Chemical Engineering

Simple ‘n Easy

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Chapter 1:
Introduction to Chemical Engineering

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- What is Chemical Engineering?
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- Chemical Engineering Accomplishments.
- Chief Concepts of Chemical Engineering.

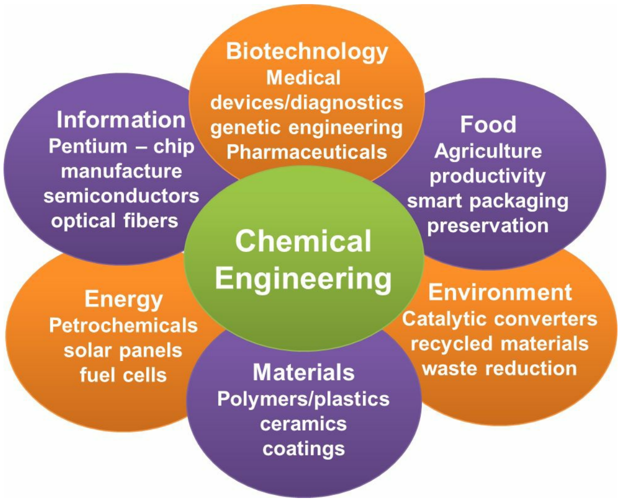
What is Chemical Engineering?

□ Chemical engineering basically is applied chemistry.

□ It is concerned with the design, construction and operation of machines and plants that perform chemical reactions to solve practical problems or make useful products.

□ Chemical Engineering is the process of converting raw materials or chemicals into more useful or valuable forms.

□ Chemical Engineering deals with biotechnology, biomedical engineering, nanotechnology and fuel cells.



□ Chemical Engineering is derived from the following branches of Science:

- Chemical
- Chemistry
- Engineering
- Physics

Concepts of Chemical Engineering

- There are following types of Chemical Engineering Concepts:
  - Unit operation.
  - Unit process.
  - Chemical process.
  - Process integration.

Unit Operations

- Unit operation is the basic step in a chemical engineering process.
- A unit operation is a method of analysis and design of chemical engineering processes in terms of individual tasks/operations.
- It is a way of organizing chemical engineering knowledge into groups of individual tasks/operations.

Unit Process

- Unit Process is a step in manufacturing in which chemical reaction takes place.
- Unit process is a process where chemical change occurs that is nitration, halogenation, sulphonation etc.

Chemical Process

- A chemical process is a method or means of somehow changing one or more chemicals or chemical compounds.
- A chemical process is a method intended to be used to change the composition of chemicals on an industrial scale, usually using technology similar or related to that used in chemical plants or the chemical industry.

Process Integration

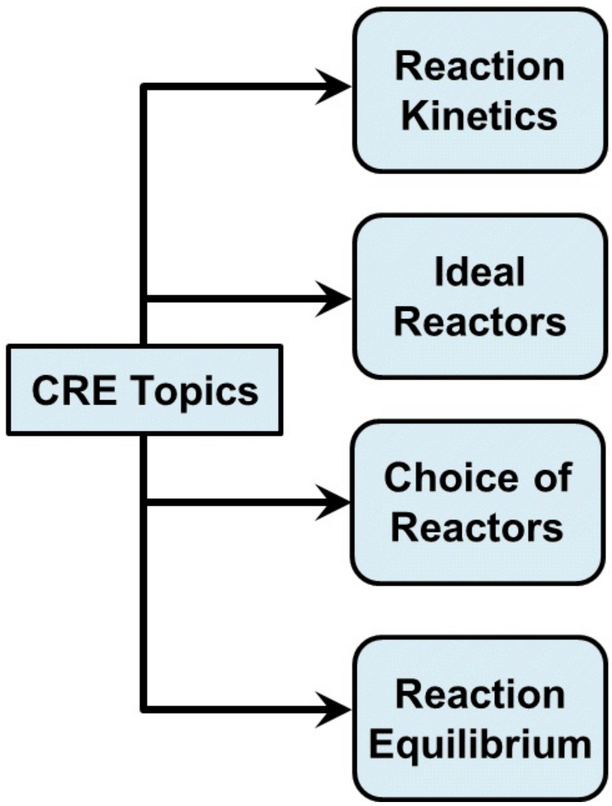
 Process Integration is a term which means a holistic approach to process design which considers the interactions between different unit operations from the outset, rather than optimizing them separately.

Chemical Engineering Accomplishments

- Production of Synthetic Ammonia and Fertilizers.
- Production of petrochemicals.
- Commercial scale production of antibiotics (biotechnology/ pharmaceuticals).
- Establishment of the plastics, synthetic fiber and rubber industry.
- Electrolytic production of Aluminum.
- Energy production and the development of new sources of energy.
- Production of fissionable isotopes.
- Production of IT products (storage devices, microelectronics, ultraclean environment etc.)
- Artificial organs and biomedical devices.
- Food processing and process simulation tools.

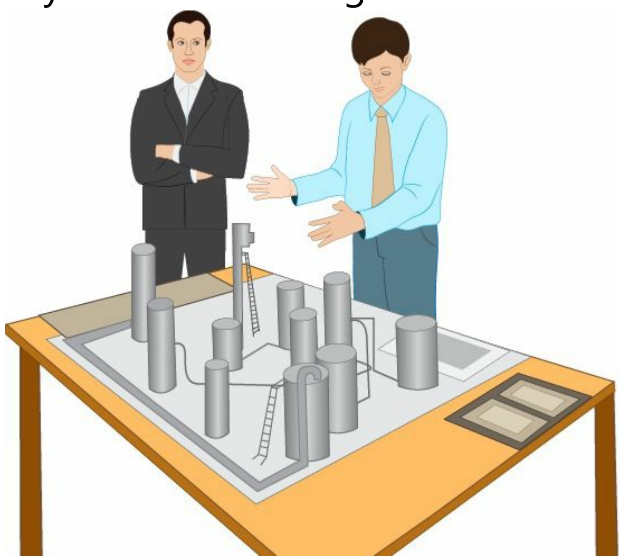
Chief Concepts of Chemical Engineering

- The chief concepts of Chemical Engineering are as follows:
- **Chemical Reaction Engineering (CRE):**
  - Plant processing and ensuring the optimal plant operation are included in the section of chemical reaction engineering.
  - In this concept, models for reactor analysis are designed and constructed by the chemical reaction engineers.
  - They use data from labs and physical parameters in order to solve problems and calculate the reactor performance.



- **Reaction Kinetics:**
  - Chemical kinetics, also known as reaction kinetics, is the study of rates of chemical processes.
- **Ideal Reactors:**
  - A reactor is an apparatus or a structure in which chemical, biological and physical processes proceed intentionally, purposefully and in a controlled manner.
- **Choice of Reactor:**
  - There are several important factors that determine the choice of reactor for a particular process.
  - In general, the choice depends on the cost of a predetermined productivity within the product's specifications.
  - This must be inclusive of the costs associated with substrate(s), downstream processing, labor, depreciation, overheads and process development.

- **Reaction Equilibrium:**
  - In a chemical reaction, chemical equilibrium is the state in which both reactants and products are present at concentrations which have no further tendency to change with time.
- **Plant Design:**
  - In the concept of chemical engineering plant design there is the creation of plans and stipulation along with the income production of plants.
  - Designs have been made by the chemical engineers according to the need of the clients.



  - However, there are some factors that determine the exact formation of that design; they are safety standard, financial support and of course the rules and regulations of the government of the state or the country where the plant is going to be introduced.
- **Process Design:**
  - Process design or unit operation acts as a physical step in the process of an individual chemical engineering.
  - These kinds of operations are normally used to build reactants, make the products purified and separated as well.
  - Crystallization, drying and evaporation is included in these processes.
  - The engineers who deal with these processes are known as process engineers.

Chapter 2: Basics of Chemistry

Topics covered in this snack-sized chapter:

- Chemistry.
- Various Disciplines of Chemistry.
- Basic Concepts of Chemistry.
- Chemical Equilibrium.
- Bonding.
- ons.
- Branches of Chemistry.
- Importance of Chemistry.

Chemistry

- It is the branch of science that deals with the identification of the substances of which matter is composed.
  - It also deals with the investigation of their properties and the ways in which they interact, combine and change.
  - It also deals with the use of the processes to form new substances.

Various Disciplines of Chemistry

- Disciplines within chemistry are traditionally grouped by the type of matter being studied or the kind of study.
- These include the following:
- **Inorganic chemistry**
  - The study of inorganic matter.
- **Organic chemistry**
  - The study of organic (carbon-based) matter.
- **Biochemistry**
  - The study of substances found in biological organisms.
- **Physical chemistry**
  - The study of chemical processes using physical concepts, such as thermodynamics and quantum mechanics.
- **Analytical chemistry**
  - The analysis of material samples to gain an understanding of their chemical composition and structure.
- **Neurochemistry**
  - The chemical study of the nervous system.

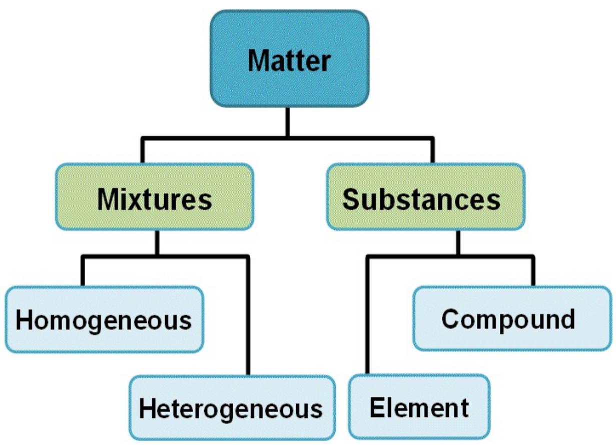
Basic Concepts of Chemistry

- Several concepts are essential for the study of chemistry.
- Some of them are as follows:
  - Matter and its classification
  - Mixtures
  - Atoms
  - Elements
  - Compounds
  - Substances
  - Molecules

Matter

- Matter includes atoms and other particles which have mass.
- Matter is anything that occupies space and has mass.

Classification of Matter



States of Matter

- There are five main states of matter:
  - Solids,
  - Liquids,
  - Gases,
  - Plasmas, and
  - Bose-Einstein condensates.
- **Solids:** Have a rigid shape and fixed volume.
- **Liquids:** Have no fixed shape and may not fill a container completely.
- **Gases:** Expand to fill the container.
- **Plasma:** The fourth state of matter.
  - Plasma is an ionized gas, a gas into which sufficient energy is provided to free electrons from atoms or molecules and to allow species, ions and electrons to coexist.

- **Bose-Einstein Condensates:**
  - Recently, scientists have discovered the Bose-Einstein condensate, which can be thought of as the opposite of plasma.
  - It occurs at ultra-low temperature, close to the point that the atoms are not moving at all.
  - A Bose-Einstein condensate is a gaseous superfluid phase formed by atoms cooled to temperatures very near to absolute zero.

Matter Properties

Extensive Property	Depends upon how much matter is being considered. Examples: Mass Length Volume
Intensive Property	Does not depend upon how much matter is being considered. Examples: Density Temperature

Mixtures

- A mixture is a combination of two or more substances in which the substances retain their distinct identities.
- **Homogeneous mixture** – Composition of substances is the same throughout.
- Example:
  - Sugar in water
- **Heterogeneous mixture** – Composition of substances is not uniform throughout.
- Example:
  - Sugar in sand

Atom

- An atom is the basic unit of chemistry.
- It consists of a positively charged atomic nucleus, which contains protons and neutrons.
- It also maintains a number of electrons to balance the positive charge in the nucleus.

Element

- A chemical element is specifically a substance that is composed of a single type of atom.
- A chemical element is characterized by a particular number of protons in the nuclei of its atoms.
- This number is known as the atomic number of the element.
    - o 116 elements have been identified.
    - o 82 elements occur naturally (Example: gold).
    - o 34 elements have been created by scientists (Example: americium).

Compound

- A compound is a substance with a particular ratio of atoms of particular chemical elements.
- This ratio determines its composition and its particular organization.
- Example: Water

Substance

- A chemical substance is a kind of matter with a definite composition and a set of properties.

Acidity and Basicity of Substance

- A substance can often be classified as an acid or a base.
- There are several theories which explain acid-base behavior.
- The simplest is Arrhenius theory, which states that:
    - o "An acid is a substance that produces hydronium ions when it is dissolved in water, and a base is one that produces hydroxide ions when dissolved in water."

Molecule

- A molecule is the smallest indivisible portion of a pure chemical substance.
- It has its unique set of chemical properties.

Chemical Equilibrium

 The concept describes the state in which the parameters such as chemical composition remain unchanged over time.

Bonding

- Atoms sticking together in molecules or crystals are said to be bonded with one another.
- A chemical bond may be visualized as the balance between:
  - The positive charges in the nuclei and the negative charges oscillating about them.

Ions

 An ion is a charged species, an atom or a molecule, that has lost or gained one or more electrons.

- Positively charged species are called cations (e.g., sodium cation Na^{+}).
- Negatively charged species are called anions (e.g., chloride Cl^{-}).

Branches of Chemistry

- Chemistry has been further divided into different branches depending upon specialized fields of study.
  - Inorganic Chemistry,
  - Organic Chemistry,
  - Physical Chemistry,
  - Industrial Chemistry,
  - Analytical Chemistry,
  - Bio-Chemistry,
  - Nuclear Chemistry.

Inorganic Chemistry

- This branch deals with the study of compounds of all other elements except carbon.
- It mainly deals with the study of minerals found in the crust of earth.

Organic Chemistry

- This branch deals with the study of carbon compounds especially hydrocarbons and their derivatives.
- Organic chemistry defines life.
- Beyond our bodies' DNA, peptides, proteins and enzymes, organic compounds are all around us.
- **They are a source of energy**: We obtain energy from organic compounds like carbohydrates (sugars) and fats, using amino acids and proteins (organic) to grow.
- **Genetic information transmission**: from one generation to the next, through organic compounds called nucleic acids.
  - **Body parts formation**: Organic chemicals make up our Hair, Skin and Fingernails.

Physical Chemistry

- This branch deals with the explanation of fundamental principles governing various chemical phenomena.
- It is basically concerned with the laws and theories of different branches of chemistry.

Industrial Chemistry

- This branch deals with the chemistry involved in industrial process.

Analytical Chemistry

- This branch deals with the qualitative and quantitative analysis of various substances.

Bio-Chemistry

- This branch deals with the chemical changes going on in the bodies of living organisms; plants and animals.

Nuclear Chemistry

 This branch deals with the study of nuclear reactions such as nuclear fission, nuclear fusion etc.

 In addition to above branches there are other branches of chemistry developed in recent years.

 These include pharmaceutical chemistry, geo-chemistry, agricultural chemistry, medicinal chemistry, solid state chemistry etc.

Importance of Chemistry

- Chemistry plays very significant role in almost all walks of life. Our daily life involves the use of many chemical products and many chemical changes although we are unaware of them.
- Some of the major contributions of chemistry to the life in modern world are as given below:

Chemistry in Medicines

- Modern chemical discoveries have done a lot to eradicate disease and to improve health.
- Some important contributions of chemistry in the field of medicines are development of:
  - Lifesaving drugs like Taxol and cisplatin (used in cancer therapy); azidothymidine (AZT) used for AIDS victims.
  - Prophylactics i.e. disease preventing screen and vaccines
  - Anaesthetics and antiseptics.
  - Disinfactants and germicides.

Chemistry in Industry

- The major contribution of chemistry in the field of Industry is the use of:
  - Synthetic fiber like rayon, nylon, dacron, orlon etc.
  - Plastics like Bakelite, teflon, polythene etc.
  - Paints, varnishes, enamels, dyes etc.
  - Cement, glass and ceramics and extraction of metals like silver, magnesium, gold iron, etc.

Chemistry in Agriculture

- The major contribution of chemistry in the field of agriculture is the use of:
  - Chemical fertilizers like urea, ammonium sulphate, calcium nitrate, etc. for the better production of crops.
  - Insecticides such as D.D.T., gammexane, methoxychlore etc., for the protection of crops from insects and help the safe storage of food grains.
  - Preservatives like sodium benzoate, sodium metabisulphate and salicylic acid for better preservation of food and check its wastage.

Chemistry in Comfort, Convenience and Pleasure:

- Domestic requirements such as paper, fabrics, soaps, cosmetics, oils, flavoring essences, dyes and perfumes.
- Air conditioning: To keep efficient in all seasons we make use of air conditioning. In this we use chemical substances like liquid ammonia or liquid sulphur dioxide.

Chemistry and Energy Resources:

- The energy resources of the world are petroleum, coal, wood and nuclear fuels.
- The reserves of coal and petroleum are being exhausted at a fast speed; therefore attempts

are being made by chemists to utilize the nuclear energy and solar energy for meeting our requirements.

- Hydrogen from sea water may provide an inexhaustible source for future energy needs.

Dark Side of Chemistry:

- Like most of the human achievements, chemistry has been used as well as misused.
- On one side it has contributed so much for the benefit of our society.
- On the other hand, it has endangered the society by providing explosives such as TNT, RDX, other deadly chemical weapons of destruction, atomic and hydrogen bombs.

Chapter 3:
Equations, Reactions and Basics of Quantum Mechanics

Topics covered in this snack-sized chapter:

Equations and Reactions

- Chemicals have both common and IUPAC names.
  - **Common:** H_2O or water,
  - **IUPAC:** Di-hydrogen monoxide,

Ions

- A neutral compound requires equal numbers of +ve and -ve charges.
  - **Cation:** +ve ion
  - **Anion**: -ve ion
- A metal atom can transfer an electron to a nonmetal.
- The resulting cation and anion are attracted to each other by electrostatic forces.
- Formulas of ionic compounds are determined from the charges on the ions.
- The goal is to balance the charge with +ve and –ve ions.

