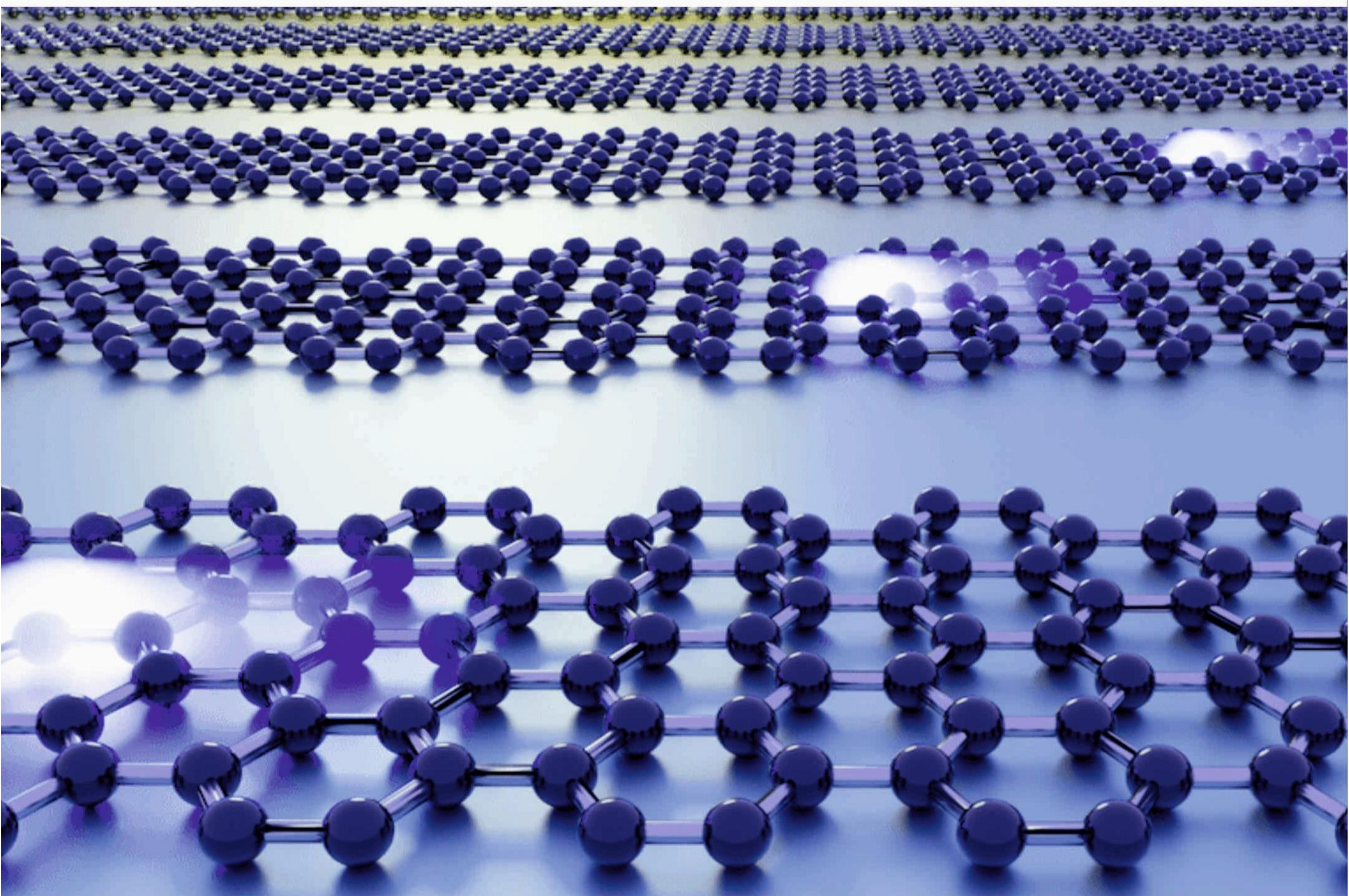
Advanced
MATERIALS
and
APPLICATIONS



Editor

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Kripa Drishti Publications, Pune.

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PREFACE

Modern undergraduates and graduate students are keenly interested in the various ways in which chemistry impacts everyday life. This interest stems partly from career imperatives, but also from a natural interest in the relationship between fundamental science and the technology that increasingly dominates our lives. Classical chemistry courses at the university level rightly emphasize fundamental science. But courses that focus on the utilization of that chemistry are still rare.

This book is an outgrowth of a course in materials chemistry that I have taught for several years in the Chemistry Department at various Institutions. It is a course taken by advanced undergraduates and by students who are in the first year of the graduate program in chemistry, most of whom have had little or no prior exposure to materials science. The class has also attracted undergraduates from materials science and chemical engineering programs who are seeking a general overview of the field. The subject matter is wide-ranging and, because the course extends over only one semester, the treatment aims for breadth, understanding, and perspective rather than great depth. The mathematical foundations of the field are deliberately excluded in order to emphasize chemical concepts rather than the traditional engineering or physics treatments. A challenge with this approach is that published material relevant to this subject is widely scattered in specialist books and research articles, and this presents a problem for students who seek to access background reading material. Thus, I have written this book in order to present a qualitative overview of relevant chemistry-related aspects and to provide a springboard to encourage readers to delve deeper into specific topics.

Each chapter ends with a brief summary of future challenges in the different fields that could form the basis of class discussions and brainstorming sessions. A few of the references are to historical, ground-breaking articles that described major discoveries. Many of the study questions pose practical challenges in new materials design that students are encouraged to address either through written reports or through class discussions. Attempts by students to solve these practical problems have proved to be a popular aspect of the course. This also provides an introduction to the ways in which science and technology become integrated in the wider world.

I am grateful to several colleagues who read sections of the manuscript and made valuable suggestions. I am also highly appreciative of the suggestions made by members of my research group and by numerous students who have taken this course and had an opportunity to see preliminary drafts of several chapters. Of course, any errors that remain are mine alone.

I hope that this book proves useful to all who have an interest in the impact of chemistry on modern technology and in the unique ways in which scientists have the knowledge, skills, and vision to bring about dramatic improvements to our way of life.

CONTENT

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1. Analysis of Performance Improvement Methods for a Vapor Compression Refrigeration System

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1.1 Introduction:

Refrigerator is a cooling appliance comprising a thermally insulated compartment and a refrigeration system is a system to produce cooling effect in the insulated compartment.

Meanwhile, refrigeration is defined as a process of removing heat from a space or substance and transfers that heat to another space or substance.

Nowadays, refrigerators are extensively used to store foods which deteriorate at ambient temperatures; spoilage from bacterial growth and other processes is much slower in refrigerator that has low temperatures.

In refrigeration process, the working fluid employed as the heat absorber or cooling agent is called refrigerant.

The refrigerant absorbs heat by evaporating at low temperature and pressure and remove heat by condensing at a higher temperature and pressure.

As the heat is removed from the refrigerated space, the area appears to become cooler.

The process of refrigeration occurs in a system which comprises of a compressor, a condenser, a capillary and an evaporator arranged as depicted schematically in Figure 1.1.

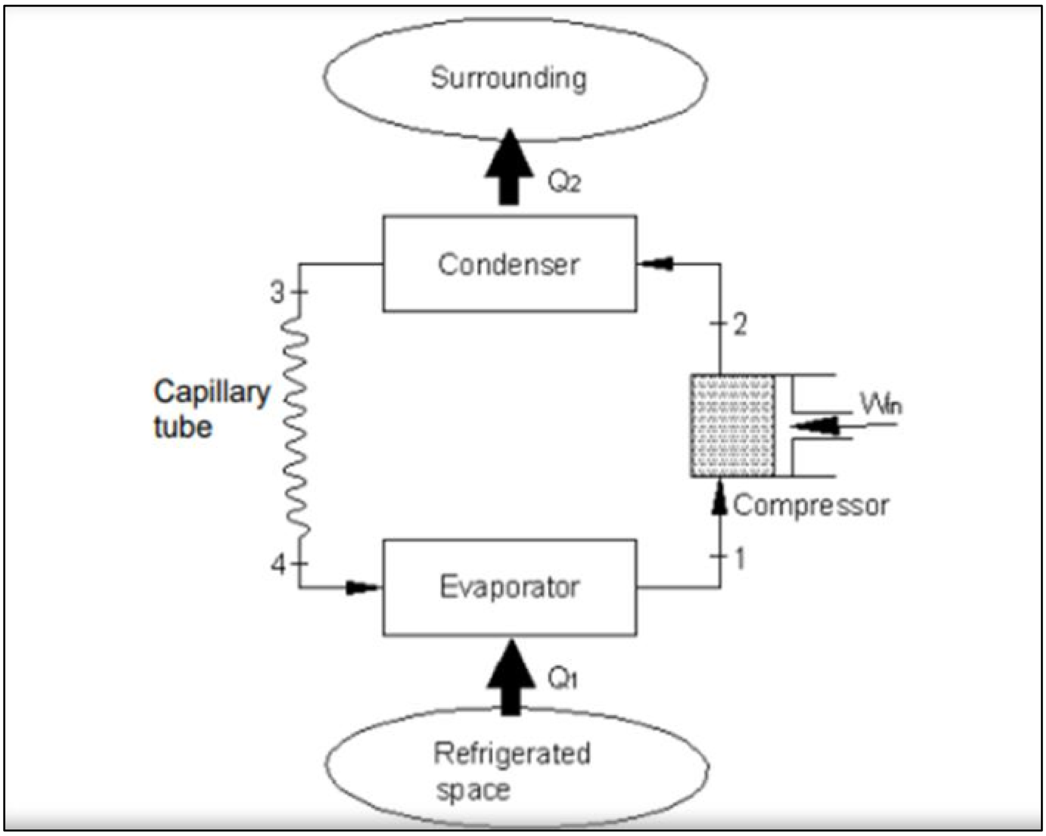

Figure 1.1: Schematic Diagram of A Refrigeration System

Compressor is a mechanical device to compress and pump the refrigerant vapor from a low-pressure region (the evaporator) to a high-pressure region (the condenser). The condenser is a device for removing heat from the refrigeration system. In the condenser, the high temperature and high-pressure refrigerant vapor transfers heat through the condenser tube wall to the surrounding. When the temperature of the refrigerant vapor reaches the saturation level, the latent heat is released causes condensation process and the refrigerant vapor changes it phases into liquid form. The capillary tube controls the refrigerant flow from the condenser to the evaporator and separates the system to high pressure and low-pressure sides. The evaporator is a device for absorbing heat from the refrigerated space into the refrigeration system by evaporating the refrigerant. To accomplish the process of the heat removing from the refrigerated space, a system called refrigeration plant is created and the plant works in a thermodynamic cycle which obeys Second Law of Thermodynamic.

The refrigeration plant used in the present work is called refrigerator. Currently, the refrigerator is used widely around the world and this appliance become necessity for household. Performance of a modern refrigerator is very efficient but the research still ongoing to optimize the system. In fact, the same system would produce different performance if it is operated in different countries especially between tropical climate countries and countries with four climate seasons. Performance study of the refrigeration system in the present work is one of effort to discover performance of the Refrigerator by Analysis three important parameters which are refrigeration capacity, compressor work and coefficient of performance (COP).

1.2 Domestic Refrigerators:

A refrigeration system provides cooling in a closed space by lowering the temperature. The refrigeration systems we use in our homes are domestic refrigerators. Domestic refrigerators are home appliances that store food and drinks. Unlike a large commercial system, a domestic refrigerator provides cooling to a smaller area.

A refrigerator is a rectangular storage container that can easily fit in a kitchen space. We also use them in ice cream parlors, small stores, and garages to keep food and drinks cold. A refrigerator transfers heat from the space inside to its external environment. It will cool the space inside to a temperature below the room temperature. If we keep food at room temperature, it can spoil easily. The growth of bacteria present in food slows down when we cool it. The cold temperatures inside a refrigerator help food stay fresh longer.

It's essential to keep perishable foods like meat and dairy products refrigerated. If we leave milk on the kitchen counter, bacteria will spoil it within two to three hours. However, keeping milk at a lower temperature will stay fresh for a week or two.

1.3 Main components of domestic refrigerator:

The essential function of refrigerators is to use the evaporation of a liquid (refrigerant) to absorb heat. The main working parts of a refrigerator include a compressor, a condenser, an evaporator, an expansion valve, and a refrigerant.

A. Compressor: Refrigerant is truly the lifeblood of a refrigerator. It starts in the form of a gas, then a liquid, and back to a gas as it cycles through the refrigerator's parts. This is the process that cools the refrigerator. In the early stages of refrigerator technology, toxic gases such as ammonia were used as refrigerants. That changed in the 1930's, when manufacturers began using freon instead. Freon was used for many decades until recent discoveries by scientists found it was harmful to the Earth's environment. Most modern refrigerators now use a compound called HFC 134a.

B. Condenser: The condenser is where the refrigerant liquefies. The condenser receives the hot vapor, which are cooled down into a liquid. It's distinguishable by its large copper coils, and you can find them along the bottom or at the back of your unit.

C. Expansion valve: This cooling process then shifts to the expansion valve, which is a thin set of copper tubes. The expansion valve lowers the liquid refrigerant's temperature and pressure dramatically, causing about half of it to evaporate. This refrigerant repeatedly evaporating at extremely low temperatures is what creates the cool temperatures inside your refrigerator and/or freezer.

D. Evaporator: The evaporator is where the cooling process ends and begins the process of the next cycle. It takes the remaining refrigerant liquid and turns it back into a vapor, which the compressor takes to start it all over again.

1.4 Review of Literature:

Vapor compression refrigeration cycle has four elements: evaporator, compressor, condenser and expansion valve, respectively [1]. Vapor compression refrigeration system is most commonly and domestic as well as large scale method of producing refrigeration effect. One hand these systems provided quick refrigeration effect and heat rejection on other hand by the chemical properties of refrigerant. The quantity of rejected heat from such systems is quite high and this heat is removed in atmosphere as a waste [2]. This refrigeration cycle is approximately a Rankine cycle run in reverse. A working fluid (often called the refrigerant) is pushed through the system and undergoes state changes (from liquid to gas and back) [3].

The latent heat of vaporization of the refrigerant is used to transfer large amounts of heat energy, and changes in pressure are used to control when the refrigerant expels or absorbs heat energy [4].

However, for a refrigeration cycle that has a hot reservoir at around room temperature (or a bit higher) and a cold reservoir that is desired to be at around 34°F, the boiling point of the refrigerant needs to be fairly low.

Thus, various fluids have been identified as practical refrigerants. The most common include ammonia, Freon (and other chlorofluorocarbon refrigerants, CFCs), and HFC-134a (non-toxic hydrofluorocarbon) [5].

Condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium [6]. Compression is the first step in the refrigeration cycle, and a compressor is the piece of equipment that increases the pressure of the working gas. Refrigerant enters the compressor as low-pressure, low-temperature gas, and leaves the compressor as a high-pressure, high-temperature gas [7].

The condenser, or condenser coil, is one of two types of heat exchangers used in a basic refrigeration loop. This component is supplied with high-temperature high-pressure, vaporized refrigerant coming off the compressor. The condenser removes heat from the hot refrigerant vapor gas vapor until it condenses into a saturated liquid state, a.k.a. condensation [8]. When the refrigerant enters the throttling valve, it expands and releases pressure. Consequently, the temperature drops at this stage. Because of these changes, the refrigerant leaves the throttle valve as a liquid vapor mixture, typically in proportions of around 75 % and 25 % respectively [9]. Throttling valves play two crucial roles in the vapor compression cycle. First, they maintain a pressure differential between low- and high-pressure sides. Second, they control the amount of liquid refrigerant entering the evaporator [10] The coefficient of performance (COP) and energy consumption need more attention to provide high performance with low energy consumption of a vapor compression refrigeration system. [11].

1.5 Working of Vapor Compressor Refrigerator System:

1.5.1 Components:

A. Evaporator: One kind of evaporator is a kind of radiator coil used in a closed compressor driven circulation of a liquid coolant. That is called a refrigeration system to allow a compressed cooling chemical, such as R-22 (Freon) or R-410A, to evaporate/vaporize from liquid to gas within the system while absorbing heat from the enclosed cooled area, for example a refrigerator or rooms indoors, in the process. This works in the closed refrigeration system with a condenser radiator coil that exchanges the heat from the coolant, such as into the ambient environment.

Figure 1.2: Evaporator

B. Expansion Device: Expansion device is also known as throttling device is an important device that divides the high-pressure side and the low-pressure side of a refrigerating system. It is connected between the receiver and the evaporator containing liquid refrigerant at high pressure and liquid refrigerant at low pressure). The expansion device performs the following function. It reduces the high-pressure liquid refrigerant to low pressure liquid refrigerant before being fed to the evaporator. It maintains the desired pressure difference between the high- and low-pressure side of the system, so that the liquid refrigerant vaporizes at the designed pressure in the evaporator. It controls the flow of refrigerant according to the load evaporator.

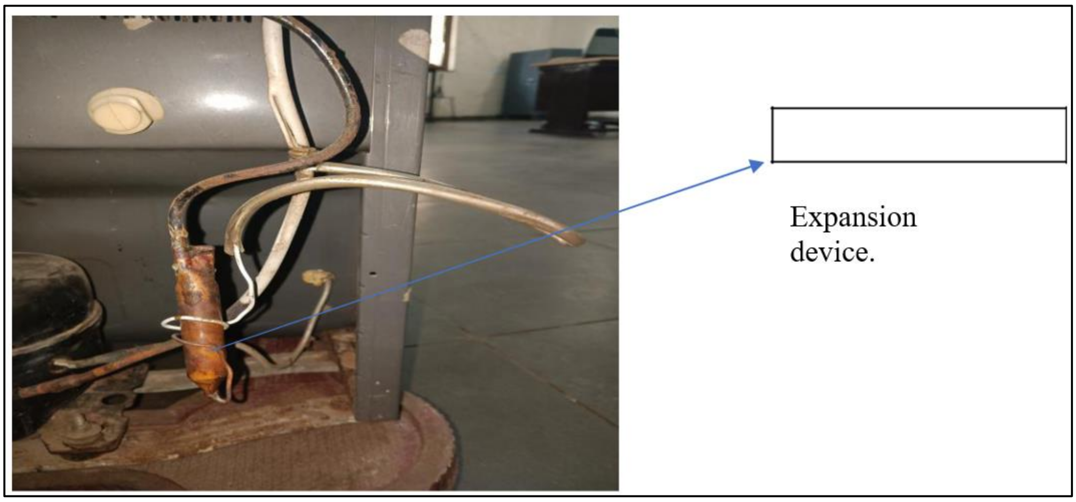

Figure 1.3: Expansion device

C. Compressors: A compressor is the most important and often the costliest component (typically 30 to 40 percent of total cost) of any vapor compression refrigeration system (VCRS). The function of a compressor in a VCRS is to continuously draw the refrigerant vapor from the evaporator, so that a low pressure and low temperature can be maintained in the evaporator at which the refrigerant can boil extracting heat from the refrigerated space. The compressor then has to raise the pressure of the refrigerant to a level at which it can condense by rejecting heat to the cooling medium in the condenser.

Figure 1.4: Compressor

D. Condenser: It is ultimately in the condenser that heat is rejected in a VCRS refrigeration machine. The vapor at discharge from the compressor is super-heated. Desirer heating of the vapor takes place in the discharge line and in the first few coils of condenser.

It is followed by the condensation of the vapor at the saturated discharge temperature. In some condensers, subcooling may also takes place near the bottom where there is only liquid.

However, the sensible heat of the latent heat of the condensation process.

Figure 1.5: Condenser

1.6 Working of Vapor Compressor Refrigerator System Cycle:

Vapor Compression Refrigeration uses mechanical energy by repeating compression and expansion of coolant fluid to achieve cooling by Joule–Thomson effect.

A majority of big refrigeration systems in use nowadays use the Vapor Compression Refrigeration.

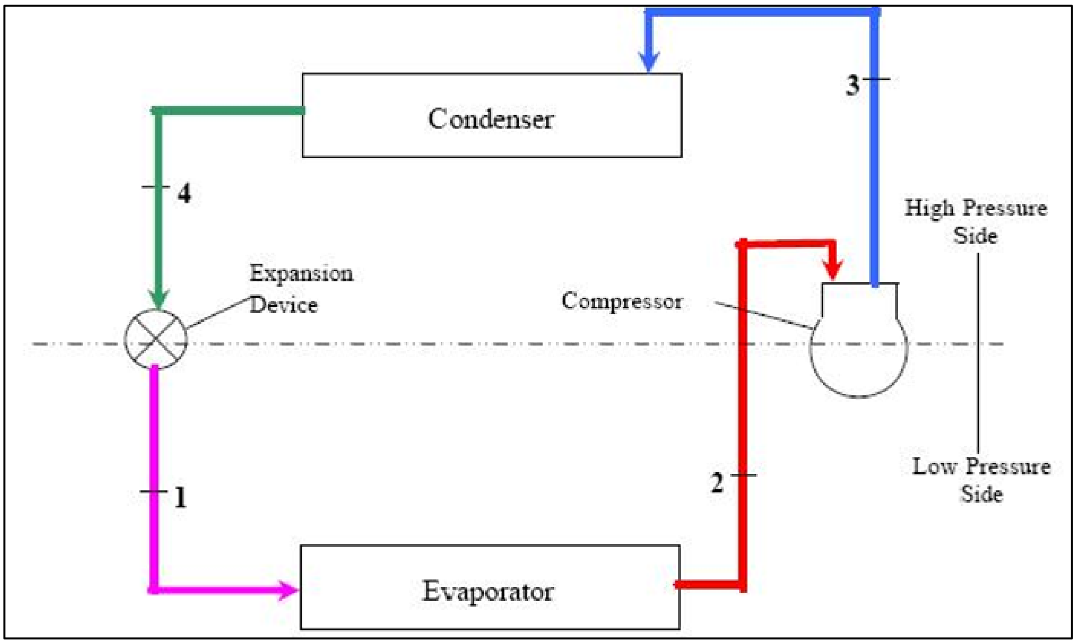

Figure 1.6: Schematic diagram of Vapor Compression Refrigeration System

From the above figure by following processes analysis:

Process (1-2) From points 1 to 2, low-pressure liquid refrigerant in the evaporator absorbs heat from its surrounding environment, usually air, water or some other liquid and gets evaporated into gas. As such, the refrigerant is slightly superheated at the outlet of the evaporator.

The evaporating liquid absorbs heat from the surroundings, thus performing the cooling or refrigeration duty for the surrounding air, water or other medium. This is where the refrigeration actually occurs

Process (2-3) From point 2 to 3 on figure-1.6, the superheated vapor from evaporator enters the compressor where its pressure is increased due to compression. The temperature also typically increases, since a part of the energy put into the compression process is transferred to the refrigerant.

Process (3-4) From point 3 to point 4 on figure-1.6, the pressurized and superheated gas from compressor outlet is sent to a condenser. The initial part of the cooling process de-superheats the gas before it is then turned back into liquid. the cooling for this process is usually accomplished by use of air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b-4 on figure-1.6), so that the refrigerant liquid is sub-cooled as it enters the expansion device. This step is where the heat absorbed from process fluid at the evaporation stage is vented out to atmosphere.

Process (4-1) From point 4 to point 1 the high-pressure sub-cooled liquid passes through the expansion device, which reduces its pressure as well as controls the flow into the evaporator. The process is repeated from now in cycle.

