethyl alcohol in the solution after 90% of the sucrose has been converted to ethyl alcohol by fermentation. The CO_2 formed in he reaction can be considered as having a negligible solubility in the solution and the last 10% of the sugar can be assumed as unchanged.
a. 6% b. 3.1% c. 5.1% d. 6.5%

96. A steel (σ_{yield} = 30 ksi) pressure tank is designed to hold pressures up to 1,000 psi. The tank is cylindrical with a diameter of 3 feet. If the longitudinal stress must be less than 20% of the yield stress of the steel, what is the necessary wall thickness, t?
a. 0.75 in. b. 1.5 in. c. 3 in. d. 3.75 in.

97. Estimate the optimum economic inside diameter of pipe when 10,000 gal of a liquid having a density of 58 lb/ft^3 flow through the pipe per hour. The flow is turbulent. The approximate value for the optimum diameter of a steel pipe may be obtained from the following dimensional equation:

$$D_i = \frac{2.2\,w^{0.45}}{0.32\rho}$$

where Di = optimum inside pipe diameter, in.
w = mass rate, 1000 lb/h
ρ = density of flowing, lb/ft^3

a. 5.3 in. b. 3.3 in. c. 4.3 in. d. 3.7 in.

98. A pressure vessel is to be made from a cylinder of diameter x meters capped with a hemisphere. The cost of the cylinder section in pesos per meter of length is 1,800 $x^{0.5}$ and also the cost in pesos of one hemispherical end is 1,400 $x^{2.4}$. The vessel is to hold 40 cubic meters. Find the optimum dimension.
a. 2.5 m b. 2.25 m c. 2.0 m d. 2.75 m

99. A condensate pump at sea level draws water from a condenser. The total friction losses at the suction side of ft. The minimum height of water level in the condenser above the pump center lime that must be maintained if the required NPSH is 12 ft for the maximum capacity of the pump is
a. 8 ft b. 16 ft c. 20 ft d. 2 ft

100. Water flows through a 5-inch pipe at a rate of 180 gpm. If the same conditions of head prevail, approximately what pipe size will be required if the flow is changed to 100 gpm?
a. 4 in. b. 3 in. c. 2 in. d. 3 ½ in.

GENERAL ENGINEERING

1. The maximum number of arbitrary constants is exactly equal to the
   a. order of the differential equation
   b. number of derivatives in the differential equation
   c. degree of the differential equation
   d. none of these

2. The general solution of $\frac{dy}{dx} - \frac{2y}{x} = 0$
   a. $y = cx^2$
   b. $cy^2 = x$
   c. $x = cy^2$
   d. $y = \ln cx^2$

3. The differential equation $dx = (y^2 - 3xy)\, dy$ is said to be
   a. homogenous differential equation
   b. linear in y
   c. linear in x
   d. non-linear in x

4. Which of the following is an exact differential equation ?
   a. $xydx + (x^2 - 1)\, dy = 0$
   b. $(2xy - \cos x)\, dx + (x^2 - 1)\, dy = 0$
   c. $xydx + (x^2 - y^2)\, dy = 0$
   d. $(x^5 + 3y)\, dx = xdy = 0$

5. The general solution of $\frac{d^2y}{dx^2} + 4y = 0$ is
   a. $y = A \cos 2x + B \sin 2x$
   b. $y = C_1 e^{2x} + C_2 e^{-2x}$
   c. $y = C_1 \cos 4x + C_2 \sin 4x$
   d. $x = A \cos 2t + B \sin 2t$

6. The differential equation $y'' + 2y' + y = 3e^{2x}$ is called
   a. homogenous first-order d.e
   b. non-homogenous 2nd-order non-linear d.e
   c. homogenous second-order linear d.e
   d. non-homogenous 2nd-order linear d.e

7. The roots of the auxiliary equation (or characteristic equation) of $y'' + 2y' + y = 3e^{2x}$ are
   a. −1 and −1
   b. +1 and +1
   c. 1 and 2
   d. −1 and −2

8. The Laplace transform of $2e^{2t}$ is
   a. $\frac{1}{s-2}$
   b. $\frac{2}{s}$
   c. $\frac{2}{s+2}$
   d. $\frac{2}{s-2}$

