



DJJ30113
MATERIAL SCIENCE
&
ENGINEERING

(CHAPTER 1 - CHAPTER 3)

NORHAZLINA AMON

KHAIRUHISHAM RAMLY

PAVITHRA MALAR

POLITEKNIK PORT DICKSON

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NORHAZLINA BINTI AMON
KHAIRUHISHAM BIN RAMLY
PAVITHRA MALAR A/P SANGA PILLAI

ACKNOWLEDGEMENT



PATRON

Mohamad Isa Bin Azhari
Director, Politeknik Port Dickson

ADVISORS

Dr. Nor Haniza Binti Mohamad
Deputy Director (Academic), Politeknik Port Dickson
Razali Bin Bakri
Head of Mechanical Engineering Department, Politeknik Port Dickson

EDITOR

Azli Bin Kasan
Head of Mechanical Programme, Politeknik Port Dickson

FACILITATORS

Nin Hayati Binti Mohd Yusof

PELJ

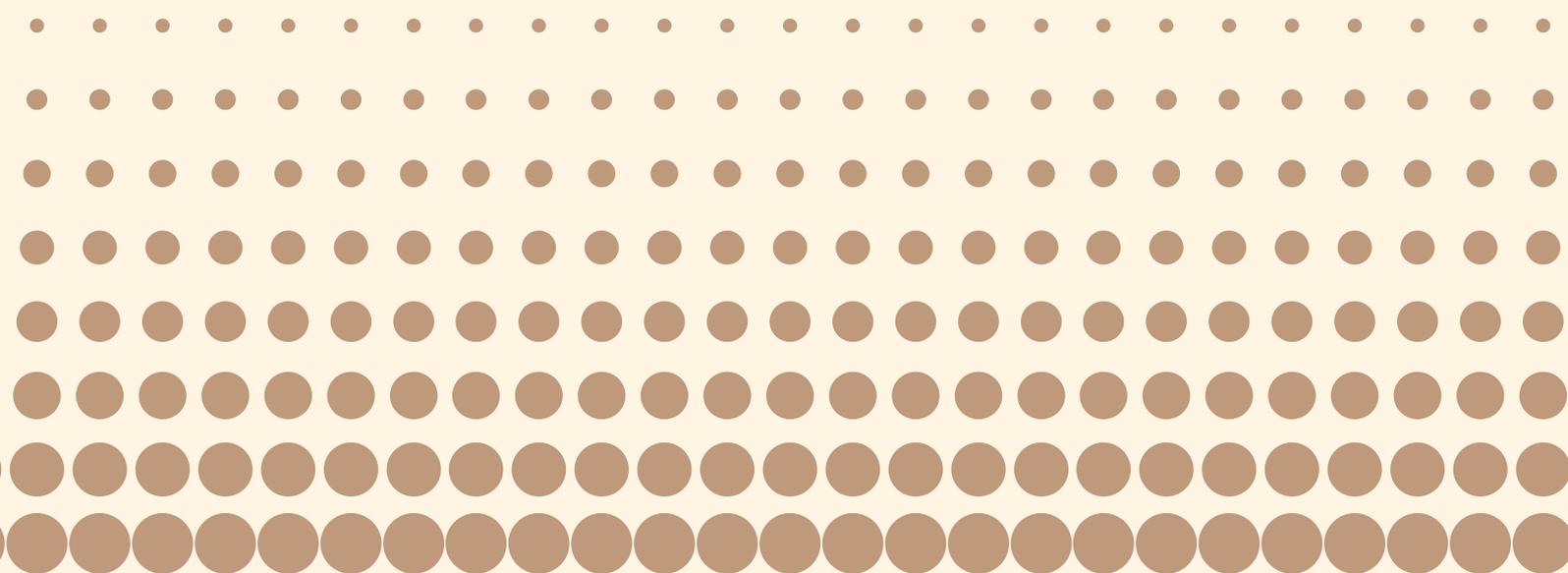
Ragunathan A/L Jayaraman

WRITERS

Norhazlina Binti Amon
Khairuhisham Bin Ramly
Pavithra Malar A/P Sanga Pillai

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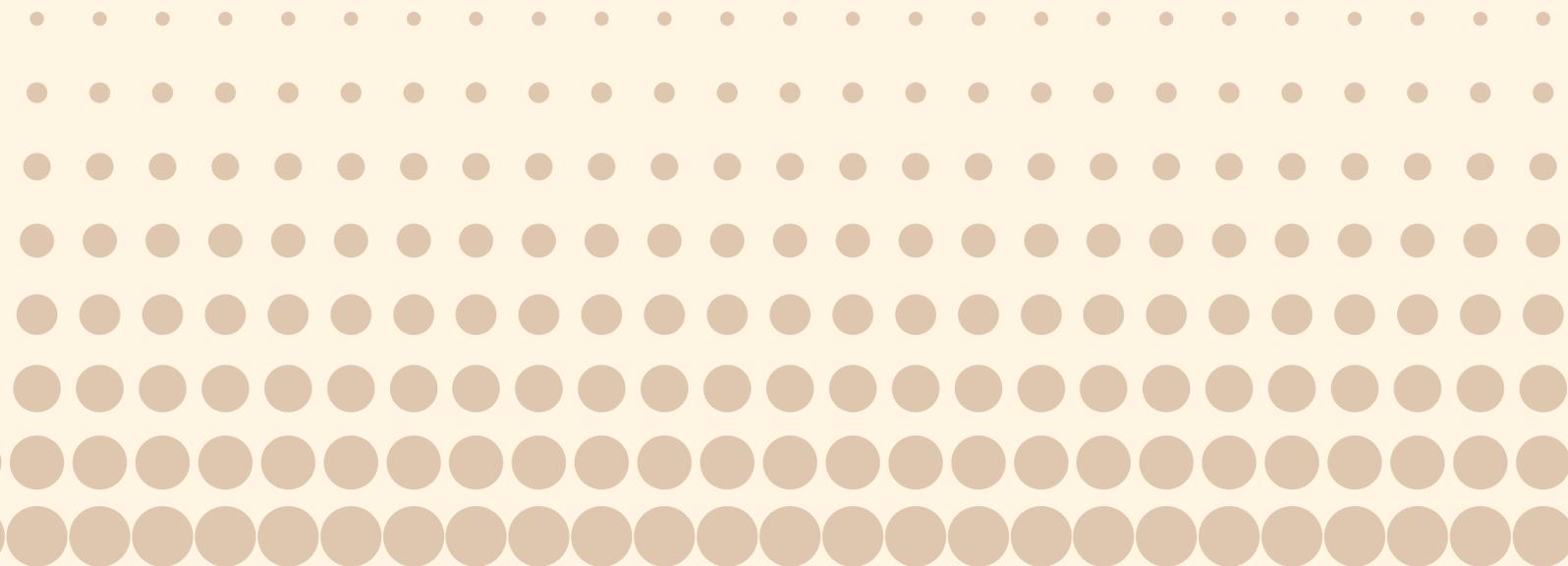


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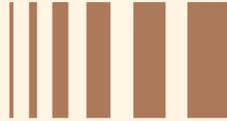
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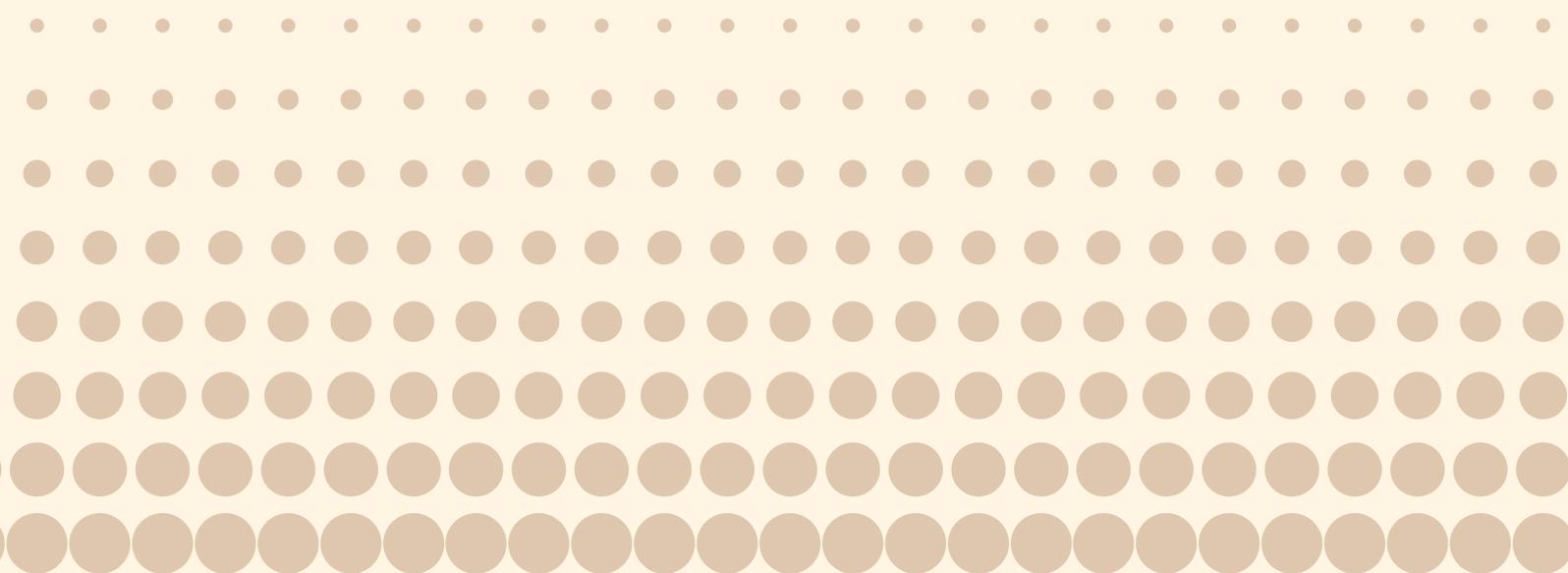
ABSTRACT