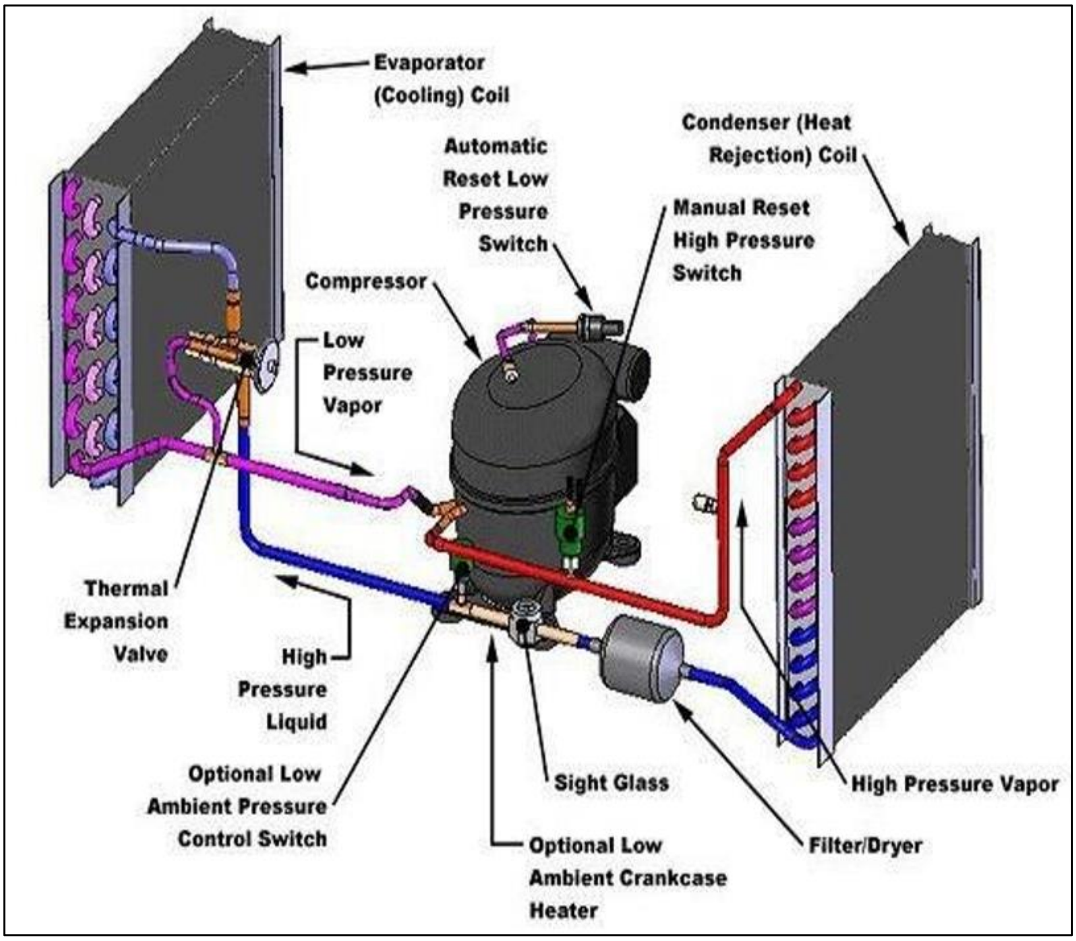

Figure 1.7: Components set-up

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1.7 Analysis of Performance:

The refrigeration is defined as the process of removal of heat from a region or state or a substance to reduce and maintain its low temperature and transferring that heat to another region, state or substance at higher temperature.

The refrigeration process that employed in the domestic refrigerator is based on a vapor compression cycle as shown in Figure 1.8 and collaborated with Figure 1.8. there are three main parameter that were considered in this study; compressor power, refrigeration capacity and coefficient of performance (COP).

Process line from 1 to 2 represents compressor power. Compressor power is defined as the power needed to do the compression process in watt.

The compressor power is determined by multiplying enthalpy change across the compressor to the mass flowrate, thus

$$P = \dot{m}(h_2 - h_1) \qquad (1)$$

Meanwhile, process from point 2 to 3 represents heat rejection through condenser. The amount of heat rejected is not significant in the present study. Process from point 3 to point 4 shows throttling effect through capillary tube whereby the working pressure of refrigerant will be reduced from discharge pressure to suction pressure.

Refrigeration capacity, which is represented by process line 4 to 1, is defined as the amount of heat absorbed by a unit mass of refrigerant in evaporator.

The refrigeration capacity can be obtained using equation below:

$$\dot{Q}_{in} = \dot{m}(h_1 - h_2) \qquad (2)$$

The coefficient of performance (COP) is a measure of efficiency of the refrigerator. The COP of a domestic refrigerator is the ratio of the refrigeration capacity to the energy supplied to the compressor. It can be expressed by equation 3. \

$$\text{COP} = \frac{\dot{Q_{in}}}{p} = \frac{\dot{m}}{m} \times \frac{(h_1 - h_4)}{(h_2 - h_1)} \qquad (3)$$

1.8 Installation of Domestic Refrigerator:

Before installing the unit, make sure that the floor in the kitchen is strong, the existing flooring will easily withstand the weight of the appliance with all its contents.

Otherwise, it will be necessary to make repairs and strengthen the floor. A simple instruction will explain how to properly install any refrigerator on the level are as follows-

a. Make sure that there are gaps between the refrigerator, walls and furniture;
b. by adjusting the height of the legs, set the fridge to the right level position;
c. Lift the front legs so that the fridge body tilts back a little so that the door can close easily;
d. check once more the level of the fridge;
e. make sure that the appliances are fixed firmly on the floor, do not wobble and do not tilt.

After the fridge is installed, you need to complete it: set the racks, shelves, baskets for vegetables, trays for eggs.

It is necessary to check that all the parts exactly fit into the appropriate grooves and do not shift during operation.

In this way you will exclude the probability of food falling down after loading the refrigerator.

Figure 1.8: Installing the Unit

1.9 Specification of Domestic Refrigerator:

Brand	Whirlpool
Model name/year	DC -5256/2012
Freezer Capacity (liter)	80
Fresh Food Compartment Capacity (liter)	230
Power Rating	160W
Current Rating	0.9A
Voltage	220-240V
Frequency	50Hz
No of door	Single
Compressor	Hermetic - sealed
Refrigerant type	R134a

Figure 1.9: Specification of Domestic Refrigerator

1.10 Comparative Analysis of Recent Researches on VCR System Using Domestic Refrigerator:

Study of 23 recent researches conducted on vapor compression refrigeration system done nationally and internationally, have been summarized in tabular form. It basically includes the methodology carried during those research works and major outcome obtained. Key recommendations as a result of the researches have been also mentioned that can be applied in domestic refrigerator for performance enhancement.

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2. Biomaterials

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Project. Tech supp-II,
ICMR NIV PUNE.

2.1 Introduction to Biomaterials:

A material intented to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body.

Metals, ceramics, plastic, glass, and even living cells and tissue all can be used in creating a biomaterial. They can be reengineered into molded or machined parts, coatings, fibers, films, foams, and fabrics for use in biomedical products and devices.

A. Biomaterials:

- Polymeric biomaterials, Bioceramics, Metallic biomaterials, Hydrogels
- Biocomposite thin films,grafts,coatings, Biologically based (derived) biomaterials, Pyrolytic Carbon for long term medical implants
- Textured and Porous materials

B. Biocompatibility:

- Biocompatibility: The ability of a material to perform with an appropriate host response in a specific application.
- Host response: the reaction of a living system to the presence of a material
  eg. Resistance to blood clotting

Resistance to bacterial colonization

Normal uncomplicated healing

- Biocompatibility→ Tissue Engineering

2.2 Some Application of Biomaterials:

Application	Types of Materials
• **Skeletel system**	
• Joint replacement(Hip, knee)	Titanium , Stainless steel, PE
• Bone plate	Stainless steel, Co-Cr alloy
• Bone cement	PMMA (Polymethyl Methacrylate)
• Artificial tendon and ligament	Hydroxylapatie Teflon, Dacron
• Dental implant	Titanium, alumina, calcium phosphate
• **Cardiovascalar sysem**	
• Blood vessel prosthesis	Dacron, Teflon, Polyurethane
• Heart valve	Reprocessed tissue, Stainless steel, Carbon
• Catheter	Silicone rubber, teflon, polyurethane
• **Organs**	
• Artificial heart	Polyurethane
• Skin repair template	Silicone-collage composite
• Artificial kidney	Cellulose, polyacrylonitrile
• Heart-lung machine	Silicone rubber
• **Senses**	
• Cochlear replacement	Platium electrodes
• Intraocular lens	PMMA, Silicone rubber, hydrogel
• Contact lens	Silicone-acrylate. Hydrogel
• Corneal bandage	Collagen, hydrogel

2.3 Leading Medical Device Company:

- Johnson & Johnson (www.jnj.com)
- Biomet INC (www.biomed.com)
- Strycker Howmedica Osteonics (www.osteonis.com)
- Sulzer Orthopedics Ltd (www.sulzerotho.com)
- Zimmer (www.zimmer.com)

- Merck & Co Inc (www.merck.com)
- Nobel biocare/AstraZeneca/Pacesetter AB/Q-med/Artimplant/Doxa

2.4 Properties of Materials:

- Solids are distinguished from the other states of matter such as liquids and gases
- Atoms are held together by interatomic forces mainly
  - Ionic bonding
  - Covalent bonding
  - Metallic bonding

A. Ionic Bonding:

- Attraction of anions and cations constitutes ionic bonding
- In ionic bond (metallic atoms) electron donors transfer one or more electrons to electron acceptors (nonmetallic)
- Anions (Nonmetals)are strongly attracted by electrostatic force
- Ionic bonds result into packing which reduces surface energy and leads to a highly ordered arrangement called crystal structure
- Bound electrons cannot be served as a carrier further
- So ionic solids are poor electrical conductors, chemically less reactive and poor overall energy content

eg. Sodium chloride, Magnesium oxide

B. Covalent Bonding:

- Elements between metals and nonmetals having equal valence electrons and equal tendency to donate and accept electrons
- eg. Carbon and Silicon, C-C
- Tendency of sharing valence electrons
- Stable electron structure
- Nearest neighbors form tetrahedron crystal

- Strong bonds – Diamond (Hardest material)
- Due to localization of the valence electrons these materials are poor electrical conductors.

C. Metallic Bonding:

- Many metals are very strong (e.g. Cobalt) and have high melting points (e.g. Tungsten)
- Very strong interatomic bonds
- Atoms are arranged in an orderly, repeating, three dimensional pattern with migration of valence electrons
- Metal crystal composed of positive ion cores and negetive electrons circulate about atoms lacking valence electrons
- Bonding arise because the negative electrons act like glue between the positive ion cores
- High electrical and thermal conductivity

2.5 Mechanical Properties of Materials:

- Elastic Behavior, Stress and strain, Tension and compression, Shear, Isotropy, Fatigue, Toughness

A. Elastic Behavior

- Hook's Law
- Initial extension is proportional to the load applied
- Most of the solids behave in an elastic manner (like Spring)

B. Stress and Strain:

- Extension for a given load varies with the geometry of the specimen
- Hook's law is not sufficient to compare relative stiffness of different materials
- To resolve this problem load and deformation is normalized
- Load per unit cross sectional area
- Elongation per unit of the original length

- Normalized Load= Stress (σ) (F/A)
- Normalized deformation = Strain (ε) (dL/L)

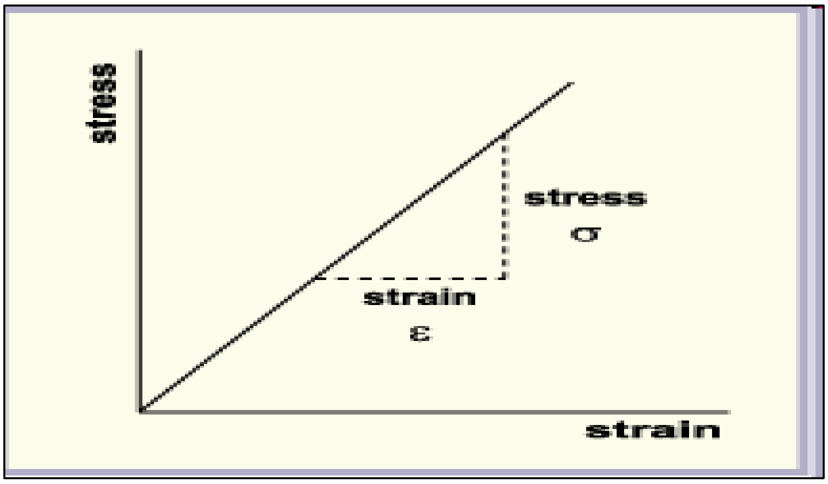

Figure 2.1: Stress and Strain

C. Tension and Compression:

- Technique for flexible materials like rubbers, polymers and soft tissues
- In tension and compression area supporting the load is perpendicular to the loading direction (Tensile stress)
- The change in length is parallel to the original length (Tensile strain)
- Unit for stress pascal (Pa) or N/mm^2

D. Shear:

- Shear stress (τ): Applied load is parallel to the area supporting it
- Shear Strain (γ): Dimensional change is perpendicular to the reference dimension
- Elastic constants
- σ = E ε, Tension or compression E=Young's Modulus
- T = G γ, Shear
- G = shear modulus
- Stronger bonds= higher values

E. Isotropy:

- Isotropic Materials: A material whose properties are same in all directions
- e.g. metals, alloy and ceramic
- Great magnitude of grains which forms aggregated crystals
- High values of E and G
- Polymeric materials such as bones, ligaments and sutures are anisotropic materials
- Need more than two elastic constants to relate stress and strain properties

F. Fatigue:

- Due to fatigue fracture occurs when the loads are applied and removed for a great no. of cycles
- Fatigue occurs even in tough and ductile materials
- e.g. Prosthetic heart valves and prosthetic joints
- Repetitive loading produce microscopic cracks which then propagate by small steps at each load cycle
- Failure occurs with stepwise propagation
- For design purpose, Endurance limit or fatigue strength= 10^6 to 10^8
- Factors affecting Fatigue strength: Environment, temp, corrosion, deterioration and cycle rate

G. Toughness:

- Ability of material to plastically deform under the influence of stress field that exist at the tip of a crack is a measure of its toughness
- Fracture toughness= f(crack propagation stress, crack depth ,shape)
- Critical stress intensity factor K_{IC}
- Unit of K_{IC} is Pa $m^{0.5}$ or $N.m^{3/2}$

2.6 Surface Properties of Materials:

- Roughness- Rough, stepped or smooth

- Wettability- hydrophilic or hydrophobic
- Surface mobility- inhomogeneous with depth or overlayered
- Chemical Composition- atomic, supramolecular or macromolecular
- Electrical charge
- Crystallinity- different combination and organizations such as a silicon 100 unreconstructed surface or a silicon 111 reconstructed
- Heterogeneity to biological reaction

2.7 Characterization of Surface Properties:

A. Contact Angle Method:

- Principle: Liquid wetting of surfaces is used to estimate the energy of surfaces
- The force balance between the liquid-vapour surface tension(γ_{lv}) of a liquid drop and the interfacial tension between solid and the drop (γ_{sl}), manifested through the contact angle (Θ) of the drop with the surface
- Depth Analyzed: 3-20 A°
- Spatial resolution: 1mm
- Analytical sensitivity: Low or high depending on chemistry
- Cost effective

B. Electron spectroscopy for chemical Analysis (ESCA):

- Principle: X-rays induce the emission of electrons of characteristic energy
- Energy of electrons provide information about the nature and environment of the atom from which it came.
- Depth Analyzed: 10-250 A°
- Spatial resolution: 10-150 µm
- Analytical sensitivity: 0.1% atom
- Expensive technique

C. Secondary Ion Mass Spectroscopy (SIMS):

- Complex instrumentation and ultrahigh vacuum chamber
- Principle: A surface is bombarded with a beam of accelerated ions. Collision of these ions with atoms and molecules on the surface transfer enough energy to them so that they can sputter from the surface into the vacuum.
- Depth Analyzed: 10 A° -1 µm
- Spatial resolution: 100 A°
- Analytical sensitivity: very high
- Expensive technique

D. Scanning Electron Microscopy (SEM):

- Based on the images
- Principle: High energy electron beam is focused on the specimen and low energy secondary electrons are emitted from each spot where the focused electron beam impacts.
- Valuable for observing defects in thin films or analyzing the chemistry of fine particulates or assessing causes of implant failure
- Depth Analyzed: 5 A°
- Spatial resolution: 40 A°
- Analytical sensitivity: high, not quantitative
- Less Expensive technique

2.8 Classes of Materials:

- Polymers, Hydrogels, Bioresorbable and Biodegradable materials, Ceramics, Natural materials, Composite thin films, grafts, Coatings medical fibers, Biological functional materials, Smart materials
- Pyrolytic carbon for long term medical implants, Textured and porous materials, Non-fouling surfaces, Metals

2.8.1 Polymers:

- Polymers represent the largest class of biomaterials
- Polymers are used in the biomedical devices which include orthopedic, Dental, soft tissue and cardiovascular implants
- Mainly two types of polymers

A. Natural Polymers: Plant and Animal Sources:

- e.g. Cellulose, sodium alginate, natural rubber, Tissue based heart valves and sutures, heparin, glycosaminoglycans

B. Synthetic Polymers:

- Hydrophobic (non water absorbing)
- e.g.PMMA- Poly Methyl Methacrylate,PVC- Poly Vinyl Chloride, PE-Poly Ethylene,PP-Poly Propylene, PTFE-Polytetra Fluoro Ethylene, PET-Polyethylene Terepthalate, PUR-Polyurathane, Silicone rubber
- Hydrophilic,water swelling or water soluble
- e.g.PLA/PGA-Poly Lactic / Glycolic Acid,PA- Poly Amide,polyethylene glycol

2.8.2 Molecular Weight:

- In polymer synthesis molecular weight plays an important role.
- Polymer is produced with the distribution of molecular weights.
- To compare two different batches of polymer Average Molecular weight is introduced.

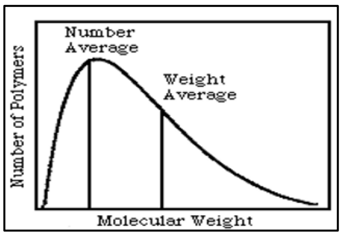

Figure 2.2.: Molecular Weight

2.8.3 Polydispersity Index (PI):

- Ratio of M_w to M_n is known as Polydispersity index.
- Measure of the breadth of the molecular weight distribution.
- For Commercial polymers PI ranges from 1.5-50
- For Biomedical applications linear polymers are used in the range of M_n(25,000 to 1,00,000) and M_w (50,000 to 3,00,000)
- For hip joint M_w ranges up to million
- Increase in molecular weight corresponds to increasing physical properties
- But melt viscosity increases with MW so process ability will decrease.

2.8.4 Polymerization (Synthesis):

- Polymer prepration fall into following catagories:

A. Addition: A reaction occurs between two molecules to form a larger molecule without the elimination of a smaller molecule.

- In addition, Polymerization, unsaturated monomers react through the stages of initiation, propagation and termination to give final polymer product.
- e.g. PVC, PE and PMMA
- Initiation → Propagation → Termination

Free radicals, cations, anions or stereospecific catalysts	Rapid chain Growth	radical, Solvent molecule, polymer molecule, initiator, an added chain transfer **agent**

Polymerization (Synthesis):

B. Condensation: A reaction occurs between two molecules to form a larger molecule with the elimination of a smaller molecule.

- Two monomers react to form a covalent bond,usually with elimination of a water,hydrochloric acid,methanol, or carbon dioxide.
- e.g. Nylon,PET

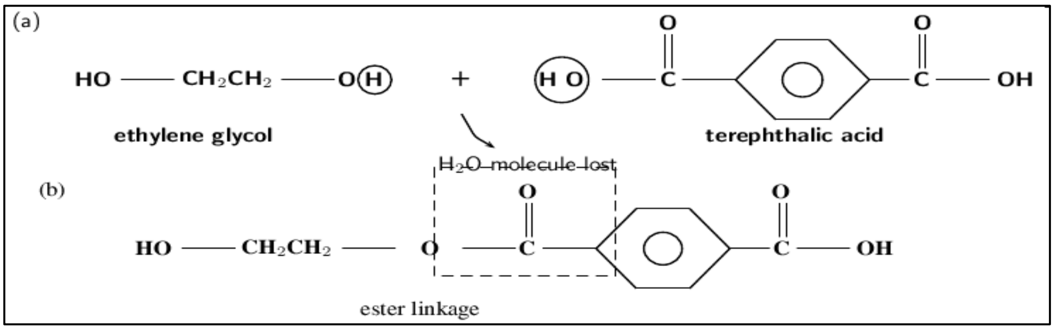

Figure 2.3.: Polymerization (Synthesis)

2.8 References:

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B. Reference book:

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3. An Introductory Approach to Biosensors: Types and their Applications

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Abstract:

Recently biosensors have been attracted the researchers due to biomedical diagnosis, monitoring of treatment and disease progression, environmental observance, food quality testing, water analysis, drug discovery, forensics and biomedical research. Biosensors are stable, low cost, and more efficient devices for various applications. Biosensors have been applied as sophisticated tools for sensing and monitoring. Biosensors are very specific towards sensitivity, reproducibility and provide more precise readings. Biosensors are very easy to use for various applications. The purpose of using a biosensor is to use the signal of the biological component, combine it with the physiological chemical element and understand the signal. The working of a biosensor is based on the biochemical specificity of the biologically active material. Biosensors are combination of the biological sensitive component (like microorganisms, cell organelles, enzymes, and antibodies as well as animal and plant cells or tissues), the transducer material (applying in an electrical or physiochemical approach) and the signal reader. Here, we present an introductory approach to biosensors, working principle, their various types and applications in multiple areas.

Keywords:

Biosensor, transducer, biochemical, materials, and applications.

3.1 Introduction:

In the past, 1906 when M. Cremer invented that the acid concentration is proportional to the electric potential which arises between fluid parts situated other sides of a glass membrane [1].

Although, introduction of pH (concentration of hydrogen ion) reveled by Soren Peder Lauritz Sorensen in 1909 and pH measurements electrode was deduced in 1922 by W.S. Hughes [2].

From 1909 to 1922, Griffin and Nelson first explained the enzyme immobilization on aluminium hydroxide and charcoal [3, 4]. Leland C. Clark, Jr invented first biosensor in 1956 for oxygen detection. He is well-known as the 'father of biosensors' and his invention about the oxygen electrode is called 'Clark electrode' [5]. After that, Leland Clark demonstrated glucose detection through electrode of an amperometric enzyme in 1962. Meanwhile, first potentiometric biosensor was developed by Guilbault and Montalvo, Jr in 1969 for detecting urea [6]. In 1975 the first biosensor was commercialized by Yellow Spring Instruments (YSI).

There is generation of biosensors is tabulated from year of 1970 to 1992 in Table 1. Invention of the i-STAT sensor was great achievement in the biosensors world. Presently, this field is developed as a research for multidisciplinary area which combines all branches of science i.e. physics, chemistry and biology along with micro/nano-technology, electronics and medical area. The progress regarding biosensors has been indexed by 'Web of Science' through many thousand reports between 2005-2022.

Table 3.1: Important development of biosensors during 1970-1992

Year	Development	Reference
1970	Discovery of ion-sensitive field-effect transistor (ISFET) by Bergveld	[7]
1975	Fibre-optic biosensor for carbon dioxide and oxygen detection by Lubbers and Opitz	[8]
1975	First commercial biosensor for glucose detection by YSI	[9]
1975	First microbe-based immunosensor by Suzuki et al.	[10]
1982	Fibre-optic biosensor for glucose detection by Schultz	[11]
1983	Surface plasmon resonance (SPR) immunosensor by Liedberg	[12]

Year	Development	Reference
1984	First mediated amperometric biosensor: ferrocene used with glucose oxidase for glucose detection	[13]
1990	SPR-based biosensor by Pharmacia Biacore	[8]
1992	Handheld blood biosensor by i-STAT	[8]

Biosensor term is designated from “biological sensor”. A biosensor is an analytical device, used for the detection of a chemical substance, which combines a biological component with a physicochemical detector [14].

3.2 Working of biosensor:

A biosensor is consisting of various essential components as given following details:

Analyte: A substance of interest which is detected. Such as, glucose is an ‘analyte’ in a bio-analytical device then it will detect glucose.

Bioreceptor: A molecule which identifies the analyte is called as a bioreceptor like enzymes, cells, aptamers, deoxyribonucleic acid (DNA) and antibodies. Signal generation process is in the form of light, heat, pH, charge or mass change, etc. which is due to interaction between bioreceptor and the analyte, known as bio-recognition.

Transducer: An element which converts one form of energy into another is deduced transducer. So, in the biosensor, transducer converts the bio-recognition process to a measurable signal. Mostly transducers produce two types’ signals i.e. optical or electrical signals those are proportional to the amount of analyte–bioreceptor interactions.

Electronics: Electronically the transduced signal are processed and prepared to display. The signals are converted from analogue to the digital form then these signals are displayed as output in numeric, graphic, tabular or an image form.

Display: The display unit can be a computer display or a printer which shows measurements and graphs. The display unit generally made of using hardware and software.

Figure 3.1 represents the schematic working process of biosensor.

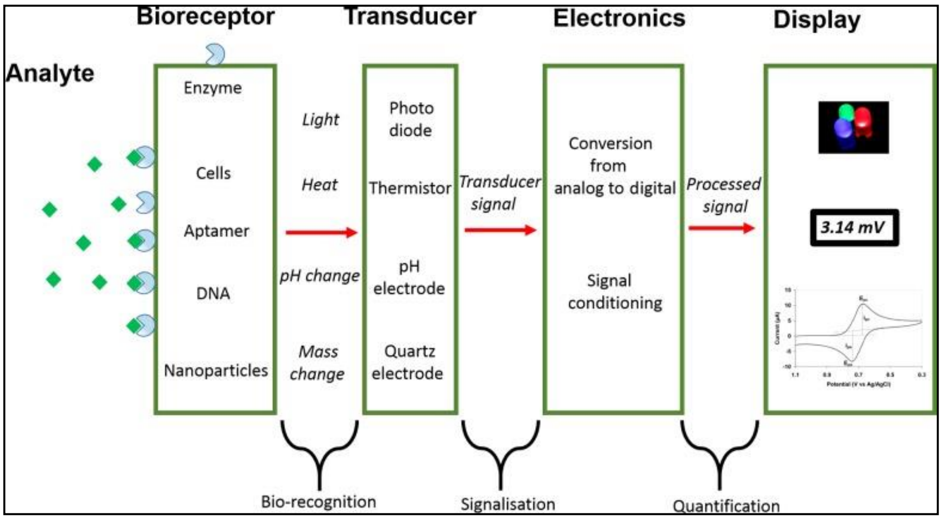

Figure 3.1: Schematic representation of a biosensor [15]

3.3 Types of Biosensors

The biosensors are found in various types which are based on the sensor device and bioreceptor. Some of them are discussed as follow:

3.3.1 Electrochemical Biosensor

This type of biosensor works to the reaction of enzymatic catalysis which provides electrons. These enzymes are called Redox enzymes. The electrochemical biosensor is three electrodes based such as a counter, reference, and working electrode. The current is measured at a fix potential. These biosensors detect many molecules in the body like glucose, cholesterol, uric acid, lactate, DNA, hemoglobin, blood ketones etc. [16].