9. A thermometer reading 18°F is brought into a room the temperature of which is 70°F. After 1 minute the reading is 31°F. The temperature reading after 5 minutes is
   a. 58°C
   b. 58°F
   c. 52°F
   d. 52°C

10. Which of the following statements is correct ?
    a. Over a project's life, a typical business will generate a greater amount of total project cash flows (undiscounted) if a faster depreciation method is adopted.
    b. No matter which depreciation method you adopt, total tax obligations over a project's life remain unchanged.
    c. Depreciation recapture equals cost basis minus an asset's book value at the time of disposal, that is, if the salvage value is less than the asset's cost basis.
    d. Cash flows normally include depreciation expenses since they represent a cost of doing business.

11. A machine purchased for ₱45,000 had a depreciable life of 4 years. It will have an expected salvage value of ₱5000 at the end of the depreciable life. Using the straight line method, what is the book value at the end of year 2?
    a. ₱27,500 c. ₱20,000
    b. ₱35,000 d. ₱25,000

12. A series of equal quarterly receipts of ₱1000 extends over a period of 5 years. What is the present worth of his quarterly payment series at 8% interest, compounded continuously ?
    a. ₱16,351 c. ₱16,320
    b. ₱15,971 d. ₱18,345

13. To raise money for your business, you need to borrow ₱20,000 from a local bank. If the bank asks you repay the loan in 5 equal annual installments of ₱5548.19, determine the bank's annual interest rate on this loan transaction.
    a. 11% c. 11.5%
    b. 12% d. 27.74%

14. Two machines are being considered for the production of a part. The material cost and selling per part are ₱6 and ₱12, respectively. Assuming that all parts that are not rejected can be sold, which machine should be selected based on expected daily profit ? The investment cost is the same for both machines and can be ignored.

	Machine A	**Machine B**
Production rate	100 parts/hour	130 parts/hour
Hours available for production	7 hours/day	6 hours/day
Operator cost	₱ 20/hour	₱ 20/hour
Parts rejected (negligible value)	3%	10%

    a. Machine A c. either
    b. Machine B d. neither

15. Which of the following account changes would be classified as a use of funds?
    a. an increase in accounts payable c. an increase in retained earnings
    b. a decrease in cash d. a decrease in mortgage bonds

16. A city government is considering increasing the capacity of the current waste water treatment plant. The estimated financial data for the project is as follows:

Description	**Data**
Capital investment	₱ 1,200,000.00
Incremental annual benefits	₱ 250,000.00
Incremental annual costs	₱ 100,000.00
Salvage value	₱ 50,000.00
Discount rate	6%
Project life	25 years

What would be the net benefit cost ratio for this expansion project ?

a. 3.26   c. 1.61
b. 3.12   d. 2.23

17. What is the height of the parabolic arch which has a span of 48 feet and having a height of 20.0 feet at a distance 16.0 feet from the center of the span?

a. 30 ft   c. 36 ft
b. 40 ft   d. 34 ft

18. An airplane went 360 miles in two hours with the wind, and flying back the same route, it took 3-3/5 hours against the wind. Determine the velocity of the wind.

a. 160 mph   c. 100 mph
b. 30 mph   d. 40 mph

19. Two thousand kg of steel containing 8% nickel is to be made by mixing steel containing 14% nickel with another containing 6% nickel. How much of each is needed?

a. 500 kgs of 14%; 1500 kgs of 6%   c. 50 kgs of 14%; 1250 kgs of 6%
b. 1500 kgs of 14%; 500 kgs of 6%   d. 1250 kgs of 14%; 750 kgs of 6%

20. A rubber ball is made to fall from a height of 50.0 ft. and is observed to rebound 2/3 of the distance it falls. How far will the ball travel before coming to rest if the ball continues to fall in this manner?

a. 250 ft   c. 200 ft
b. 275 ft   d. 225 ft

21. In how many ways can a committee of 3 consisting of 2 chemical engineers and 1 mechanical engineer be formed from 4 chemical engineers and 3 mechanical engineers?

a. 32   c. 18
b. 64   d. none of these

22. A chemist of a distillery experimented on two alcohol solutions of different strengths: 35% alcohol and 50% alcohol, respectively. How many m^3 of each strength must he use in order to produce a mixture of 60.0 m^3 that contain 40% alcohol?