This e-book is successfully prepared in which it explores the latest syllabus content of DJJ30113 Material Science and Engineering from the Department of Polytechnic and Community College Education, Ministry of Higher Education. This course focuses on material structures, properties, fabrication methods, corrosion, thermal processing and material testing mostly of metals and alloys.

In this version, the e-book covers three chapters out of eight chapters that have been designed in Material Science and Engineering Syllabus. Chapter 1 Introduction to Material Science and Engineering will be covering the fundamental of material science and engineering; and the classification of materials. Whereas Chapter 2 Material Structure and Interatomic Bonding comprises the fundamentals of atomic structure; interpretation of periodic table, drawing the atomic bonding in solids; and constructing the metallic crystal structures. Meanwhile, Chapter 3 Mechanical Properties of Metals and Failure will be composed of concepts of stress-strain; elastic and plastic deformation from the stress-strain curve, and analysis of failures in engineering materials.

This e-book includes a well-organized feature that will expedite the learning process. These learning aids include numerous illustrations to visualize what is being presented; notes and mind maps; end of chapter questions and problems, solutions to selected problems to help in self-assessment and also an interactive activity which includes YouTube links and Interesting Facts, Tips and Hints to help students understand better.



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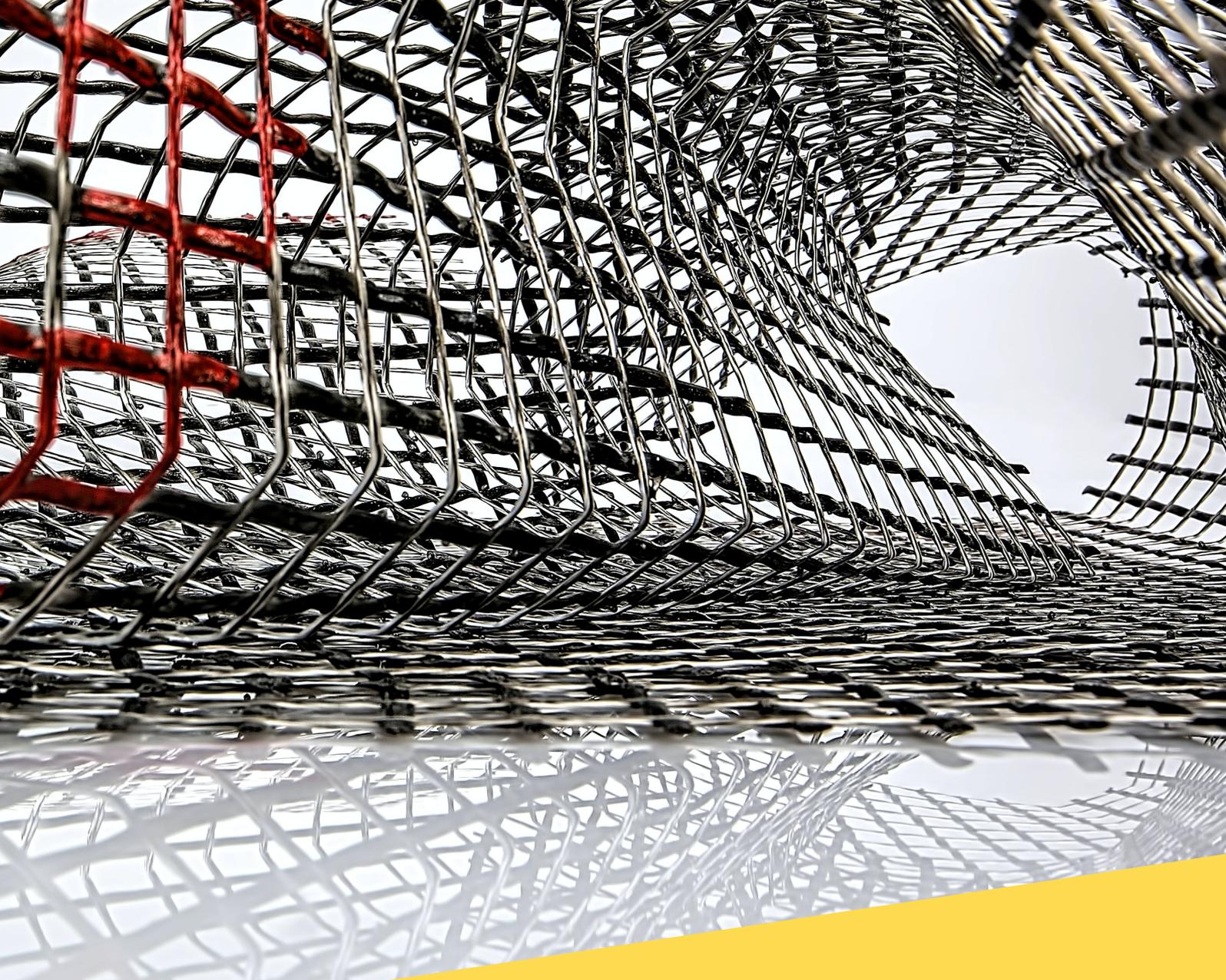
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CHAPTER