Electrochemical biosensors are also classified into four types:

A. Amperometric Biosensors
B. Potentiometric Biosensors
C. Impedimetric Biosensors
D. Voltammetric Biosensors

3.3.2 Optical Biosensor:

These biosensors work on optical analysis. The transducing elements such as antibodies and enzymes and optical fiber are used in these sensors.

The optical fibers sense the elements applying various characteristic of light such as absorption, scattering and fluorescence [17].

3.3.3 Piezoelectric Biosensor:

These biosensors are based on mass and also expressed as Acoustic Biosensors because sound vibrations principle works there. When mechanical energy is converted to electric energy then this process is known as piezoelectricity. The piezoelectric effect analyzes changing in pressure, acceleration, temperature, force [18].

3.3.4 Microbial biosensor:

Microbial biosensor works when micro-organisms and a transducer are coupled for fast, perfect sensing of target analytes in various areas like medicine, environmental monitoring, defense, food processing and safety.

3.3.5 Enzyme biosensor:

This biosensor is applied to couple an enzyme with a transducer to produce a signal and this signal is amplified, stored, processed for the detection. These type of biosensors are fabricated using sensitive membrane - immobilized enzyme and electrode transducer system [19].

3.4. Applications of Biosensor:

Biosensors are used widely to increase the quality of life. These are being used for environmental monitoring, disease identification, food safety, defense, and drug discovery, Common healthcare checking, metabolites measurement, screening for sickness, insulin treatment, clinical psychotherapy, diagnosis of disease, in military, agricultural, veterinary applications, drug improvement, offense detection, processing and monitoring in industrial, ecological pollution control, study and interaction of biomolecules, detection of crime, pesticide detection, pharmaceuticals manufacturer and organs replacement etc.

The detection of biomolecule is a signal about the disease or targeted drug such as electrochemical biosensor is applied to detect protein cancer biomarkers [20].

Biosensors monitor food traceability, quality, safety and nutritional value as per standard parameter to use ingredients [21].

Toxic elements can be traced from chemical and biological materials which can be used in defense. Biosensors can be used for the artificial implantation devices like pacemakers, prosthetic devices, and sewage epidemiology.

Figure 3.2 deduces applications of biosensor in various areas.

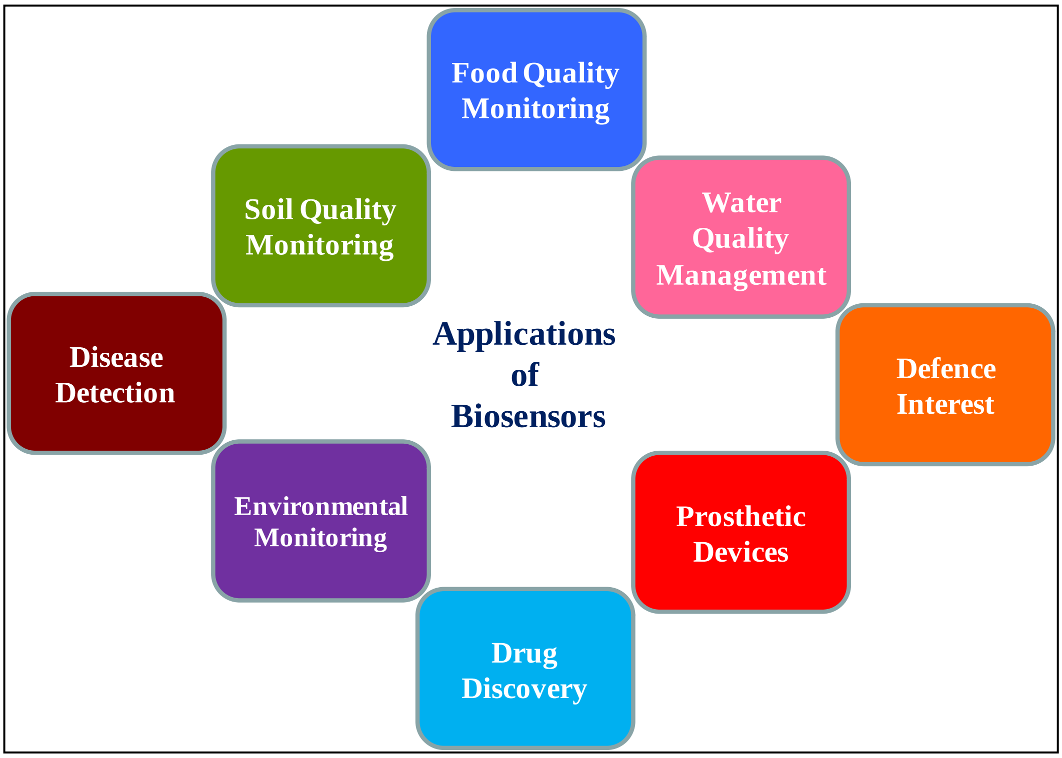

Figure 3.2: Schematic Representation of Biosensor Applications

3.5 Conclusion:

Biosensor is a system which sense, measures, and produce information about physiological change or existence of many chemical or biological elements in the ecological system. Biosensors combine the selectivity of biological system with the processing power of modern microelectronics to offer powerful new analytical tools with major applications in medicine, environmental diagnostic, food industries and agriculture. The advantages of biosensors are that these are small size, low cost, rapid results and easy to use.

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4. Energy Materials and their Applications

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Abstract:

To fulfill the world's future energy needs, it is essential to develop new and innovative energy materials. It is also of utmost significance for energy applications in numerous technological fields. For effective and affordable energy conversion and storage, we are interested in creating novel materials and procedures. In order to develop materials and structures with specific functionalities for effective energy storage and conversion, our research focuses on low-cost, one-step synthesis and fabrication of electrodes with novel structures, in situ characterization, and multi-scale modeling of membranes, thin films, gradient porosity, and nanostructured electrodes with heterogeneous surfaces and interfaces. This covers the creation, assessment, and transfer of energy materials to applications. Photovoltaics (PV), solar fuels, biomass to liquid fuels, thermoelectric materials, battery electrode materials, hydrogen storage, and energy-saving catalysts for the chemical industry are just a few of the many energy-related subjects covered in this session. We shall talk about Energy Materials and Their Applications in this paper.

Keywords:

Energy Materials, Applications, Development, Novel Energy, Energy Storage, Gradient Porosity, Photovoltaics, Solar Fuels, Transmission, Nanomaterials, Macroscopic, Potential, Kinetic Energy.

4.1 Introduction:

Energy materials are a vast range of substances that can be used for energy transmission or conversion. Energy materials can also contribute to improving the efficiency or lowering the power consumption of current electronics. Engineering devices are just one area of research in energy materials. There are restrictions to the materials that are frequently employed in the industry to make next-generation optoelectronic devices. [1]

We must enhance the characterization of atomic-scale properties, control and reproducible growth processes, and rational design of nanomaterials in order to open up new opportunities in a variety of engineering applications, from photonics to energy production. Except for energy, which can only be indirectly viewed and quantified since it presents itself in diverse ways, every physical quantity may be accurately defined. As a result, work and energy share the same unit and are closely related. Since energy is a scalar physical quantity, its magnitude can be used to describe it in its entirety.

Additionally, it should be emphasized that the form may alter if research relating to energy shift from a macroscopic to a microscopic perspective, and vice versa. For instance, mechanical energy, such as friction, may only represent heat energy at the tiny scale. [2]

The attributes of energy can be used to further define it. Potential and Kinetic Energy are the two categories into which all others can be generically classified. When there are no frictional forces acting on the particle, the total of these two energy is always constant.

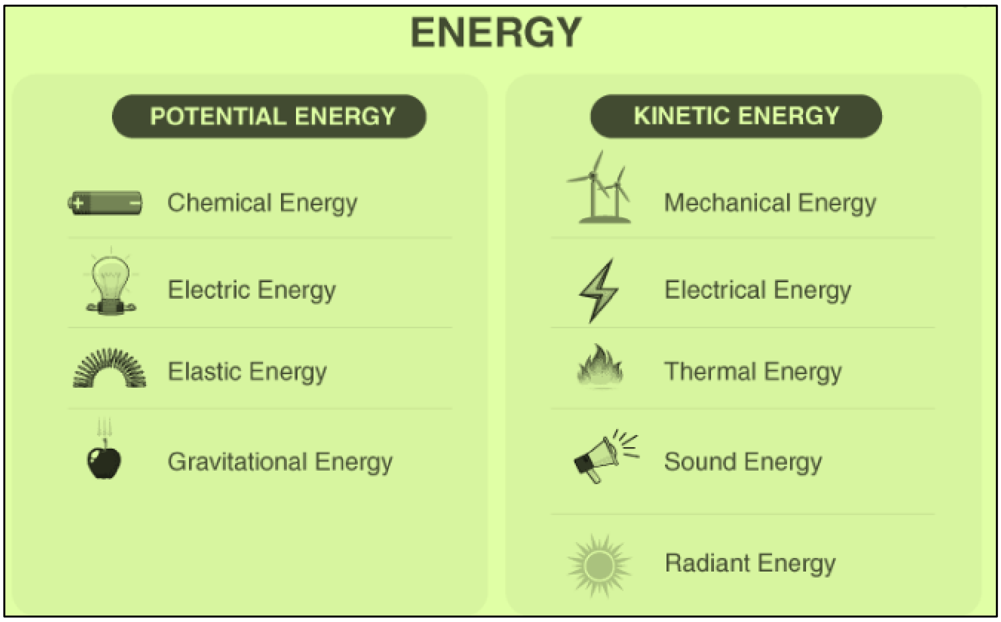

Figure 4.1: Types of Energy

Motion is what **kinetic energy** is. An object's kinetic energy increases with speed. Kinetic energy includes the energy of rivers (hydraulic energy) and the wind (wind energy). This energy can be used to operate a generator or to turn water mills, windmills, or pumps that are connected to turbines into mechanical energy.

Potential Energy is the energy that is held in both stationary objects and position. It is a potential kind of energy, as its name suggests, meaning that it only emerges when it is transformed into kinetic energy. For instance, when a ball is lifted, it gains potential energy (caused by gravity), which only manifests itself when it falls.

Chemical energy is the energy held in atom and molecule bonding. Chemical energy can be found in things like batteries, biomass, oil, natural gas, and coal. For instance, when humans burn wood in a fireplace or gasoline in a vehicle's engine, chemical energy is transformed into thermal energy.

Transverse waves of electromagnetic energy are known as **radiant energy**. Visible light, x-rays, gamma rays, and radio waves are all examples of radiant energy. One kind of radiant energy is light.

Mechanical energy is stored as tension in objects. Examples of mechanical energy that has been stored are compressed springs and stretched rubber bands.

The small, electrically charged electrons that generally flow through a wire are responsible for delivering electrical energy. An illustration of **electrical energy** in nature is lightning.

The energy that an object has due to its height or vertical position is known as **gravitational potential energy**. A book that is higher up on a bookshelf has more gravitational potential energy than a book that is lower down. [3]

The Energy Materials Team is working to create cutting-edge nanostructures and nanocomposites for 3-D integration, thermal control of electrical and photonic devices, and energy generation and storage. This activity's goal is to use nanomaterials in particular Energy-related applications while also doing applied research to close the knowledge gap between science and technology.

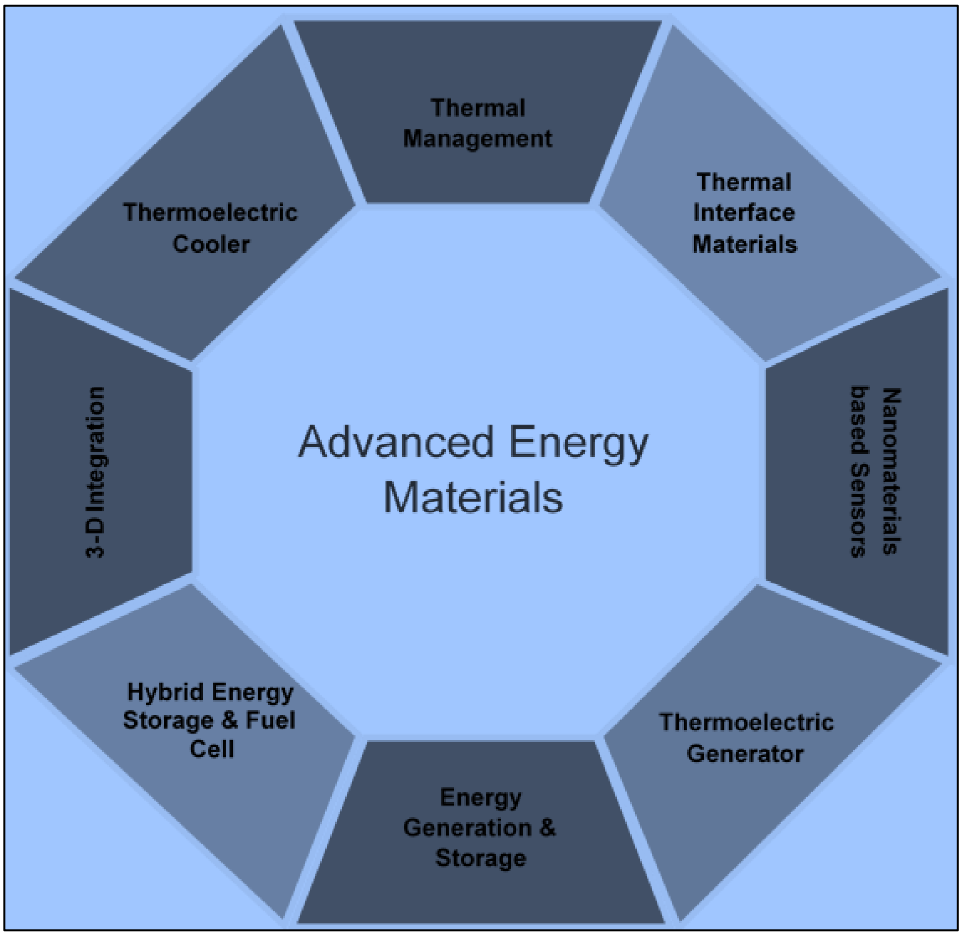

Figure 4.2: Advanced Energy Materials

The advances in material science have a major impact on the development of energy storage and conversion technologies. Researchers today stand at a position that could be rich in enormous chances to eradicate the energy and environmental problems thanks to new equipment for creating and studying innovative materials for green energy and the quick accumulation of knowledge about them.

Indeed, there has been significant improvement in the use of green energy, including solar energy, biofuels, and wind power. In addition to harnessing green energy, the light-emitting devices are revolutionizing the lighting industry by being energy-efficient. Although colleagues are making an effort in these areas, the achievements are still far below the expectations. [4]

Energy materials are components for machinery that harvests energy from resources as efficiently as possible. Therefore, all materials used in technology to transform primary energy into energy carriers that reach consumers as secondary energy and ultimately into energy that is actually used for human purposes, such as air conditioning, a comfortable lifestyle, transportation, and the production of goods, are considered energy materials.

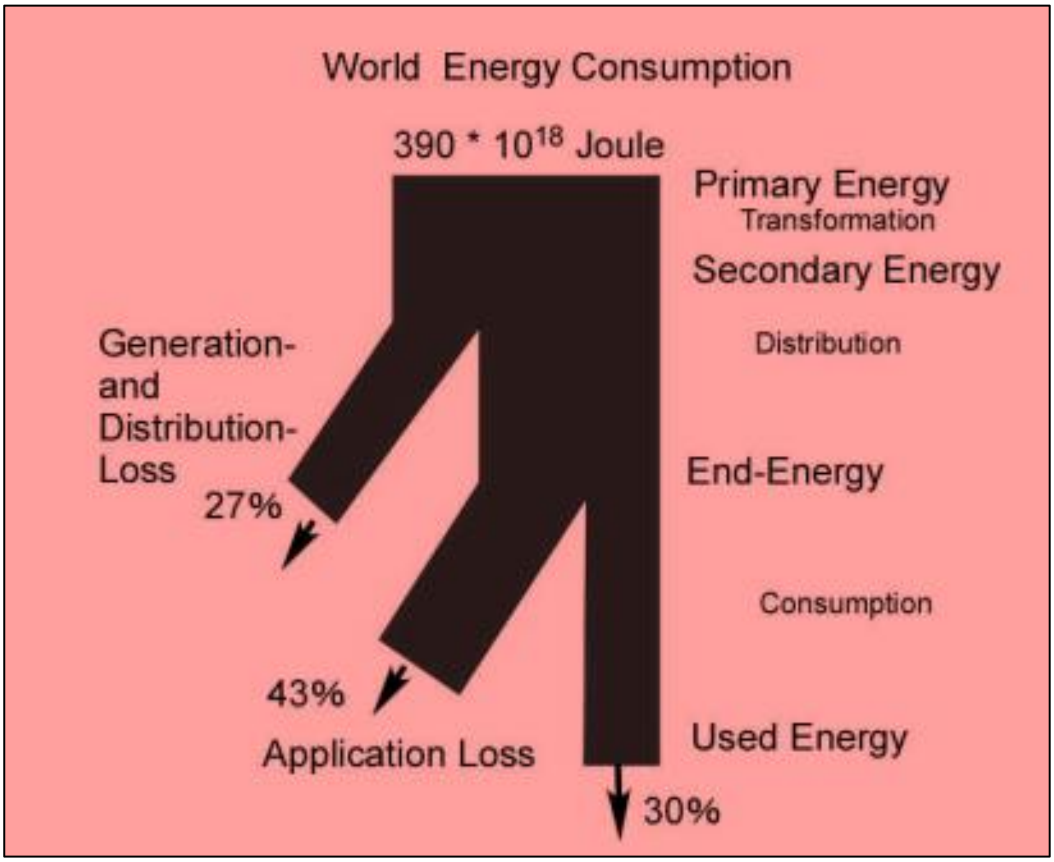

Figure 4.3: Future energy materials face a challenge in reducing energy loss during production, distribution, and use.

Figure 4.3 demonstrates how much energy is lost throughout each stage of energy transformation using current technologies. Only 63% of the primary energy, which is contained in fuels or comes from renewable sources, is supplied to consumers as secondary energy. The losses result from heat dissipation, inadequate equipment, inefficient technology, transportation or storage losses, among other things.

Fuel cells are being developed by materials scientists in an effort to replace electricity and gasoline as the primary energy sources in many applications. Currently, energy is carried by electricity and gasoline. [5]

4.2 The Numerous Energy Uses in Daily Life:

4.2.1 Residential Uses of Energy:

These are the most fundamental energy uses when discussing home use. You can work from home on your laptop or computer, watch television, wash your clothes, heat and light your house, take a shower, operate appliances, and cook.

The majority of consumers are unaware that there are options, businesses, and innovations that can support them in monitoring and reducing their energy usage.

4.2.2 Commercial Uses of Energy:

Energy is used for business purposes in the commercial sector. This includes power utilized by businesses and companies throughout our cities for computers, fax machines, workstations, copiers, to mention a few, as well as heating, cooling, and lighting of commercial buildings and spaces.

In order to combat the waste culture existing at our workplaces, energy conservationists should launch energy-saving campaigns.

4.2.3 Transportation:

Energy is the only factor that influences transportation in any way. The transportation sector consumes over seventy percent of all petroleum. The transport sector encompasses all types of vehicles, including motorbikes, trucks, buses, and personal automobiles.

Aircraft, railroads, ships, and pipelines are all included. If we take into account the uses and address them individually, worldwide efforts at energy conservation can be achieved.

materials pertaining to energy applications, such as:

- Alternative Energy Vectors
- Thermoelectric
- Semiconductors
- Photovoltaics (PV)
- Fuel Cells
- Energy Storage.

Materials for potential future energy uses can include, among others, polymeric, complex oxide, nanoionics, caloric, and porous materials. [6]

Energy-related materials may contribute to improving the efficiency or lowering the power consumption of current technology. Engineering devices are just one area of research in energy materials.

The term "energetic material" refers to a fairly broad category of substances, ranging from low explosives like gunpowder, dynamite, and TNT to basic automotive fuels like gasoline and diesel.

- Solar Energy
- Solar Systems Integration
- Concentrating Solar Thermal for Electricity, Chemicals, and Fuels
- Photovoltaic Materials, Devices, Modules, and Systems
- Renewable Energy
- Energy Storage & Grid Modernization
- Fossil & Nuclear Energy
- Bioenergy
- Geothermal
- Renewable Fuels
- Solar Thermal
- Batteries & Fuel Cells
- Electric Grid

- Grid Scale Storage
- Superconductors
- CO2 Capture, Storage & Conversion
- Combustion
- Enhanced Oil Recovery
- Natural Ga
- Unconventional Oil & Gas

On earth, energy comes in a variety of ways. The elemental source of energy on earth is said to be the sun. Energy is seen as a quantifiable property in physics that may be transferred from an item to carry out work. Thus, we might characterize energy as the capacity to engage in any kind of physical action. As a result, the simplest way to describe energy is as the capacity for work. [7]

Energy "can neither be created nor destroyed but can only be converted from one form to another," according to the rules of conservation of energy. The SI unit for energy is called a joule.

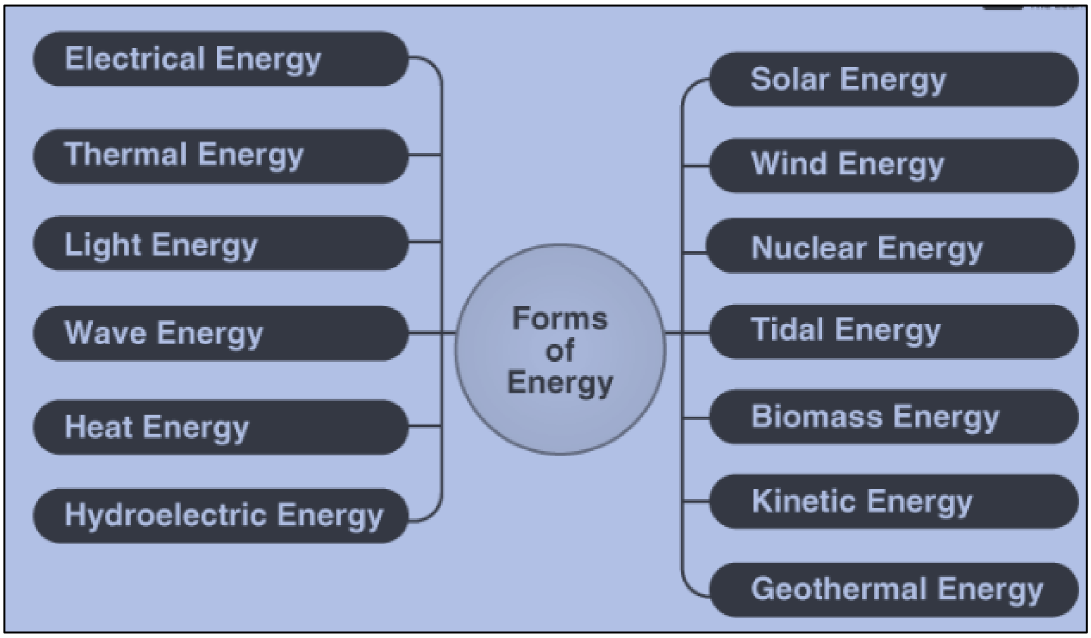

Figure 4.4: Forms of Energy

4.3 Units of Energy:

The unit of measurement for energy in the International System of Units is joule. James Prescott Joule is honored with the name of the energy unit. The energy used to apply a force of one newton over a distance of one meter is measured in joules, a derived unit.

However, there are also additional units outside of the SI that are used to measure energy, including ergs, calories, British Thermal Units, kilowatt-hours, and kilocalories, which need to be converted before being expressed in the SI system. [8]

Due to its abundance, low cost, high specific heat, and high density, water is regarded as one of the greatest materials that may be utilized to store thermal energy in the form of sensible heat. Additionally, if water is employed in the solar thermal system as the heat transfer fluid, a heat exchanger is avoided. Water has traditionally been used in commercial applications to store thermal energy in liquid-based systems.