Naming Compounds

- Cation first then anion.
- **Monoatomic cation** = name of the element:
  - Na^+ = sodium ion
- **Monoatomic anion** = root + -ide
  - Cl^- = Chloride ion
  - $CaCl_2$ = Calcium Chloride

Prefix	Number
Mono-	1
Di-	2
Tri-	3
Tetra-	4
Penta-	5
Hexa-	6
Hepta-	7
Octa-	8
Nona-	9
Deca-	10

Chemical Equations

- According to the principle of the conservation of matter, an equation must be balanced.
- It must have the same number of the same kinds of atoms on both sides.

Balancing Chemical Reactions

- When balancing a chemical reaction, you may add coefficients in front of the compounds to balance the reaction, but you may not change the subscripts.
- Changing the subscript changes the compound.
- Steps to balance a chemical reaction:
  - Write the correct formula for the reactants and the products.
  - Find the number of atoms of each element on the left side and compare those against the number of the atoms of the same element on the right side.
  - Determine where to place coefficients in front of formulas so that the left side has the same number of atoms as the right side for each element in order to balance the equation.

Reactions

	Elements combine and form a compound. $C + O_2 \rightarrow CO_2$

Synthesis Reactions	
	A compound breaks up into the elements or simpler compounds. **$2H_2O \rightarrow 2H_2 + O_2$**

Decomposition Reactions	
	One element replaces another in a compound. **$Zn(s) + 2HCl\ (aq) \rightarrow$** **$ZnCl_2 + H_2\ (g)$**
	A metal replaces a metal in a compound and a nonmetal

Double Single Replacement Reactions	replaces a nonmetal in a compound. **AB + CD → AD + CB**
	Always involve molecular oxygen O_2, and are almost always exothermic (i.e., they give off heat). $\mathbf{C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O}$

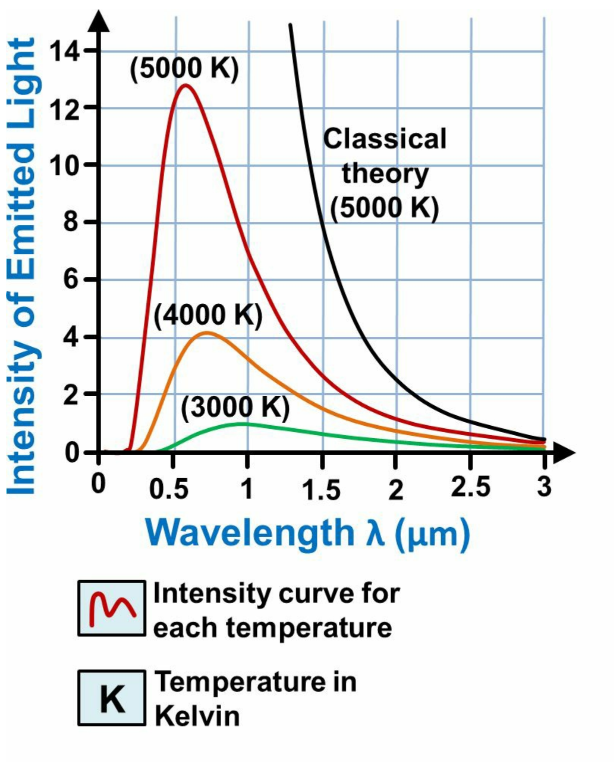
Combustion Reactions

Basics of Quantum Mechanics

- There were three critical experiments in the pre-quantum era which should be explained in order for the applications of quantum mechanics to be understood.
    - Black Body Radiation,
    - Photoelectric Effect,
    - Optical Line Spectra.

Black Body Radiation

- A black body is a body that completely absorbs all the electromagnetic radiation falling on it.
- When such an object is heated sufficiently, it starts to emit light at the red end of the spectrum- it is **"red hot".**
- Heating it further causes the color to change, as the light at shorter wavelengths (higher frequencies) begins to be emitted.
- It means that a perfect emitter is also a perfect absorber.
- When it is cold, such an object looks perfectly black, as it emits practically no visible light, because it absorbs all the light that falls on it.
- Consequently, an ideal thermal emitter is known as a black body, and the radiation it emits is called black body radiation.

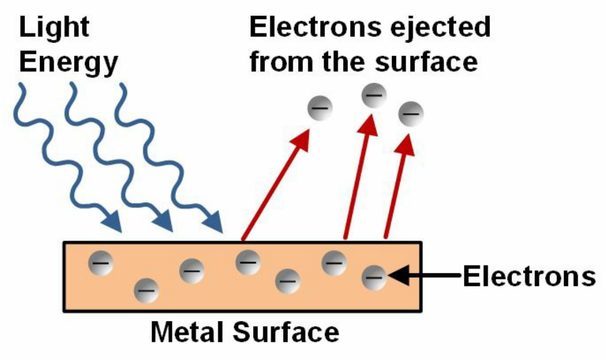


Conclusion from above graph:

- As the temperature increases, the peak wavelength emitted by the black body decreases.
- As temperature increases, the total energy emitted increases, because the total area under the curve increases.
- The curve gets infinitely close to the x-axis but never touches it.
- Blackbody radiation does not depend on the type of the object emitting it.
- The entire spectrum of blackbody radiation depends on only one parameter, the temperature T.

Photoelectric Effect

 The Photoelectric Effect refers to the emission or ejection of electrons, typically from the surface of a metal, in response to incident light.

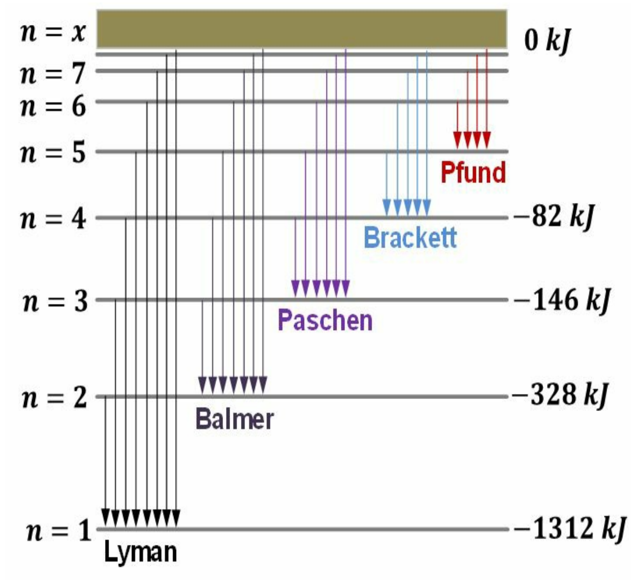


 Energy contained within the incident light is absorbed by electrons within the metal, giving the electrons sufficient energy to be 'knocked' out of, or emitted from, the surface of the metal.

 The minimum energy required to eject an electron from a surface is called the photoelectric work function.

Optical Line Spectra

□ The spectral lines of hydrogen correspond to particular jumps of the electron between energy levels, is known as **Optical Line Spectra.**



□ When an electron jumps from a higher energy to a lower, a photon of a specific wavelength is emitted.

□ The simplest model of the hydrogen atom is given by the Bohr model.

□ The wavelengths of emitted/absorbed photons are given by the Rydberg formula:

$$\frac{1}{\lambda} = R\left(\frac{1}{(n')^2} - \frac{1}{(n)^2}\right)$$

□ Where,

- **n** is the initial energy level,
- **n'** is the final energy level, and
- **R** is the Rydberg constant;

R = 1.097373 X 10^7 m^{-1}

□ There are many clusters of lines in the Hydrogen spectrum.

- The **Lyman series (**$n' = 1$**)** in the ultraviolet,

$$\frac{1}{\lambda} = R\left(\frac{1}{(1)^2} - \frac{1}{(n)^2}\right)$$

$n = 2, 3$ ....

- The **Balmer series (**$n' = 2$**)**, is in the visible region,

$$\frac{1}{\lambda} = R\left(\frac{1}{(2)^2} - \frac{1}{(n)^2}\right)$$

$$n = 3, 4 \dots \dots$$

- The **Paschen Series ($n' = 3$)** and the **Brackett Series ($n' = 4$),** in the infrared region and
- The **Pfund Series** ($n' = 5$)**,** in the far infrared etc.

- Balmer examined the four visible lines in the spectrum of the hydrogen atom.
- Their wavelengths are 410 nm, 434 nm, 486 nm, and 656 nm.

The De Broglie Wave Equation

- The theory was explained by Louis de Broglie in 1924 in his PhD thesis.
- The De Broglie relations explain that:
  - The wavelength is inversely proportional to the momentum of a particle and the frequency is directly proportional to the particle's kinetic energy.
- **The De Broglie Relations:** The De Broglie equations relate the wavelength λ and frequency f to the momentum p and kinetic energy E, respectively, as:

$\lambda = \frac{h}{p}$ and $f = \frac{E}{h}$

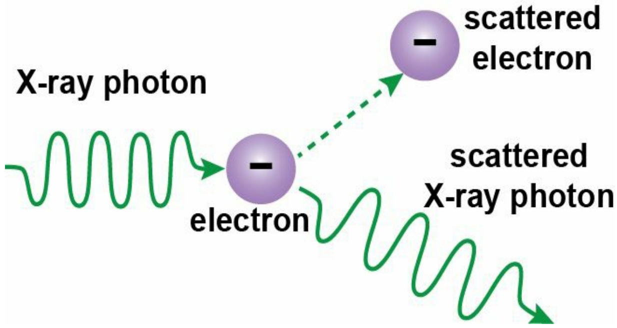
  - Where, h is Planck's constant

Wave Particle Duality

- Wave-Particle Duality postulates state that:
  - All particles exhibit both wave-like and particle-like properties.
- This is a central concept of quantum mechanics.
- This duality addresses the inability of classical concepts like "particle" and "wave" to fully describe the behavior of quantum-scale objects.

Compton Effect

 The duality between the wave and particle nature of light was highlighted by the American physicist Arthur Holly Compton in an X-ray scattering experiment conducted in 1922.



 Compton sent a beam of X-rays through a target material and observed that a small part of the beam was deflected off to the sides at various angles.

 He found that the scattered X-rays had longer wavelengths than the original beam.

- The change could be explained only by assuming that the X-rays scattered from the electrons in the target as if the X-rays were particles with discrete amounts of energy and momentum.

The Schrodinger Wave Equation

 Austrian Physicist Erwin Schrodinger made a profound discovery in 1926 by showing that the discrete energy states of Matter could be determined by Wave Equations,

- Used in physics, specifically quantum mechanics, it is an equation that describes how the quantum state of a physical system changes in time.

 The probability of finding an electron at any point around the nucleus can be determined with the help of the Schrodinger wave equation which is given by:

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{8\pi^2 m(E-V)}{h^2}\Psi = 0$$

Or

$$H\Psi = E\Psi$$

 Where,

x, y and ***z*** are the 3 spatial co-ordinates.
m = Mass of electron.
h = Planck's constant.
E = Total energy.
V = Potential energy of electron.
Ψ = Amplitude of wave (also called the wave function).
∂ = for an infinitesimal change.

Chapter 4:
Chemical Thermodynamics

Topics covered in this snack-sized chapter:

- Thermodynamics.
- Approaches to Study Thermodynamics.
- Thermodynamic Equilibrium.
- System and Surroundings.
- Heat energy.
- Gas Law.
- Laws of Thermodynamics.
- Thermodynamic Process.
- Gibbs Free Energy.
- Ideal Gas Law.
- Van der Waals Equation.

Thermodynamics

- Thermodynamics is an essential part of the study of mechanical engineering.
- It involves knowledge basic to the functioning of prime movers such as petrol and diesel engines, steam turbines and gas turbines.
- Thermodynamics is the study of transformations of energy.

Approaches to Study Thermodynamics

- There are two approaches to study Thermodynamics:
  - Microscopic
  - Macroscopic

Microscopic

- The microscopic view is used in the disciplines of kinetic theory and statistical mechanics.
- 1 A (Angstrom), which equals 10^{-8} cm, is the typical microscopic length scale.

Macroscopic

- The macroscopic view is used to reduce information required to describe a system to a manageable level.
- 1 cm is the typical macroscopic length scale.
- It is large enough to be visible in the ordinary sense.

Thermodynamic Equilibrium

 Thermodynamic equilibrium implies that a system state cannot change in the absence of unbalanced driving forces within the system.

 Thermodynamic equilibrium requires:

- **Thermal Equilibrium**: Constant temperature.
- **Mechanical Equilibrium:** Constant pressure at a given point; not throughout.
- **Chemical Equilibrium:** No chemical reactions.
- **Phase Equilibrium**: Each phase at equilibrium.

System and Surroundings

System

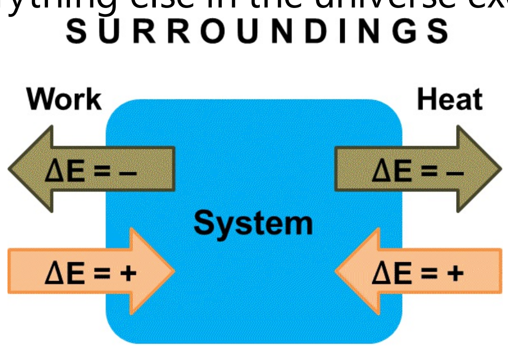
- The system is the part of the world in which we have a special interest.
- A system is any three-dimensional region of space bounded by one or more arbitrary geometric surfaces.
- System boundary may be real or it could be imaginary.

Classification of Systems

- **Open System:** An open system can exchange matter as well as energy with its surroundings.
- **Closed System:** A closed system can exchange energy with its surroundings. No transfer of matter across the boundaries is possible.
- **Isolated System:** An isolated system can exchange neither energy nor matter with its surroundings.

Surrounding:

- The surrounding is everything outside the boundaries.
- The surrounding includes everything else in the universe except the system.



Heat energy

Specific Heat

 The specific heat of a substance is the heat energy required to raise the temperature of unit mass of the substance by one degree.

 Different substances have different specific heats, for instance copper is 390 J/kgK and cast iron is 500 J/kgK.

Latent Heat

 Latent means ‘hidden’, and is used in this connection because, despite the addition of heat energy, no rise in temperature occurs.

 This phenomenon occurs when a solid is turning into a liquid and when a liquid is turning into a gas that is whenever there is a ‘change in state’.

 When a solid is turning into a liquid, the heat energy supplied is called the latent heat of fusion.

 When a liquid is turned into a gas, it is called the latent heat of vaporization.

Gas Law

Ideal Gas:

- The ideal classical gas allows us to understand much about the behavior of dilute gases.
- The ideal gas law relates important thermodynamic properties, and is often used to calculate density.
- One form of the law is

$$PV = nR_uT$$

- Where,
  - P is the absolute pressure,
  - V is the volume, n is the number of moles,
  - R_u is the universal gas constant (the same for all gases), and
  - T is absolute temperature.
- Theoretically ideal gases strictly follow Boyle's and Charles' laws.

Boyle's Law

- This says that if the temperature of a gas is kept constant, the product of its pressure and its volume will always be the same. Hence,

$$p \times V = \text{constant Or,}$$
$$p1V1 = p2V2 = p3V3, \text{etc.}$$

Charles' Law

- This says that if you keep the pressure of a gas constant, the value of its volume divided by its temperature will always be the same. Hence,

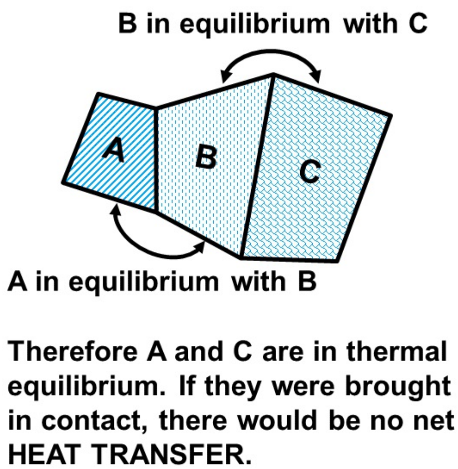
$$V/T = \text{constant Or,}$$
$$V1/T1=V2/T2=V3/T3, \text{etc.}$$

Laws of Thermodynamics

- There are four laws of Thermodynamics:
  - Zeroth law of thermodynamics
  - First law of thermodynamics
  - Second law of thermodynamics
  - Third law of thermodynamics

Zeroth Law of Thermodynamics

- The "Zeroth Law" states that if two systems are at the same time in thermal equilibrium with a third system, they are in thermal equilibrium with each other.



- In this diagram A in equilibrium with B and B in equilibrium with C therefore A and C are in equilibrium.

First Law of Thermodynamics

- The first law of thermodynamics is the application of the conservation of energy principle of heat and thermodynamic processes.
- The change in a stationary object's internal energy is equal to the heat transferred into that object minus the work that the object did on its surroundings.

$$\Delta U = Q - W$$

  - Change in internal energy: ΔU
  - Heat added to the system: Q
  - Work done by the system: W
  - **Internal Energy U** – Measure of thermal energy of system, it is the intrinsic energy of the fluid.
  - **Heat in** – Heat added to system by candle.
  - **Work done** – Work done by the system by moving piston, it is the form of energy transfer when energy crosses the system boundary without a temperature difference.
  - If $dW > 0$ Work is done on the system by the surroundings.

- If $dW < 0$ Work is done by the system on the surroundings.

Second Law of Thermodynamics

- The Second Law of Thermodynamics states that: "In any spontaneous process, there is always an increase in the entropy of the universe."

Entropy:

- The measure of a system unavailability to do work, which is explained in the second law of thermodynamics; "useless" energy whose energetic prevalence over the total energy of a system is directly proportional to the absolute temperature of the system.
- From our definition of system and surroundings:

$$\Delta S_{universe} = \Delta S_{system} + \Delta S_{surroundings}$$

Direction of a process:

- The second law helps determine the preferred direction of a process.
- A reversible process is one which can change state and return to the original state.
- **For example:** Heat engine- Which transforms heat into work, which is a cyclic process.

Third Law of Thermodynamics

- Third law of thermodynamics states: "The entropy of a perfect crystal at absolute zero is exactly equal to zero".
- The entropy of a system approaches a constant value as the temperature approaches zero.
- The entropy of a system at absolute zero is typically zero, and in all cases is determined only by the number of different ground states it has.