1

INTRODUCTION TO MATERIAL SCIENCE AND ENGINEERING

By the end of this lesson, you should be able to:

- Explain the fundamental of material and engineering.
- Classify the materials.

03

INTRODUCTION

04

FUNDAMENTAL OF MATERIAL
SCIENCE AND ENGINEERING

07

MATERIALS CLASSIFICATION

- a. Metals
- b. Ceramics
- c. Polymers
- d. Composites
- e. Advanced Materials:
 - Biomaterials
 - Semiconductors
 - Nano Engineered Materials
 - Smart Materials

INTRODUCTION

Why is it important for you to understand materials?

Materials are used to create the products, devices, and components that you buy and use. You must know the material characteristics and understand how the structure impacts the material properties in order to select acceptable materials and processing procedures for certain applications.

Materials science is defined in the reading for this session as the study of relationships between material structures and properties, as well as the design and creation of novel materials.

The creation of goods from existing materials in the development of new materials processing techniques is known as materials engineering.

When dealing with a material, it's important to remember that its structure, qualities, processing, and performance are all linked.





1.1 FUNDAMENTAL OF MATERIAL SCIENCE AND ENGINEERING

What is Material Science?
Investigating the relationships between a material's structure and its properties.

What is Material Science & Engineering?
Designing or engineering a material's structure to create a specific set of properties.

The interrelationships of four components of the discipline of material science are depicted Figure 1.0.