Table 4.1 displays The following are Selected Materials for Sensible Heat Storage:

Table 4.1: Material for Sensible Heat Storage

Phase	Medium	Temp Rang [°C]	Density Kg/m^3	Specific Heat J/kg K
Solid	Rock	7-27	2560	879
	Brick	17-37	1600	840
	Concrete	7-27	2100	880
	Sand	7-27	1550	800
	Soil	7-27	2040	1840
Liquid	Water	7-97	1000	4180
	Engine Oil	Up to 157	888	1880
	Ethanol	Up to 77	790	2400
	CalorieaHT43	12-260	867	2200
	Butanol	Up to 118	809	2400
	Other Organic	Up to 420	800	2300

Materials used in energy harvesting and energy storage systems, such as thin film solar cells and batteries, behave differently depending on their morphology and composition at the nano- and micro-scale. We examine these features at various length scales using focused ion beam (FIB) milling along with scanning and transmission electron microscopy (SEM/TEM). [9]

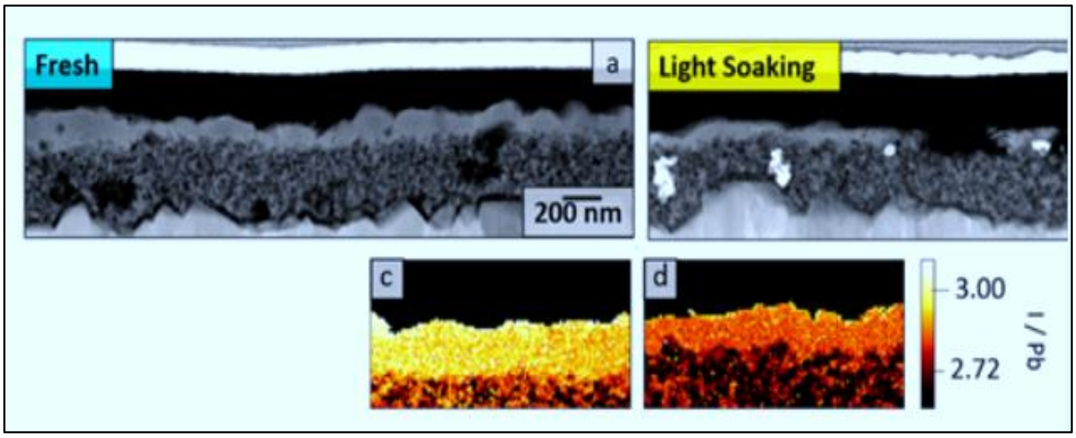

Figure 4.5: Caption: a) HAADF STEM images for a large area fresh cell and b) for a cell after 200h of light soaking. (c) Calculated atomic ratio maps for iodine/lead in the fresh and (d) stressed cells obtained from energy dispersive X-ray spectroscopy (EDX).

4.4 Energy Storage:

Energy storage is a frequently underutilized yet crucial energy technology. It can improve energy systems' functionality and increase their effectiveness, economics, dependability, and environmental impact. It is essential for making many renewable energy sources more widely used. [10]

The recent Long-term Energy Plan for Ontario, which calls for the purchase of 50 MW of energy storage capacity by the end of 2014, recently highlighted this surge in interest in energy storage.

As a result, the Independent Electricity System Operator (IESO) and Ontario Power Authority (OPA) jointly developed an energy storage procurement framework, which received endorsement from the province's energy minister.

To encourage a better understanding of and experience with a variety of energy storage technologies, the procurement framework allows for

- The services that energy storage systems can offer,
- The advantages they offer operations and
- The best way to incorporate storage into electricity markets.

The following are some of the energy storage's advantages, which are frequently extremely substantial:

Energy storage enables peak needs to be lowered or transferred to periods of lower demand when energy consumption varies dramatically over time, frequently with large economic benefits.

Energy storage is particularly useful for eliminating mismatches between times of energy supply and demand and for bridging those periods between energy supply and demand.

Energy storage is especially helpful for bridging periods between energy supply and energy demand, and reducing the mismatches between periods of energy supply and demand.

The use of energy storage significantly improves the performance of energy systems that utilise intermittent energy sources.

Through the use of energy storage, operational performance flexibility can be improved.

Utilizing energy storage can lessen the environmental effects of burning fossil fuels.

There are numerous different kinds of energy storage technologies and systems (see Figure 6). Chemical, electrical, thermal, thermochemical, mechanical, and other classifications can be used to separate these.

Batteries, hydrogen storage, flywheels, compressed gas storage, pumped storage, magnetic storage, capacitor storage, chemical storage, thermal energy storage (both sensible and latent), thermochemical energy storage, organic and biological energy storage, and others are examples of specific types of energy storage.

Even though a lot of energy storage is developed and commercially available, new storage technologies are constantly being researched, and existing ones are constantly being improved. Some technologies, like thermal energy storage, are currently both marketable and the subject of in-depth research. [11]

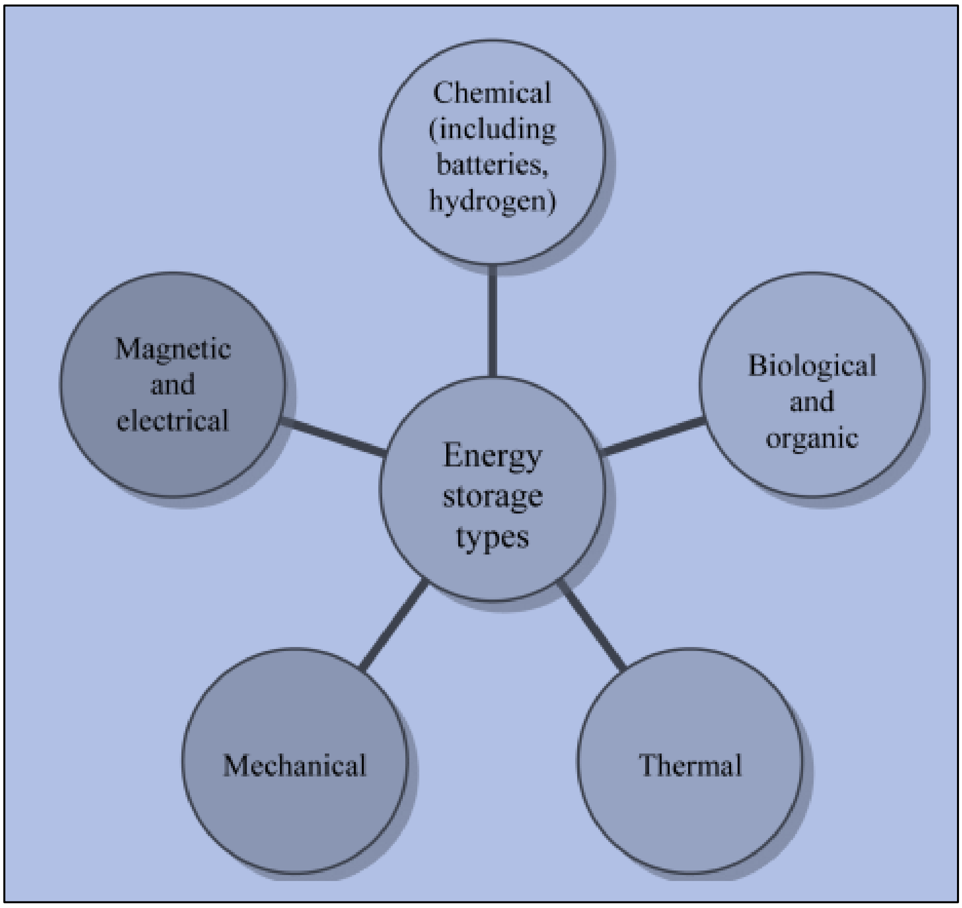

Figure 4.6: Energy storage types classified by type of stored energy.

4.5 Conclusion:

Energy materials are components for machinery that harvests energy from resources as efficiently as possible. Our society is mostly driven by energy. Various energy producing techniques can also be harmful to the environment. Depending on the amount of theory and technology available at the time, the understanding of porous energy materials displayed distinct characteristics in various eras.

The design and optimization of their structures and operational parameters remain difficult and call for additional work from the industrial and academic sectors despite the rise in breakthrough materials and energy technologies.

Thus, converting all materials into virtual data spaces rather than relying just on experimental research has steadily gained interest.

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5. Optimization of Ejector Design Using CFD Analysis

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Abstract:

The satellite launch vehicle, GSLV has a cryogenic upper stage, which uses the cryogenic engine. In order to test and qualify the upper stage engine, used in a high-altitude Test Facility is used. The HAT facility is configured with a vacuum chamber, a second throat diffuser, a gas cooler, and an ejector and the diffuser system. Each subsystem has to be analyzed numerically and optimized for its better performance. This report deals with the Ejector system. In the first step, the basic dimensions of the ejector are derived from the one-dimensional gas dynamic equation. This report describes the performance of Ejector (designed by ID), the need for optimization, optimization of the Ejector system using CFD. A 2 – dimensional axis-symmetric geometry with nozzle and mixer system is considered for the analysis. A two – dimensional structured mesh, standard k-ε modeling for turbulence and species transport (not reacting) equations for species transport is considered for the analysis. The effect of varying the Nozzle exit diameter was studied to optimize the ejector for both no-load and full load conditions using CFD fluent software.

5.1 Introduction:

Leading countries in the world like the USA, USSR, France, China, India, etc. are involved in space research and developing their nations in various fields like defense, telecommunication, weather forecasting, etc. Nowadays space technology has become a part of the everyday life of millions of people.

A good example is the mutest images we see on the television screen. A communication satellite has revolutionized global communication which holds great promise for the near future. Satellite observations are increasingly important for accurate and timely weather forecasting. Such developments will exert even greater influences in our living conditions and quality of life. A satellite is a payload carried by the launch vehicle and injected into the desired orbit. Generally, there are six types of satellites. They are a military satellite, weather satellite, communication satellite, Navigation satellite, space research satellite, and bio satellite. A satellite is generally launched towards the east so as to take advantage of the earth's eastward rotation. The satellite moving from west to east in a circular orbit of about 36000 km above the equator takes 24 hrs.

5.2 Related Works:

E.J.; DeHart, J.H studied combination of computer analysis and scale model testing was utilized to develop a nozzle that would increase the performance of thrust augmentation ejectors, Scale model tests were conducted on various multi-lobed and vortex generating nozzles. Predicted jet characteristics were obtained by calculating a finite difference solution of Reynolds equations for the three-dimensional flow field. A two-equation turbulence kinetic energy model was used for closure. It is demonstrated that the thrust augmentation of the XFV-12A ejector can be increased from 1.45 to 1.4 by the addition of lobes to the baseline nozzle, and a corresponding increase of throat width.

The report documents the WIND k-epsilon model validation results for a two-dimensional ejector nozzle flow by Gilbert, G.B., and Hill, P.G.Comparisons are made between the NPARC and WIND k-epsilon model implementations and with the WIND SST model results. In addition, the effects of the Sarkar compressibility correction and the variable C mu option on the stability and convergence of the WIND k-epsilon model are discussed by Gilbert, G.B., and Hill, P.G.The focus of this investigation was the turbulent flow through a two-dimensional ejector nozzle which was tested by Gilbert and Hill (1973).

This flow features the turbulent mixing between the primary jet entrained secondary air as well as the interaction with the wall boundary layers. The rectangular mixing section is formed by the symmetrically contoured upper and lower walls and the two flat sidewalls.

The widths of both the primary nozzle discharge slot and the mixing section were 8.00 inches. Suction slots were placed in the corners of the mixing section to prevent flow separation. The experimental data to be used for comparison purposes consists of velocity and temperature measurements at several axial locations. The inflow conditions used in the numerical computations correspond to those of run 9 in the report by Gilbert and Hill (1973).

V. M. Puzyrev and R. K. Tagirov proposed method for calculating the two-dimensional non-viscous flows in ejector nozzles of arbitrary shape, for two operating cycles: the subsonic flow cycle of a secondary stream and a cycle when the secondary stream attains critical velocity i.e.; it is cut off, the possibility is allowed for the appearance of a direct compression shock in the supersonic part of the secondary stream

Emilia Wagnerova, Ivan Imri s developed the continuous production of copper dried concentrate and fluxes were injected through the top-blowing lance into the molten bath. The properties of the equipment designed were determined by both classical measurements of the airflow parameters through an ejector with an annular supersonic nozzle that was confirmed by the sheer and the shade methods of flow visualization.

Vaclav Dvorak, Pavel Safarik deals with an experimental, theoretical and numerical study of the interaction of supersonic flows on the trailing edge of a primary flow nozzle of an ejector. The mechanism of mutual deflection of supersonic flows is explained. The influences of backpressure and stagnation pressure ratio of both flows on the interaction are presented. Recommendations for the design and for the operation of supersonic ejectors are formulated.

The satellite launch vehicle consists of different stages that have a cryogenic upper stage, which uses the cryogenic engine. In order to test and qualify the upper stage engine, high altitude test facility is required. The HAT facility is configured with a vacuum chamber, a second throat diffuser, a gas cooler, and an ejector and the diffuser system.

Each subsystem has to be analyzed numerically and optimized for its better performance. This report deals with the Ejector system. In the first step, the basic dimensions of the ejector are derived from the one-dimensional gas dynamic equation.

This report describes the better performance of Ejector, need for optimization of the ejector system using CFD. A 2d axis-symmetric geometry with nozzle and mixer system is considered for the analysis. A 2d structured mesh standard k- ε modeling for turbulence and species transport is considered for the analysis.

Based on the above cases, the optimum configuration of the ejector system with the nozzle A.R of 4.6, the distance between the nozzle exit and the mixer throat of 925 mm.

The GN2 supply pressure of 25 bars has arrived through detailed CFD analysis which yields the better performance of No-load suction Pr. Of 22.9 m bar and the full load suction pressure of 784.85m bar. It is exactly matching with the one-dimensional gas dynamic equation value as well as the system requirement of cryo-rocket engine HAT facility.

5.3 Materials and Methods:

5.3.1 Computational domain and grids:

A 2 – dimensional axisymmetric geometry with nozzle and mixer system is considered for the numerical analysis.

The geometry is done in the CAD system and it is imported in Gambit. Structured mesh has been used throughout the analysis and the total number of nodes was 68734.

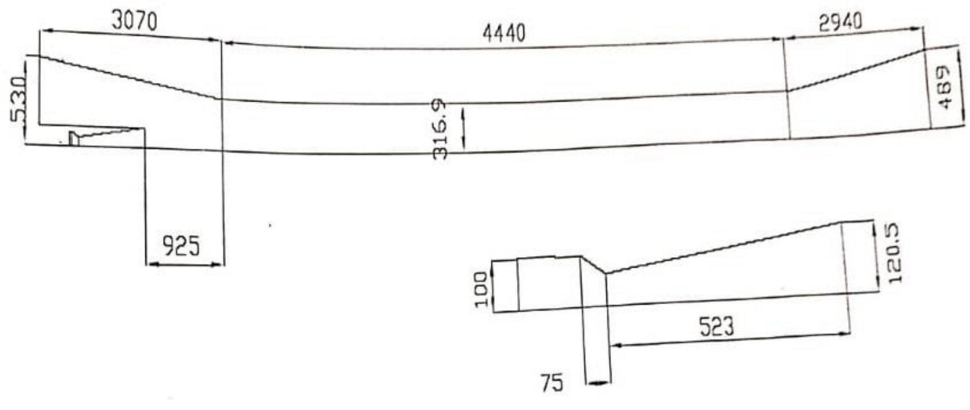


Figure 5.1: Geometry of Ejector

5.3.2 Numerical methods:

Gambit is a preprocessor that is used for geometry preparation and grid generation. Using Gambit 2-D and 3-D geometries can be drawn. Realistic geometries are too complicated to be generated in Gambit. So, the design is done in the CAD system and it is imported into it. Gambit is based on ACIS geometrical system which is the most widely used 3-D modeling technology. It can also import STEP, IGES STL files.

The geometry or topology of Gambit is Vertex, Edge, Face, Volume.

5.3.3 Governing equations:

The governing flow equation based on the physical principle that energy is conserved is known as the “Energy Equation”.

$$\frac{\partial \rho E}{\partial t} - div(\rho E V) = \frac{\partial (u\tau_{xx})}{\partial x} + \frac{\partial (u\tau_{yx})}{\partial y} + \frac{\partial (u\tau_{zx})}{\partial z} + \frac{\partial (v\tau_{xy})}{\partial x} + \frac{\partial (v\tau_{yy})}{\partial y} + \frac{\partial (v\tau_{zy})}{\partial z} + \frac{\partial (w\tau_{xz})}{\partial x} + \frac{\partial (w\tau_{yz})}{\partial y} + \frac{\partial (w\tau_{zz})}{\partial z} + \frac{\partial}{\partial x}\left[k\frac{\partial T}{\partial x}\right] + \frac{\partial}{\partial y}\left[k\frac{\partial T}{\partial y}\right] + \frac{\partial}{\partial z}\left[k\frac{\partial T}{\partial z}\right] + S_g$$

In the above equation, a divergence term appears on the left-hand side. These terms involve the divergence of the flux of some physical quantity: ρV, $\rho uV, \rho vV, \rho wV \rho EV$.

These flux terms are solved during a CFD analysis and the primitive variables can be calculated from them.

The k-ϵ model is the most widely used and validated turbulence model. It has achieved notable success in calculating the wide variety of thin shear layer and recirculating flows without the need for case-by-case adjustment of the model constants.

The model performs particularly well in confined flows where Reynolds shear stress is most important. Some reasons to select this model for the present work are

- Simplest turbulence model for which only initial and boundary conditions need to be supplied.
- Excellent performance for many industrial relevant flows.
- Well established, most widely validated turbulence model

The transport equations for this model are as follows

Turbulent energy (k)

$$\frac{\partial}{\partial t}(\rho) + \frac{\partial}{\partial x_i}\left[\rho u_j k - (\mu + \frac{\mu_t}{\sigma_k}\mu_{t)}\frac{\partial k}{\partial x_j}\right]$$
$$= \mu_t(P + P_B) - \rho\varepsilon - \frac{2}{3}\left(\mu\frac{\partial u_i}{\partial x_i} + \rho k\right)\frac{\partial u_i}{\partial x_i} + \mu_t P_{NL}$$

Where

P=$2S_{ij}\frac{\partial u_i}{\partial x_j}$ $\quad$ $P_B = -\frac{g_1}{\sigma_{h,t}}\frac{1}{\rho}\frac{\partial P}{\partial x_i}$

$$P_{NL} = -\frac{\rho}{\mu_t}\mu'_i\mu'_j\frac{\partial \mu_i}{\partial x_j} - \left[P - \frac{2}{3}\left(\frac{\partial \mu_i}{\partial x_i} + \frac{\rho k}{\mu_t}\right)\frac{\partial \mu_i}{\partial x_i}\right]$$

$P_{NL} = 0$ for nonlinear models and σ_k is an empirical coefficient.

The first term on the right-hand side of the turbulent energy equation represents turbulent generation by shear and normal stresses and buoyancy forces, the second viscous dissipation and the third amplification or attenuation due to compressibility effects.

The last term accounts for non-linear contributions. Turbulence dissipation rate (ε)

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_j}\left[\rho u_j\varepsilon - (\mu + \frac{\mu_t}{\sigma_\varepsilon}\mu_{t)}\frac{\partial \varepsilon}{\partial x_j}\right]$$
$$= C_{\varepsilon 1}\frac{\varepsilon}{k}\left[\mu_t P - \rho\varepsilon - \frac{2}{3}\left(\mu\frac{\partial u_i}{\partial x_i} + \rho k\right)\frac{\partial u_i}{\partial x_i}\right] + C_{\varepsilon 3}\frac{\varepsilon}{k}\mu_t P_B - C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k}$$
$$+ C_{\varepsilon 4}\rho\varepsilon\frac{\partial u_i}{\partial x_i} + C_{\varepsilon 1}\frac{\varepsilon}{k}\mu_t P_{NL}$$

Where $\sigma_{\varepsilon,C_{\varepsilon1},C_{\varepsilon2,C_{\varepsilon3}} \text{ and } C_{\varepsilon4}$ are the empirical coefficients whose values are given in the table.

The right-hand side terms represent the analogous effects to those described above for the k equation.

The turbulent viscosity $\mu_t = f_\mu c_\mu \rho \, k^2/_\varepsilon$ with f_μ set equal to unity.

C_μ	0.09
σ_k	1.0
σ_ε	1.22
$C_{\varepsilon1}$	1.44
$C_{\varepsilon2}$	1.92
$C_{\varepsilon3}$	1.44
$C_{\varepsilon4}$	-0.33
k	0.42

5.3.4 Boundary Conditions:

The inlet pressure and temperature were 25bar and 250 k and outlet pressure as 1 bar and 300 k.

Case 1

Effect of Area ratio of GN2 supply Nozzle on the Ejector system:

The effect of area ratio on ejector no load & full load variations are given in table 5.1 & 5.2.

Table 5.1: Results of No-load Analysis

Area Ratio	Operating Pressure (bar)	No-load Pressure
4.4	25	34.78

Area Ratio	Operating Pressure (bar)	No-load Pressure
4.6	25	22.9
4.8	25	175.07

Table 5.2: Results of Full load analysis

Area Ratio	Operating Pressure (bar)	Full load Pressure (m bar)
4.4	25	916.04
4.6	25	784.75
4.8	25	911.85

Effect of the area ratio of GN2nozzle:

From the above results, the observations are as followed.

In this case, three area ratios 4.4,4.6,4.8 have been considered for the ejector nozzle. The GN2 supply pressure is kept constant (pressure=25 bar). The spacing of the ejector Nozzle exit from the mixer throat is kept constant (d=925 mm).

The No-load suction pressure obtained for the ejector is 34.78m bar, three cases as shown in table 5.1. It is found that the suction pressure at no load and full load for area ratio 4.6 is the lowest and it is matching with the one-dimensional value as per the design document of Cryo-rocket engine HAT facility.

Based on the above result the optional area of 4.6 is arrived for the desired no load and full load pressure. The tangential shear mixing of passive and active fluid is achieved as the area ratio 4.6. The Variations of Static Pressure static temperature, Mach Number, flow velocity for No-load as well as Full load conditions with area ratio 4.6 are given in figures.

Effect of Ejector spacing for constant area ratio on the ejector system:

The effect of Ejector spacing for constant area ratio no load & full load variations are given in table 5.3 & 5.4.

Table 5.3: Results of No-load Analysis

Length (mm)	Operating Pressure (bar)	No-load Pressure (m bar)
850	25	32.47
925	25	22.9
1000	25	37.23

Table 5.4: Results of Full load Analysis

Length (mm)	Operating Pressure (bar)	Full load Pressure (m bar)
850	25	915.19
925	25	784.75
1000	25	909.7

Effect of GN2 supply nozzle exit plane location from the mixer throat:

From the above results, the observations are as followed.

The spacing of ejector Nozzle exit from the mixer throat is varying 850 mm,925 mm and 1000 mm have been considered for the ejector Nozzle for constant area ratio 4.6. The GN2 Supply pressure is kept constant (pressure = 25 bar).

The No-Load suction pressure obtained for the ejector is 32.47 m bar,22.9m bar,37.23m bar for the three cases as shown in table 5.3. It is found that the suction pressure at No load and full load for the distance of 925 mm and it is matching with the one-dimensional value as per the design document of the Cryo-rocket engine HAT facility.

In general, no-load pressure parallel the small spacing from mixture throat at the minimum and full load pressure parallel be higher. Based on the above result the spacing of 925 mm is suitable for the no-load and full load pressure requirement.

The variations of Static Pressure, Static Temperature, Mach Number, Flow Velocity for No-load as well as Full load conditions with area ratio 4.6 are given in figures.