Thermodynamic Process

Isobaric Process

- An isobaric process is one that occurs at a constant pressure.
- The values of the heat and the work both are generally nonzero.
  - The work done is:

$$W = -P(V_f - V_i)$$

Where,

- P is the constant pressure
- V_i is initial volume
- VF is the final volume
- W is work

Isovolumetric Process

- An Isovolumetric (isochoric) process is one in which there is no change in the volume.
- Since the volume does not change:

$$W = P\Delta V = 0$$

Where,

W is work done

P is pressure

ΔV is the change in volume

- From the first law:

$$\Delta E_{int} = Q + W \Rightarrow \Delta E_{int} = Q$$

Isothermal process

- An isothermal process is one that occurs at a constant temperature.
- Since there is no change in temperature:

$$\Delta E_{int} = 0 \Rightarrow Q = -W$$

- Any energy that enters the system by heat must leave the system by work.

Adiabatic process

- The process is adiabatic because it takes place in an insulated container.
- No heat exchanged.

Q = 0 and $\Delta E_{int} = W$

Isentropic process

- An isentropic process or isoentropic process is one in which the entropy of the system remains constant.

Isenthalpic process

- An isenthalpic process or isoenthalpic process is a process that proceeds without any change in enthalpy, H; or specific enthalpy.

Gibbs Free Energy

 The Gibbs free energy of a system at any moment in time is defined as the enthalpy of the system minus the product of the temperature times the entropy of the system.

$$G = H - TS$$

 From our definitions of system and surroundings:

$$\Delta S_{universe} = \Delta S_{system} + \Delta S_{surroundings}$$

Ideal Gas Law

□ An ideal gas is an idealized model for real gases that have sufficiently low densities.

□ The condition of low density means thatthe molecules of the gas are so far apartthat they c

□ The ideal gas law expresses the relation-ship between the absolute pressure (P), the Kelvin temperature (T), the volume (V) and the number of moles (n) of the gas.

$$PV = nRT$$

- Where R is the universal gas constant

$R = 8.314\ J/(mol \cdot K)$

Van der Waals Equation

 In Ideal gas law equation V cannot be decreased indefinitely, so replace v by v – b Then,

$$P = \frac{RT}{V - b}$$

• Next account for intermolecular attraction which will reduce pressure as molecules are forced closer together.

This term is proportional to v^{-2}, then $P = \frac{RT}{v-b} - \frac{a}{v^2}$, or

$$\left(P + \frac{a}{v^2}\right)(v - b) = RT$$

• This equation has a critical value of T which suggests a phase change.

Chapter 5:
Biochemical Engineering

Topics covered in this snack-sized chapter:

- Biochemical Engineering.
- What Types of Molecules does Biochemists Study?
- What are the Uses of Biochemistry?
- What Disciplines are related to Biochemistry?
- Major Types of Biochemical Reactions.
- Function of Biochemical Engineers.
- Getting the Information.
- What Biochemical Engineers do?

Biochemical Engineering

□ Biochemical engineering is a branch of chemical engineering that mainly deals with the design and construction of unit processes that involve biological organisms of molecules.

□ Biochemistry is the science in which chemistry is applied to the study of living organisms and the atoms and molecules which comprise living organisms.

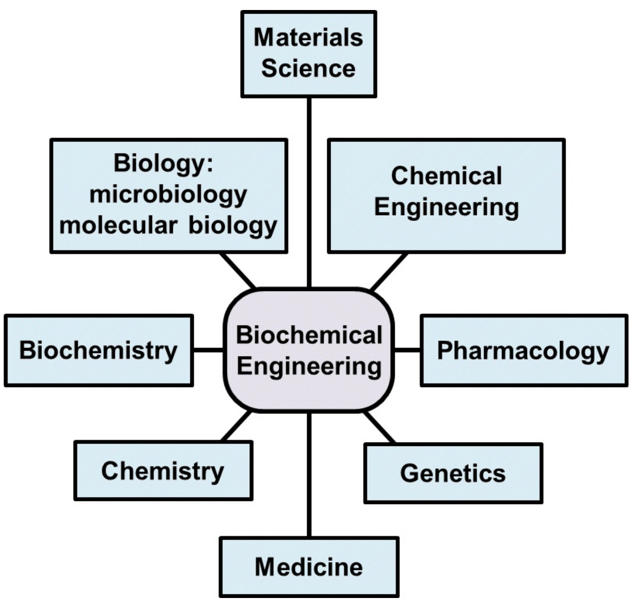
□ Biochemistry, sometimes called biological chemistry, is the study of chemical processes in living organisms, including, but not limited to, living matter.

□ Biochemistry governs all living organisms and living processes.

□ Living organisms should be able to:
- o Transform matter and energy into different forms.
- o Show response to changes in their environment.
- o Show growth and reproduction.

□ All living organisms undergo changes due to large organic compounds called macromolecules.

□ Applications of biochemical engineering are used in the food, feed, pharmaceutical, biotechnology and water treatment industries.



□ The practice of Biochemical Engineering chiefly involves the study of Enzymes.

- Enzymes are biological catalysts that are actually molecules of protein.
- They are generated by living cells i.e. cells of plants, animals and microorganisms.
- The enzymes act as catalysts in various biochemical reactions.

What Types of Molecules does Biochemists Study?

- The principal types of biological molecules or biomolecules are:
  - Proteins
  - Carbohydrates
  - Nucleic acids and
  - Lipids
- Many of these molecules are complex molecules called polymers, which are made up of monomer subunits.

What are the Uses of Biochemistry?

- Two of the biggest fields of work that require biochemistry knowledge are pharmaceuticals and genetics.
- Biochemistry is used to learn about the biological processes which take place in cells and organisms.
- Biochemistry may be used to study the properties of biological molecules, for a variety of purposes.
  - For example, a biochemist may study the characteristics of keratin in hair so that a shampoo may be developed that enhances curliness or softness.
- Biochemists find uses for biomolecules.
  - For example, a biochemist may use certain kinds of lipid as a food additive.
- Alternatively, a biochemist might find a substitute for a usual biomolecule.
  - For example, biochemists help to develop artificial sweeteners.
- Biochemists can help cells to produce new products.

What Disciplines are related to Biochemistry?

- Biochemistry is closely related to other biological sciences that deal with molecules.
- There is considerable overlap between these disciplines:
  - Molecular Genetics
  - Pharmacology
  - Molecular Biology
  - Chemical Biology
- **Genetic research** is a field in which many experts in biochemistry take part.
  - The current research regarding stem cells has led to very important information about chemical processes that essentially cause cell death called apoptosis.
- **Biotechnology**, the use of living things to make products, is another field in which the biochemistry expert thrives.
- As well, the food industry attracts biochemists.
  - In studies regarding food, biochemists might work in a number of practical ways, such as:
  - Product development of foods which are least likely to cause weight gain or developing foods that have highly beneficial qualities.
  - Most wineries and breweries use biochemistry frequently to evaluate yeasts and acids used to make alcohol.
- Experts in biochemistry might also use their skills to make chemical products like herbicides or pesticides.
- Many works in small research labs that may study specific things or analyze materials for contaminants.
  - **For example:** Testing water and food for live parasitic agents is a valued act of biochemistry.
- Biochemists have a choice of fields that include:
  - Applications in medicine,
  - Genetics,
  - Food Science,
  - Biotechnology and
  - Pharmaceuticals.

Major Types of Biochemical Reactions

- **Oxidation:**
  - Oxidation is the loss of electrons.
- **Reduction:**
  - Reduction is the gain of electrons.
- **Hydrolysis:**
  - Hydrolysis is the chemical process in which a molecule is cleaved into two parts by the addition of a water molecule.
- **Phosphorolysis:**
  - Phosphorolysis is the splitting of a bond by the addition of phosphoric acid to a compound.
- **Decarboxylation:**
  - Decarboxylation is the loss of carbon dioxide.
- **Deamination:**
  - Deamination is the removal of amino group.
- **Transamination**:
  - Transamination is the transfer of amino group from one molecule to another.

Function of Biochemical Engineers

- **Analysis of various Data or Information:**
  - This involves identification and the synthesis of the fundamental principles, reasons, as well as facts of data and information with the process of breaking down the information or the available data into several distinctive parts or portions.
- **Processing the Information:**
  - It involves compilation, coding, categorization, calculation, tabulation, auditing and verification of information or data.
- Taking various decisions and solving problems.
- Analysis of various information and evaluation of results for the best solution of problems.
- Revising and using various relevant knowledge.
- Keeping up with the latest technology and application of the new knowledge in the job.
- Thinking creatively.
- Development, design and creation of new systems, applications, ideas, relations and products along with artistic contributions.
- Monitoring various processes, materials involved as well as the surroundings.
- Documentation and recording of Information.
- Transcribing, recording and along with maintenance of information in written or electromagnetic form.
- Interaction with computers.
- Using computers as well as computer systems (including the hardware and software) in order to do the programming, set up various functions, enter the data or process the information.
- Communication with the supervisors, peers and the Subordinates.
- Providing various relevant information to the supervisors, co-workers and subordinates through telephone, writing, through e-mails or in person.

Getting the Information

- **Communicating with Persons outside the Organization**:
  - Communicating with people beyond the organization and playing the role of a representative of the organization when interacting with customers, public, government and various other sources
- **Establishment and Maintenance of Interpersonal Relationships:**
  - Developing constructive as well as cooperative relationships with others and maintaining them over a considerable period of time.
- **Scheduling Various Work & Activities:**
  - Scheduling various events, programs as well as activities, in coordination with others involved.
- **Training and Developing Others:**
  - Identification of developmental requirements of others, along with coaching, mentoring and helping them in other ways to improve their knowledge.
- **Monitoring and Controlling Resources:**
  - Overseeing and controlling various resources and monitoring the expenditure.
- **Provide Consultation and Advice:**
  - Providing guidance as well as expert's advice to the management or others on various technical and process-related issues .
- **Staffing Organizational Units:**
  - Interviewing, selecting, hiring and promoting employees in accordance to requirement in an organization.
- **Resolving Conflict Situation and Negotiation with Others:**
  - Handling various complaints, settlement of disputes and resolving grievances and conflicts amongst employees or otherwise negotiating with others.
- **Handling and Moving Objects:**
  - Giving a helping hand to others in handling, installations, setting up, moving materials and changing the order of putting up things.
- Observation and receipt of information from the various relevant sources.

What Biochemical Engineers do?

 Consulting with the chemists and biologists in the development or evaluation of novel technologies.

 Development of methodologies for the purpose of transferring procedures or various biological processes from the laboratories to the sites of commercial production and manufacturing.

 Go through the current scientific or trade trend to stay ahead in the field of scientific, technological or industrial sector.

 Designing follow-up experiments, that are based on the data generated, to meet the established objectives of the process.

 Maintenance of databases for experimentations.

 Preparation of technical reports, documents containing a data summary or articles on research in scientific publication and applications of the patent.

 Interaction with research and bio-manufacturing individuals to make sure that the compatibility of design & production is maintained.

 Designing and conducting studies for determination of optimal conditions for growth of cells, production of protein, expression or recovery of protein or virus, with the use of chromatography, and filtration equipment like centrifuges or bioreactors.

 Development of statistical models or simulations used in biochemical production.

Chapter 6:
Chemical Kinetics

Topics covered in this snack-sized chapter:

- Chemical Kinetics.
- Rate of a Reaction.
- Applications.
- Rate Constant (K).
- Rate Law.
- Activation Energy.
- Endothermic Reactions.
- Exothermic Reactions.
- Reversible Reactions.
- Chemical Equilibrium.
- Le-Chatelier's Principle.
- Spontaneity of Reactions.

Chemical Kinetics

- Chemical Kinetics is normally known as reaction kinetics.
- Chemical kinetics is the branch of chemistry, which deals with the study of reaction rates and their mechanism.
- The word kinetics is derived from the Greek word “Kinesis” meaning movement.
- Thermodynamics tells us only about the feasibility of a reaction whereas chemical kinetics tells about the rate of a reaction.

Rate of a Reaction

Reaction Rate:

 The change in the concentration of a reactant or product with time.

 General equation for a reaction:

$A \rightarrow B$

$Reactant \rightarrow Product$

 In order to monitor a reaction's speed or rate, we can look at one of two things:

- Decrease in reactant
- Increase in product

 Can be represented as:

$$Rate = -\Delta[A] / \Delta t$$ or

$$Rate = \Delta[B] / \Delta t$$

 Factors that affect Reaction Rate

 Factors that affect Reaction Rate are:

- Nature of the reactants
- Physical State
- Concentration
- Temperature
- Catalysts
- Pressure

Nature of the Reactants

 The reaction rate depends upon the types of substances that are taking part in the process of reaction.

 In case of acid or base reaction the reaction rates become faster; on the other hand in case of the formation of a covalent bond between the molecules and the formation of large molecules the reaction rate turned to be really very slow.

 Hence it can be said that the nature and strength of the reacting substances influence the rate of the reaction.

Physical State

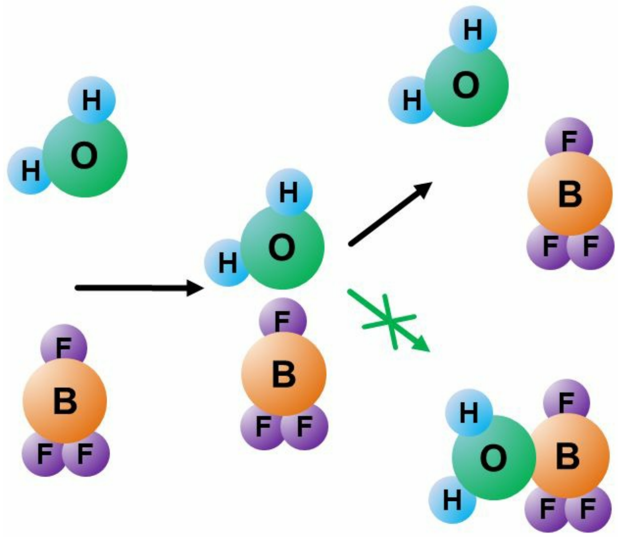
 The physical state of a reactant is equally significant in the matter of the rate of a reaction. Physical state means the solid, liquid or gas state of any substance.

 When two reactants in one reaction process are in the same phase or state then they are brought into contact by the thermal motion as in aqueous solution.

 However, when reactants are in different states, the reaction process becomes limited to the boundary between the reactants.

Concentration

- Concentration is another significant part of reactions.



- According to the collision theory of chemical reactions particles must have a collision in order to react together.
- The frequency of the molecules that are colliding with each other will increase when the concentration of the reactants increases.
  - By increasing the quantity of one or more of the reactants, these collisions will happen more frequently, and ultimately it leads to the increase of the reaction rate.

Temperature

- Like the above mentioned factors, temperature also plays a vital role in the reaction rates.
- Molecules have more thermal energy in higher temperature.
- Collision frequency becomes greater at higher temperatures; however, it does not have a great contribution in the reaction rate.

Catalysts

- The catalyst is a substance that augments the rate of a chemical reaction however it remains chemically unchanged after the reaction process.
- With several reaction mechanisms, catalyst increases the rate of reaction.
- The position of the equilibrium is not affected by the catalyst, as the catalyst accelerates the backward and forward reactions evenly.

Pressure

- The rising of pressure in a gaseous reaction increases the amount of collisions between several reactants.
- It automatically increases the rate of reaction as well.
- Pressure jump approach can be helpful in understanding the reaction's kinetics.
  - Making quick changes in pressure and the observation of the relaxation time of the return to equilibrium are involved in this approach.

Applications

- The study of chemical reactions or kinetic reactions offers great tools for chemists and chemical engineers to understand and define several chemical processes in different sectors.
  - Food decomposition, stratospheric ozone decomposition, microorganism growth and the complex chemistry of biological systems can get assistance through the study of reaction kinetics.

Rate Constant (K)

- The rate constant is denoted by K.
- A rate constant is a constant of proportionality between the reaction rate and the concentration of the reactant.
- K may change slightly over the time.
- K is represented as:

$$\mathbf{K = rate/\ [reactant]}$$

- K is not affected by the [reactant] or rate alone since it is a ratio of these two.

Rate Law

□ Rate Law expresses the relationship of the rate of a reaction to the rate constant and the concentrations of the reactants raised to some power.

□ Using the general reaction:

$$aA + bB \rightarrow cC + dD$$
$$Rate = k\,[A]^x[B]^y$$

□ Reaction is x^{th} **order** in A.

□ Reaction is y^{th} **order** in B.

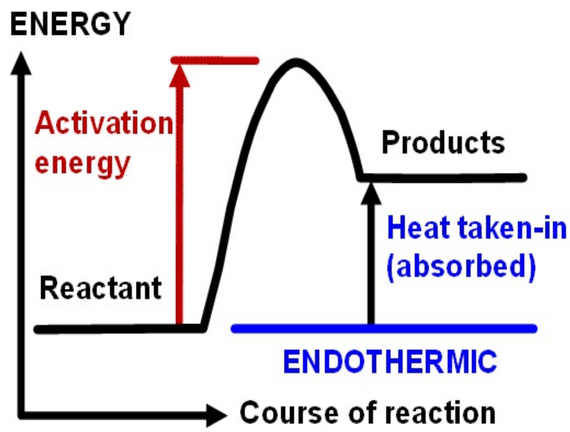
□ Reaction is $(x+y)^{th}$ **order overall.**

Activation Energy

- The minimum energy required to transform reactants into the activated complex.
- The minimum energy required to produce an effective collision.
- Flame, high temperature and radiation are all sources of activation energy.

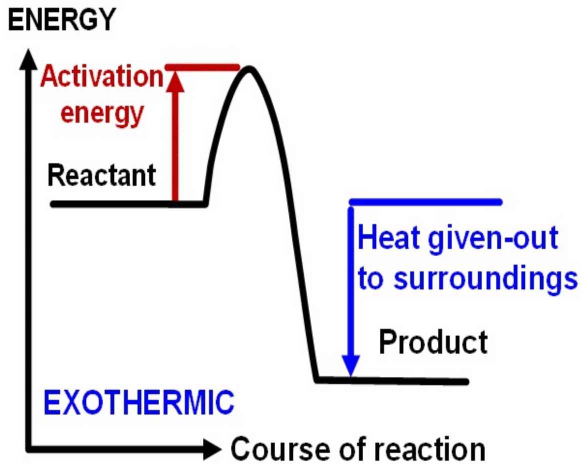
Endothermic Reactions

 Endothermic reactions: These are the reactions in which energy (usually in the form of heat) is absorbed.