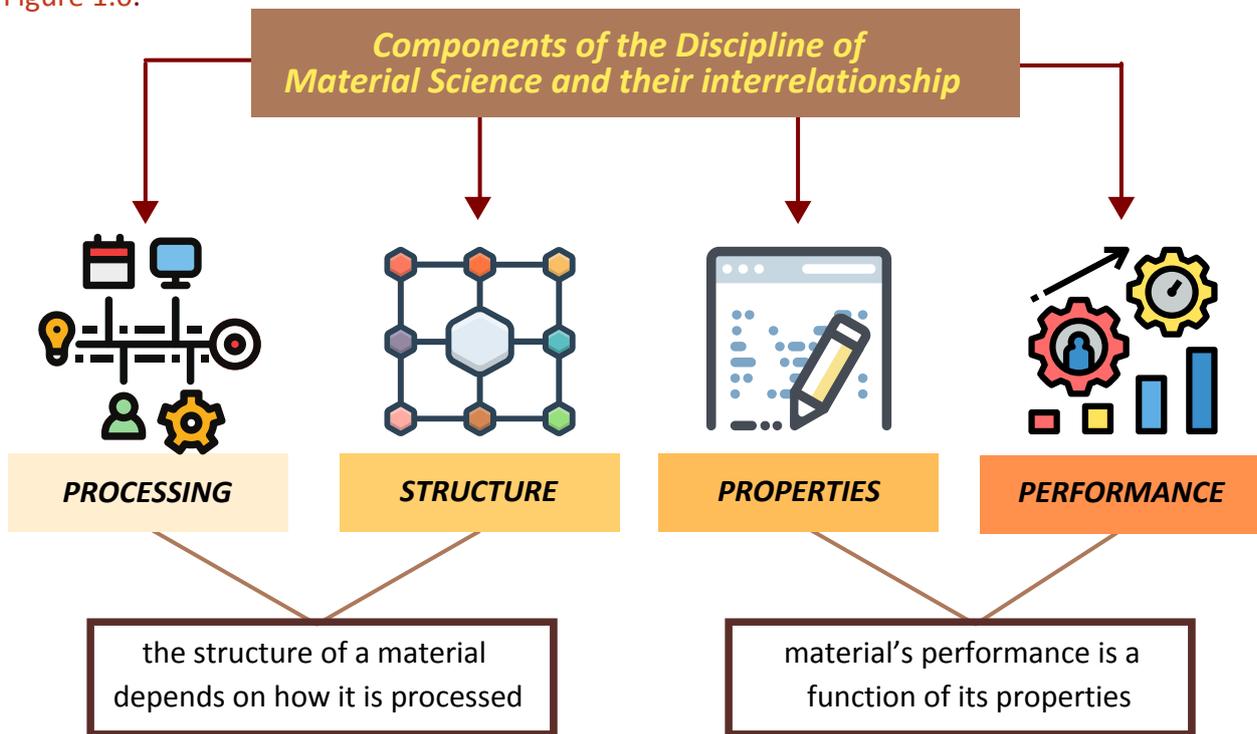
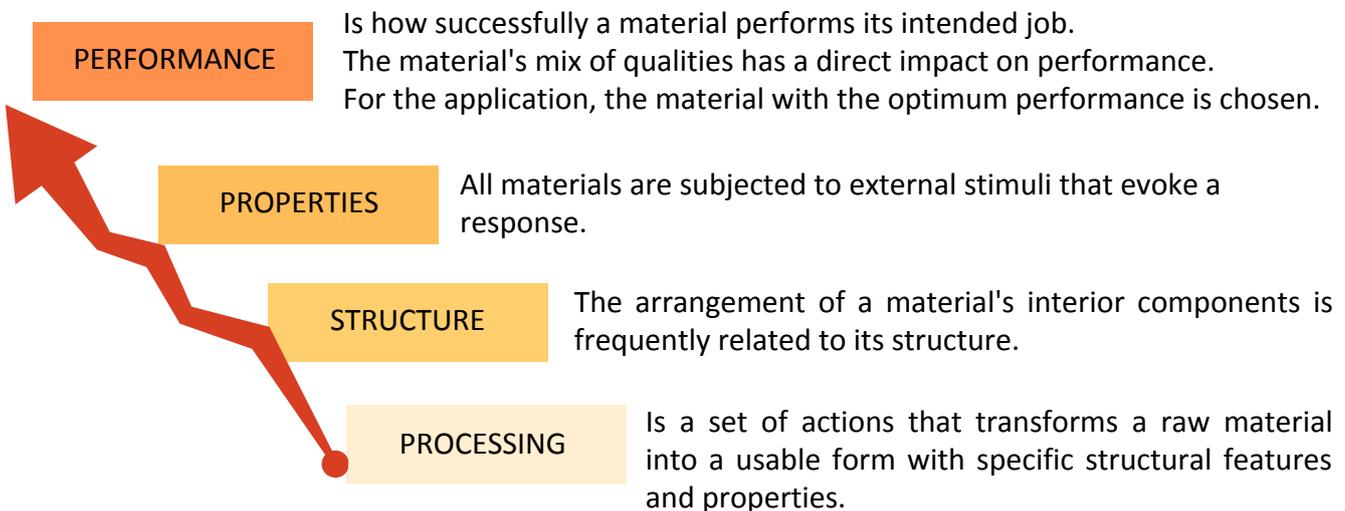


Figure 1.0 : Four components of the discipline of materials science and engineering.



WHY STUDYING MATERIAL SCIENCE ?



To be able **to choose** a material for a specific application while taking cost and performance into consideration.



To **understand** the limits of materials and how their qualities change over time.



To be able **to create** new material with some advantageous properties.