Case 3:

Effect of GN2 supply flow rate:

Table 5.5: Results of No-load Analysis:

Operating Pressure (bar)	GN2 Flow rate (Kg/s)	No-load Pressure
20	48.29	279.35
25	60.18	22.9
30	72.44	27.89

Table 5.6: Results of Full load analysis:

Operating Pressure (bar)	GN2 Flow rate (Kg/s)	Full load Pressure (m bar)
20	48.29	902.39
25	60.18	784.75
30	72.44	919.01

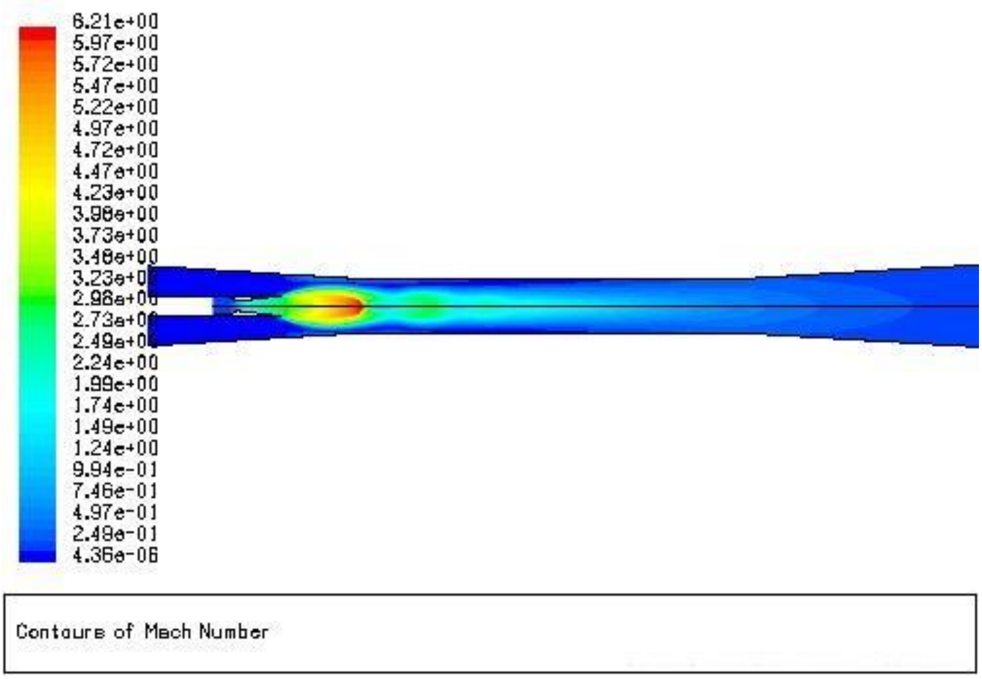
Effect of GN2 supply flow rate:

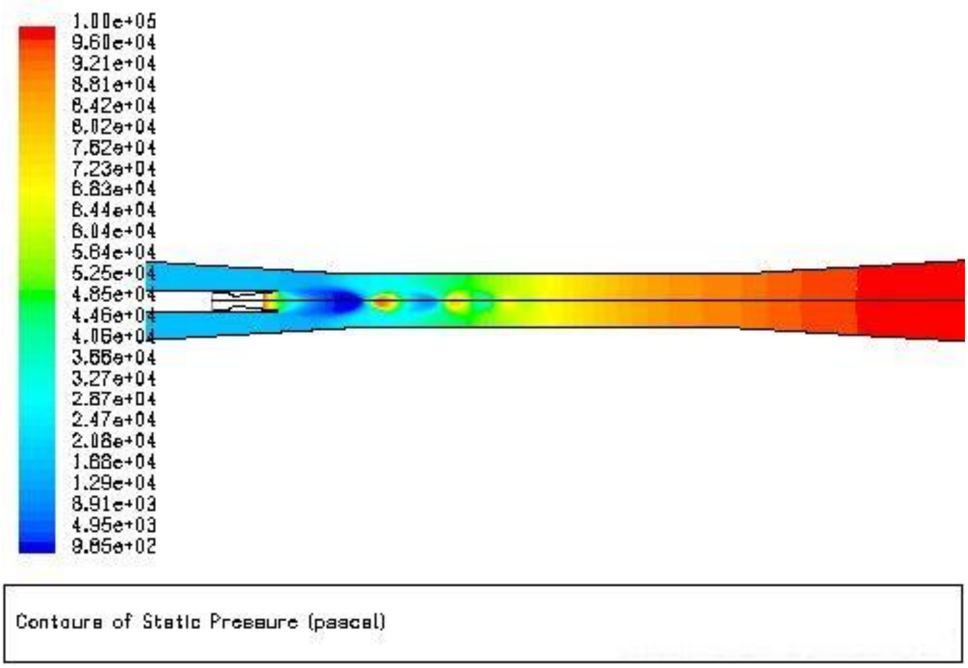
From the above results, the observations are as followed. In this case, three operating pressure 20 bar, 25 bar, and 30 bar have been considered for the ejector Nozzle area ratio is 4.6 and the Nozzle exit from the mixer throat is 925 mm. The GN2 flow rate obtained for the ejector is 48.29,60.18,72.44 for the three cases as shown in table 5.5. It is found that the suction pressure at No load and Full Load for pressure 25 bar is the lowest and it is matching with the one-dimensional value as per the design document of Cryo-rocket engine HAT facility.

The ejector mixer throat is designed for the chocking condition of the desired flow rate. Based on the above, the optimum of the GN2 supply rate of 60 kg/s is best suitable for the desired no load and full load condition. The variations of Static Pressure, Static Temperature, Mach Number, Flow Velocity for No-load as well as Full load conditions with area ratio 4.6 are given in figures.

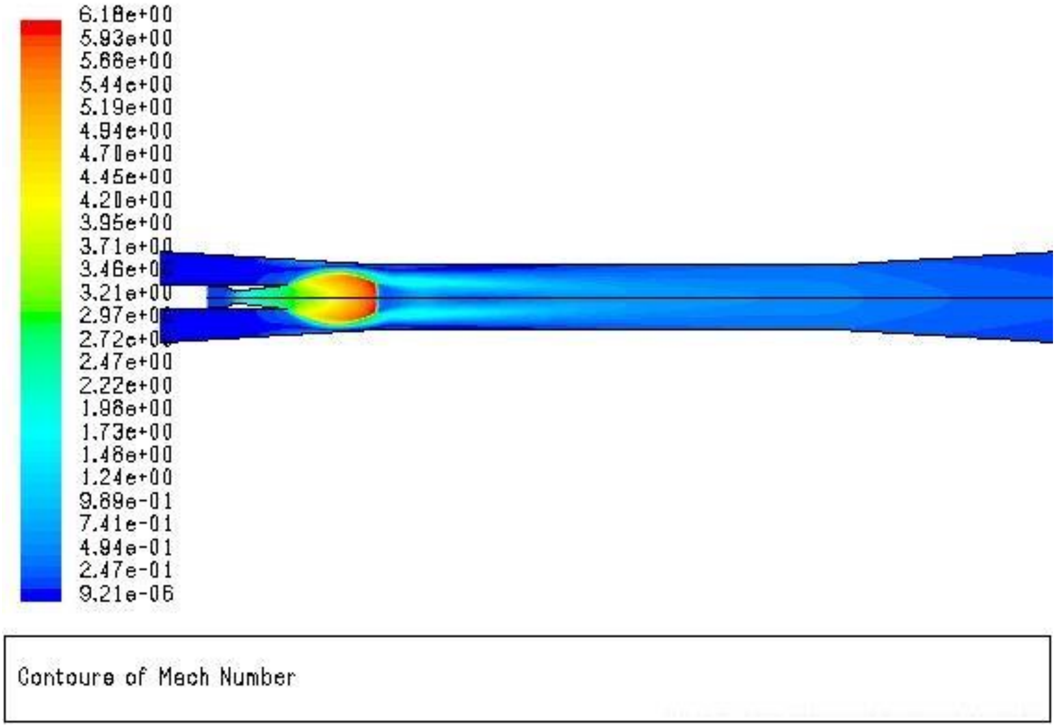
5.4 Results and Discussion:

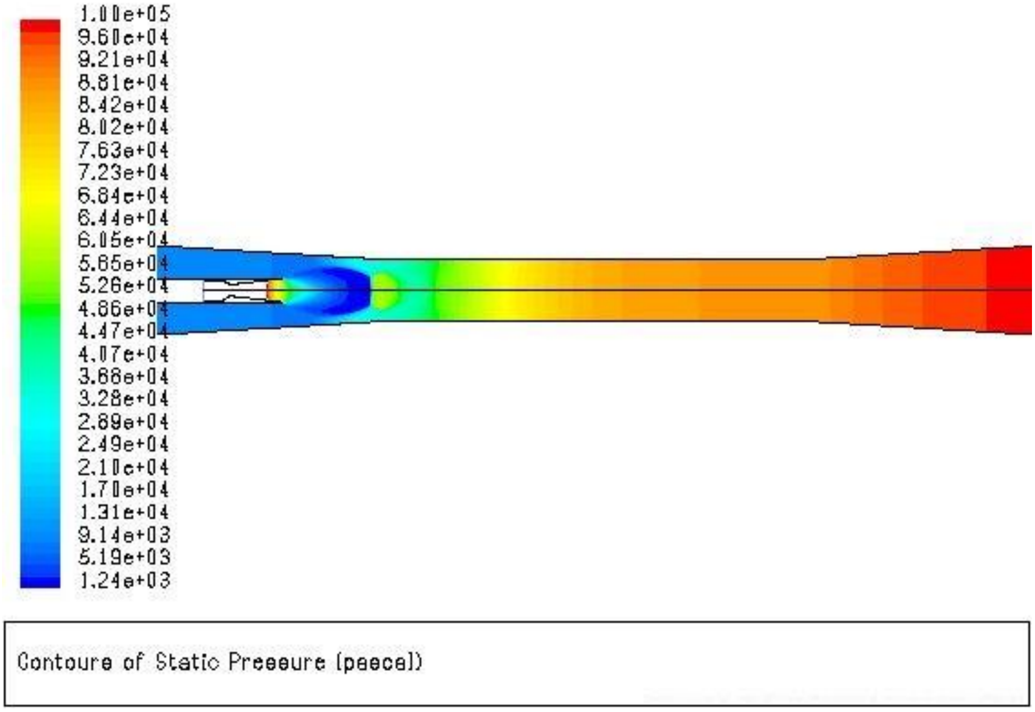
PC=20bar; MGN2=48kg/s



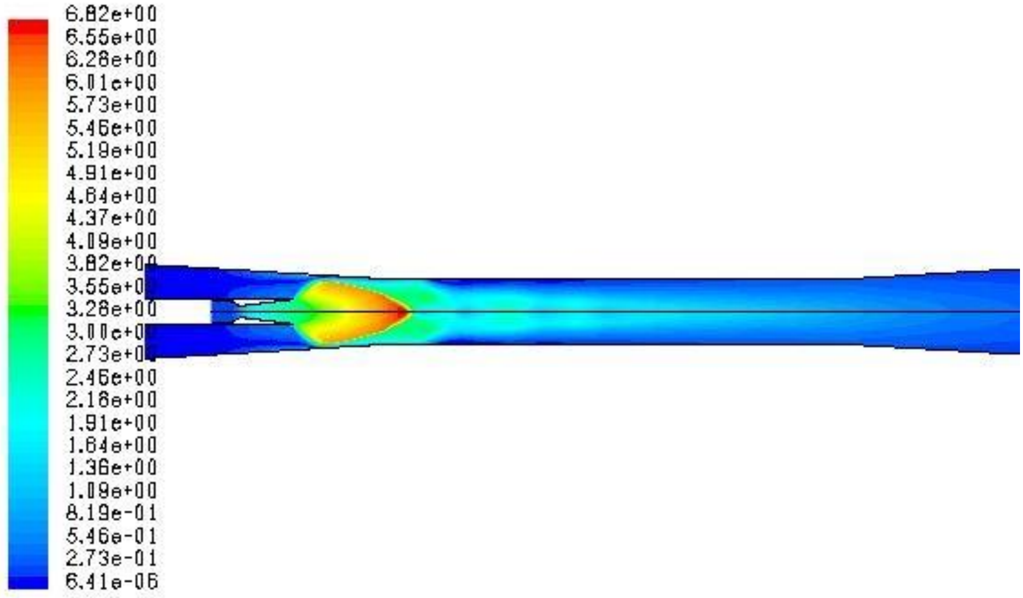


PC=22.5bar;MGN2=54kg/s

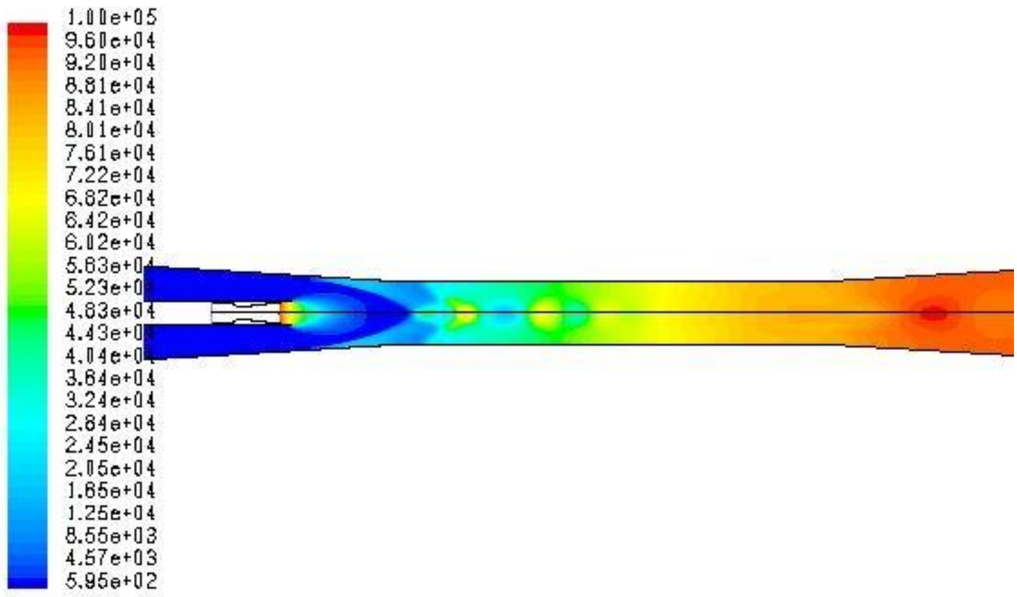




PC=25bar;MGN2=60kg/s

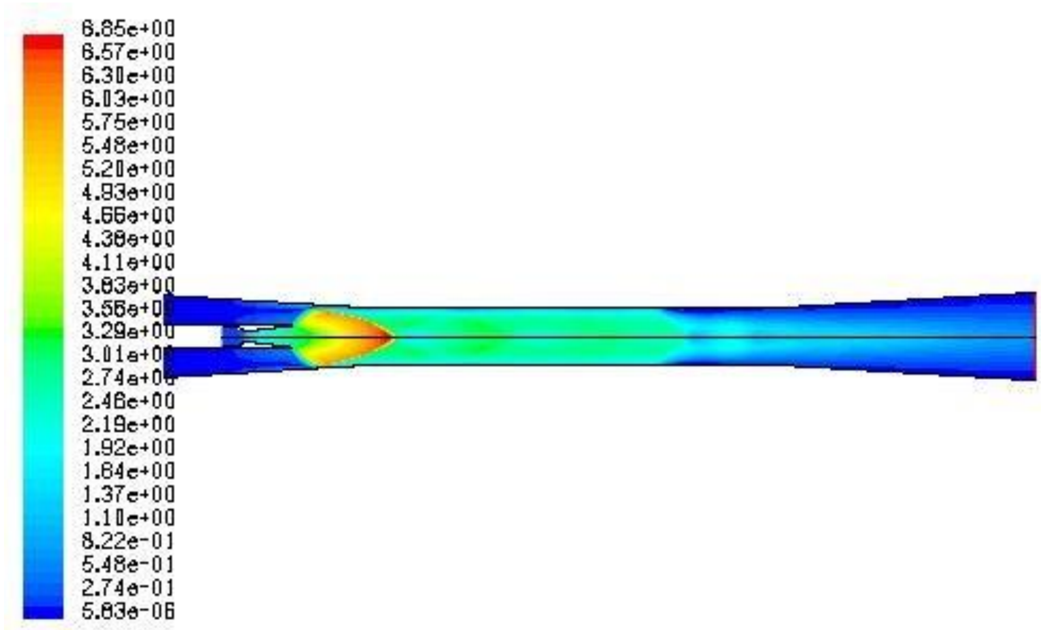


Contours of Mach Number

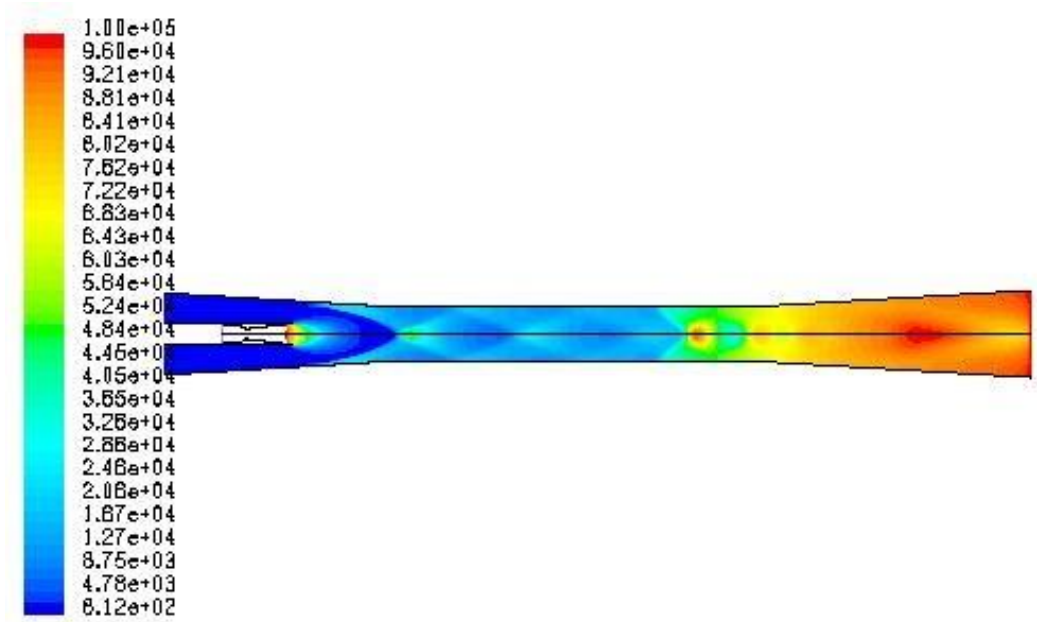


Contours of Static Pressure (pascal)

PC=30bar;MGN2=72kg/s



Contours of Mach Number



Contours of Static Pressure (pascal)

5.5 Conclusion:

Based on the above case studies, the optimum configuration of the ejector system with the nozzle A.R of 4.6, the distance between the nozzle exit and the mixer throat of 925 mm. The GN2 supply Pressure of 25 bars has arrived through detailed CFD analysis which yields the better performance of No-load suction Pr. of 22.9 m bar and the full load suction Pressure of 784.85 m bar. It is exactly matching with the one-dimensional gas dynamic equation value as well as the system requirement tor Cryo-rocket engine HAT facility.

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6. Characterization and Microscopy

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Abstract:

The Center for Electron Microscopy and Analysis (CEMAS) is at the center of this endeavor. For both industry and academics, CEMAS is the leading center for materials characterization. The Center combines multidisciplinary skills to enhance our characterization capabilities, drive synergy, and push the envelope of what is achievable in electron microscopy. This work discusses characterisation methods for examining the physical structure, including atomic force microscopy (AFM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM).

A polished surface will only provide accurate information about a given specimen if all preparation stages and steps are taken into account, followed, and carefully and professionally completed. It can be concluded that microscopy as a technique will continue to play a critical role during decision-making with a good quality optical microscope.

The course "Scanning Electron / Ion / Probe Microscopy in Materials Characterization" will give students, engineers, technicians, and researchers (material and biological scientists), in-depth knowledge of three different microscopy techniques. The surface morphology of solid materials (mainly) at the nanoscale range can be obtained using any one of these three scanning microscopy techniques. We shall talk about microscopy and characterization in this essay.

Keywords:

Electron, Microscopy, Materials, Characterization, Scanning, Optical, Microscope, Images, Materials Science, Atoms, Light, Elements, Polymer.

6.1 Introduction:

6.1.1 Microscopy Characterization:

The Microscopy Characterization facility is made up of a number of microscopy tools that are useful for a wide range of biomedical applications. These tools enable researchers to collect images and conduct structural studies on everything from individual molecules to living nanoscale cells.

In terms of materials science, characterization refers to the comprehensive and all-encompassing process of probing and measuring a material's structure and properties. Without it, no scientific understanding of engineering materials could be established. It is an essential procedure in the field of materials research.

The term's application is frequently ambiguous; for example, some definitions restrict the term's use to methods that examine the microscopic structure and characteristics of materials, whereas others apply it to any process of materials analysis, including macroscopic methods like mechanical testing, thermal analysis, and density calculation.

From angstroms, where individual atoms and chemical bonds can be seen, to centimeters, where coarse grain patterns in metals can be seen, the scale of the structures seen in materials characterization spans from these. [1]

One of the main techniques for material characterisation and scientific inquiry in general is microscopy, which refers to the use of microscopes to analyze various materials and surfaces. A variety of techniques are used by microscopes to produce enlarged images of objects and surfaces.

There are numerous varieties of microscopes, and they can be categorized in various ways. One way is to explain how an instrument interacts with a sample and generates images by either sending an electron or light beam through the sample in its optical path, detecting photon emissions from the sample, or using a probe to scan across and a short distance from the sample's surface. The optical microscope, which is the most popular and the first to be created, employs lenses to refract visible light that has passed through a thinly sectioned sample to create an observable image. The electron microscope (both the transmission electron microscopy and the scanning electron microscope), the fluorescence microscope, and other scanning probe microscope types are further important types of microscopes. [2]

6.1.2 Optical Microscopy (OM):

OM is a very adaptable imaging method that is frequently used to investigate the kinetics and behavior of crystallization in polymeric materials. When it comes to polymeric materials, OM is used to investigate the crystal formation of polymeric matrices caused by clay. The degree of dispersion of nanoparticles, mostly carbon-based nanofillers like carbon nanotubes, graphene, and graphite oxide, in immiscible polymer mix nanocomposites in the molten state of polymer matrices can also be studied using OM.

A class of characterization methods known as microscopy explores and maps the surface and sub-surface structure of a material. These methods can collect information on a sample's structure on a variety of length scales using photons, electrons, ions, or physical cantilever probes. Typical instances of microscopy methods include:

- Optical microscopy
- Scanning electron microscopy (SEM)
- Transmission electron microscopy (TEM)
- Field ion microscopy (FIM)
- Scanning probe microscopy (SPM)
- Atomic force microscopy (AFM)
- Scanning tunneling microscopy (STM
- X-ray diffraction topography (XRT) [3]

6.1.3 Comparing Image Formation in Light and Electron Microscopes:

The light microscope (left), the transmission electron microscope (middle), and the scanning electron microscope (right) are three common types of microscopes used for materials characterization. Figure 6.1 depicts schematic cross-sections of imaging modes for each of these three microscope types. Common components include a condenser lens above the specimen to focus the light or electron beam and an illumination source, such as an electron cannon or a source of visible light. The SEM is built differently from a light microscope and a TEM after the condenser lens. In the latter two, a static, nearly parallel beam of illumination is projected onto a viewing point or onto a camera for recording, with the objective lens that creates the image placed below the specimen. The method by which the picture is formed and projected for viewing and recording is the same as that of the light microscope, despite the TEM incorporating some additional lenses.

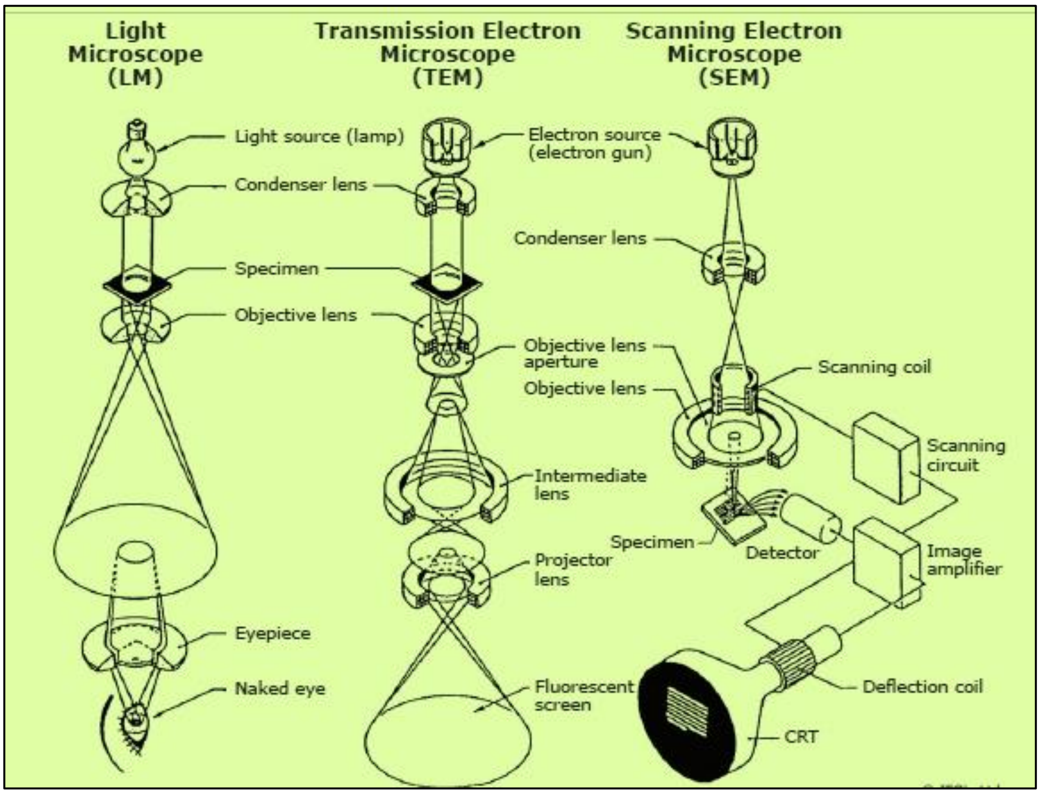

Figure 6.1: shows cross-sections of the imaging modes in the light microscope, TEM, and SEM schematically. [4]

In material science, characterization is a crucial area. For a better understanding, it refers to figuring out the material's physical and chemical properties. The performance of the material can then be optimized using this high level of knowledge. Characterization procedures are frequently employed in membrane research to verify the excellence and purity of the manufactured membranes. Characterization methods are very effective instruments for analyzing membrane performance and researching membrane breakdown. The interaction between the polymer and the fillers can be better understood thanks to characterization techniques.