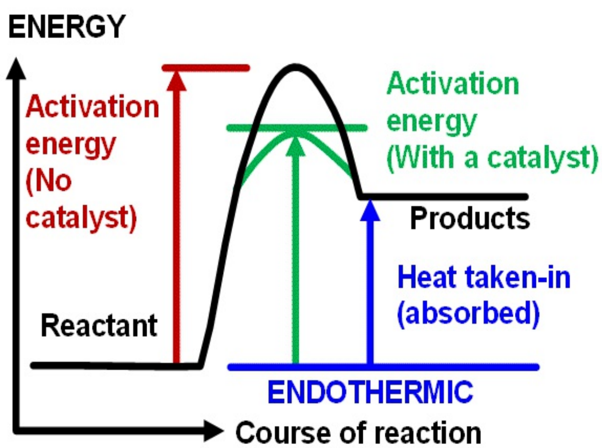


Exothermic Reactions

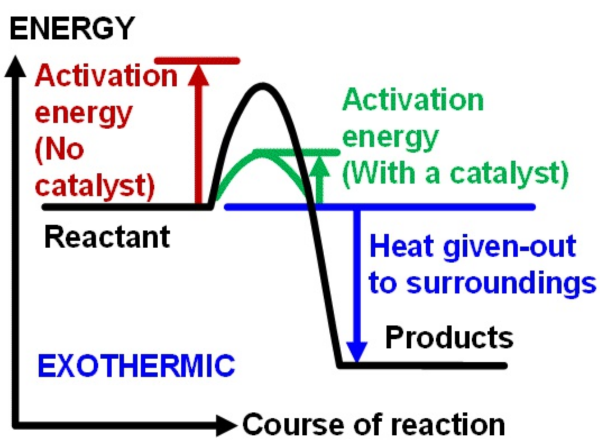
□ **Exothermic reactions:** These are the reactions in which energy (usually in the form of heat) is released.



Endothermic Reaction with a Catalyst



Exothermic Reaction with a Catalyst



Reversible Reactions

- A chemical reaction in which the products can react to re-form the reactants.

Chemical Equilibrium

□ When the rate of the forward reaction equals the rate of the reverse reaction and, the concentration of products and reactants remains unchanged.

$2HgO(s) \leftrightarrows 2Hg\,(l) + O_2(g)$

□ Arrows going both directions ($\leftrightarrows$) indicate equilibrium in a chemical equation.

Le-Chatelier's Principle

- When a system at equilibrium is placed under stress, the system will undergo a change in such a way as to relieve that stress.
- When you take something away from a system that was in equilibrium, the system shifts in such a way as replace what you’ve taken away.
- When you add something to a system at equilibrium, the system shifts in such a way as to use up what you’ve added.
- Example:
- A closed container of ice and water at equilibrium.
  - The temperature is raised.

$$Ice + Energy \leftrightarrows Water$$

  - The equilibrium of the system shifts to the right to use up the added energy.

Spontaneity of Reactions

- Reactions proceed spontaneously in the direction that lowers their free energy G.

$$\Delta G = \Delta H - T\Delta S$$

- If ΔG is negative, the reaction is spontaneous.
- If ΔG is positive, the reaction is not spontaneous.
  - **H** is enthalpy, **T** is temperature in Kelvin, **S** is entropy.

ΔH	TΔS	ΔG	Spontaneity
-Ve	+Ve	-Ve	Spontaneous
+Ve	-Ve	+Ve	Non-Spontaneous
-Ve	-Ve	-Ve (Low Temperature)	Spontaneous if the absolute value of ΔH is greater than the absolute value of $T\Delta S$ (low temperature)
+Ve	+Ve	-Ve (High Temperature)	Spontaneous if the absolute value of $T\Delta S$ is greater than the absolute value of ΔH (high temperature)

Reaction Mechanism

- The reaction mechanism is a summary of the overall process through which reactants become products.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Rate-Determining Step

- In a multi-step reaction, the slowest step is the rate-determining step. It determines the rate of reaction.

Chapter 07:

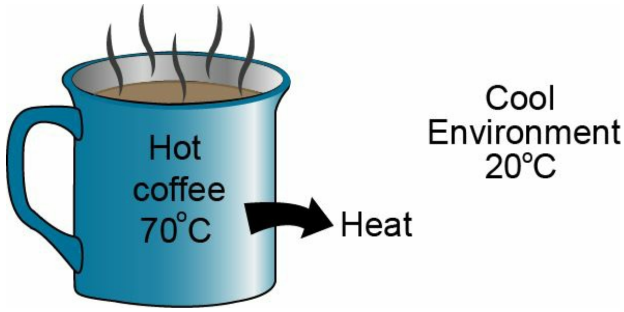
Heat and Mass Transfer

Topics covered in this snack-sized chapter:

- Heat Transfer.
- Ways of Heat transfer.
- Heat Quantities.
- Mass Transfer.
- Boiling.
- Types of Boiling.
- Condensation.
- Types of Condensation.
- Evaporators.
- Types of Evaporators.

Heat Transfer

- Heat is the form of energy transferred between two systems or between a system and its surroundings owing to temperature difference.
- It is the form of energy that can be transferred from one system to another as a result of temperature difference.



  - Heat energy can be transported through a solid, liquid, gas or vacuum.
- The study of heat and mass transfer is very useful for chemical engineering as well as for thermodynamics.
- System does not possess heat, i.e., heat is not a property of a given system.
- Heat is relevant to a process not a state.
- Heat transfer is a directional quantity i.e. both magnitude and direction.
  - Heat transfer to system is positive i.e. $Q > 0$.
  - Heat transfer from system is negative i.e. $Q < 0$.
  - Adiabatic system (no heat transfer) i.e. $Q = 0$.
- Conditions for no heat transfer:
  - Insulated system
  - No temperature difference
- Heat transfer provides important physical laws that allow calculation of instantaneous heat rate, length of time required for process to occur and temperature distribution within material at any time.
  - Heat transfer is the subject of thermal engineering that deals with the generation, utilization and exchange of heat and thermal energy between physical systems.
  - In heat transfer primary concern is heat energy that can be transferred from one system to another.

Ways of Heat transfer

- The process of heat transfer can be categorized into several modes. These are:
  - Conduction
  - Convection
  - Radiation

Conduction

- Conduction is the transfer of energy from more energetic particles of a substance to less energetic adjacent particles due to interactions between them.
- The transfer of energy between objects that are in physical contact.
- The time rate of energy transfer by conduction is quantified by Fourier's law.
- Molecular interactions are required.
- Medium required for conduction.
- For Example:
  - When we heat one end of a solid rod, it's another end becomes hot.
  - Heat goes from one end of the rod to the other end by conduction.
  - Most important in solids, and all solids are heated through conduction.
  - Better the conductor, the more rapidly heat will transfer.

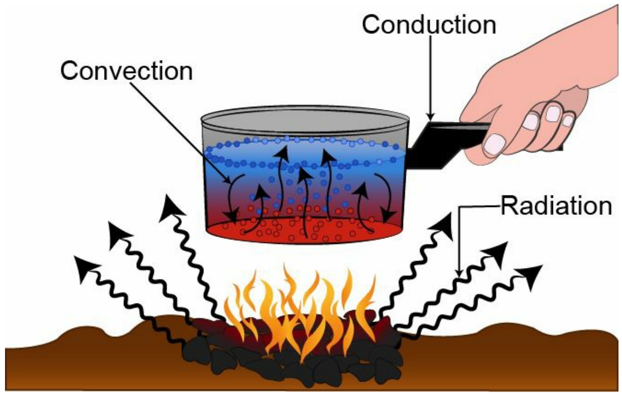
Convection

- Convection is an energy transfer between a solid surface and an adjacent fluid (gas or liquid) by the combined effects of conduction and bulk flow within the gas or liquid.
- The rate of energy transfer by convection is quantified by Newton's law of cooling.
- Medium required.
- For Example:
  - When we heat a liquid in a flask, the particles of the liquid at the bottom get heated, become lighter and actually rise up.
  - The cold liquid particles from above come down and receive the heat, the process is repeated.
  - All liquid and gases are heated by convection.

Radiation

- Thermal radiation is energy transported by electromagnetic waves (or photons).
- Transfer of heat due to emission of electromagnetic waves, usually between surfaces, separated by a gas or vacuum.
- Radiation is the fastest mode of heat transfer.
- The time rate of energy transfer by radiation is quantified by expressions developed from the Stefan-Boltzmann law.
- Electromagnetic nature.

- No medium required.
- The process of heat transfer through conduction, convection and radiation is shown below:



Heat Quantities

Quantity	Symbol	SI Unit
Heat	Q	Joule (J)
Heat Rate	q	Watt (W)
Heat Flux	q''	W/m^2
Heat rate per unit length	q'	W/m
Volumetric heat generation	q	W/m^3

Mass Transfer

- Mass transfer refers to mass in transit due to a species concentration gradient in a mixture.
- Mass transfer occurs in many processes like absorption, evaporation, adsorption, drying, precipitation, membrane filtration and distillation.
- The process of purification of blood in the kidneys and liver and the process of alcohol distillation can also be noted as a form of mass transfer.

Boiling

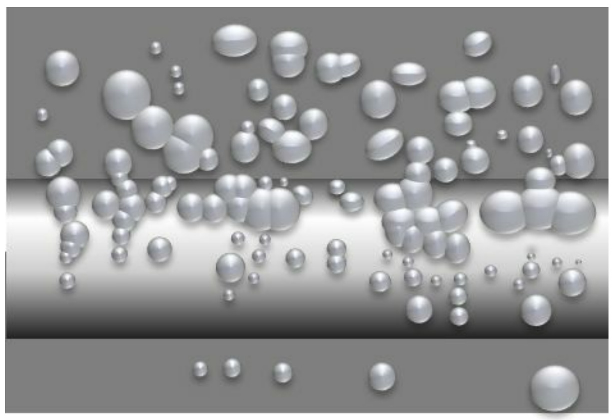
- Boiling is associated with transformation of liquid to vapor at a solid/liquid interface due to convection heat transfer from the solid.
- In thermodynamics, phase change at constant pressure occurs without a temperature change. The difference in enthalpy is the latent heat of transformation.

Types of Boiling

- Following are the types of boiling
  - Nucleate boiling
  - Pool boiling
  - Film boiling
  - Flow boiling

Nucleate Boiling

- **Isolated bubbles:** Bubbles form at nucleation sites and separate from the surface; fluid mixing induces increased convective heat transfer.
- **Jets or columns:** More nucleation sites are activated; densely populated bubble jets at the surface inhibit liquid motion; convective heat transfer coefficient begins to decrease.



Pool Boiling

- Nukiyama (1934) identified different regimes in pool boiling.
- Measured ΔT_e vs. q_s in a submerged wire.
- One method of removing water and other contamination from a gas is to pass it through a cooled tube so that contaminants with high freezing and liquefaction points (e.g., water) tend to be collected in the wall.

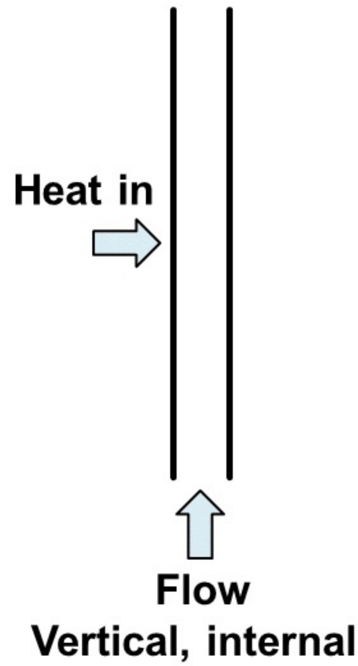
Film Boiling

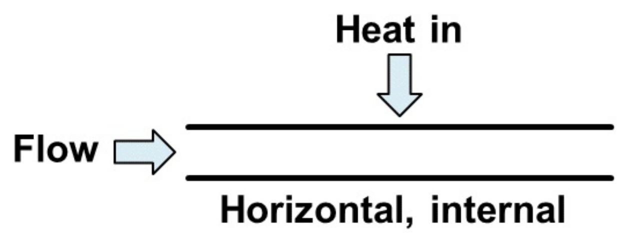
- If a surface heating the liquid is significantly hotter than the liquid then film boiling will occur.
- Where a thin layer of vapor, which has low thermal conductivity, insulates the surface.
- This condition of a vapor film insulating the surface of the liquid characterizes film boiling.
- Heat transfer is only by conduction and radiation through the vapor.

Flow Boiling

- Depends greatly on geometry and orientation.
- External flow: Overheated plates or cylinders.

 Internal (duct) flow: in piping; sometimes called two-phase flow





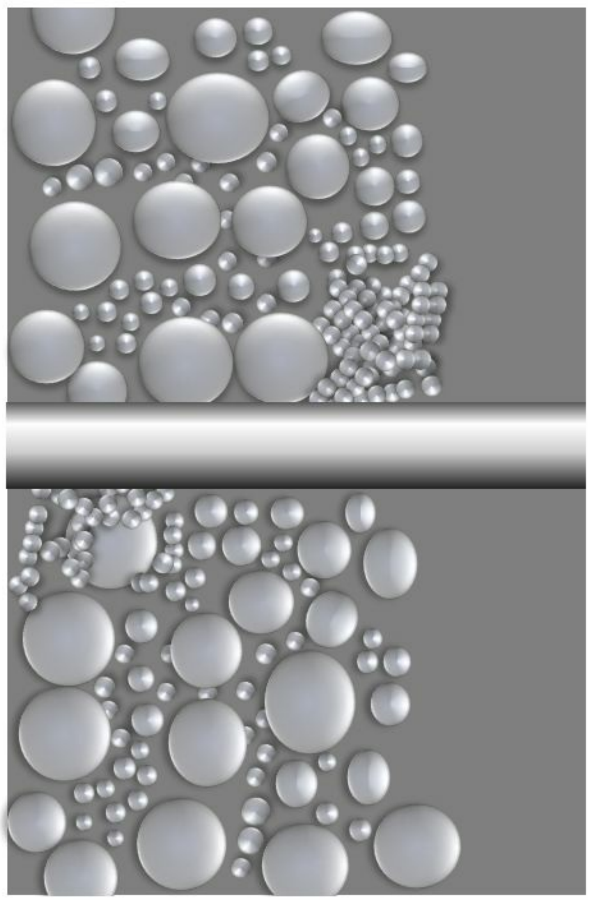
Condensation

 Condensation occurs when the temperature of a vapor is reduced below its saturation temperature.

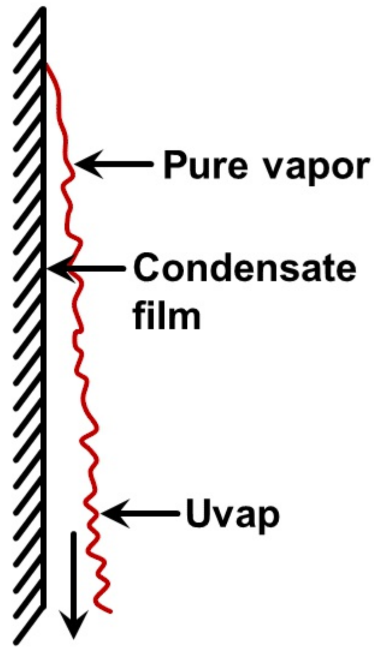
Types of Condensation

- **Surface condensation:** This is the most familiar type of condensation, taking the form of water on window panes, cold wall surfaces and tiles.
  - **Drop wise condensation:** higher heat transfer rate.
  - **Film condensation:** lower heat transfer rate.
- **Homogeneous condensation**, example like in a fog.
- **Direct contact condensation:** vapor condenses at a vapor-liquid interface.

Drop wise condensation:



Film condensation:


Pure vapor
Condensate
film
Uvap

Evaporators

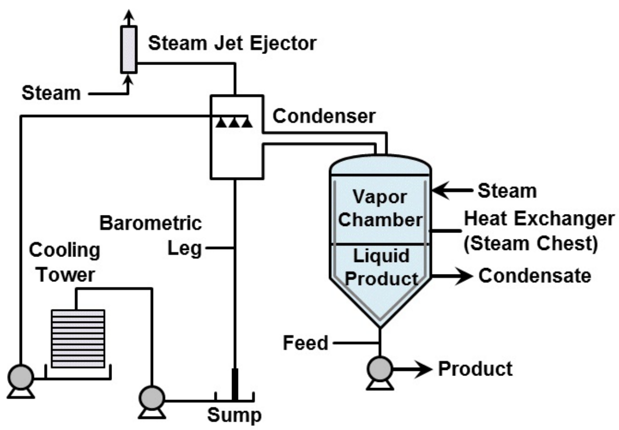
 Evaporation is the partial removal of water from dilute liquid foods to obtain a concentrated liquid product.

 Unlike drying, it occurs at the boiling point.

 The final product is still a liquid.

 Latent heat is transferred from steam to the food, which raises the temperature of the food. Its vapor pressure rises until it reaches the pressure of the surroundings, at which point the temperature reaches the boiling point.