Material scientists and engineers have the following responsibilities::



Materials scientists **research and develop** new materials.



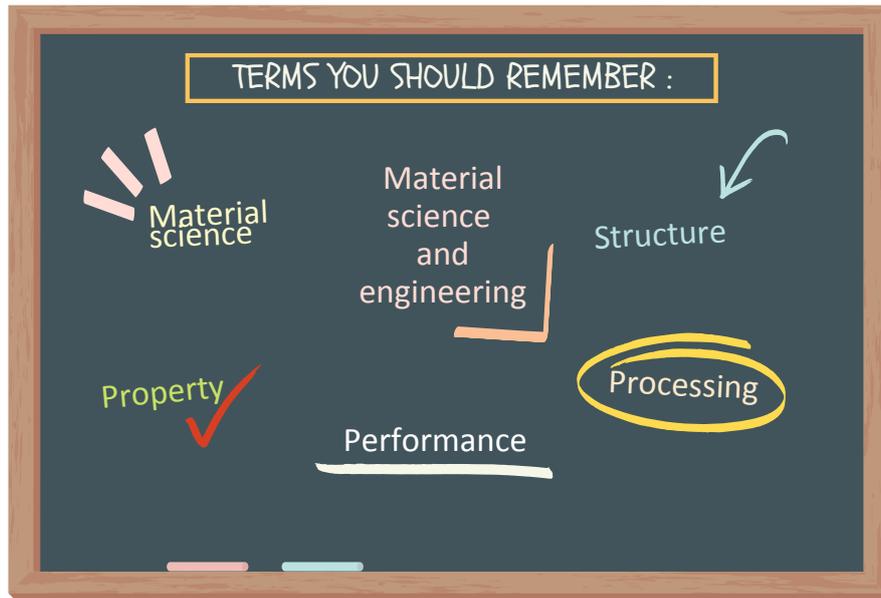
Materials engineers **use materials and develop** new processes.



Figure 1.1 : An assortment of carbonated beverages in glass, plastic, and metal containers.

Credit: Francois Schnell via Flickr

Materials selection has a role in our daily lives, such as when purchasing fizzy beverages. Glass, metal, and plastic containers are used for carbonated beverages. What considerations encourage carbonated beverage makers (Figure 1.1) to provide their goods in a variety of materials? When evaluating the various materials for carbonated beverage containers, what are the benefits and drawbacks? Many considerations must be considered when choosing a material for a product, including the material's qualities, performance, and lifetime; raw material availability; prices and energy consumption throughout the manufacturing process; sustainability; waste management, and so on.



Showtime !

<https://youtu.be/JZ9BkoLWdlg>

Checkpoint 1

1. Explain the fundamental of material science. *(Sec.1.1/pg.4)*
2. List down the FOUR (4) components of materials science and engineering, as well as their interrelationships. *(Sec.1.1/pg.4)*
3. What are the differences between material science and material science and engineering? *(Sec.1.1/pg.4)*
4. What are the purposes of studying material science? *(Sec.1.1/pg.5)*
5. Give four components of the discipline of materials science and engineering. *(Sec.1.1/pg.4)*



1.2 MATERIAL CLASSIFICATION

- Metals, ceramics, and polymers have been conveniently divided into three fundamental classes, as illustrated in **Figure 1.2**.
- Composites are made up of two or more of the three main material classifications mentioned above.
- Another classification is advanced materials, those used in high-tech applications, **semiconductors, biomaterials, smart materials, and nanoengineered materials** as shown in **Figure 1.3**.
- These materials are usually upgraded or specifically created to be high-performance.

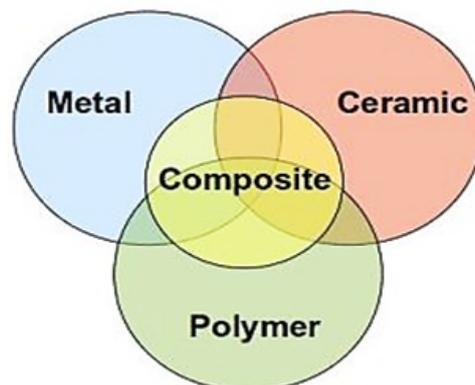


Figure 1.2 : Three basic classification of solid materials.