A. Electron Microscopy:

Each analytical approach used in electron microscopy uses an electron beam as a source to bombard the sample being studied. This is what distinguishes electron microscopy from other types of analysis.

The electron beam interacts with matter to produce a variety of signals that can be used for imaging as well as for studying a material's topographical, crystallographic, and structural properties. These properties can all be correlated with the material's chemical, electrical, optical, and luminescence properties. Scanning electron microscopy, electron probe microanalysis, and transmission/scanning transmission electron microscopy are some of the methods we employ. X-ray diffraction is used in addition to these microscopy techniques. [5]

Transmission electron microscopy (TEM) and scanning electron microscopy (SEM), in addition to light optical microscopy, are particularly significant. Targeted investigation of important sample areas is also possible using the focused ion beam (FIB) technique on the SEM. Both the crystallographic orientation (EBSD) and chemical composition (EDX) can be ascertained through a corresponding analysis. For the high-resolution analysis of surface features, an atomic force microscope and a shared laser scanning microscope are also available. The phases that exist in the materials can be examined using the X-ray diffractometers that are readily available (for example, crystal structure, lattice parameters, texture, etc.). Up to 1100°C can be investigated in a heating chamber.

These target fracture surfaces are primarily characterized using optical and scanning electron microscopy. The MEE team has gained proficiency in operating.

- (relatively) low magnification/resolution optical microscopes.
- high magnification, and ultra-high resolution scanning electron microscopes. [6]

B. Light Microscopy:

An essential tool for characterizing particles and materials is **light microscopy** analysis. It detects small objects using visible light. When using a light microscope, it is possible to observe samples up to 1,000 times closer than normal with little to no sample preparation. A sample can be seen in its current state while taking note of attributes like color, transparency, and morphology.

Types of Light Microscopy:

- Polarized light microscopy (PLM) - PLM may identify optical characteristics that specifically distinguish particular chemical phases.
- Phase contrast microscopy (PCM).
- Microscopy using bright field and dark field reflected light.
- Stereo microscopy.
- The sample is irradiated by ultraviolet light during fluorescence microscopy, which causes some phases to emit visible light. The sample is identified using the generated spectrum.

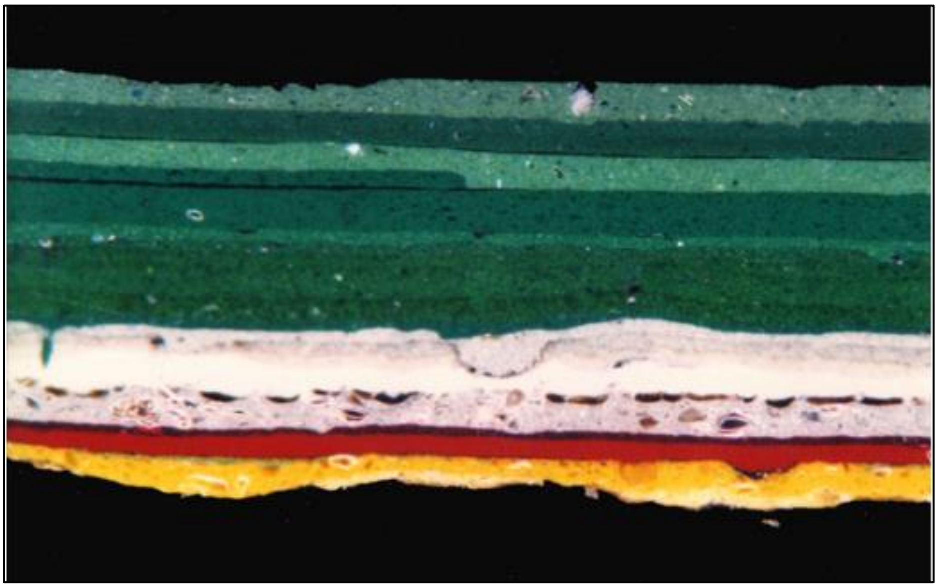

Figure 6.2: A cross section of paint chips for light microscopy examination

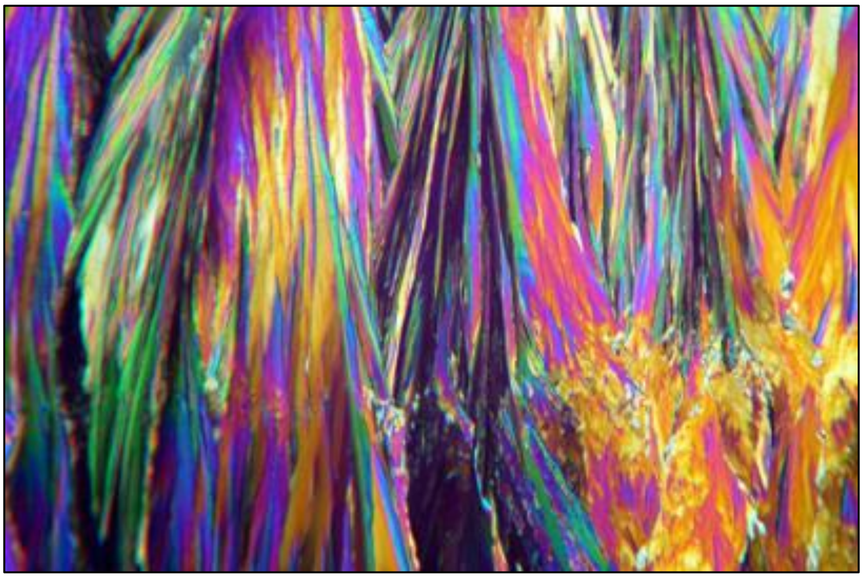

Figure 6.3: Organic Crystal Fusion Preparation

The principal tool used by scientists and engineers to analyze the microstructure of materials is light or optical microscopy. The use of a light microscope to examine the microstructure of materials dates back to the 1880s.

Since that time, metallurgists have extensively used light microscopy to study metallic materials. For metallurgists, light microscopy evolved into a distinct discipline known as metallography. The fundamental methods created by metallography can also be utilized to examine ceramics and polymers in addition to metals. [7]

A. Optical Principles:

- **Image Formation:**

The generation of images, magnification, and resolution are all aspects of the optical principles of microscopes. The behavior of a light path in a compound light microscope, as shown in Figure 6.4, can be used to illustrate image generation. At position A, a specimen (object) is positioned between one and two focal lengths away from an objective lens. A magnified inverted picture is created when light rays from the object focus at location B after initially converging at the objective lens.

The second lens (projector lens) further converges the light rays from the picture to create the final, magnified image of the item at C.

Figure 6.4's light path creates the actual image at C, which is different from what our eyes view, on a screen or camera film. On a screen, only an actual image may be created and captured for photography. [8]

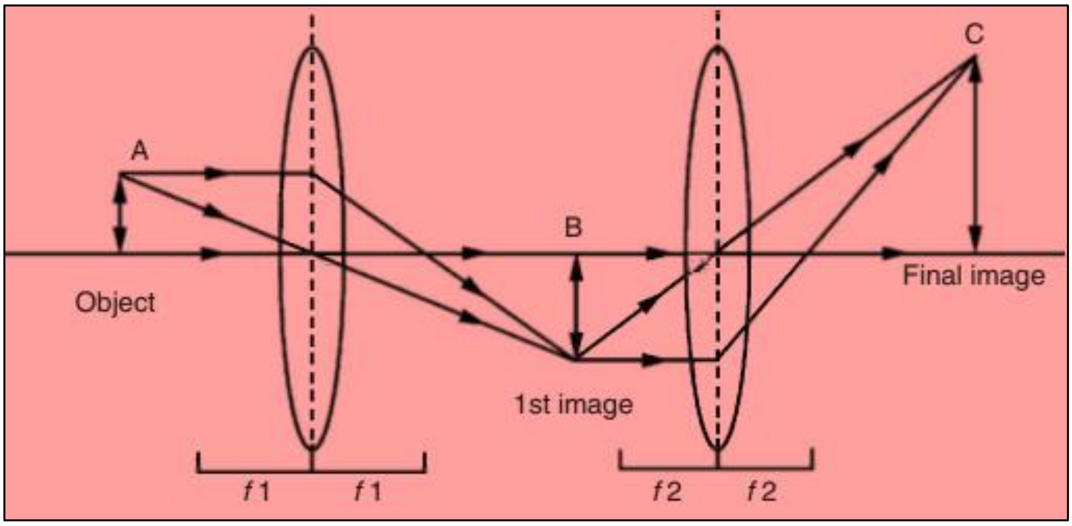

Figure 6.4: Principles of magnification in a microscope.

Different categories can be used to categorize microscopes. One classification is based on the element that interacts with the sample to produce the image, such as light or photons (for optical microscopes), electrons (for electron microscopes), or a probe (for scanning probe microscopes).

As an alternative, microscopes can be categorized according to whether they analyze the sample all at once (wide field optical microscopes and transmission electron microscopes) or via a scanning point (confocal optical microscopes, scanning electron microscopes, and scanning probe microscopes). In optical microscopes, electromagnetic waves are used; in electron microscopes, electron beams are used.

The wavelength of the radiation used to scan the sample in these microscopes determines their resolution; shorter wavelengths provide higher resolution. [9]

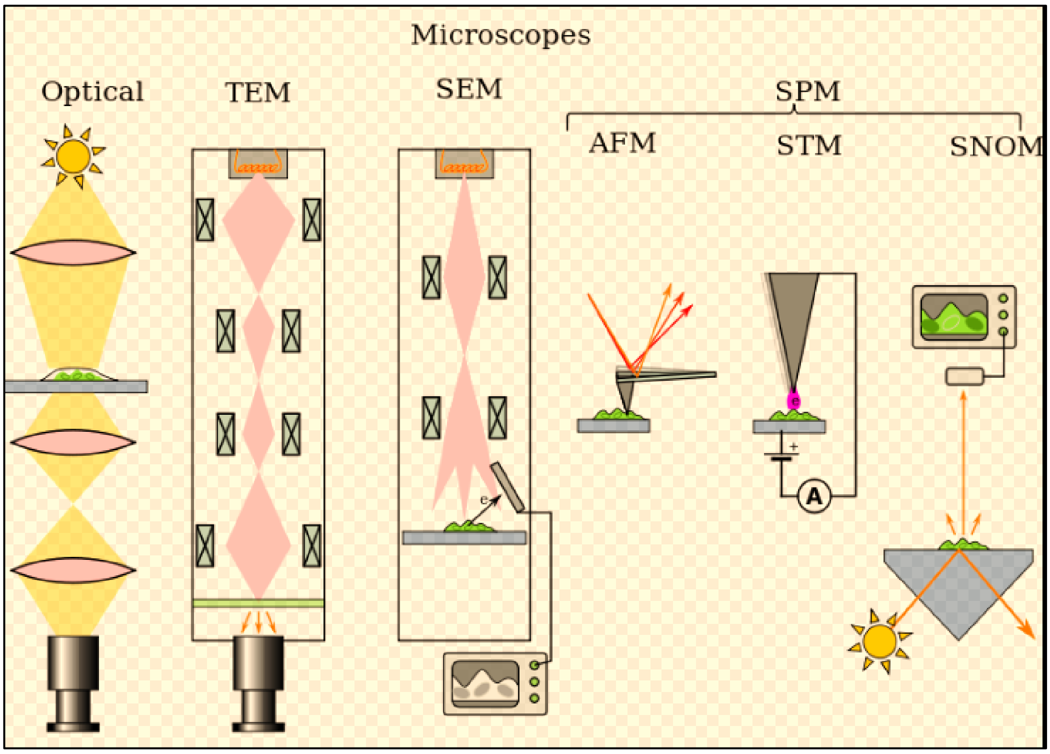

Figure 6.5: Different types of microscopes are depicted by the fundamentals of their beam pathways.

Using lenses to focus a beam of light or electrons onto the sample, scanning optical and electron microscopes, such as the confocal microscope and scanning electron microscope, examine the signals produced by the beam's interactions with the sample.

After that, the point is moved over the sample to examine a rectangle area. The data from scanning a physically small sample area is displayed on a comparatively big screen to magnify the image. The resolution limit of these microscopes is the same as that of broad field optical, probe, and electron microscopes.

The optical microscope is the most popular and oldest form of microscope. This optical device has one or more lenses that expand the image of a sample that is put in the focal plane. Refractive glass, occasionally acrylic or quartz, is used in optical microscopes to focus light on the eye or another light detector.

The same principles govern how mirror-based optical microscopes function. Assuming visible light, the typical magnification of a light microscope is up to 1,250×, with a theoretical resolution limit of around 0.250 micrometers or 250 nanometers. This caps the amount of feasible magnification at ~1,500×.

This magnification may be exceeded by specialized methods (such as scanning confocal microscopy and Vertigo SMI), but the resolution is diffraction restricted.

The spatial resolution of the optical microscope can be enhanced by using shorter wavelengths of light, such as ultraviolet, as well as tools like the near-field scanning optical microscope. [10]

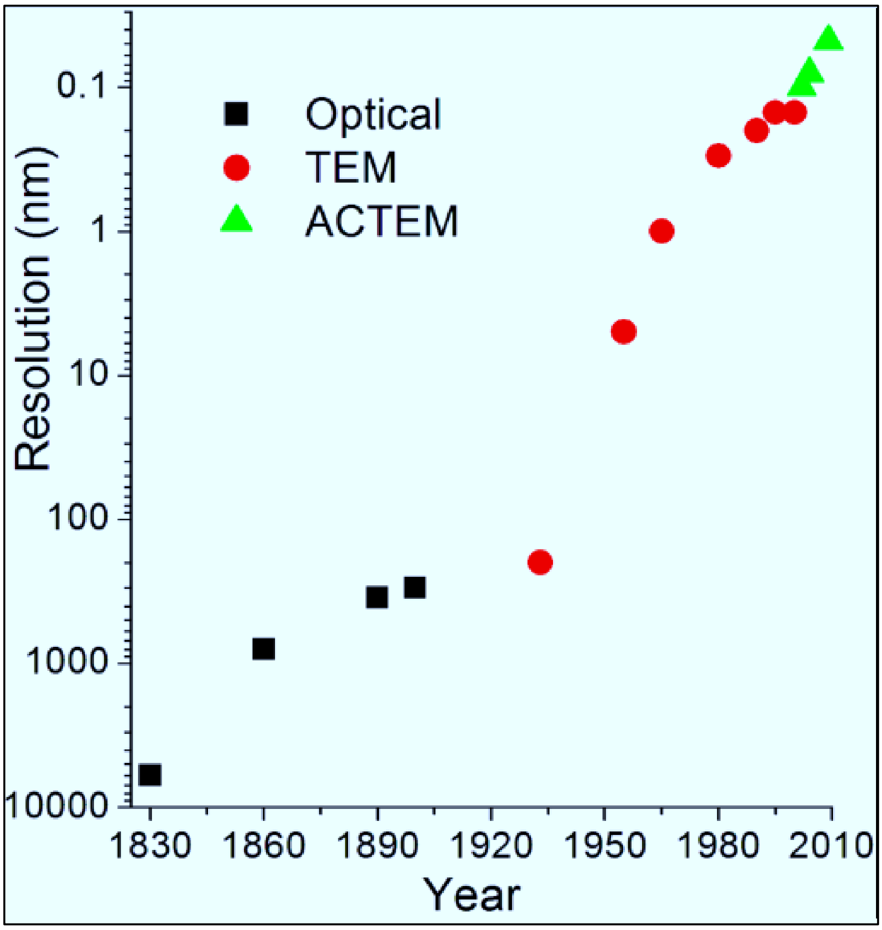

Figure 6.6: illustrates the development of spatial resolution attained using optical, transmission (TEM), and aberration-corrected electron microscopes (ACTEM).

6.1.4 Electron Microscope:

The two main categories of electron microscopes are TEMs (transmission electron microscopes) and SEMs (scanning electron microscopes). To focus an electron beam with a high energy on a sample, they both have a set of electromagnetic and electrostatic lenses. Similar to basic optical microscopy, a TEM involves the passage of electrons through the material. Since most materials heavily scatter electrons, this calls for meticulous sample preparation. The samples also need to be very thin (less than 100 nm) for the electrons to travel through them. [11]

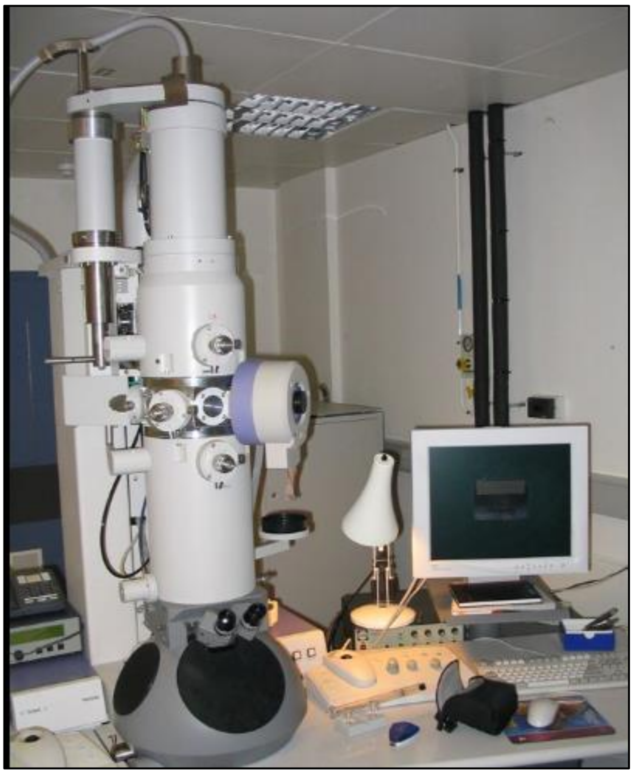

Figure 6.7: Modern transmission electron microscope

6.2 Scanning Tunneling Microscopy:

Quantum tunneling is the foundation of the STM. A bias (voltage differential) provided between the two can cause electrons to tunnel through the space between them when a conducting tip is brought extremely close to the surface being studied.

The local density of states (LDOS) of the sample, applied voltage, and tip position all influence the tunneling current that results. Information is gathered by keeping an eye on the current as the tip scans the surface and is typically shown as an image.

STM can be difficult to use since it needs electronics of the highest caliber, surfaces that are impeccably clean and steady, sharp tips, and superb vibration control. [12]

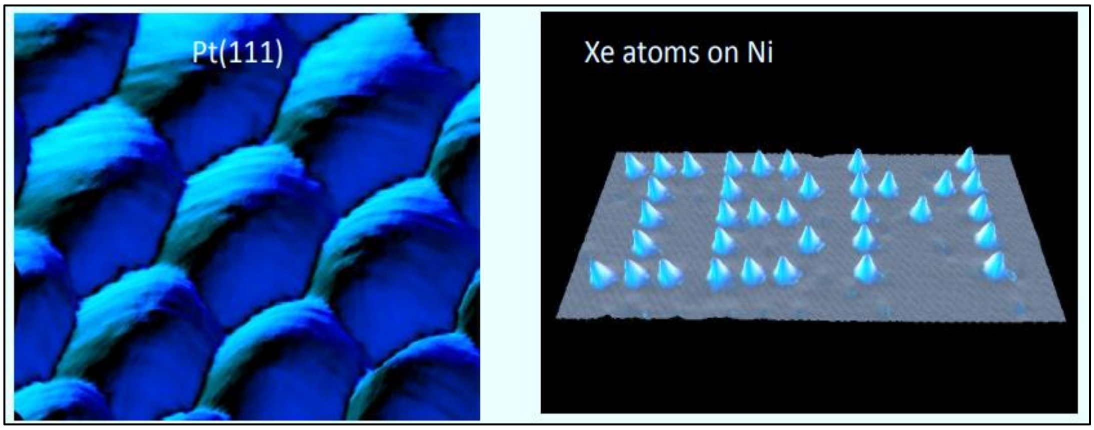

Figure 6.8: Scanning Tunneling Microscopy

6.2.1 Microscope Components:

In comparison to a low-power or dissection microscope, a compound microscope has higher magnification capabilities.

It is employed to examine minute specimens, such as cell structures, which are not visible at lower magnification levels.

Components for both the structural and optical parts of a compound microscope. The head, arm, and base are the three basic structural parts.

- The optical components found in the microscope's upper section are found in the body or head.
- The arm joins and supports the microscope's base and head. It is also used to transport the microscope.

- The base of the microscope contains the illuminator as well as supporting the microscope.
- The microscope's optical section consists of:

a. Eyepiece
b. Eye tube
c. Objective lenses
d. Nosepiece
e. Adjustment knobs
f. Stage
g. Illuminator
h. Condenser and condenser focus knob
i. Diaphragm

6.2.2 Functions of Microscope:

A microscope's main use is to examine biological samples. Magnification and resolution are the only two ideas that a microscope relies on to operate.

Simply put, magnification is the microscope's capacity to enlarge the image. While the resolution affects one's ability to analyze minute details.

The two types of microscopes that are most frequently used in classrooms for educational purposes are compound and dissection microscopes.

6.2.3 Functions of compound microscope:

- It makes the research of bacteria and viruses simpler.
- They are employed in pathology labs to facilitate simple disease diagnosis.
- They are additionally employed in forensic labs to recognize human fingerprints.

Simple Microscope with Parts Name:

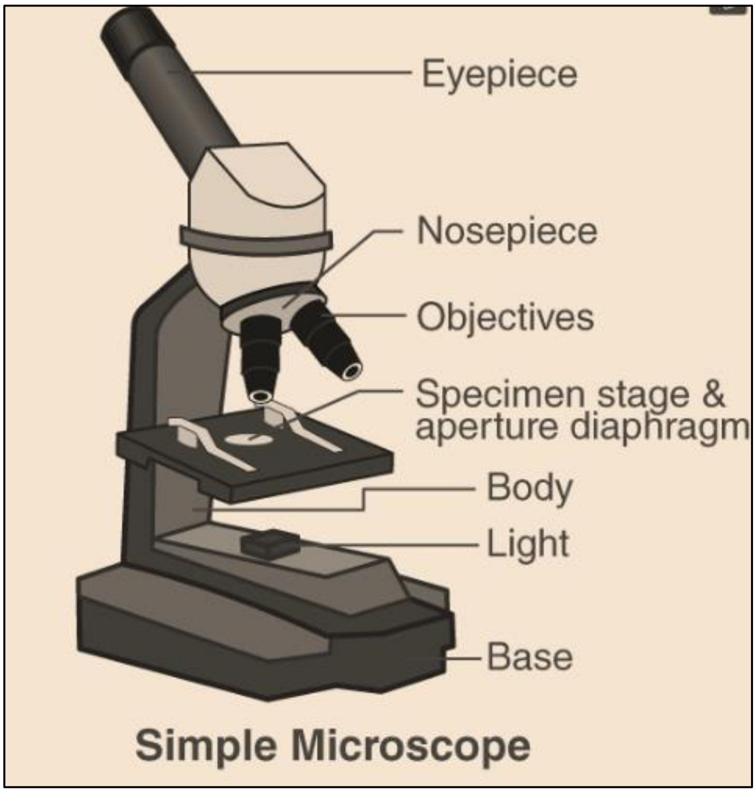

Figure 6.9: Simple Microscope with Parts Name

A rudimentary light microscope with only one lens is referred to as a simple microscope. Simple microscopes don't have a condenser component. They use natural light and fewer hooks and knobs for adjusting things.

Compound microscopes, on the other hand, feature two adjustment knobs: fine and coarse. Additionally, they have a greater magnification than a standard microscope. [13]

6.3 Conclusion:

At sub-nanometer resolution, several types of functional characteristics are now investigated. Most of the time, single scalar integers are used to represent attributes like resistivity, conductivity, surface potential, and charge density.

The enormous variety of specialized microscopes and related techniques that are currently available for materials characterization only scratches the surface of what may be done with microscopes at the two extremes of the resolution scale. microscopy's enormous capacity for data collection and its crucial role in the characterization and advancement of today's high-performance materials. The topics will include preparation of various types of samples, evaluation of findings/data, and basic concepts of these approaches as well as many parameters that affect image quality.