a. 20 m^3 35% alcohol ; 50 m^3 50% alcohol
b. 50 m^3 35% alcohol ; 20 m^3 50% alcohol
c. 40 m^3 35% alcohol ; 20 m^3 50% alcohol
d. 20 m^3 35% alcohol ; 40 m^3 50% alcohol

23. If a two digit number has x for its unit's digit and y for its ten's digit, represent the number.
    a. $10y + x$
    b. xy
    c. $10x + y$
    d. yx

24. The volume of a hemisphere varies directly as the cube of its radius. The volume of the hemisphere with 2.54 cm radius is 20.75 cm^3. What is the volume of a sphere with 3.25 cm radius of the same kind of material?
    a. 76.95 cm^3
    b. 57.64 cm^3
    c. 86.92 cm^3
    d. 43.46 cm^3

25. A 400-mm diameter pipe can fill the tank alone in 5.0 hours and another 600-mm pipe can fill the tank alone in 4.0 hours. A drain pipe 300-mm diameter can empty the tank in 20.0 hours. With all three pipes open, how long will it take to fill the tank?
    a. 2.0 hours
    b. 2.75 hours
    c. 2.25 hours
    d. 2.50 hours

26. The intensity of sound varies directly as the strength of the source and inversely as the square of the distance from the source. Write the equation which describes this relation.
    a. $I = KSd^2$
    b. $I = Kd^2/S$
    c. $I = d^2S/K$
    d. $I = KS/d^2$

27. Determine the probability of throwing a total sum of 4 in a single throw with two dice.
    a. 1/12
    b. 1/18
    c. 1/9
    d. 5/36

28. Two planes leave Manila for a southern city, a distance of 900 kms. Plane A travels at a ground speed of 90 kph faster than plane B. Plane A arrives in their destination 2.0 hours and 15 minutes ahead of plane B. What is the ground speed of plane A?
    a. 205 kph
    b. 287 kph
    c. 315 kph
    d. 240 kph

29. Water is pouring into a conical vessel 15 cm deep and having a radius of 3.75 cm across the top. If the rate at which the water rises is 2 cm/sec, how fast is the water flowing into the conical vessel when the water is 4 cm deep ?
    a. 4.57 m^3/sec
    b. 6.28 m^3/sec
    c. 2.37 m^3/sec
    d. 5.73 m^3/sec

30. The axis of the hyperbola, which is parallel to its directrices, is known as
    a. major axis
    b. conjugate axis
    c. minor axis
    d. transverse axis

31. Find the area in the first quadrant bounded by the parabola $y^2 = 4x$, $x = 1$ and $x = 3$.
    a. 5.595
    b. 5.5955
    c. 9.555
    d. 9.955

32. The surface area of a sphere (initially zero) increases uniformly at the rate of 26 cm^2/sec. Find the rate at which the radius is increasing after 2 seconds.
    a. 0.509 cm/sec
    b. 0.59 cm/sec
    c. 0.62 cm/sec
    d. 0.52 cm/sec

33. The cost C of a product is a function of the quantity x of the product: $C(x) = x^2 - 4000x + 50$. Find the quantity for which the cost is minimum.
    a. 3000
    b. 1000
    c. 2000
    d. 1500

34. A rectangular tank with open top has a volume of 10 m^3. The material for the square base costs ₱150.00/m^2 and ₱60.00/m^2 for the wall. Determine the most economical height.
    a. 3 m
    b. 2.5 m
    c. 3.5 m
    d. 2 m

35. Find the coordinates of the centroid of the plane area bounded by the parabola, $y = 4 - x^2$ and the x-axis
    a. (1,0)
    b. (0,1)
    c. (0,1.6)
    d. (0,2)

36. The area in the second quadrant of the circle $x^2 + y^2 = 36$ is revolved about the line $y + 10 = 0$. What is the volume generated?
    a. 2208.53
    b. 2218.33
    c. 2228.83
    d. 2233.43

37. A garden hose with a cross-sectional area of 2.0 cm^2 has a flow of 200 cm^3/sec. What is the average velocity of the water?
    a. 1.5 m/s
    b. 2.5 m/s
    c. 2.0 m/s
    d. 1.0 m/s