SOURCE :

<https://sengerandu.wordpress.com/tutorials/physical-metallurgy/engineering-materials/>

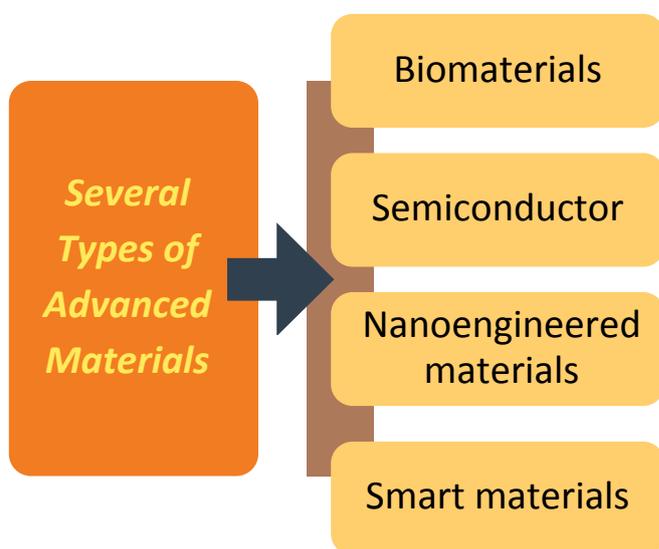


Figure 1.3 : Advanced materials

Materials are classified into several main groups as shown in **Figure 1.4**. Each of them has different criteria.

Example of such criteria are:

- The structure of crystal (arrangement of atoms and bonds between them)
- Properties
- Use

1.2

MATERIAL CLASSIFICATION



Figure 1.4 : The Classification of Materials



<https://www.youtube.com/watch?v=cSPfe77LIGw>

1.2.1 Metal

General

- Typically **hard, opaque, lustrous material** with **good electrical and thermal conductivity** (an element, compound, or alloy).
- Metals and their alloys are an extremely organised arrangement of atoms (a very orderly manner).
- Compose one or more metallic elements.

Properties

- **Strong and stiff** in comparison.
- Ductile (capable of large amounts of deformation without fracture).
- Fracture-resistant (which accounts for their widespread use in structural applications).
- Extremely **good electrical and thermal conductors**.
- **Not transparent** to visible light.
- The appearance of a polished metal surface is lustrous.

Examples

Metal can be categorized into two main types:

- **Ferrous Metals**

Having iron as a common element.

Cast iron contains more than 2% carbon, while steel contains less than 2%.

Example: Cast Iron, Wrought Iron, Steel, Silicon Steel, High-Speed Steel, Spring Steel, etc.

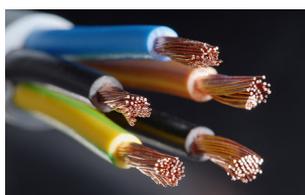
- **Non-Ferrous Metals**

The metals that do not contain iron.

Example: Aluminum, zinc, copper, and brass.



Iron – Railway track



Copper – Electrical wire



Aluminum - Kitchen utensils and packaging.

1.2.2 Ceramic

General

Ceramics are inorganic compounds comprised of metal oxides, nitrides, carbides, or silicates that combine **metallic and nonmetallic components**.

Properties

- Relatively stiff and strong—the stiffness and strength of this material are equivalent to those of metals.
- Typically **very hard, extremely brittle** (lack ductility), and highly susceptible to fracture
- They are more resistant to high temperatures and harsh environments than metals and polymers and are **insulated against the flow of heat and electricity**.

Examples



Aluminium Oxide



Silicon Dioxide



Silicon Nitride



Silicon Carbide

Applications



Tiles



Grinding wheel



Brick

1.2.3 Polymers

General

- Polymers include materials like **plastic and rubber**. Many of them are organic compounds chemically made up of **carbon, hydrogen, and other nonmetallic components**.
- **Large molecular structures** with a carbon atom backbone, which are generally chain-like in character.
- **Polymerisation** is a process that joins monomer molecules together to produce polymer chains by chemical reaction.

Properties

- Generally distinct to the metallic and ceramic materials.
- **Low density, lightweight, and low thermal and electrical conductivity** are common characteristics.
- Many polymers are **ductile and flexible (plastic)**, allowing them to be easily moulded into complex shapes.

Examples

- Polyethylene (PE)
- Polyvinyl chloride (PVC)
- Nylon, Teflon
- Polycarbonate (PC)
- Polystyrene (PS)
- Rubber

Applications



PVC – pipes



PE – bottles, bin, plastic bag



PC – sheet, billboard



PS – Packaging

Basic Polymer Structure

Monomer



- Is single unit and small molecule.
- Also known as “MER”.
- Covalently bond into long chains.