 Bubbles of vapor form in the liquid, and vapor is removed at the surface



Types of Evaporators

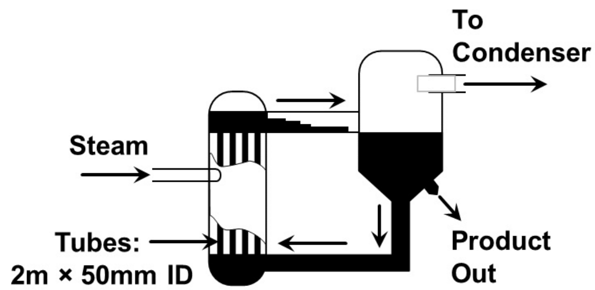
□ Natural circulation evaporator

□ Forced circulation evaporator

□ Rising Film Evaporator

□ Falling film evaporator

Natural Circulation Evaporator

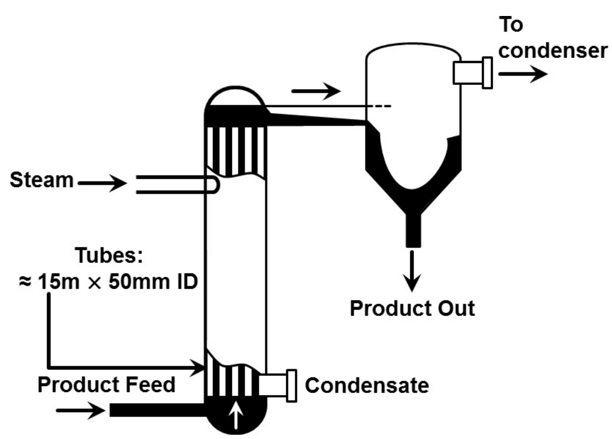


□ Short tubes are arranged vertically in the steam chest.

□ Heated product rises by natural convection through the tubes.

□ Concentrated liquid moves through an overflow vessel, and then falls back to base of tubes.

Rising Film Evaporator



□ Low-viscosity liquid boils inside long vertical tubes.

□ Vapors form near the bottom and cause liquid to rise and form a thin film that moves quickly up the tubes.

□ High heat transfer rates achieved.

□ Product not usually recirculated.

□ Need $T_s - T_b > 14°C$.

□ Residence time around 3-4 minutes.

Falling Film Evaporator

- Thin liquid film falls by gravity along walls of the tube.
- Can incorporate more effects than rising film (10 or more).
- Can handle more viscous materials.
- Residence time 20-30 seconds.
- Good for heat sensitive juices.

Forced Circulation Evaporator

- Liquid circulated at high rates (2-6 m/s) through the heat exchanger.
- Hydrostatic head over tubes keeps pressure lower in separator.
- Boiling does not occur in calandria; liquid flashes in a separator to from vapor.

Chapter 8: Solids, Liquids and Gases

Topics covered in this snack-sized chapter:

- ☐ Intermolecular Forces.
- ☐ Phase Difference.
- ☐ Types of Solid.
- ☐ Various Lattice Structures.
- ☐ Phase Diagram.
- ☐ The Liquid State.
- ☐ Vapor Pressure.
- ☐ Viscosity.
- ☐ Gases.
- ☐ Diffusion.
- ☐ Effusion.
- ☐ Kinetic Energy of Gas Particles.
- ☐ Gas Pressure.
- ☐ Gas Laws.
- ☐ Combined Gas Law.
- ☐ Boyle's Law.
- ☐ Charles's Law.
- ☐ Absolute Temperature Scale.
- ☐ Absolute Zero.
- ☐ Avogadro's Law.
- ☐ Dalton's Law of Partial Pressure.
- ☐ Gay Lussac's Law.
- ☐ Ideal Gas Equation.

Intermolecular Forces

 Intermolecular forces are the forces of attraction and repulsion between interacting particles.

Gases	Very little intermolecular attraction

Solids	Very strong intermolecular attraction
Liquids	Strong intermolecular attraction

	Neither definite volume nor definite shape. Particles are at great distances from one another. Particles are free to move.

Liquids **Gases**	Definite volume but indefinite shape. Particles close together but not in fixed positions. Particles are free to move.
	Definite volume and shape Particles packed in fixed positions.

Solids	Particles are not free to move.

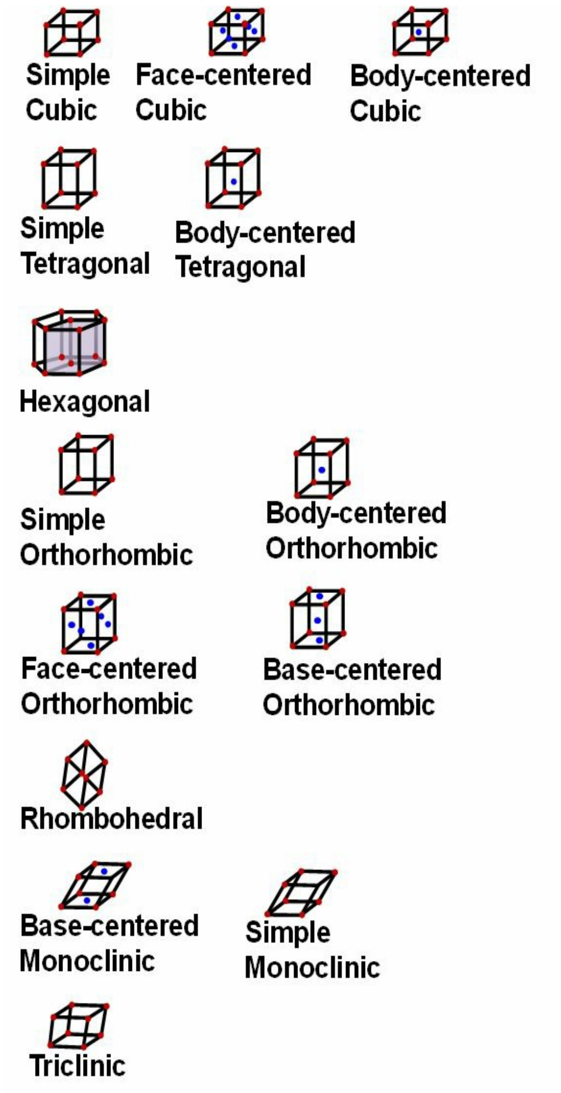
Types of Solid

	Highly regular arrangement of the components. Table salt (NaCl), Pyrite (FeS_2). More than 90% of naturally occurring and artificially prepared solids are crystalline.

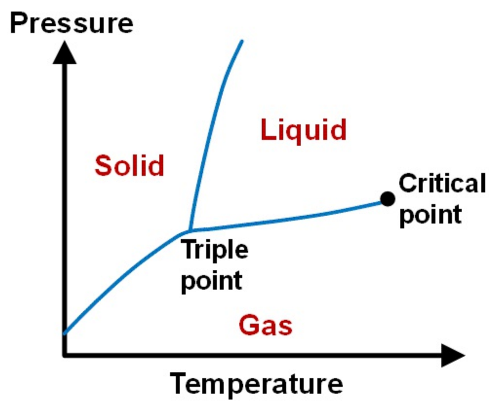
Amorphous Crystalline Solids	Considerable disorder in their structures. Glass and plastic.
	A 3-dimensional system of points designating the centers of the components that makes up the substance.

Lattice

Various Lattice Structures



Phase Diagram



- Phase diagrams represent phases as a function of temperature and pressure.
- **Critical temperature:** temperature above which the vapor cannot be liquefied.
- **Critical pressure:** pressure required to liquefy at the critical temperature.
- **Critical point:** critical temperature and pressure.

The Liquid State

- Intermolecular forces are stronger in the liquid state than in the gaseous state.
- Molecules in liquids are so close that there is very little empty space between them.
- Under normal conditions, liquids are denser than gases. Liquids have a definite volume because the molecules do not separate from each other.
- Molecules of liquids can move over one another freely. Liquids can flow, can be poured, and can assume the shape of the container in which they are stored.

Vapor Pressure

- The pressure exerted by liquid at a given temperature is called its vapor pressure.

Viscosity

 Viscosity is a measure of resistance to flow, which arises due to the internal friction between layers of fluid as they slip over one another while liquid flows.

Gases

- Gases are highly compressible. Gases exert pressure equally in all directions.
- Gases have much lower density than the solids and liquids.
- The volume and shape of gases are not fixed.
- These assume volume and shape of the container.
- Gases are mixed evenly and completely in all proportions without any mechanical aid.
- Gases are fluid – they flow. Gases effuse and diffuse.

Diffusion

- **Diffusion** describes the mixing of gases.
- The rate of diffusion is the rate at which gases mix.

Effusion

 The movement of a gas through a pore or capillary into another gaseous region or in a vacuum.

 The relative rates of effusion of two gases at the same temperature are given by the following equation:

$$\frac{Rate_1}{Rate_2} = \sqrt{\frac{M_2}{M_1}}$$

 The relative distances travelled by two gases are:

$$\frac{Distance_1}{Distance_2} = \sqrt{\frac{M_2}{M_1}}$$

 Where, M_1 and M_2 represents the atomic or molecular weights of gases.

Kinetic Energy of Gas Particles

 At the same conditions of temperature, all gases have the same average kinetic energy:

$$KE = \frac{1}{2}mv^2$$

Where,

m=mass, v=velocity

Gas Pressure

- **Gas pressure** is caused by the collisions of molecules with the walls of a container and is equal to force/unit area.
- **SI units = Newton/meter^2 = 1 Pascal (Pa).**
- 1 standard atmosphere = 101.3 kPa.

Unit/Symbol/Definition

Millimeter of mercury

mm Hg

Pressure that supports a 1 mm column of mercury in a barometer.

Atmosphere
Atm

Average atmospheric pressure at sea level and 0°C.

Gas Laws

 This law includes Boyle's Law, Charles' Law, Avogadro's Law, Dalton's Law, Gay-Lussac's Law.

Combined Gas Law

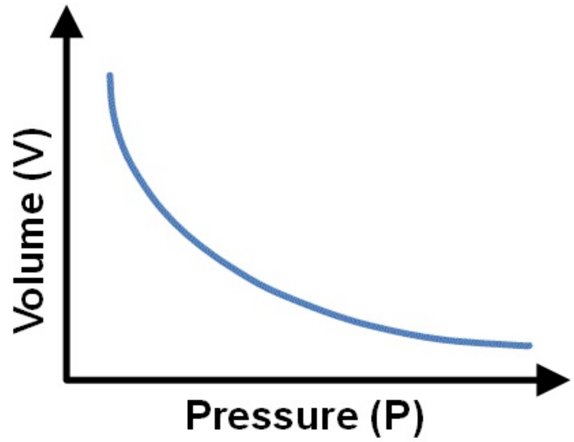
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

 The combined gas law expresses the relationship between pressure, volume and temperature of a fixed amount of gas.

 Boyle's law, Gay-Lussac's law, and Charles' law can be derived from this by holding a variable constant.

Boyle's Law

(Pressure-Volume relationship)



□ "At constant temperature, the pressure of a fixed amount (i.e., number of moles n) of gas varies inversely with its volume."

$$P \propto \frac{1}{V} (at\ constant\ T\ and\ n)$$

$$P = k_1 \frac{1}{V}$$

$$\left(\text{where, } k_1 \text{ is the proportionality constant}\right)$$

□ If a fixed amount of gas at a constant temperature **T** occupying volume **V_1** at pressure **P_1** undergoes expansion so that the volume becomes **V_2** and the pressure becomes **P_2**, then according to Boyle's law:

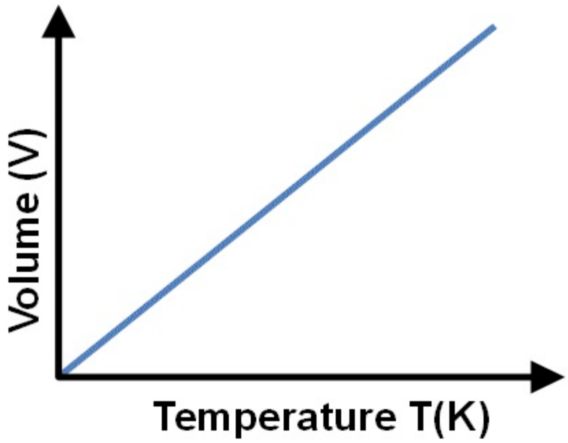
$$P_1V_1 = P_2V_2 = constant$$

□ Note that the gas law problems involving temperature require that the temperature be in Kelvins

$$Kelvins = °C + 273$$

Charles's Law

(Temperature-Volume Relationship)



□ Pressure remaining constant, the volume of a fixed mass of gas is directly proportional to its absolute temperature.

$$V = k_2 T$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Absolute Temperature Scale

- 0^o **Celsius** on the Celsius scale is equal to 273.15 **Kelvin** at the absolute scale.

Absolute Zero

 The lowest hypothetical or imaginary temperature at which gases are supposed to occupy zero volume is called **absolute zero**.

Avogadro's Law

(Volume – Amount Relationship)

□ **Avogadro's law states that:** "Equal volumes of all gases under the same conditions of temperature and pressure contain an equal number of molecules."

$$V \propto n$$

- Where, **n** is the number of moles of gas and V is the volume of gas.

$$V = k_3 n$$

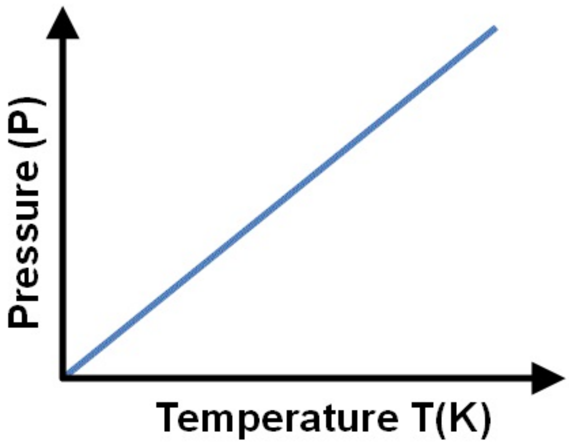
- The number of molecules in one mole of a gas has been determined to be **6.022×10^{23} mol^{-1}** and is known as **Avogadro's constant**.

Dalton's Law of Partial Pressure

 It states that: "Total pressure exerted by a mixture of non-reacting gases is equal to the sum of the partial pressures exerted by them."

$$P = P_1 + P_2 + P_3 + P_4 \ldots$$

Gay Lussac's Law



 "The pressure and temperature of a gas are directly related, provided that the volume remains constant."

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Ideal Gas Equation

 A gas that strictly follows Boyle's law, Charles' law, and Avogadro's law is called an **ideal gas**.

 Such a gas is hypothetical.

 The ideal gas equation is given by:

$$PV = nRT$$

Where,
P = pressure in **atm**
V = volume in **liters**
n = **moles**
R = proportionality constant
= 0.08206 L **atm/mol•K**
T = temperature in **Kelvins**

Chapter 09:

Fluid and Particle Dynamics

Topics covered in this snack-sized chapter:

- Introduction.
- Fluid.
- Categories of Fluid Mechanics.
- Laminar and Turbulent Flows.
- Streamlines, Streak Lines, Path Lines.
- Reynolds Number.
- Fluid Dynamics.
- Fundamentals of Particle Dynamics.

Introduction

- Fluid mechanics is the study of fluids and the forces on them.
- Fluid Mechanics is the area of physics which mathematically describes the behavior of fluids at rest (fluid statics) and in motion (fluid dynamics).

Fluid

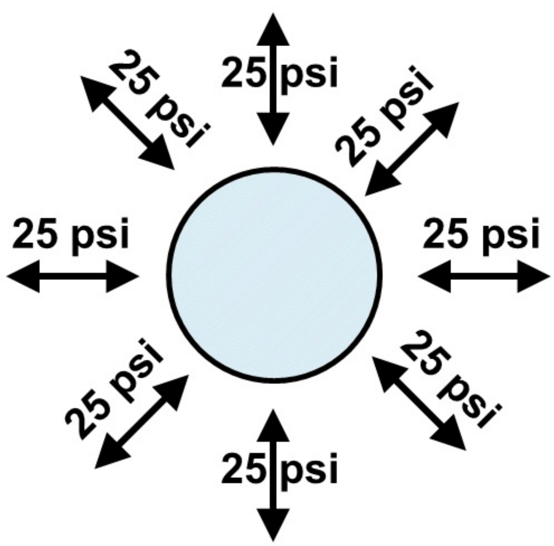
- Any substance which can flow, we normally think of fluids as either liquids or gases, but there are also cases where solids such as fine powders can behave as fluids.
- A solid generally has a definite shape; a fluid has a shape determined by its container.
    - Fluids include liquids, gases and vapors, or mixtures of these.

Categories of Fluid Mechanics

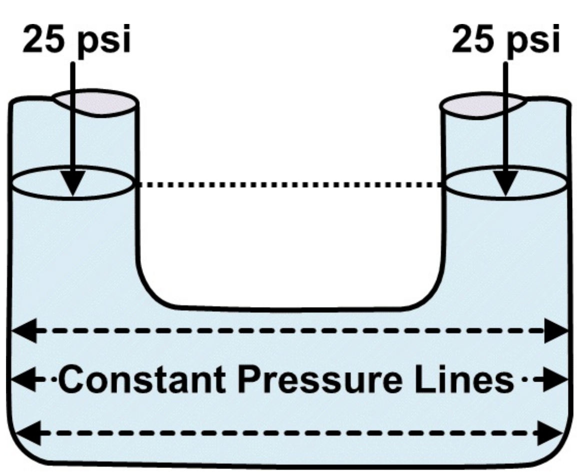
- Fluid mechanics are classified in following categories
  - Fluid statics
  - Fluid kinematics
  - Fluid dynamics

Fluid Statics

- The study of fluids at rest.
- For a fluid at rest or moving in such a manner that there is no relative motion between particles there are no shearing forces present is known as Fluid Statics.
- The figure below shows that if pressure with the same magnitude and opposite direction is applied to the object or fluid it does not alter its position.



- If pressure with equal magnitude is applied at both ends of the tube:
  - Fluid remains in a stationary condition. This is shown is figure below.



Fluid kinematics

- Kinematics is the branch of mechanics that deals with quantities involving space and time only.
- It is used to describe the motions of particles and objects, but does not take the forces that cause these motions into account.