38. A 100-ohm resistor, a 0.0001 F capacitor, and a 0.10-H inductor are connected in series to a 120-volt rms generator. If the generator frequency is 60 Hz, find the impedance and the effective current.
    a. 101 ohm; 1.19 A
    b. 105 ohm; 1.50 A
    c. 111 ohm; 1.80 A
    d. 116 ohm; 2.15 A

39. The rms speed of the molecules in an ideal gas with molecular mass of 32.0 u is 400 m/sec. What is the average translational kinetic energy and temperature of the gas?
    a. 5.00 x 10 exp-21 J; 220 K
    b. 5.25 x 10 exp-21 J; 225 K
    c. 4.25 x 10 exp-21 J; 205 K
    d. 4.5 x 10 exp-21 J; 210 K

40. Mixtures of oxygen and helium can be tolerated by divers. What proportion should be oxygen if the diver works 50.0 meters below the surface and the partial pressure of oxygen should be 0.30 atm? (The pressure changes by 1 atm. for each 10.30 meter of depth change in water).
    a. 5.12%
    b. 4.88%
    c. 6.00%
    d. 5.86%

41. Find the total water pressure on a vertical circular gate, 2.0 meters in diameter, with its top 3.5 meters below the water surface.
    a. 169.5 kN
    c. 138.7 kN
    b. 107.9 kN
    d. 186.5 kN

42. A log of mass 40-kg is dropped into a river at 0°C. If the relative density of the log is 0.80, what will be the volume of the log above the surface?
    a. 0.02 m^3
    c. 0.08 m^3
    b. 0.040 m^3
    d. 0.01 m^3

43. If the nominal interest rate is 3%, how much is ₱5,000.00 worth in 10 years in a continuously compounded account?
    a. ₱7,500.00
    c. ₱6,350.00
    b. ₱6,750.00
    d. ₱5,750.00

44. How long (in years) will it take money to quadruple if it earns 7% compounded semi-annually?
    a. 20.15
    c. 40.30
    b. 33.15
    d. 26.30

45. A housewife bought a brand new washing machine costing ₱12,000.00 if paid in cash. However, she can purchase it on installment basis to be paid within 5 years. If money is worth 8% compounded annually, what is her yearly amortization if all payments are to be made at the beginning of each year?
    a. ₱2,782.85
    c. ₱2,872.58
    b. ₱2,400.00
    d. ₱2,827.58

46. The ratio of the interest payment to the principal for a given unit of time and is usually expressed as a percentage of the principal is known as
    a. nominal interest
    c. investment
    b. interest
    d. interest rate

47. The interest rate at which the present worth of cash flow on a project is zero, or the interest earned by an investment.
    a. effective rate
    c. nominal rate
    b. yield
    d. rate of return

48. A method of depreciation whereby the amount to recover is spread over the estimated life of the asset in terms of the periods or units of output.
    a. SYD method
    c. Sinking fund method
    b. Declining balance method
    d. Straight line method

49. The purchase of a motor for ₱6,000 and a generator for ₱4,000 will allow a small company to generate its own power. The configuration can be assembled for ₱500. The service will operate for 1,600 hours per year for 10 years. The maintenance cost is ₱300 per year and the cost to operate is ₱0.85 per hour for fuel and other related cost.

Using straight-line depreciation, what is the annual cost for the operation? There is a salvage value for the system at ₱400 at the end of 10 years.

a. ₱2,760.00 c. ₱2,670.00
b. ₱2,567.00 d. ₱2,657.00

50. The cost of a product is a function of the quantity x of the product given by the relation: $C(x) = x^2 - 4000x + 50$. Find the quantity for which the cost is a minimum.

a. 1000 c. 1500
b. 2000 d. 3000

51. A manufacturing firm maintains one product assembly line to produce signal generators. Weekly demand for the generators is 35 units. The line operates for 7 hours per day, 5 days per week. What is the maximum production time per unit in hours required for the line to meet the demand?

a. 1.0 hour c. 0.75 hour
b. 3.0 hours d. 2.25 hours

52. The recorded current value of an asset is known as

a. salvage value c. present worth
b. book value d. scrap value

53. This occurs in a situation where a commodity or service is supplied by a number of vendors and there is nothing to prevent additional vendors entering the market.