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7. Electric, Photonic and Magnetic Materials

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Abstract:

Modern life has been profoundly altered by electronic and photonic materials. Without them, it would not be possible to use computers, telecommunications networks, compact disc players, video cameras, or any of the other devices to which we have grown used. The basic building blocks of nanobioelectronic for analyzing and modifying electrical impulses in the body are electrode materials with a small footprint. Bulk crystal formation, organic semiconductors, the development of thin films and nanostructures, flexible electronics, and bioelectronic interfaces are all current research topics. Due to their expanding use in the microelectronic, magnetic, and opto-electronic devices that enable goods like computers, hard drives, mobile phones, and other products, these materials are of utmost significance to contemporary society. For example, organic semiconductors are used in flexible electronics and opto-electronic devices, complex oxide materials are used in the development of new magnetoelectronic devices, and magnetic materials are used in spintronic devices. CEMS faculty and students are conducting cutting-edge research on all of these materials. We will cover electric, photonic, and magnetic materials in this essay.

Keywords:

Magnetic, Electronic, Photonic, Materials, Bioelectronic, Microelectronic, Solar Cells, Opto-Electronic Devices, LED Bulbs, Computers, Sensors, Solar Energy.

7.1 Introduction:

Electronic materials are a particular class of materials that are frequently employed as fundamental components in a wide range of device applications. These components can be found in common electronic devices such tablets, GPS units, LED bulbs, mobile phones, computers, laptops, TVs, and monitors as well as LEDs, memory, and displays. To meet the technological challenges involved with the creation of these gadgets, it is necessary to continuously work to develop state-of-the-art materials that can accommodate changing dimensions and levels of functionality.

These materials offer a wide range of possible uses, including waste heat recovery, solid-state lighting, chemical and medical sensors, solar energy, and computation. Faculty from MSE who specialize in these fields usually work with campuses' various departments' institutes. Our department's ongoing research initiatives include: [1]

- For the conversion of waste heat, high performance thermoelectric
- Metal-organic chemical vapor deposition with molecular beam epitaxy to create epitaxial heterostructures
- Ultraviolet nanowire LEDs
- Laminates of superconducting metal and oxide for energy transmission and storage
- Ceramics that are magnetic and dielectric for use in communications
- Emergent phenomena at interfaces include piezoelectricity, superconductivity, and ferromagnetism.
- Electronics based on spin and magneto-electric materials
- semiconductors with an ultra-wide band gap for high-power and high-frequency applications
- Thermo-magnetic effects and the Spin-See beck effect in solids

Electronics Materials: Electronic devices including transistors, diodes, and integrated circuits (ICs), which make up the core of contemporary electronics, are made of electronics materials. These substances frequently possess qualities including strong electrical conductivity, semiconductivity, and thermal stability. [2]

Photonics Materials: The study and manipulation of light for uses like optical communication, imaging, and sensing are all part of the field of photonics, which makes use of photonics materials. High optical transparency, little optical loss, and the capacity to bend, diffract, and guide light are just a few of the characteristics that distinguish photonics materials. Nonlinear optical materials, photonic crystals, and optical fibers are a few examples of photonics materials. Photons are produced and used in photonics in a controlled setting. Photonic applications use the visible and infrared bands of the electromagnetic spectrum as examples of the radiant energy that photons generate.

Magnetic Materials: Technologies that rely on magnetic qualities, such as data storage, motors, and sensors, require magnetic materials. These materials have distinctive magnetic behaviors due to their ferromagnetic, paramagnetic, or diamagnetic features, which enable them to interact with magnetic fields.

Electronically, electro-optically, and opto-electronically active polymers are rapidly being studied in terms of their physical and chemical properties for scientific research, technological advancement, and commercialization.

There is an increasing need for effective and transparent communication among the communities of chemistry, polymer physics, and materials because of the quick development and growing number of applications of polymers as active functional materials in the construction of electronic and optoelectronic devices, such as diodes, light-emitting diodes, switches, photovoltaic cells, analytical sensors, batteries, optical fibers, etc. [3]

7.2 Magnetic Materials and Classifications:

Five types of materials are known to make up the majority of permanent magnets in use today: ferrite, alnico, flexible rubber, and rare earth magnets like cobalt and neodymium. Surprisingly, each of these displays traits that are wildly distinct from one another. It has been established that the design of magnetic components is an essential component of the design of power electronic systems. Understanding the specifics of the magnetic materials and pertinent technology is crucial for realizing the designs of magnetic components like inductors and transformers. Due to variations in atomic structure, a material's response to being placed in a magnetic field varies greatly. [4]

In plain language, the quantity of unpaired electrons in each atom determines the magnetic behavior. Most materials can be categorized as ferromagnetic, diamagnetic, or paramagnetic based on the unpaired electrons that aid in producing a net magnetic field in that material. Figure 7.1 displays a straightforward depiction of the same.

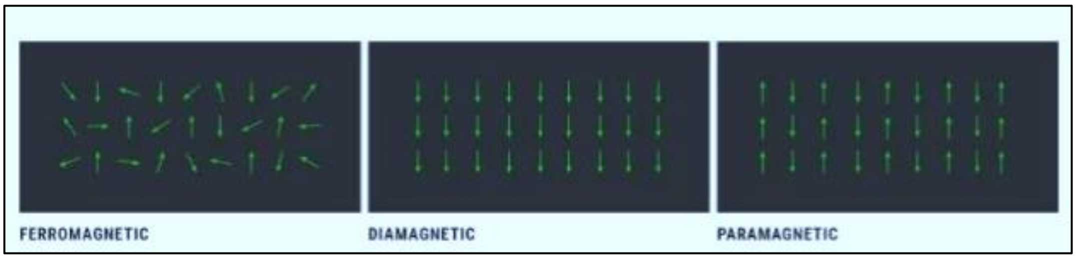

Figure 7.1: Classification of Magnetic Materials

Iron, cobalt, and nickel are examples of ferromagnetic materials, which produce a small net magnetic field as a result of having a few unpaired electrons in their atoms.

Diamagnetic materials, unlike the majority of the elements in the periodic table, are known to repel any magnetic field that is applied from the outside.

They also do not produce their own magnetic field. Materials that are paramagnetic have relatively little susceptibility to the magnetic field.

The majority of elements belong into this group because, while having a weak magnetic field attraction, they are typically considered to be non-magnetic in nature. [5]

A. Magnetic Materials:

The Englishman William Gilbert (1540–1603), who wrote the influential book On the Magnet in 1600, conducted the first genuinely scientific investigation into magnetism.

Using iron magnets and lodestones in his experiments, he was able to draw a precise picture of the Earth's magnetic field and dispel numerous myths that had obscured the issue.

After Gilbert, no fundamental discoveries were made for more than a century and a half, but there were many useful advancements achieved in the production of magnets.

Compound steel magnets, which were created in the seventeenth century and were formed of numerous magnetic steel strips joined together, were able to lift 28 times as much iron as they weighed. reversible and irreversible processes of magnetization, magnetic domains and domain barriers, magnetic anisotropy, and magnetostatics; magnetic recording, hard and soft magnetic materials; magnetism in amorphous and nanocrystalline materials; thin film magnetic characteristics, Amorphous and nanocrystalline magnetic materials, as well as magneto resistive materials, are nanoparticles; Ferromagnetic polymers, magnetic polymers containing iron, nickel, cobalt, ruthenium, or osmium, and magnetic polymers with conductivity are all examples of magnetically active polymers. [6]

7.3 Types of Magnetism:

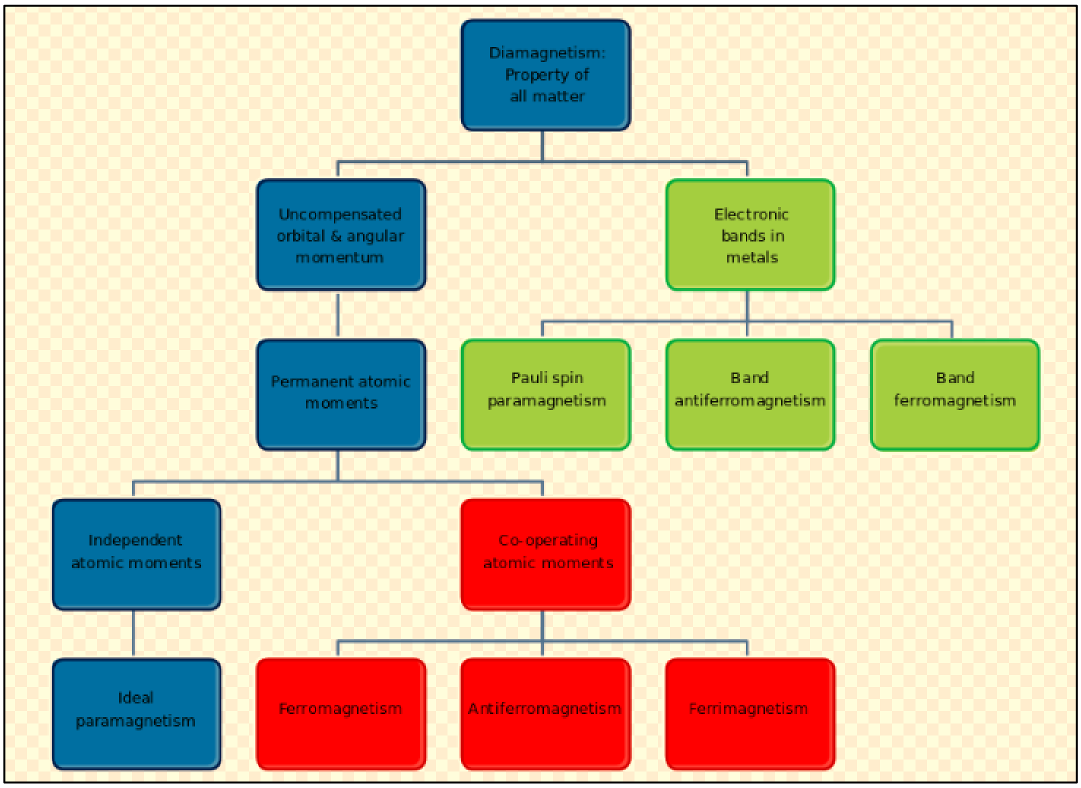

Figure 7.2: Hierarchy of types of magnetism

7.3.1 Electromagnet:

An electromagnet is a type of magnet where an electric current creates the magnetic field. When the current is cut off, the magnetic field vanishes. The magnetic field is often produced by a large number of wire turns that are positioned closely together.

In order to create a stronger magnet, the turns of the wire are frequently twisted around a magnetic core made of a ferromagnetic or ferrimagnetic material, such as iron. [7]

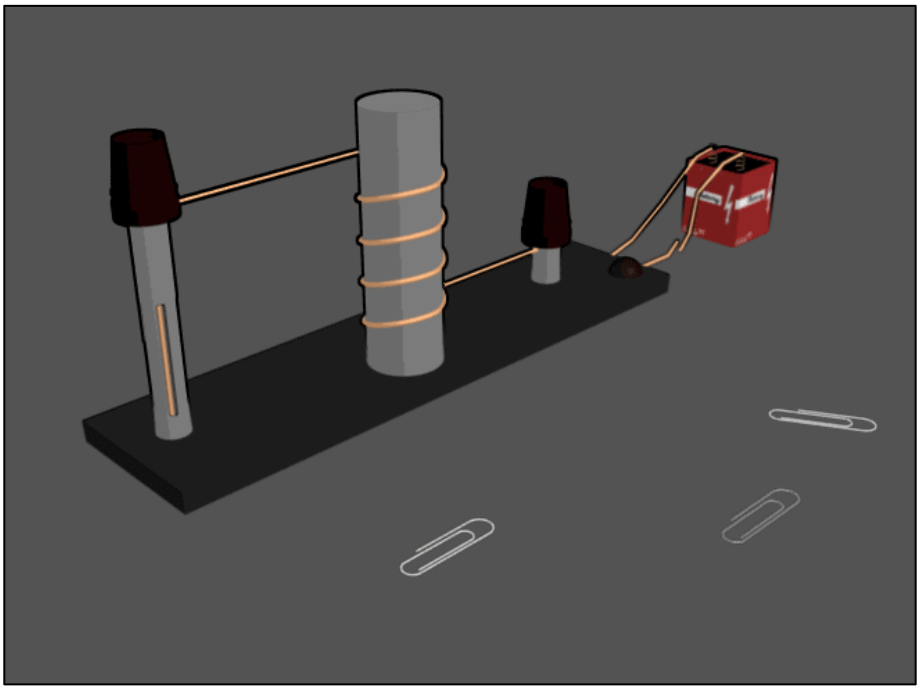

Figure 7.3: When current is added to an electromagnet, a magnetic field is created that attracts paper clips. When the magnetic field and current are turned off, the electromagnet loses them.

An electromagnet's key benefit over a permanent magnet is the ability to swiftly alter the magnetic field by adjusting the amount of electric current flowing through the winding.

An electromagnet, in contrast to a permanent magnet, needs a constant flow of current to sustain the magnetic field. [8]

Table 7.1: Typical soft magnetic materials of many types' key performance indicators. (Note: The data in the table should only be used as a general guide because the magnetic characteristics of soft magnetic materials are particularly sensitive to the production process. Please check with the sales agent for the numbers that are more specific and useful.) [9]

	Composition (wt%)	Max. relative permeability μ_{MAX}	Coercive field Hc (A/m)	Saturation polarization J_S (T)	Curie temperature T_C (°C)	Saturation magnetostriction λ_S (ppm)	Electrical resistivity ρ (μΩ*cm)
Iron/low carbon steel	$Fe_{\sim 100}$	$1\text{-}10 \times 10^3$	10-100	2.16	770	5	10
NO Fe-Si	$Fe_{bal}Si_{1\text{-}4}$	$3\text{-}10 \times 10^3$	30-80	1.96-2.12	735-765	10	25-50
GO Fe-Si	$Fe_{97}Si_3$	$15\text{-}80 \times 10^3$	4-15	2.02	750	1-3	45
Fe-(6.5 wt%)Si	$Fe_{93.5}Si_{6.5}$	$5\text{-}30 \times 10^3$	10-40	1.8	690	0.5	80
Permalloy	$Fe_{17}Ni_{79}Mo_4$	500×10^3	4	0.87	460	1	55
Permendur	$Fe_{49}Co_{49}V_2$	7×10^3	30-100	2.35	930	60	40
Sintered ferrites	$(Mn, Zn)Fe_2O_4$	$10^3\text{-}10^4$	5-20	0.4-0.55	130-280	-2	$0.1\text{-}6 \times 10^8$
	$(Ni, Zn)Fe_2O_4$	$10^2\text{-}10^3$	20-200	0.2-0.35	110—400	-20	$> 10^{13}$
Sendust	$Fe_{85}Si_{9.5}Al_{5.5}$	$50\text{-}110 \times 10^3$	1-10	1.70	670	1	110
Amorphous alloys	$Fe_{bal}Si_{7.6}B_2$	100×10^3	2-5	1.56	415	37	120
Nanocrystalline alloys	$Fe_{bal}Cu_{1.3}Nb_{5.7}Si_{7.7}B_2$	500×10^3	0.5-1	1.24	600	2	120

7.3.2 Photonic Material:

Ray optics, electromagnetic optics, and guided wave optics; the optical characteristics of semiconductors, dielectrics, and polymers; LEDs, lasers, photodetectors, modulators, optical filters, and photonic crystals; Physics of light-matter interactions; Radiation-sensitive resisters and photoactive polymers optical characteristics of polymers with s- and p-conjugates, process of relaxation in organic polymer systems, polymer light emission, Photorefractive polymers, polymers with strong two-photon activity, and device design principles for LEDs, lasers, and photo-detectors are examples of polymeric materials with nonlinear optical features.

A photon (light) is created, detected, and then modified through transmission, emission, signal processing, modulation, switching, amplification, and sensing.

This is the basic concept of the science of photonics. The proper application of light as a tool for human benefit is the most significant aspect of photonics.

A wide range of technologies, including optical fibers, lasers, detectors, quantum electronics, fibers, and materials, make up photonics.

The term "photonics" was first used to refer to a branch of study that focuses on using light to carry out operations that are typically associated with the traditional subject of electronics, such as communication, data processing, and so forth.

Following the discovery of lasers in 1960, research in the subject of photonics started. Other advancements followed, such as the development of information-transmitting optical fibers, the introduction of the laser diode in the 1970s, and erbium fiber amplifiers. [10]

An application of producing, detecting, and manipulating light in the form of photons through emission, transmission, modulation, signal processing, switching, amplification, and sensing is known as photonics.

Quantum electronics and photonics are closely related, with quantum electronics focusing on the theoretical side and photonics on its industrial applications.

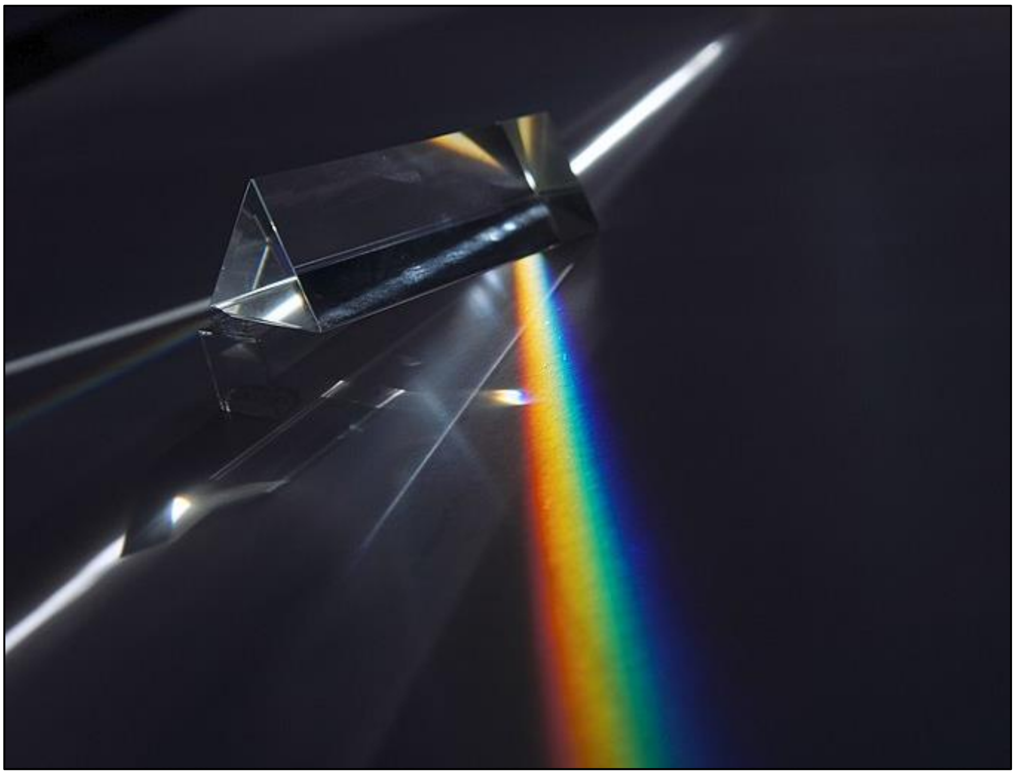

Figure 7.4: Dispersion of Light (Photons) by a Prism

7.3.3 Electric Material:

Conductivity applications, electronic applications (EMI shielding, frequency-selective surfaces, satellite communication lines), and electroactive applications Diodes, transistors, photodetectors, solar cells (photovoltaics), displays, lasers, optical fibers and optical communications, photonic devices, magnetic data storage, and spintronics are just a few examples of the applications.

Polymer applications for electroluminescence, light emitting diodes, optical switches, and optical fiber applications are also included. [11]

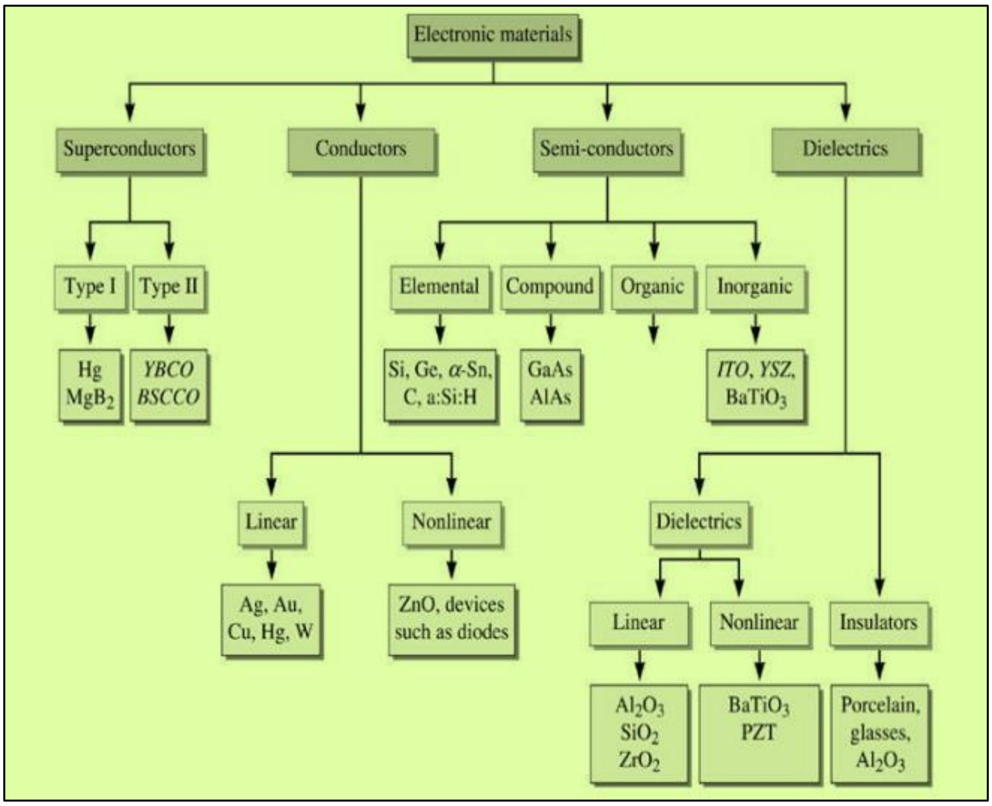

Figure 7.5: Classification of technologically useful electronic material

Engineering materials are significant in daily life due to their flexible structural characteristics. They do play a significant role in addition to these characteristics because of their physical characteristics. Electrical, thermal, magnetic, and optical qualities are some of a material's main physical characteristics. Engineering materials' electrical characteristics and uses in electrical applications are both varied. Electrical characteristics are used to categorize materials into conductors, semiconductors, insulators, and superconductors.

This chapter's main goal is to investigate materials' electrical properties, or, more specifically, how they react to an applied electric field. We start with the concept of electrical conduction, including the terms used to describe it, the mechanism by which electrons conduct, and how the electron energy band structure of a material affects its conductivity. [12]

In addition to insulators and semiconductors, these concepts also apply to metals. The features of semiconductors are given special consideration, followed by semiconducting devices. The dielectric properties of insulating materials are also covered. In terms of electronics, the materials can be divided into Insulators, Semiconductors, and Conductors.

- Insulators – Materials with a large prohibited gap that prevent conduction from occurring are known as insulators. Example: Rubber with wood.
- Semiconductors – These materials have a narrow forbidden energy gap, allowing for conduction to occur when an external energy source is applied. Germanium and silicon are two examples.
- Conductors − Conductors are those types of materials in which the forbidden energy gap vanishes as the valence band and conduction band approach and overlap. Aluminum and copper, for instance.

7.4 Electronic Materials and Devices:

The materials employed as key components in many different device applications are often of the electronic variety. These components may include memory, displays, and LEDs, and they are commonly found in everyday electronic devices including cell phones, computers, laptops, tablets, GPS units, LED lightbulbs, TVs, and monitors. To meet the technological challenges involved with the creation of these gadgets, it is necessary to continuously work to develop state-of-the-art materials that can accommodate changing dimensions and levels of functionality.

For instance, the discovery of technologies like liquid crystals, organic semiconductors, and electroluminescent materials made it possible to switch from CRT-based displays to LCD and eventually LED-based displays.

The response of electrons and other charged particles to external stimuli, such as electrical potential difference and its variation, incident electromagnetic radiation, magnetic field, heat, mechanical forces, etc., determines a material's electronic properties.

The internal structure of a material at various length scales, chemical composition, intrinsic and extrinsic flaws, as well as the dimensionality (zero, one, two, or three dimensional) of the material are all significantly connected with how the material responds to stimulation from the outside.

Table 7.2: Typical Magnetic Materials Used in Electrical Machine Cores:

Sample	Material Type	Material Composition	Sheet Thickness (mm)	Flux Density at 0.8 kA/m (T)	Flux Density at 2.5 kA/m (T)	Resistivity (μΩcm)	Material Density (g/cm³)
A	CoFe	49% cobalt, 49% iron, 2% V	0.2–0.5	2.1	2.23	40	8.12
B	NiFe	40% nickel, 60% iron	0.1–0.5	1.44	1.48	60	8.2
C	High-silicon-content SiFe	6.5% silicon, iron balanced	0.1–0.2	1.29	1.4	82	7.49
D	Thin nonoriented SiFe	3% silicon, 0.4% aluminum, iron balanced	0.1–0.3	1.15	1.63	52	7.65
E	Nonoriented SiFe	1–3% silicon, iron balanced	0.35–1	—	1.64	20–60	7.6–7.8
F	Amorphous iron	20% (silicon and boron), 80% iron	0.025	1.55	—	130	7.18
G	SMC	<1% lubrication, iron balanced	Solid material	0.71	1.22	20,000	7.57

Signals are encoded using current or voltage in electronics, which is dependent on the motion of electrons.