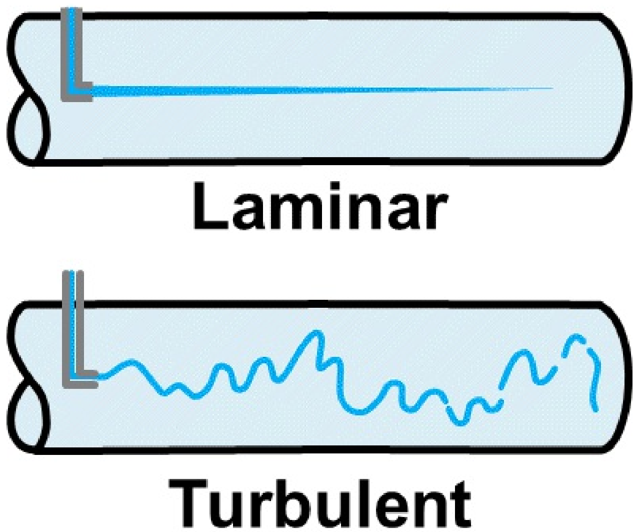
Laminar and Turbulent Flows

Laminar Flow

- It is sometimes known as streamline flow, occurs where the fluid moves slowly in layers in a pipe, without much mixing between the layers.

Turbulent Flow

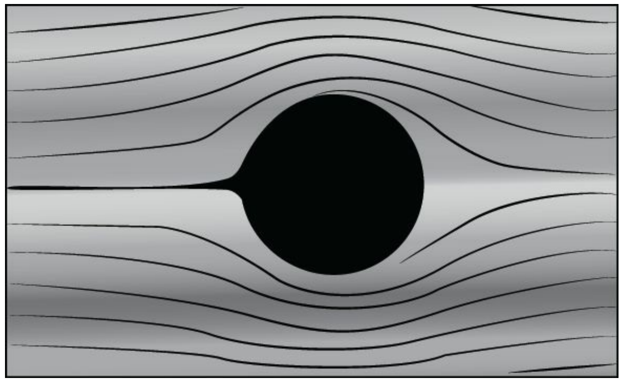
- Opposite of laminar, where considerable mixing occurs, velocities are high.



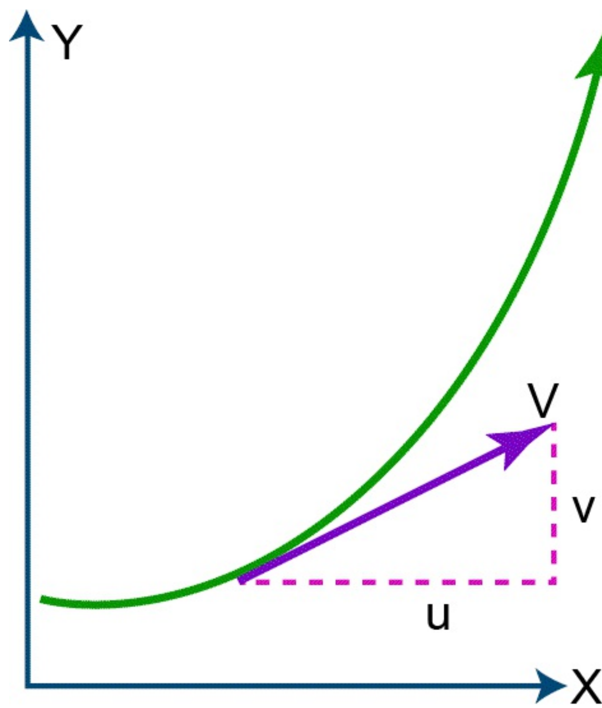
Streamlines, Streak Lines, Path Lines

- Streamlines, streaklines and pathlines are used in the visualization of fluid flow.
  - Streamlines mainly used in analytic work.
  - Streaklines and pathlines used in experimental work.

Streamlines



- A curve that is everywhere tangent to the direction of the velocity vectors is called a streamline.
- Streamlines are tangent to the velocity field.
- Below is a photograph of streamlines for laminar flow around an object.



- The slope of the streamline is equal to the tangent of velocity field.

$$\frac{dy}{dx} = \frac{v}{u}$$

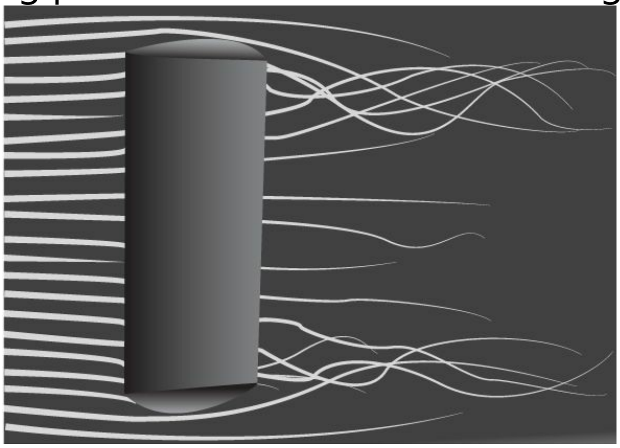
  - The streamlines can be determined from velocity field by integrating the lines define the tangents.

Path Lines

- A Path line is the actual path traveled by an individual fluid particle over some time period from one point to the next.

Streak Lines

- Streak lines consist of all the particles in a flow that have passed through a common point.
- Streaklines of smoke moving past obstruction shown in the figure below:



- For steady flow:

$$\text{streamline} = \text{streakline} = \text{pathline}$$

Reynolds Number

- Whether a flow will result in laminar or turbulent flow is primarily determined by the Reynolds number (R_e),

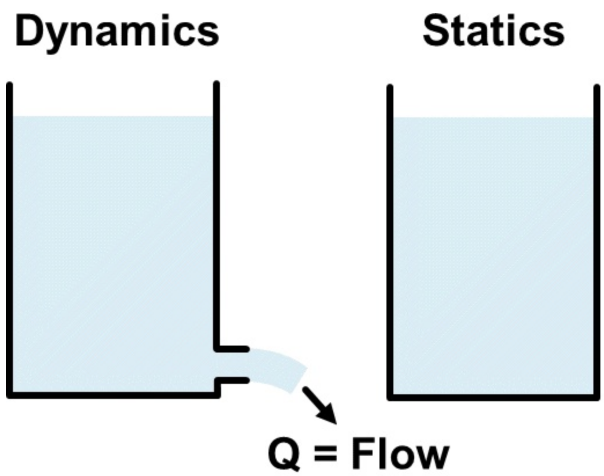
$$Re = \frac{\rho v D}{\mu}$$

- Density is ρ, diameter of pipe is D, fluid velocity is v and viscosity is μ.
  - The flow is laminar for **Re < 2000,**
  - The flow is transitional between **2000 < Re < 4000,**
  - The flow is turbulent for **Re > 4000,**

Fluid Dynamics

□ Fluid dynamics is a sub-discipline of fluid mechanics that deals with fluid flow.

□ The study of the effect of forces on fluid motion is known as Fluid dynamics.



□ The solution to a fluid dynamics problem typically involves calculating various properties of the fluid, such as velocity, pressure, density and temperature, as functions of space and time.

Particle:

□ A Particle is an object whose size and shape can be ignored when studying its motion.

□ Only the position of the mass center of the particle needs to be considered.

Fundamentals of Particle Dynamics

- The fundamentals of Particle Dynamics are based on the three Laws of Motion, as propagated by Sir Isaac Newton.
- Newton's three laws of motion are the rules that tell us how the velocity as well as the energy and momentum of an object can change.

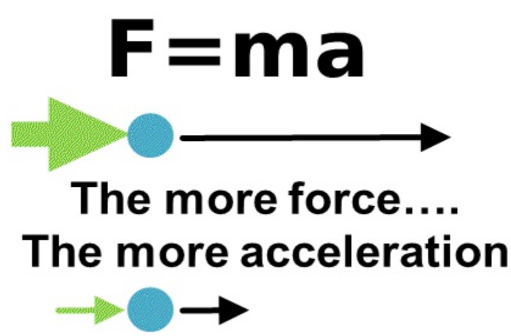
Newton's First Law:

- Newton's first law of motion states that an object at rest tends to stay at rest and an object in motion continues in motion with the same speed and in the same direction unless acted on by an outside force. This is also called Inertia.

Newton's Second Law:

- When a particle acts on by an unbalanced force, the particle will be accelerated in the direction of the force

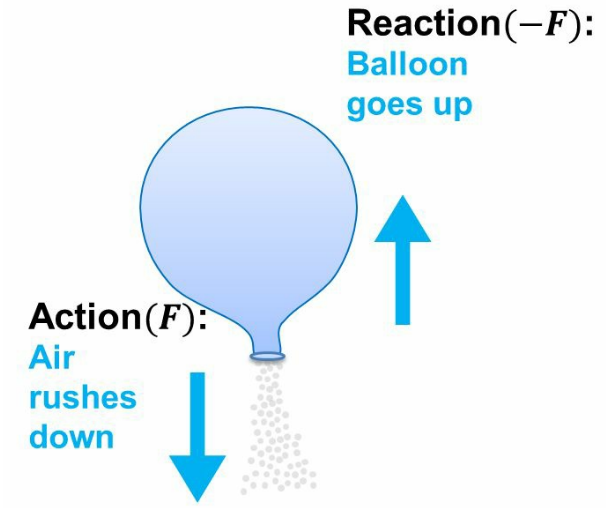
  then magnitude of the acceleration will
  be directly proportional to the force and inversely proportional to the mass of the particle.



- Where,
  - **F** is the external force acting on the body,
  - **m** is the mass of the body,
  - **a** is the acceleration of the particle in the direction of the force,

Newton's Third Law:

- For every action there is an equal and opposite reaction.
- The forces of action (F) and reaction $(-F)$ between contacting bodies are equal in magnitude and opposite in direction.
- This is sometimes called the Law of Action and Reaction.



- Example:
  - In the above figure enclosed air particles push balloon wall outwards and the balloon wall pushes enclosed air particle inwards.

Chapter 10: Solutions

Topics covered in this snack-sized chapter:

- Solutions.
- Solute.
- Solvent.
- The Heat of Solution.
- Electrolyte.
- Suspensions.
- Colloids.
- Solubility.
- Factors Affecting Solubility.
- Effect of Temperature.
- Nature of Solute and Solvent.
- Effect of Pressure.
- Solubility of Gases: Henry's Law.
- Raoult's Law for Non-Volatile Solute.
- Raoult's Law for Volatile Solute.
- Type of Solutions.
- Mole Fraction.
- Molality (m).
- Molarity (M).
- Elevation of Boiling Point.
- Depression of Freezing Point.
- Osmosis.
- Osmotic Pressure.
- Isotonic Solutions.
- Common Terms Used.

Solutions

- A solution is a homogeneous mixture of two or more substances.

Solute

- A solute is the dissolved substance in a solution.
    - Salt (solute) in salt water
    - Sugar (solute) in milk

Solvent

- A solvent is the dissolving medium in a solution.
  - Water (solvent) with salt water
  - Milk with (solvent) sugar

The Heat of Solution

 The heat of a solution is the amount of heat energy absorbed (endothermic) or released (exothermic) when a specific amount of solute dissolves in a solvent.

Electrolyte

- A substance whose aqueous solution conducts an electric current.
  - **Example:** Tap water, NaCl solution.

Suspensions

- A suspension is a heterogeneous mixture in which solute-like particles settle out of a solvent-like phase sometime after their introduction.
- The particles are so large (larger than 1 micrometer) that they settle out of the solvent if not constantly stirred.
  - Example: Sand in water.

Colloids

- A type of homogeneous mixture in which the dispersed particles do not settle out.
- The particle is intermediate in size between those of a suspension and those of a solution.
  - Examples: Smoke, blood, fog, milk etc.

Solubility

 The solubility of a solute in a solvent at a particular temperature is defined as “the number of grams of the solute necessary to saturate 100gm of the solvent at that temperature”.

Factors Affecting Solubility

- There are three main factors that control solubility of a solute:
  - Temperature
  - The nature of solute or solvent
  - Pressure

Effect of Temperature

- Generally, solubility increases with a rise in temperature and decreases with a fall of temperature but this is not necessary true in all cases.
- In endothermic processes, solubility increases with the increase in temperature and vice versa.
  - Example: the solubility of potassium nitrate increases with the increase in temperature
- In exothermic processes, the solubility decreases with the increase in temperature.
  - Example: the solubility of calcium oxide decreases with the increase in temperature
- The solubility of solids increases with temperature
  - The rate at which solids dissolve increases with increasing surface area of the solid
- Gases are more soluble in cold solvent than in hot solvent.

Nature of Solute and Solvent

- The solubility of a solute in a solvent purely depends on the nature of both solute and solvent.
- A polar solute dissolved in a polar solvent.
- Solubility of a non-polar solute in a solvent is large.
- A polar solute has low solubility or is insoluble in a non-polar solvent.

Effect of Pressure

- The effect of pressure is observed only in the case of gases.
- An increase in pressure increases the solubility of a gas in a liquid.
  - Example: carbon dioxide is added to cold drinks (such as Coca Cola, Pepsi etc.) under pressure.

Solubility of Gases: Henry's Law

□ Henry's law is used to quantify the solubility of gases in solvents.

□ The solubility of a gas in a liquid is directly proportional to the pressure of the gas.

$$p = k_H c$$

□ Where:

$\mathbf{k_H}$ is a temperature-dependent constant

p is the partial pressure (atm), and

$\mathbf{c}$ is the concentration of the dissolved gas in the liquid (mol/L)

Raoult's Law for Non-Volatile Solute

□ Partial vapor pressure of a solvent over a solution of non-volatile solute is directly proportional to the mole fraction of the solvent in the solution.

$$p_{solution} = x_{solvent} \times p^{o}_{solvent}$$

□ Where:

$p^{o}_{solvent}$ is the vapor pressure of the pure solvent at a given temperature.

$$\frac{p_{solution}}{p^{0}_{solvent}} = x_{solvent}$$

$$\frac{p^{0}_{solvent} - p_{solution}}{p^{0}_{solvent}} = x_{solute}$$

Raoult's Law for Volatile Solute

This law states that:

- For a solution of volatile liquids the partial vapor pressure of each component in the solution is directly proportional to its mole fraction.
- If A and B are the components of a solution with mole fractions $\mathbf{x_A}$, $\mathbf{x_B}$ respectively, then by this law we have:

$$p_A = x_A p_A^o$$

$$p_B = x_B p_B^o$$

Type of Solutions

- **Saturated:** A solution that contains the maximum amount of solute that may be dissolved under existing conditions.
- **Unsaturated:** A solution that contains less solute than a saturated solution under existing conditions.
- **Supersaturated:** A solution that contains more dissolved solute than a saturated solution under the same conditions.

Mole Fraction

□ The mole fraction x_A of a component "A" in solution with another component "B" is defined by:

$$x_A = \frac{n_A}{n_A + n_B}$$

Where:

- N is the number of moles.

Molality (m)

 The molality of a solution is defined as the number of moles of the solute that are present in 1 kg of the solvent.

$$m = \frac{moles\ of\ solute}{Number\ of\ kilograms\ of\ solvent}$$

 Molality of a solution remains constant with the variation of temperature.

Molarity (M)

 The molarity of a solution is expressed as the number of moles of a solute present in 1 liter of the solution.

$$M = \frac{moles\ of\ solute}{Number\ of\ liters\ of\ solution}$$

 The molarity of a solution changes with temperature.

Elevation of Boiling Point

□ The elevation of boiling point ΔT_b is directly proportional to the molal concentration of the solute in the solution.

$$\Delta T_b = K_b m$$

□ Here, **m** (molality) is the number of moles of solute in 1 kg of solvent.

□ The constant of proportionality K_b is called the **boiling point elevation constant**.

Depression of Freezing Point

□ The depression of the freezing point ΔT_f is directly proportional to molality, m of the solution.

$$\Delta T_f = K_f m$$

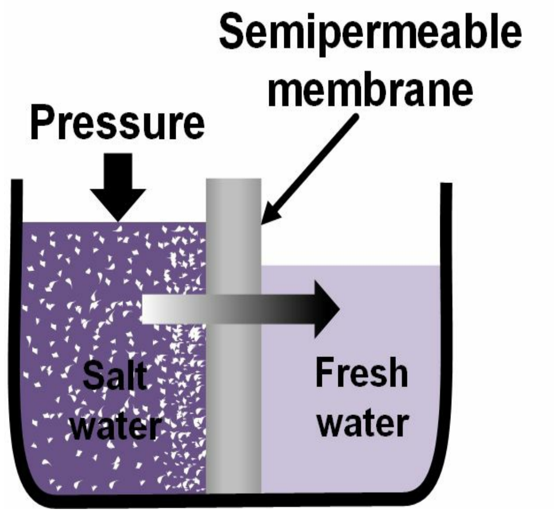
Where:

m (molality) is the number of moles of solute in 1 kg of solvent

K_f is called the Freezing Point Depression Constant.

Osmosis

- Osmosis is the phenomenon in which a solution is separated from a solvent by a **semi-permeable membrane** that:
  - Allows the flow of the solvent into a region of higher solute concentration, aiming to equalize the solute concentrations on the two sides



- It may also be used to describe a physical process in which any solvent moves, without input of energy.
- The net movement of a solvent is from the less-concentrated **(hypotonic)** to the more-concentrated **(hypertonic)** solution, which tends to reduce the difference in concentrations.

Osmotic Pressure

□ The flow of the solvent to the solution separated by a semipermeable membrane can be stopped if some definite extra pressure is applied to the solution.

□ The pressure that stops the flow of solvent into the solution is called **Osmotic Pressure** and it is denoted by π.

□ The osmotic pressure is proportional to the molarity (**M**), of the solution at a given temperature **T**.

$$\pi = MRT$$

$$\pi = \frac{n}{V}RT$$

Where:

- **R** is the gas constant
- **V** is the volume of a solution in liters containing **n** moles of the solute

- If **w** grams of solute whose molecular mass is M_{solute} be present in the solution, then:

$$\pi V = \frac{w}{M_{solute}} RT$$

$$M_{solute} = \frac{wRT}{\pi V}$$

- Osmotic pressure is a colligative property, which depends only on the number of dissolved particles in solution and not on their identity.
  - Osmotic pressure depends on the molar concentration of the solute but not on its identity.