a. oligopoly c. elastic demand
b. monopoly d. perfect competition

54. A machine is under consideration for investment. The cost of the machine is ₱25,000.00. Each year it operates, the machine will generate a savings of ₱15,000.00. Given an effective annual interest of 18%, what is the discounted payback period, in years, on the investment for the machine?

a. 1.566 c. 2.233
b. 2.677 d. 2.155

55. The lessening of the value of an asset due to the decrease in the quantity available.

a. depletion c. incremental cost
b. depreciation d. inflation

56. A man bought an equipment which costs ₱524,000.00. Freight and installation expenses cost him ₱31,000.00. If the life of the equipment is 15 years with an estimated salvage value of ₱120,000.00, find its book value after 8 years.

a. ₱296,000.00 c. ₱259,000.00
b. ₱323,000.00 d. ₱244,000.00

57. What horizontal force P can be applied to a 100-kg block in a level surface with coefficient of friction of 0.20 that will cause an acceleration of 2.50 m/sq.sec?

a. 446.2 N c. 53.8 N
b. 224.5 N d. 343.5 N

58. A 10-kg weight is suspended by a rope from a ceiling. If a horizontal force of 5.80 kgs is applied to the weight, the rope will make an angle with the vertical equal to

a. 30°	c. 75°
b. 45°	d. 60°

59. A man can exert a maximum pull of 1000 N but wishes to lift a new stone door for his cave weighing 20,000 N. If he uses a lever, how much closer must the fulcrum be to the stone than to his hand?

a. 10 times nearer	c. 20 times nearer
b. 20 times farther	d. 10 times farther

60. An automobile has a power output of 1.0 hP. When it pulls a cart with a force of 300 N, what is the cart's velocity?

a. 0.249 m/s	c. 24.9 m/s
b. 249 m/s	d. 2.49 m/s

61. A cable weighing 60 N/m is suspended between two supports on the same level at 300 meters apart. The sag is 60.0 meters. Compute the distance of the lowest point of the cable from the ground level.

a. 188.2 m	c. 205.5 m
b. 196.8 m	d. 200.5 m

62. What is the stress in a thin-walled spherical shell of diameter D and a wall thickness t when subjected to internal pressure P?

a. $S = D/Pt$	c. $S = 4D/Pt$
b. $S = PD/t$	d. $S = PD/4t$

63. What is the modulus of elasticity if the stress is 44,000 psi and unit strain of 0.00105?

a. 41,202,000	c. 41,905,000
b. 43,101,000	d. 42,300,000

64. A simply supported beam, 10 meters long carries a uniformly distributed load of 20 kN/m. What is the value of the maximum shear of the beam due to this load?

a. 500 kN	c. 1,000 kN
b. 250 kN	d. 100 kN

65. A water reservoir of 24 meters high and 12 meters in diameter is to be filled with water. Find the minimum thickness of the reservoir plating if the stress is limited to 50 MPa.

a. 26.0 mm	c. 21.0 mm
b. 28.0 mm	d. 24.5 mm

66. A simply supported beam, 10 meters long carries a uniformly distributed load of 20 kN/m. What is the value of the maximum moment of the beam due to this load?

a. 2,000 kN-m	c. 10,000 kN-m
b. 250 kN-m	d. 5,000 kN-m

67. In polar coordinate system, the distance from a point to the pole is known as
    a. y-coordinate   c. x-coordinate
    b. polar angle   d. radius vector

68. The volume of any solid of revolution is equal to the generating area times the circumference of the circle described by the centroid of the area. This is commonly known as
    a. First Proposition of Pappus   c. Simpson's Rule
    b. Second Proposition of Pappus   d. Cavalier's Principle

69. The point through which the resultant of the distributed gravity force passes regardless of the orientation of the body in space is known as
    a. center of attraction   c. center of gravity
    b. moment of inertia   d. center of inertia

70. It is the surface generated by moving a straight line (called the generator) which is always parallel to a fixed line and which always intersects a fixed plane curve.
    a. cylindrical surface   c. locus of a point
    b. paraboloid   d. spherical surface