The speed at which electrons may flow limits the frequency at which electrical circuits can operate. This speed is influenced by inductive and capacitive effects as well as resistive losses related to electron propagation in materials.

Because of the intense interaction between electrons, which is mediated by their electric fields, electronic systems are capable of powerful nonlinear behaviors, such as switching and state transitions.

Fundamentally, electrons can be contained in stationary states in constrained areas of space because they have mass, which is crucial for memory. Electron propagation across wires, resistance, capacitance, inductance, and non-linear behavior as exemplified by transistors are the characteristics of electronic circuits (Figure 7.6). [13]

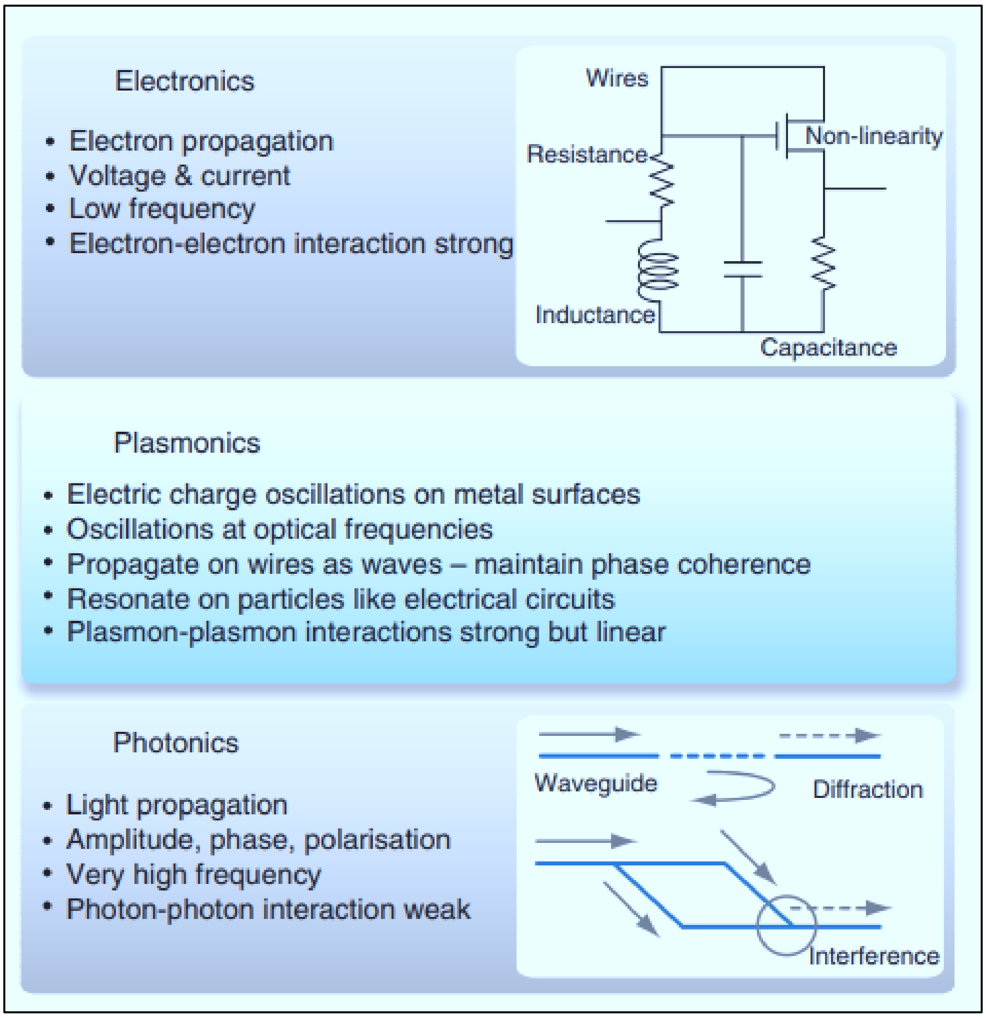

Figure 7.6: shows an evaluation of electronic and photonic circuits. The plasmonic field is situated between [14]

7.5 Conclusion:

The development of new materials with improved properties, improved performance, and novel functionalities for a variety of applications in industries like telecommunications, computing, energy, and healthcare continues to be a focus of research in these fields, pushing the boundaries of materials science. Joining this material science congress would be beneficial for meeting international scientists on one platform. The investments in materials research that are most likely to pay off are fundamental studies to deepen our understanding of current materials, the creation of new materials with extraordinary properties, processing of materials, packaging, and thermal management, theory and modeling, and materials for revolutionary technologies.

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8. Mechanical Properties of Materials

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Abstract:

A material's mechanical properties are those that concern how it responds to an applied load. The range of a material's applicability and the anticipated service life are established by the mechanical characteristics of metals. Material classification and identification techniques also make use of mechanical qualities. Strength, ductility, hardness, impact resistance, and fracture toughness are the most often used characteristics.

The list of mechanical qualities is quite lengthy, so we should probably start by acknowledging that. When describing a substance, some terms are more crucial and prevalent than others. As a result, we are approaching the subject from an engineer's viewpoint. When designing something, he needs to understand the basics of how different metal types compare to one another. For their design applications, every design engineer must be able to choose the best materials, and in order to do so, they must be aware of the materials' mechanical properties. The mechanical properties of materials will be covered in this essay.

Keywords:

Mechanical, Properties, Material, Strength Ductility, Hardness, Impact Resistance, Fracture, Engineering, Raw Materials, Metal's Spectrum, Mechanical Strength.

8.1 Introduction:

The mechanical qualities of a material are those that influence its ability to be molded into a suitable shape and mechanical strength. Some common mechanical qualities have extensive uses in the automotive and space sectors.

These characteristics are related to the materials' ability to withstand loads and mechanical forces, and they are measured in terms of how the material responds to a force. Mechanical qualities can be identified to give the engineer design data or to verify the quality of the raw materials.

The behavior of materials under the influence of loads, or external forces, is determined by their mechanical properties. The predicted service is determined by the mechanical properties of metals, which are defined by the metal's utility spectrum.

Before selecting a material for a specific technical product or application, it is essential to understand its mechanical qualities. According to Wikipedia, "the mechanical properties of engineering materials are those that influence their mechanical strength and capacity for shaping into a desired shape." alternatively, "Mechanical properties are physical properties that a material exhibits upon the application of forces." [1]

It's crucial to comprehend the material's mechanical characteristics. The mechanical qualities of a substance are those that influence its mechanical strength and capacity for shaping into a desired shape.

A material's typical mechanical properties include some of the following:

- Strength
- Stiffness
- Toughness
- Hardness
- Ductility
- Brittleness
- Elasticity
- Fatigue
- Plasticity
- Creep
- Malleability

8.1.1 Strength:

Strength is the capacity of a material to withstand breakdown or deformation in the presence of loads or outside forces. Materials that we choose for our engineering goods need to be sufficiently strong mechanically to function under a variety of mechanical forces or loads.

Strength can be divided into six main subcategories:

Compressive Strength: The capacity of a material to endure a force that causes it to shrink. Consider the material as being squeezed.

Shear Strength: A material's capacity to withstand forces that would otherwise cause its internal structure to slide against itself.

Tensile (or ultimate) Strength. The capacity of a substance to bear a load that stretches or pulls it apart without breaking.

Yield Strength. The capacity of a substance to resist being stretched or torn apart under stress without deforming.

Elastic Strength. The capacity of a substance to regain its former shape after being under stress.

Fatigue Strength. The capacity of a material to endure recurrent and/or varying pressures (such loading and unloading). [2]

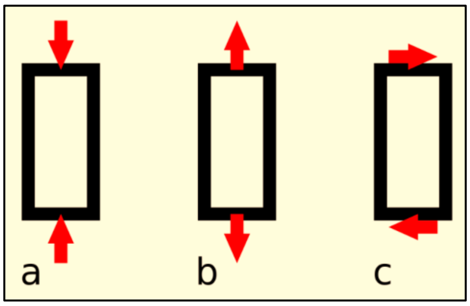

Figure 8.1: Material Being Loaded in A) Compression, B) Tension, C) Shear.

8.1.2 Stiffness:

It is described as a material's capacity to withstand deformation under stress. Stiffness or rigidity refers to a material's resistance to elastic deformation or bending. The indicator of stiffness is the modulus of elasticity. A material has a high degree of stiffness or rigidity if it deforms under load only slightly or hardly at all.

Aluminum suspended beams, for example, will "sag" or deflect more even if both materials may be strong enough to support the requisite weight. This indicates that a steel beam is more rigid or stiff than an aluminum beam. It gauges a material's capacity to resist deflection under an applied load. For instance, even though cast iron is significantly more rigid and less likely to deflect than steel, which is much stronger overall, cast iron is still recommended for machine beds and frames to prevent alignment and precision loss. [3]

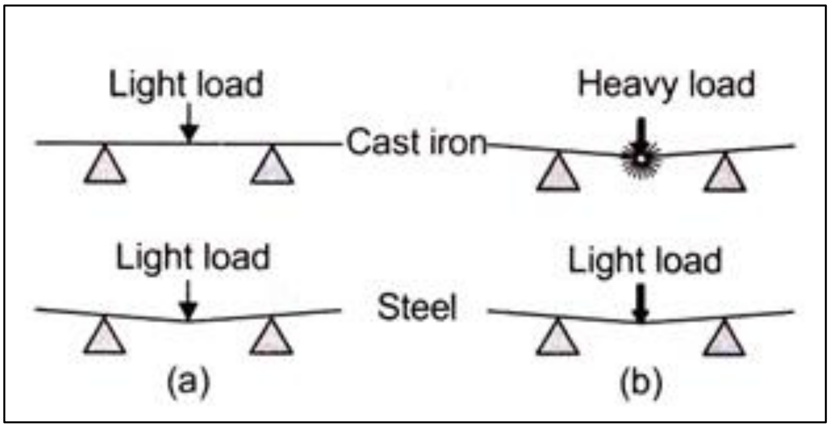

Figure 8.2: Stiffness (Rigidity) (a)The tested materials deflect under a light load (b) The tested materials deflect under a heavy load.

8.1.3 Toughness:

It refers to a material's capacity to take in energy and undergo plastic deformation without breaking. The quantity of energy per unit volume determines its numerical value. The measure is Joule/m3. The toughness value of a material can be determined using its stress-strain characteristics. To be tough, materials must be strong and ductile. A metal's toughness is assessed using impact testing equipment.

8.1.4 Hardness:

One of the key mechanical characteristics of engineering materials is hardness, which enables the material to withstand localized permanent deformation and scratching.

Figure 8.3: Hardness

There are several ways to assess hardness, including scratch resistance, indentation resistance, and rebound resistance.

a. **Scratch Hardness:** The ability of a material to resist scratches to the outer surface layer caused by external force is known as scratch hardness.
b. **Indentation Hardness:** It is the capacity of a material to resist a punch from an outside item that is both hard and sharp.
c. **Rebound Hardness:** Dynamic hardness is another name for rebound hardness. The material is tested by measuring the height of "bounce" of a diamond-tipped hammer dropped from a fixed height. Table 8.1 provides the Moh's scale of hardness measurement. The element and acting load can be used to calculate the measurement, as stated in table 8.1. The hardest material is diamond, which can be cut or punctured by another diamond. [4]

Table 8.1: Moh's scale of Hardness (Scale value in number)

Scale	Element	Applying load for penetration
1	Talc	Can be crushed by a finger nail
2	Gypsum	Scratched by a finger nail
3	Calcite	By a bronze coin
4	Fluorite	By glass
5	Apatite	By penknife
6	Orthoclase	By Quartz
7	Quartz	By Hard steel file
8	Topaz	By Corundum
9	Corundum	By Diamond
10	Diamond	Only by diamond

8.1.5 Ductility:

The ability of a solid substance to deform when put under tensile stress is known as its ductility. One method to describe ductility is the ability of a substance to be dragged or pulled into a wire. This mechanical quality, which is temperature-dependent, is also a component of a material's plasticity. The ductility of a substance increases with temperature.

8.1.6 Brittleness:

A material's brittleness refers to how easily it fractures under the influence of a force or load. When brittle material is stressed, it experiences very little energy and cracks without experiencing a lot of strain. Brittleness is the antithesis of a material's ductility. Brittleness of a material is temperature-dependent. At low temperatures, some metals that are ductile at normal temperature become brittle. [5]

Figure 8.4: Brittleness

8.1.7 Elasticity:

A material's ability to return to its original shape after deformation when the stress or load is relieved is referred to as elasticity. Elastic materials include rubber, heat-treated springs, and others.

Figure 8.5: Elasticity

8.1.8 Fatigue:

The weakening of a material brought on by repeated loading is known as fatigue. Microscopic cracks start to form at grain boundaries and interfaces when a material is subjected to cyclic loading and loading that exceeds a threshold value but is far below the material's strength (ultimate tensile strength limit or yield stress limit). [6]

The crack eventually grows to a dangerous extent. The wear and tear of a material over time due to repeated straining action is known as fatigue. The term "fatigue" is used to characterize a material's wear and tear as a result of repeated applied stresses.

8.1.9 Plasticity:

Plasticity is the property of a material under which the material is permanently deformed and is unable to return to its original shape even after the removal of the load. Only once the material has passed its elastic limit does plastic deformation occur.

Materials like clay, lead, and other plastic materials are plastic at room temperature, and steel is plastic at forging temperature, therefore this feature is useful in forming, shaping, extruding, and many other hot or cold working processes. In general, this property increases with an increase in temperature of materials.

8.1.10 Creep:

A metal item will experience a slow, irreversible deformation known as creep when it is subjected to high continuous tension at a high temperature over an extended length of time. Continuously applying high loads at higher temperatures can cause a fracture to form, which can then spread toward what is known as creep failure.

A part will experience creep, which is a slow and irreversible deformation, if it is exposed to a steady tension at a high temperature over a protracted length of time. When designing IC engines, boilers, and turbines, property is taken into account. Viscous flow is the most basic type of creep deformation. Creep is particularly sensitive to temperature in materials like plastics, rubber, and amorphous ones.

Creep strength is the stress for a given rate of strain at a fixed temperature. When a material is subjected to constant loads for a long time, it may deform further until it eventually tends to fracture under the same load. We call this creep. The sample will gradually grow if a load is applied and left on it for several months or perhaps several years. At higher temperatures, creep in metals with high melting points becomes an issue.

Testing for creep and stress rupture is used to determine how much stress a material can tolerate before failing and elongating.

For items in the oil & gas, aerospace, automotive, power generation, medical, and many other industries, they are crucial indicators.

The image depicts the three phases of a conventional creep curve. The initial creep begins quickly and then slows down.

However, the rate of the secondary creep is quite constant. Tertiary Creep, which began in the third stage but was speeded up, ends when the material ruptures or fractures. It is related to both grain boundary void generation and necking. [7]

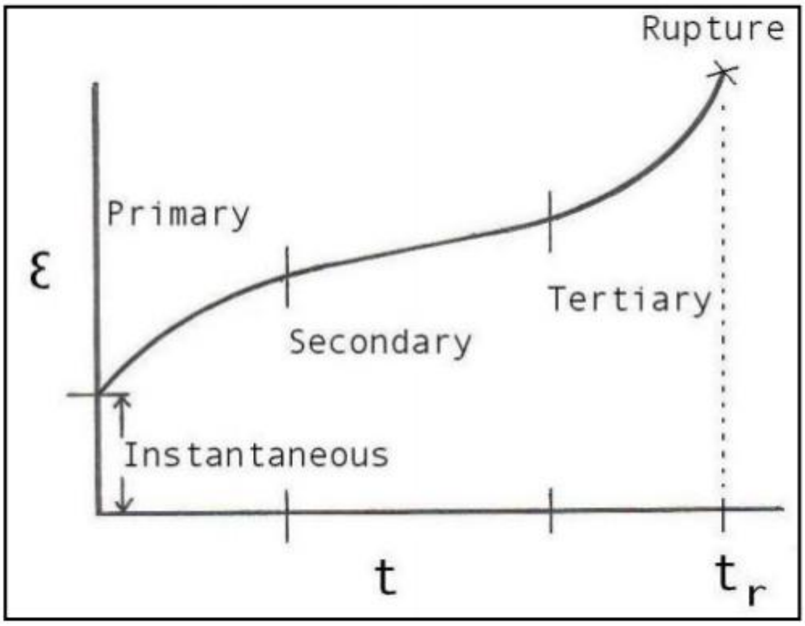

Figure 8.6: Classical Creep Curve

8.1.11 Malleability:

It is due to specific features that metals may be pounded into thin sheets. The ability of metals to be beaten or formed into thin sheets is known as malleability, which is the subject of this article.

8.2 Properties of Materials:

Materials have the following three qualities:

- Material's mechanical characteristics
- Materials' electrical characteristics
- The material's physical and chemical characteristics.

The way a material responds to being loaded depends on its mechanical qualities.

The mechanical qualities of a material are those that have an impact on its mechanical strength and capacity for shaping into a desired shape. Elasticity, plasticity, malleability, ductility, toughness, brittleness, tenacity, fatigue, fatigue resistance, impact resistance property, machineability, strength, strain energy, resilience, proof resilience, modulus of resilience, creep, rupture, and modulus of toughness are just a few of the mechanical properties. [8]

8.2.1 Applications of Mechanical Properties:

In terms of materials science, a material's mechanical properties are critically significant. Each mechanical feature has a particular use in the design of components for the manufacturing industries, such as the automotive, forging, power generation, and aerospace sectors.

Table 8.2: lists a few applications and their characteristics.

Sr. No.	Properties	Applications
1	Proportional limit	Precision instruments, springs
2	Plasticity	forming, forging, shaping, extruding, hot & cold working, ornamental work, stamping, rolling, drawing, pressing
3	Elasticity	Desirable for materials used in tools and machines.
4	Malleability	rolling, hammering
5	Toughness	Desirable for shock & impact loads.

Sr. No.	Properties	Applications
6	Resilience	springs
7	Creep	In designing IC engines, boilers, turbines
8	Hardness	resistance to wear, scratching, deformation
9	Fatigue	High speed aero and turbine engine

8.2.3 Material Stress and Strain:

We must first clarify some of the underlying physical ideas that underlie the mechanical features. Stress is the primary one. Stress reveals the magnitude of the force acting on a certain location. It is commonly stated in MPa or N/mm2 in mechanical engineering. Both of those are interchangeable. The following is the equation for stress:

$\sigma=F/A$, where F is force (N) and A is area (mm2).

The second crucial idea is strain. Since strain is a ratio of lengths, it lacks a unit. The formula is as follows:

$\varepsilon=(l-l0)/l0$, where l0 is starting or initial length (mm) and l is stretched length (mm). [9]

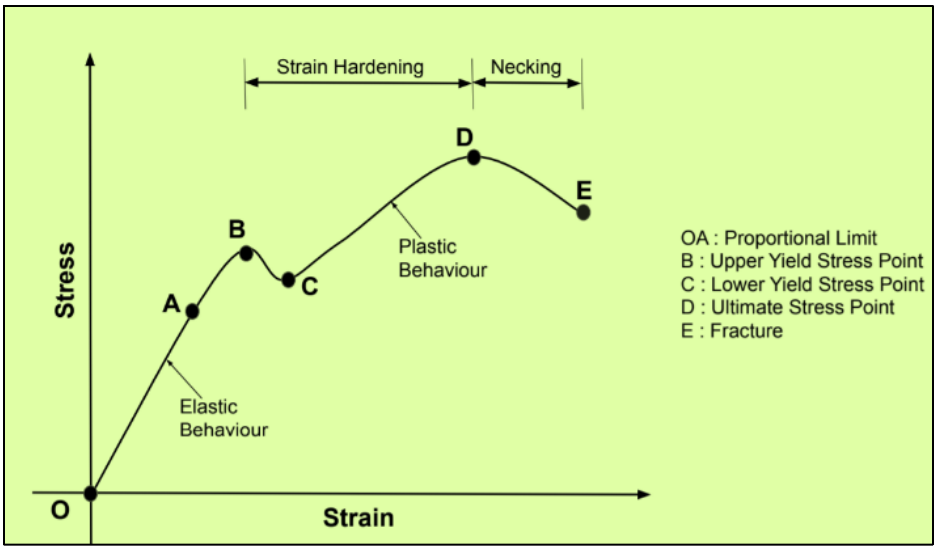

Figure 8.7: Material Stress and Strain

It is necessary to provide more context for the engineering stress-strain curve's general shape. Stress and strain are linearly correlated in the elastic area. The specimen experiences gross plastic deformation when the load surpasses a threshold value that corresponds to the yield strength. If the load is released to zero, it will become permanently distorted.

With rising plastic strain, or strain-hardening of the metal, the stress required to produce ongoing plastic deformation rises. A L = A0 L0 states that the specimen's volume is constant during plastic deformation, and as it lengthens, its cross-sectional area falls equally along the gage length. [10]

8.2.4 Mechanical Properties of Carbon Fiber:

A lengthy chain of carbon atoms that are chemically bound together is referred to as carbon fiber. Carbon fiber's physical characteristics include:

- High tensile strength
- High strength to weight ratio
- Low thermal expansion

These characteristics make carbon steel ideal for application in sectors including aerospace engineering, the military, and motorsports where materials need to be strong but lightweight.

8.2.5 Mechanical Properties of Steel:

Steel is an iron and carbon-based alloy. Each type of steel, which comes in a variety of iron, carbon, and other metal compositions, has slightly unique qualities. But generally speaking, the following characteristics apply to the majority of steel types:

- High tensile strength
- High hardness
- High yield strength
- High weight to strength ratio
- High ductility

Steel is the best material for use in building construction because of these characteristics. In fact, when compared to other building materials, steel has the best strength-to-weight ratio.

8.2.6 Mechanical Properties of Polycarbonate:

One particular kind of plastic that is naturally translucent is polycarbonate (PC). It is a strong, high-performing, amorphous thermoplastic polymer. It is easy to shape, thermoform, and work with. PC is renowned for maintaining its strength and color over time.

The following are some properties of polycarbonate:

- High impact resistance
- High tensile strength
- High dimensional durability
- Excellent electrical & thermal insulator
- Easy to fabricate and machine.

It is utilized in a variety of items, such as compact disc players, safety helmets, auto headlight lenses, roof and glazing applications, as well as a wide range of other products.

8.2.7 Mechanical Properties of Titanium:

Since titanium metal is corrosion-resistant, lightweight, and strong, it is a very durable metal for industrial purposes. Although it is twice as strong as high-strength steel, it is 40% lighter than steel. [11]

8.2.8 Mechanical Properties of Polylactic Acid (PLA):

PLA (polylactic acid) is a reusable and biodegradable polyester made from sustainable feedstock. Due to its inexpensive cost of production from renewable resources, PLA has gained popularity.

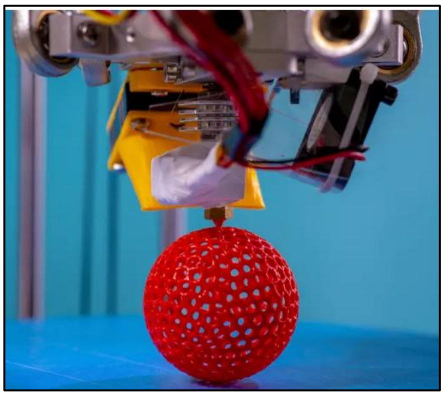

Figure 8.8: Material Stress and Strain

8.2.9 Mechanical Properties of Copper:

A very ductile metal with remarkable electrical and thermal conductivity is copper (Cu). Nature contains copper in its free metallic form. It is employed by the jewelry, electrical, marine, defense, building, and construction industries.

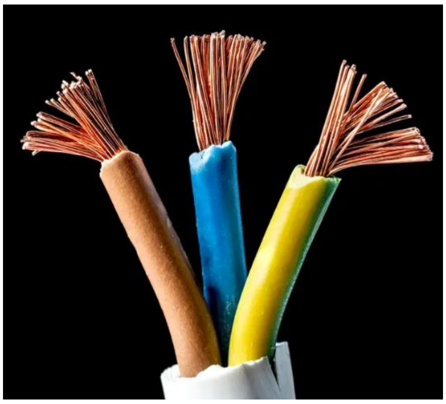

Figure 8.9: Mechanical Properties of Copper [12]

8.3 Conclusion:

the many mechanical property classifications, their applications, and testing methods. Since the success of the material selection depends entirely on how an engineer chooses a material for their developing products, knowing them is necessary to turn the idea design into a product in an industry.

Also mentioned below is innovative technology created in India for home improvement. We really hope that we have allayed your questions regarding the properties of metals. You can get in touch with us or post a question in the comments if you still have any questions about "Mechanical Properties of Materials."

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