Isotonic Solutions

- Solutions having the same osmotic pressure are called **isotonic solutions**.
  - Example: normal saline solution (0.9% NaCl) is considered isotonic with blood (although it actually has a slightly higher degree of osmolality).

Common Terms Used

Concentration:

 A measure of the amount of solute in a given amount of solvent or solution.

Grams per Liter:

 The mass of solute divided by the volume of a solution, in liters.

Parts per Million

 The ratio of parts of solute to one million parts of solution.

Percent Composition:

 The ratio of one part of solute to one hundred parts of the solution, expressed as a percent.

Chapter 11: Chromatography and Types

Topics covered in this snack-sized chapter:

- Chromatography.
- Adsorption Chromatography.
- Column Chromatography.
- Thin Layer Chromatography.
- Partition (Paper) Chromatography.

Chromatography

- The name chromatography is based on the Greek word "Chroma," for color.
  - Since the method was first used for the separation of colored substances found in plants.
- This method is used to identify, purify and/or separate constituents of a mixture that are present in very small amounts.
- This is based on the differential absorption of the different constituents of mixture on various absorbents.
  - For example, magnesium oxide, silica gel, etc.
- The mixture is dissolved in a fluid called the mobile phase, which carries it through a structure holding another material called the stationary phase.
- The various constituents of the mixture travel at different speeds, causing them to separate. The separation is based on differential partitioning between the mobile and stationary phases.
- Types of Chromatography are:
  - Adsorption chromatography and
  - Partition chromatography

Adsorption Chromatography

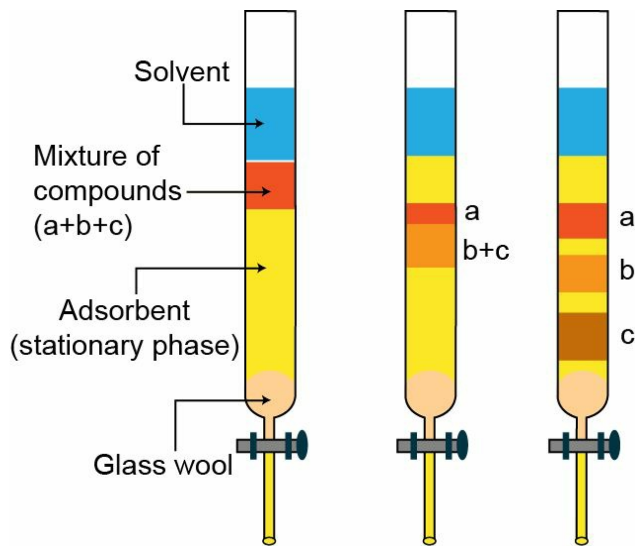
- Adsorption chromatography is based on the fact that:
  - Different compounds are adsorbed on an adsorbent to different degree.
  - Commonly used adsorbents are cellulose, paper, silica gel and alumina.

Method:

- In this technique, the mixture of substances is applied onto a stationary phase, which may be a solid or a liquid.
- A pure solvent or a mixture of solvents, or a gas, is allowed to move slowly over the stationary phase.
- The components of the mixture get gradually separated from one another.
- Following are two main types of chromatography techniques based on the different adsorption principles.
  - Column chromatography, and
  - Thin layer chromatography

Column Chromatography

- Column chromatography involves separation of a mixture over a column of adsorbent (stationary phase).
  - Packed in a long burette-like glass tube,
  - The column is fitted with a stopcock at its lower end.
  - A plug of cotton or glass wool is placed at the bottom of the column to support the adsorbent.
  - One-fourth of the tube is left empty.
- An appropriate eluent, which is a liquid or a mixture of liquids, is allowed to flow down the column slowly.
- Depending upon the degree to which the compounds are adsorbed, complete separation takes place.
- The most readily adsorbed substances are retained near the top and others come down to various distances in the column.

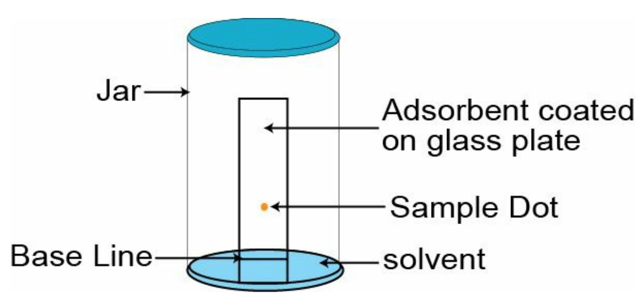


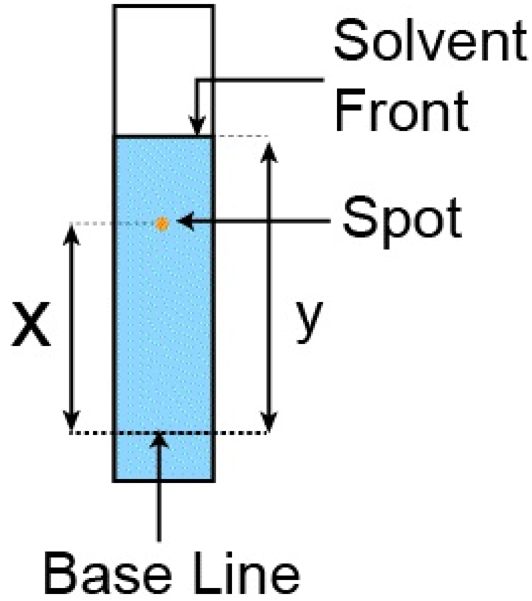
Thin Layer Chromatography

- In this chromatography, the stationary phase is a thin layer of an adsorbent (generally alumina) coated on a flat glass strip.
  - The solvent (mobile phase) moves up the layer due to the capillary action and thus causes the separation of the constituents of the mixture.
  - The constituents are identified by measuring their R_F values.
- **Thin layer chromatography (TLC)** is another type of adsorption chromatography.
  - Which involves separation of substances of a mixture over a thin layer of an adsorbent coated on glass plate.
- A thin layer (about 0.2mm thick) of an adsorbent (silica gel or alumina) is spread over a glass plate of suitable size.
  - The plate is known as a thin layer chromatography plate or Chroma plate.
  - The solution of the mixture to be separated is applied as a small spot about 2 cm above one end of the TLC plate.
  - The glass plate is then placed in a closed jar containing the eluent.
  - As the eluent rises up the plate, the components of the mixture move up along with the eluent to different distances depending on their degree of adsorption and separation takes place.
  - The relative adsorption of **each component of the mixture** is expressed in terms of its retardation factor, i.e., R_f value.

$$R_f = \frac{\text{Distance moved by the substance from base line (x)}}{\text{Distance moved by the solvent from base line (y)}}$$

- The spots of colorless compounds, which are invisible to the eye, can be detected by putting the plate under ultraviolet light.
- Another detection technique is to place the plate in a covered jar containing few crystals of iodine.
  - Spots of compounds, which adsorb iodine, will show up as brown spots.
  - Sometimes, an appropriate reagent may also be sprayed on the plate.
- **For example,** amino acids may be detected by spraying the plate with ninhydrin solution.




Solvent
Front
Spot
x
y
Base Line

Partition (Paper) Chromatography

□ Paper chromatography is an analytical method technique for separating and identifying mixtures that are or can be colored, especially pigments.

□ Partition chromatography is based on:

- **Continuous differential partitioning** of the components of a mixture between stationary and mobile phases.
- **Paper chromatography** is a type of partition chromatography.

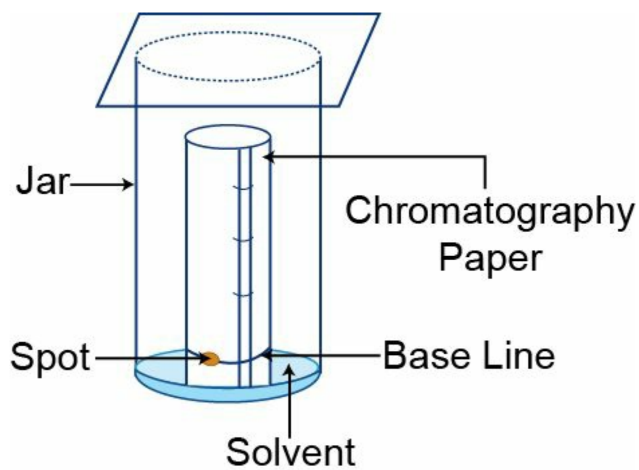
□ **Method:**

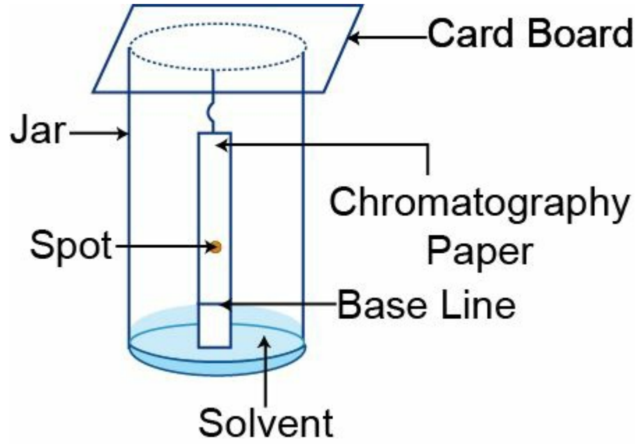
□ In paper chromatography, a special quality paper known as chromatography paper is used.

□ Chromatography paper contains water trapped in it, which acts as the stationary phase.

□ A strip of chromatography paper spotted at the base with the solution of the mixture is suspended in a suitable solvent or a mixture of solvents.

- This solvent acts as the mobile phase.
- The spots of the separated colored compounds are visible at different heights from the position of the initial spot on the chromatogram.
- The spots of the separated colorless compounds may be observed.
- Either under ultraviolet light or
- By the use of an appropriate spray reagent.




Card Board
Jar
Chromatography
Paper
Spot
Base Line
Solvent

Chapter 12: Unit Process and Process Control

Topics covered in this snack-sized chapter:

- Unit Processes.
- Nitration.
- Halogenation.
- Sulphonation.
- Process Control.
- Types of Process Control Systems.
- Process Variables.
- Statistical Process Control.

Unit Processes

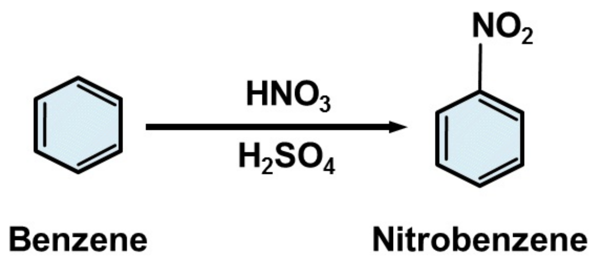
- A Unit Process is a step in manufacturing in which chemical reaction takes place.
- Unit process means there are chemical changes occurs:
  - Nitration
  - Halogenation
  - Sulphonation

Nitration

□ Nitration is a general chemical process for the introduction of a nitro group into a chemical compound.

□ Nitration is especially useful because the nitro group can be reduced to an NH2 group.

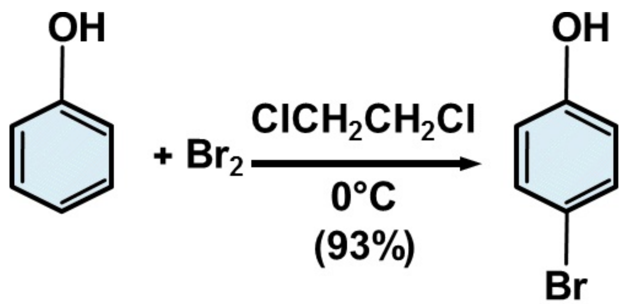
□ Nitration of Benzene



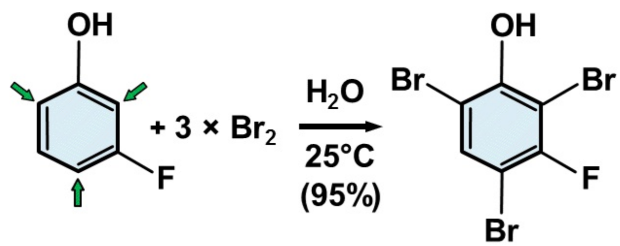
- o Sulfuric Acid Activation of Nitric Acid
- o The first step in the nitration of benzene is to activate HNO3 with sulfuric acid to produce a stronger electrophile, the nitronium ion.

Halogenation

- Halogenation replaces an H on benzene by a chlorine or bromine atom.
- Halogenation adds a chlorine or bromine atom to phenol.
- A catalyst such as $FeCl_3$ is used in chlorination; $ClCH_2CH_2Cl$ in bromination.
- Halogenation of Phenols - Non-Polar Solvents.



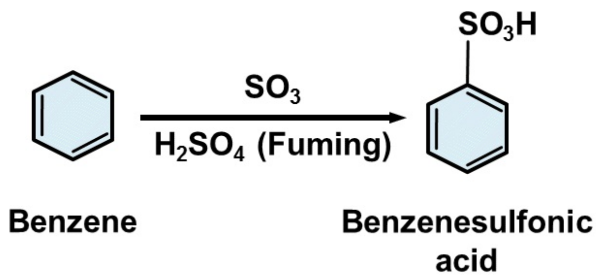
  - Mono-halogenation occurs in non-polar solvents (1, 2-dichloroethane).
- Halogenation of Phenols - Polar Solvents



  - Multiple halogenation in polar solvent (water)

Sulphonation

- Carried out using concentrated sulfuric acid containing dissolved sulfur trioxide.
- Concentrated sulfuric acid containing dissolved sulfur trioxide is fuming sulfuric acid.
- The sulphonation reaction is reversible whereas the halogenation and nitration reactions are not.
- Sulphonation of Benzene:



  - To produce benzene sulfonic acid from benzene, fuming sulfuric acid and sulfur trioxide are added.
  - Fuming sulfuric acid, also referred to as oleum, is a concentrated solution of dissolved sulfur trioxide in sulfuric acid.
  - The sulfur in sulfur trioxide is electrophilic because the oxygen pulls electrons away from it because oxygen is very electronegative.
  - The benzene attacks the sulfur (and subsequent proton transfers occur) to produce benzene sulfonic acid.

Process Control

- The field of control within chemical engineering is often known as process control.
- It deals primarily with the control of variables in a chemical process in a plant.
- Process control means the effective changing of the process based on the outcomes of process monitoring.
- In other word process control is the technique that is used during the manufacturing of a product to control process variables.
- Manufacturers control the process of production chiefly for 4 reasons:
  - Increase the efficiency of the production
  - Ensure security
  - Reduce the variability
  - Increase productivity
- The maximum use of the process control can be found in various industries like oil refining, chemicals, paper manufacturing, power plants and many more others. It allows the mass production of nonstop processes of these industries.
- Automation can be enabled through process control that can help a small staff or operating staff to control a complex process from a central control room.
- Two types of involvements are possible in the system of process control, among these two, one is automated and the other one is based on the considered opinion of the engineers.
  - Out-of-control action plans, where a detail of the action that to be taken if any out-of-control situation arrives.
  - The process engineer normally has a flow chart with a proper procedure in order to handle each exclusive out-of-control process.
  - On the other hand there are some Advance Process Control Loops that bring the automated changes to the process in order to control the out-of-control measurement.

Types of Process Control Systems

- **Discrete**: Mainly found in motion, packaging and manufacturing applications.
- **Batch:** Some applications need that exact amounts of raw materials to be united in definite methods for particular durations to create a transitional or final result.
- **Continuous:** The control of the water temperature in a heating jacket is an example of continuous process control, where physical system is symbolized with the help of variables that are even and continual in time.
- **The Significance of Process Control:** The system of process control has great impact on the entire procedure of production of various products.
- The main impacts of process control are as follows:
  - Since process control reduce the variability, so it can save money by reducing the requirement of product padding to obtain the needed product specifications.
  - Some processes are meant to enhance the efficiency of the production. The efficiency of the process can be ensured by the accurate control of temperature.
  - Process control is also very important in order to ensure the safety of the entire production.
  - Some great loss can be happen during processes due to chemical or nuclear reactions. However, it can be controlled if manufacturers maintain a specific control of all the processing variables.
  - With the quality of reducing variability, process control ensures the high quality of the products.

Process Variables

- A process variable refers to the condition of the process fluid, may be liquid or gas, which can change the process of manufacturing in some ways.
- For instance, if anyone is sitting near the fire then in that situation temperature would be considered as the process variable.
- Some common process variables are:
  - Pressure
  - Temperature
  - Level
  - Flow
  - Density
  - ph (acidity or alkalinity)
  - Mass
  - Liquid interface (the relative amounts of different liquids that are combined in a vessel)
  - Conductivity

Statistical Process Control

 Statistical Process Control that is mostly used as SPC is an efficient technique of checking a process with the help of control charts.

 The quality of the final product or the service can be detected and corrected by collecting data from the samples at several points during the process.

 This helps to reduce the waste at the final production and lessen the chances to deliver defective products to the customers as well.

 It is really very significant in the early exposure and prevention of the problems.

 The term Multivariable Process Control is a kind of Statistical Process Control or SPC, where a group of variables is detected and the combined variations of this group are captured with the help of a step test.

Chapter 13:
Transport and Storage of Fluids

Topics covered in this snack-sized chapter:

Transport and Storage of Fluids.
Transport of Fluids.
Storage of Fluids.
Future of Chemical Engineering.
Research and Development of Plastics.
Future Prospects of a Chemical Engineer.

Transport and Storage of Fluids

 Transportation and Storage of Fluids includes and involves the research and understanding of the properties and behaviors shown by the fluids.

 The subject mainly revolves around the study of fluid dynamics i.e. the motion of fluids in the force field.