71. The specific gravity of the substance is the ratio of the density of the substance to the density of water. Another term for specific gravity is
    a. specific weight   c. relative density
    b. unit weight   d. density

72. A sequence of numbers where every term is obtained by adding all the preceeding terms such as 1,5,14,30,.... is called
    a. Triangular number   c. Pyramidal number
    b. Euler's number   d. Tetrahedral number

73. An equation in which a variable appears under the radical sign is called
    a. literal equation   c. irrational equation
    b. radical equation   d. irradical equation

74. A complex number associated with a phase-shifted sine wave in polar form whose magnitude is in RMS and angle is equal to the angle of the phase-shifted sine wave is known as
    a. Argand's number   c. Imaginary number
    b. Phasor number   d. Real number

75. The rectangular coordinate system in space is divided into 8 compartments which are known as
    a. axis   c. octants
    b. coordinates   d. quadrants

76. The locus of a point that move so that its distance from a fixed point and a fixed line is always equal, is known as
    a. a parabola
    b. a hyperbola
    c. a circle
    d. an ellipse

77. To cut a right circular cone in order to reveal a parabola, it must be cut
    a. perpendicular to the axis of symmetry
    b. at any acute angle to the axis of symmetry
    c. parallel to an element of a cone and intersecting the axis of symmetry
    d. parallel to the axis of symmetry

78. A series of numbers which are perfect square numbers (i.e. 1,4,9,16,....) is called
    a. Euler's number
    b. Fourier's series
    c. Fermat's number
    d. Fibonacci number

79. An integer is said to be prime if
    a. it has no other integer as a factor except itself or 1
    b. it is an even integer
    c. it is an odd integer
    d. it is factorable by any value

80. If the roots of an equation are zero, then they are classified as
    a. conditional solutions
    b. extraneous roots
    c. hypergolic solutions
    d. trivial solutions

CONVERSION FACTORS

Length

1 in. = 2.540 cm = 25.4 mm
100 cm = 1 m (meter) = 1000 mm = 10^9 nm (nanometer)
1 micron = 10^{-6}m = 10^{-4}cm = 10^{-3}mm = 1 μm (micrometer)
1 Å (angstrom) = 10^{-10}m = 10^{-4} μm (micrometer)
1 mile = 5280 ft = 1.609 km
1 m = 3.2808 ft = 39.37 in.

Mass

1 lb_m = 453.59 g = 0.45359 kg
1 lb_m = 16 oz = 7000 grains
1 kg = 1000 g = 2.2046 lb_m
1 ton (British) = 1016 kg
1 ton (U.S.) = 907.2 kg
1 ton (short) = 2000 lb_m
1 ton (long) = 2240 lb_m
1 ton (metric) = 1000 kg
1 stone = 6.35 kg

Area

1 sq. meter = 10.764 sq. ft.
1 sq. cm. = 0.1550 sq. inch
1 sq. ft. = 144 sq. in. = 929 sq. cm.
1 hectare = 10,000 sq. m. = 107,639 sq. ft.
1 sq. mile = 2.58999 sq. km.
1 sq. yard = 9 sq. ft. = 8361.274 sq. cm.

Volume

1 liter = 1000 cm^3
1 $in.^3$ = 16.387 cm^3
1 ft^3 = 28.317 liters
1 ft^3 = 0.028317 m^3
1 ft^3 = 7.481 U.S. gal
1 m^3 = 264.17 U.S. gal
1 m^3 = 1000 liters

1 U.S. gal = 4 qt
1 U.S. gal = 3.7854 liters
1 U.S. gal = 3785.4 cm^3
1 British gal = 1.20094 U.S. gal
1 barrel = 115.627 liters
1 bushel = 35.24 liters
1 ounce (oz) = 29.5735 cm^3

Density and Standard Volume

1 g-mole ideal gas at 0°C, 760 mm Hg = 22.4140 liters = 22,414 cm^3
1 lb-mole ideal gas at 0°C, 760 mm Hg = 359.05 ft^3
1 kg-mole ideal gas at 0°C, 760 mm Hg = 22.414 m^3
Density of dry air at 0°C, 760 mm Hg = 1.2929 g/liter = 0.080711 lb_m/ft^3

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1 sq. meter = 10.764 sq. ft.
1 sq. cm. = 0.1550 sq. inch
1 sq. ft. = 144 sq. in. = 929 sq. cm.
1 hectare = 10,000 sq. m. = 107,639 sq. ft.
1 sq. mile = 2.58999 sq. km.
1 sq. yard = 9 sq. ft. = 8361.274 sq. cm.

Volume

1 liter = 1000 cm^3
1 $in.^3$ = 16.387 cm^3
1 ft^3 = 28.317 liters
1 ft^3 = 0.028317 m^3
1 ft^3 = 7.481 U.S. gal
1 m^3 = 264.17 U.S. gal
1 m^3 = 1000 liters

1 U.S. gal = 4 qt
1 U.S. gal = 3.7854 liters
1 U.S. gal = 3785.4 cm^3
1 British gal = 1.20094 U.S. gal
1 barrel = 115.627 liters
1 bushel = 35.24 liters
1 ounce (oz) = 29.5735 cm^3

Density and Standard Volume

1 g-mole ideal gas at 0°C, 760 mm Hg = 22.4140 liters = 22,414 cm^3
1 lb-mole ideal gas at 0°C, 760 mm Hg = 359.05 ft^3
1 kg-mole ideal gas at 0°C, 760 mm Hg = 22.414 m^3
Density of dry air at 0°C, 760 mm Hg = 1.2929 g/liter = 0.080711 lb_m/ft^3

Molecular weight of air = 28.97 lb_m/lb-mole
1 g/cm^3 = 62.43 lb_m/ft^3 = 1000 kg/m^3
1 g/cm^3 = 8.345 lb_m/U.S. gal
1 lb_m/ft^3 = 16.0185 kg/m^3

Force

1 g cm/s^2 (dyn) = 10^{-5} kg m/s^2 N (newton)
1 g cm/s^2 = 7.2330 x 10^{-5} lb_m ft/s^2 (poundal)
1 kg m/s^2 = 1 N (newton)
1 lb_f = 4.4482 N
1 kg_f = 9.80665 N
1 g cm/s^2 = 2.2481 x 10^{-6} lb_f
1 dyne = 1 x 10^{-5} N

Pressure

1 bar = 1 x 10^5 Pa (pascal) = 1 x 10^5 N/m^2
1 psia = 1 $lb_f/in.^2$
1 psia = 2.0360 in. Hg at 0°C
1 psia = 2.311 ft H_2O at 70°F
1 psia = 51.715 mm Hg at 0°C (ρ_{Hg} = 13.5955 g/cm^3)
1 atm = 14.696 psia = 1.01325 x 10^5 N/m^2 = 1.01325 bars
1 atm = 760 mm Hg at 0°C = 1.01325 x 10^5 Pa
1 atm = 29.921 in. Hg at 0°C
1 atm = 33.90 ft H_2O at 4°C
1 psia = 6.89476 x 10^4 g/cm s^2
1 psia = 6.89476 x 10^4 dyn/cm^2
1 dyn/cm^2 = 2.0886 x 10^{-3} lb_f/ft^2
1 psia = 6.89476 x 10^3 N/m^2
1 lb_f/ft^2 = 4.7880 x 10^2 dyn/cm^2 = 47.880 N/m^2
1 mm Hg (0°C) = 1.333224 x 10^2 N/m^2 = 0.1333224 kPa

Power

1 hp = 0.74570 kW
1 hp = 550 ft lbf/s
1 hp = 0.70741 Btu/s
1 watt (W) = 14.34 cal/min
1 Btu/hr = 0.29307 W (watt)
1 J/s (joule/s) = 1 W
1 kW = 1.34 hp

Heat, Energy, Work

1 J = 1 N m = 1 kg m^2/s^2 = 10^7 erg
1 kg m^2/s^2 J (joule) = 10^7 g cm^2/s^2 (erg)
1 Btu = 1,055.06 J = 1.05506 kJ
1 Btu = 252.16 cal (thermochemical)
1 kcal (thermochemical) = 1000 cal = 4.1840 kJ
1 cal (thermochemical) = 4.1840 J
1 cal (IT) = 4.1868 J
1 Btu = 778.17 ft lb_f
1 hp hr = 0.7457 kW hr