Transport of Fluids

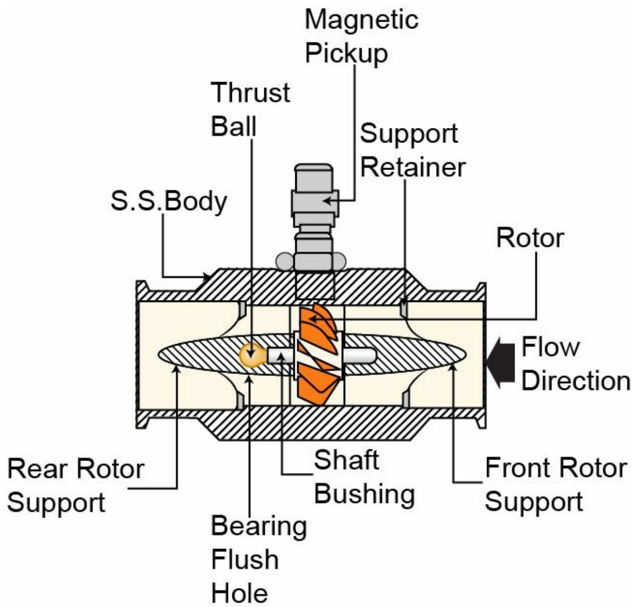
- Transport or flow of fluid can be classified into two categories:
  - Incompressible flow
  - Compressible flow
- Another very important factor of the flow or transportation and storage of fluid is the measurement of flow.
- It is the area that deals with the various techniques of measuring the pressures, temperatures, velocity and the rate of flow of a particular liquid.
- Measurement of flow on the other hand deals with pressure, which is of two types:
  - Local Static Pressure
  - Average Static Pressure

Local Static Pressure

- It is the pressure on the stationary surface of the liquid or the fluid on a static surface parallel to the flow.

Average Static Pressure

- Average static pressure is measured by obtaining a suitable average value when the flow of the liquid is in straight lines parallel to the confining walls, such as in straight ducts that are kept at sufficient distance downstream from bends or other types of disturbances.
- Other factors involving the transport and storage of fluids are:
  - Static temperature
  - Velocity Measurements
- The different equipment's used in measurement of flow and storage of liquid are:
  - Resistive Thermal Detectors
  - Anemometers
  - Turbine Flow Meter
  - Current Meter
  - Laser Doppler Anemometer
  - Flow Visualization Meter
  - Pitometer
  - Liquid Column Manometers
  - Multiplying Gauge



Turbine Flow Meter

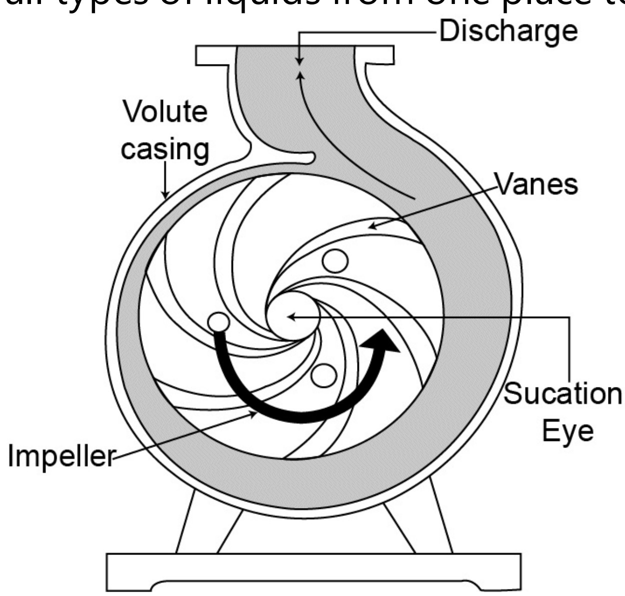
 Now, one of the most important applications of storage and transportation is pumping of liquids.

 We can make fluids flow through a channel by the following methods:

- By the action of the centrifugal force
- By the volumetric displacement
- By mechanical impulse
- By the transfer of momentum
- By the electromagnetic force
- By the gravitational force

 Several pumps are used for the transportation and storage of fluids. They are:

 Centrifugal Pumps: These pumps are mainly used in the chemical industry for transferring or transporting all types of liquids from one place to another.



Centrifugal Pumps

 Process Pumps: There are various applications of process pumps and accordingly, the types of process pump varies – double suction single stage pump, close couple pump, canned motor pump, inline vertical pump.

- **Sump Pumps:** These are single stage vertical pump, which are used to drain liquid or fluid out shallow pits or sumps.
- **Propeller Pumps:** They are very high-capacity pumps and they are used for the transportation or flow of liquid at a speed more than 200 gallons per minute.
- **Turbine Pumps:** These pumps are driven by turbines and are used in facilitating mixed flow of liquids.
- **Regenerative Pumps:** These types of pumps apply a combination of mechanical impulse as well as centrifugal force.
- **Positive-Displacement Pumps:** There are different types of Positive-Displacement pumps like reciprocating pump. Again, there are 3 types of reciprocating pumps – piston pumps, diaphragm pumps and plunge pumps.
- **Rotary Pumps:** These pumps facilitate the displacement of fluid by rotation. Various types of Rotary pumps are Gear Pumps and Screw Pumps.
- **Fluid Displacement Pumps:** It displaces a liquid with the help of a secondary fluid instead of any mechanical action.
- **Jet Pumps:** These pumps transport fluids by the application of high speed and high pressure jets.

Storage of Fluids

- Another phenomenon that comes into the frame of discussion automatically with the transport or flow of liquid is storage. Now, storage of fluid involves the usage of tanks of several types.
- Various tanks used for the purpose are:
  - **Atmospheric Tanks:** These types of tanks are designed mainly to maintain an atmospheric pressure of more or less a few lbs of pressure per square feet.
  - **Pressure Tanks:** These tanks are cylindrical in shape with a cone or dome-shaped roof which exerts pressure more than a few lbs per square feet.
  - **Underground or Pond Storage tanks:** These tanks are used to store low cost fluids which remain unaffected by rain and various forms of pollutions occurring because of exposure to atmosphere.
  - **Thermal storage tanks:** One form of seasonal thermal energy storage (STES) is the use of large surface water tanks that are insulated and then covered with earth berms to enable the year-round of solar-thermal heat that is collected primarily in the summer for all-year heating.
  - The thermal storage medium is gravel and water in large, shallow, lined pits that are covered with insulation, soil and grass.

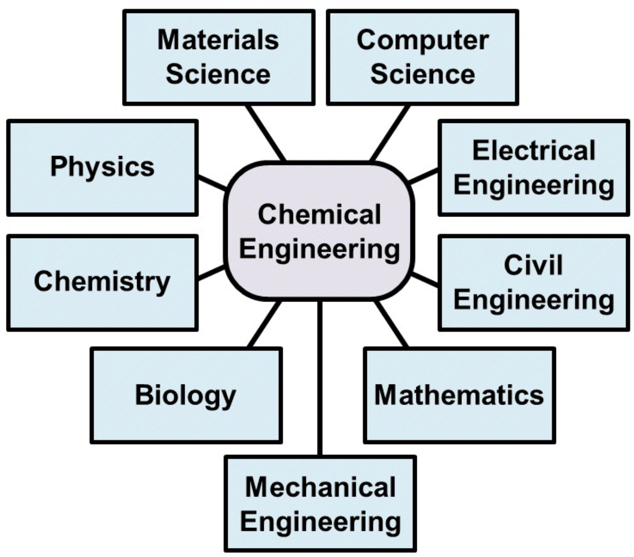
Future of Chemical Engineering

 Chemical Engineering holds a bright future not only for the industrial research and developments but also for the emerging students.

 The following are the areas where Chemical Engineering is likely to play a very important role.

- Research on "Nanocom" and "Nanomaterial"
- Research and development on Polymer Nano reinforcement.
- Future research and synthesis of organic materials and compounds.
- Research in the field of Quantum biochemistry.

Chemical Engineering at the Center



Chemical Engineering is connected to many disciplines

- Research and development of Biosynthesis.
- Research and development of proteins and small-molecule drugs at atomic resolution.
- Development of Molecular Electronics and its background and study of Molecular Electronics and Molecular Computing.
- Research on Quantum Dots and their unique properties.
- Use of molecular electronics in the further development of bioelectronics.

Research and Development of Plastics

- Engineering and manufacturing of biodegradable plastic compounds.
- Development of polypropylene compounds rich in minerals which are used for the development and designing of a wide variety of new age garden furniture and other applications of daily use.
- Development of PBT filled with glass, mineral and various fire retardant additives.
- Development of nylon containing glass as well as minerals.
- Development of fire-retardant, thermoplastic, compounds which are based on polyolefin.
- Development of Master Batches which can be used as additives.
- Research and development of Carbon nanotubes.
- Monitoring of chemical injections.
- Extension of Microcells.
- Developing the properties of polymer by the additives which play a significant role in the development and growth of plastics, and this is poised to develop further in the future with the help of chemical engineering.
- Research and development of high-performance additives.
- Development of Antioxidants, light stabilizers, flame or fire retardants, process of recycling, development of Nano composites and modification of Polymers.
- Development of Plastic electronics.
- Fast programmable and environmentally clean Laser Marking is also likely to be facilitated by chemical engineering.
    - o It is widely used in marking the dates of manufacture and expiry and the product codes.

Future Prospects of a Chemical Engineer

- The emerging Chemical Engineers have a very bright future in store for them. A student of chemical engineering can get employed as:
    - Aerospace Engineer,
    - Researcher of Biotechnology,
    - Chemical Engineer in a Chemical Plant,
    - Civil Engineer,
    - Software Developer in Software Development Firms.
- Chemical Engineering is also considered as the gateway to green engineering. The upcoming trend of green engineering is based on the principles of Chemical Engineering.
- The basic areas where works are:
- **Prevention:**
    - It is always wider to prevent the formation of waste rather than cleaning up waste after its creation. Prevention is better than cure.
- **Syntheses of Less Hazardous Chemicals:**
    - Wherever applicable and possible, synthetic methods should be sued top develop substances that contain little or no toxicity to human and animal health and the environment – in one word, they should be 'green'.
- **Development of Safe Chemicals:**
    - Various chemical products need to be developed so as to affect their desired purpose keeping their toxicity to the minimal.
- **Use of Safer Solvents:**
    - The use of various auxiliary substances like solvents and separation agents should be rendered unnecessary whenever possible.
- **Designing Energy Efficiency:**
    - Requirement for energy in chemical processes should be recognized for their impacts on environment as well as economy.
- **Usage of Renewable Feedstock's:**
    - A raw material or a feedstock should be made renewable whenever it is possible and practical from technical and economical point of view.
- **Designing for Degradation:**
    - Chemical products need to be designed to ensure that once their functions end, they disintegrate into harmless products that do not remain in the environment.

Chapter 14:
Organic Chemistry

Topics covered in this snack-sized chapter:

- Organic Chemistry.
- Organic Chemistry is all around us.
- Diversity of Organic Chemicals.
- The Versatile Carbon Atom.
- Molecular Shapes- 3D Notations.

Organic Chemistry

- The branch of chemistry that deals with the structure, properties, and reactions of compounds that contain **"carbon"**.
- Over 10 million compounds have been identified.
  - About 1000 new ones are identified each day!
- Organic chemistry is the science of
  - Designing
  - Synthesizing
  - Characterizing
  - Developing applications for molecules that contain carbon

Organic Chemistry is all around us

Organic Chemistry defines Life

- In addition to our bodies' DNA, peptides, proteins, and enzymes, organic compounds are all around us.

They are a Source of Energy

- We obtain energy from organic compounds like carbohydrates (sugars) and fats, using amino acids and proteins (organic) to grow.

Genetic Information Transmission

- From one generation to the next, through organic compounds called nucleic acids.

Formation of Body Parts

- Organic chemicals make up our:
  - Hair
  - Skin
  - Fingernails

Diversity of Organic Chemicals

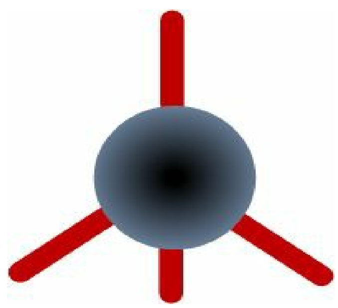
- The diversity of organic chemicals is due to the versatility of the carbon atom.
- Organic molecules contain both carbon and hydrogen.
- Though many organic chemicals also contain other elements, it is the carbon-hydrogen bond that defines them as organic.

The Versatile Carbon Atom

- The element carbon is one of the most versatile elements on the periodic table in terms of the number of compounds it may form.
- Carbon appears in the second row of the periodic table.
- Has four bonding electrons in its valence shell
- Similar to other non-metals, carbon needs four electrons to completely fill its valence shell.
- It is intermediate in electronegativity (2.5).
- It forms strong bonds with C, H, O, N, and some metals.
- Electronic configuration of carbon for the excited state:

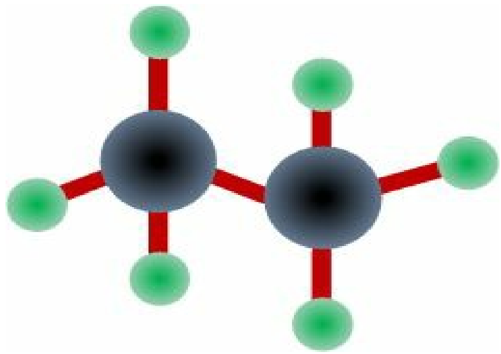
$$\mathbf{C}: 1s^2 2s^1 2px^1 2py^1 2pz^1$$

- Carbon, therefore, forms four bonds with other atoms (each bond consisting of one of carbon's electrons and one of the bonding atom's electrons).
- Every valence electron participates in bonding, thus a carbon atom's bonds will be distributed evenly over the atom's surface.
- These bonds form a tetrahedron as shown below:

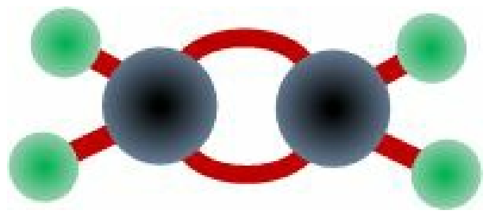


□ To add to the complexity of organic chemistry, neighboring carbon atoms can form double and triple bonds in addition to single carbon-carbon bonds:

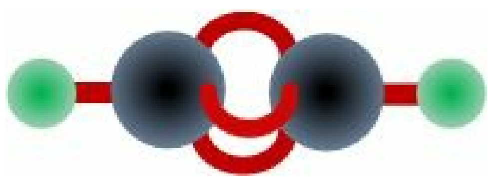
- **Single bonding:**



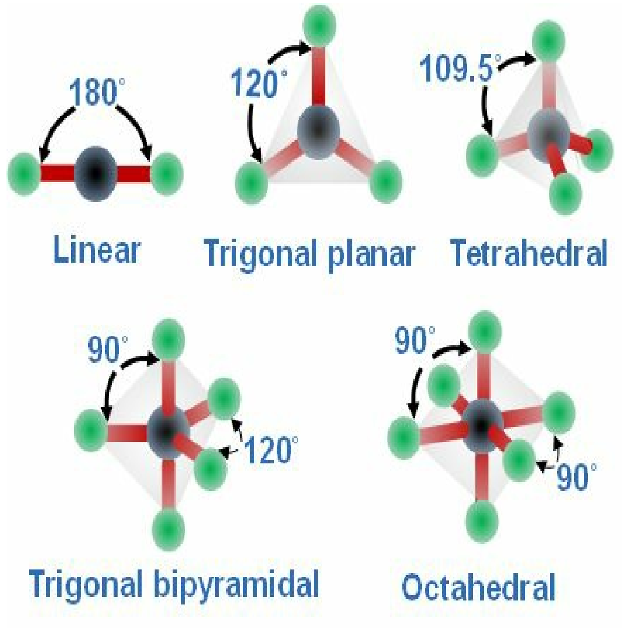
- **Double bonding:**



- **Triple bonding:**



Molecular Shapes- 3D Notations



Few Facts

- In terms of the Ph.D. population, organic chemistry is the largest chemistry discipline, in both total numbers, annual Ph.D. graduates, and in annual production.
- Organic compounds provide foundations for
  - Biochemistry
  - Biotechnology
  - Medicine
- It is the main element in industries such as:
  - Rubber
  - Plastic
  - Fuel
  - Pharmaceutical
  - Cosmetics
  - Detergent
  - Coatings
  - Dyestuffs
  - Agrichemicals
- Most modern, high-tech materials are composed, at least in part, of organic compounds.
- Clearly, organic chemistry is critically important to our high standard of living!

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- Under no conditions should the medical information provided in the app be considered in any way to lead to the formation of a doctor-patient relationship.
- While attempts are made to provide accurate information there are limitations on the accuracy, reliability and suitability of any accessible medical information accessed via the application.
- The information should not be relied on to suggest a course of treatment for a particular individual, an illness or a medical condition.
- It should not be used in place of or substitute for a visit or consultation with your physician or other qualified health care provider.
- Always consult with your physician or other qualified health care provider before embarking on a new treatment, diet or fitness program.
- You should never disregard medical advice or delay in seeking it because of something you have read either in this application or elsewhere.

Copyright Infringement Notification

- To file a copyright infringement notification with us, you will need to send a written communication that includes substantially the following (please consult your legal counsel or see Section 512(c) (3) of the Digital Millennium Copyright Act to confirm these requirements):

1. A physical or electronic signature of a person authorized to act on behalf of the owner of an exclusive right that is allegedly infringed.
2. Identification of the copyrighted work claimed to have been infringed, or, if multiple copyrighted works at a single online site is covered by a single notification, a representative list of such works at that site.
3. Identification of the material that is claimed to be infringing or to be the subject of infringing activity and that is to be removed or access to which is to be disabled, and information reasonably sufficient to permit the service provider to locate the material.
4. Information reasonably sufficient to permit the service provider to contact the complaining party, such as an address, telephone number, and, if available, an electronic mail address at which the complaining party may be contacted.
5. A statement that the complaining party has a good faith belief that use of the material in the manner complained of is not authorized by the copyright owner, its agent, or the law.
6. A statement that the information in the notification is accurate, and under penalty of perjury, that the complaining party is authorized to act on behalf of the owner of an exclusive right that is allegedly infringed.

Contact Us

For queries, please contact us at:

Email: Team@WAGmob.com
Phone: +1 206 501 4359

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All the best,

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