1 hp hr = 2544.5 Btu
1 ft lb_f = 1.35582 J
1 ft lb_f/lb_m = 2.9890 J/kg

Thermal Conductivity

1 Btu/hr ft °F = 4.1365 x 10^{-3} cal/s cm °C
1 Btu/hr ft °F = 1.73073 W/m K

Heat-Transfer Coefficient

1 Btu/hr ft^2 °F = 1.3571 x 10^{-4} cal/s cm^2 °C
1 Btu/hr ft^2 °F = 5.6783 x 10^{-4} W/cm^2 °C
1 Btu/hr ft^2 °F = 5.6783 W/m^2 K
1 kcal/hr m^2 °F = 0.2048 Btu/hr ft^2 °F

Viscosity

1 cp = 10^{-2} g/cm s (poise)
1 cp = 2.4191 lb_m/ft s
1 cp = 6.7197 x 10^{-4} lb_m/ft s
1 cp = 10^{-3} Pa s = 10^{-3} kg/m s = 10^{-3} N s/m^2
1 cp = 2.0886 x 10^{-5} lb_f s/ft^2
1 Pa s = 1 N s/m^2 = 1 kg/m s = 1000 cp

Diffusivity

1 cm^2/s = 3.875 ft^2/hr
1 cm^2/s = 10^{-4} m^2/s
1 m^2/s = 3.875 x 10^4 ft^2/hr
1 centistoke = 10^{-2} cm^2/s

Mass Flux and Molar Flux

1 g/s cm^2 = 7.3734 x 10^3 lb_m/ft^2
1 g-mole/s cm^2 = 7.3734 x 10^3 lb-mole/hr ft^2
1 g-mole/s cm^2 = 10 kg-mole/s m^2 = 1 x 10^4 g-mole/s m^2
1 lb-mole/ft^2 = 1.3562 x 10^{-3} kg-mole/s m^2

Heat Flux and Heat Flow

1 Btu/hr ft^2 = 3.1546 W/m^2
1 Btu/hr = 0.29281 W = 12.958 lb-ft/min = 7 x 10^{-2} cal/s

Heat Capacity and Enthalpy

1 Btu/lb_m °F = 4.1868 kJ/kg K
1 Btu/lb_m °F = 1.000 cal/g °C
1 Btu/lb_m = 2326.0 J/kg
1 ft lb_f/lb_m = 2.9890 J/kg
1 cal (IT)/g °C = 4.1868 kJ/kg K

Mass-Transfer Coefficient

1 k_c cm/s = 10^{-2} m/s
1 k_c ft/hr = 8.4668 x 10^{-5} m/s
1 k_x g-mole/s cm^2 mol frac = 10-kg mole/s m^2 mole frac
1 k_x g-mole/s m^2 mole frac = 1 x 10^4 g-mole/s m^2 mole frac
1 k_x lb-mole/hr ft^2 mole frac = 1.3562 x 10^{-3} kg-mole/s m^2 mole frac
1 k_xa lb-mole/hr ft^3 mole frac = 4.449 x 10^{-3} kg-mole/s m^3 mole frac
1 k_G kg-mole/s m^2 atm = 0.98692 x 10^{-5} kg-mole/s m^2 Pa
1 k_Ga kg-mole/s m^{3}atm = 0.98692 x 10^{-5} kg-mole/s m^3 Pa

Standard Acceleration of Gravity

$g = 9.80665$ m/s^2 = 980.665 cm/s^2 = 32.174 ft/s^2
g_c (gravitational constant) = 32.1740 lb$_m$ ft/lb$_f$ s^2 = 980.665 g$_m$ cm/g$_f$ s^2

Universal Gas Constant R

1.9872	cal/g-mole K
1.9872	Btu/lb-mole K
82.057	cm^3 atm/g-mole K
8314.34	J/kg-mole K
82.057 x 10^{-3}	m^3 atm/kg-mole K
8314.34	kg m^2/s^2 kg-mole K
10.731	ft^3 lb$_f$/in.^{2} lb-mole °R
0.7302	ft^3 atm/lb-mole °R
1545.3	ft lb$_f$/lb-mole °R
8314.34	m^3 Pa/kg-mole K

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