Polymer



- A polymer is a long chain made up of a repeated pattern of monomers.

Basic polymer structure is known as polymers chain link as shown in Figure 1.5.

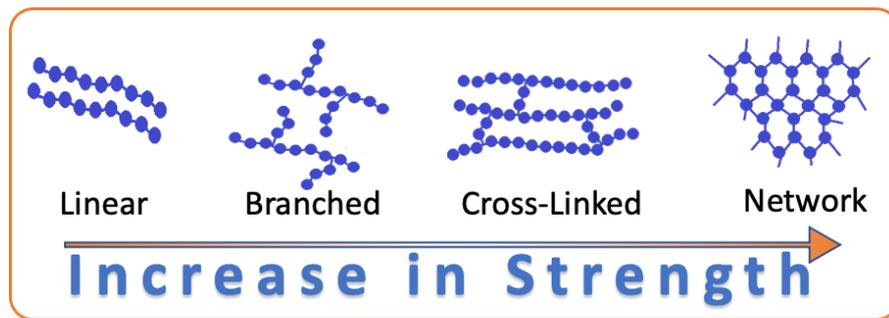
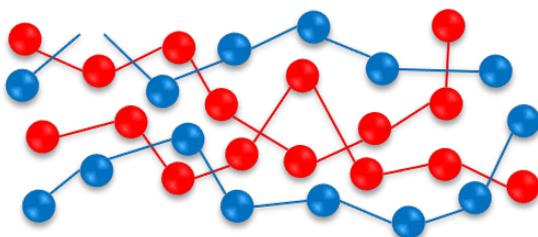


Figure 1.5 : Types of polymer chain link and strength

Classification of Plastic

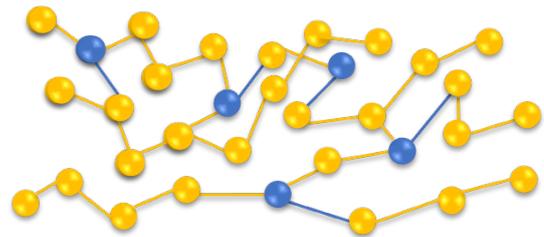
THERMOPLASTIC

- Thermosoftening.
- Tangle polymer chains.
- No Cross-Links between chains.
- Weak forces of attraction between chains.
- Softens when heated.



THERMOSETTING

- Thermoset
- Polymer chains are held together by strong Covalent Cross-Link bonding that does not break on heating.
- Remains hard when heated.



1.2.4 Composites

General

- A composite is **composed of or a combination of two** (or more) individual materials (metal, polymer, ceramic).
- A composite's design goal is **to achieve a combination of properties that are not displayed by any single material**, as well as to include the best characteristics of each of the component materials.
- Alloys and composites are not the same things. Alloys are metals that have been mixed with other elements. The elements in an alloy are mixed together and are no longer distinct components.

Properties

- Composites, as a class of engineering materials, have virtually limitless possibilities for **increasing strength, stiffness, and corrosion resistance**.
- The elements of a composite, their physical structures, and how they are blended to produce the final substance determine the qualities of the composite.

Examples

- Fibreglass is a material made up of tiny glass fibres embedded in a polymeric material (normally epoxy or polyester).
- Glass is stiff and strong (but also brittle), whereas polymers are ductile (but also weak and flexible).
- As a result, the finished fibreglass is stiff, tough, flexible, and ductile. Furthermore, it has a low density.

Applications



Epoxy and Polyester -
Automobile parts



Fibreglass - Tennis racket



Fibreglass - Boat hull



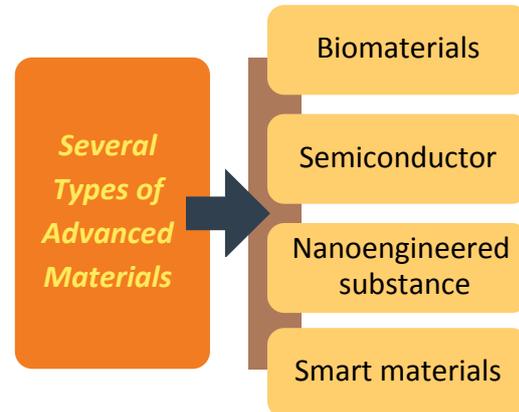
Epoxy - Helmet & bullet
proof jacket



1.2.5 Advanced Materials

General

- Traditional materials with improved qualities or newly invented materials with high-performance capabilities are classified as advanced materials.
- Materials that are utilised in high-technology applications.



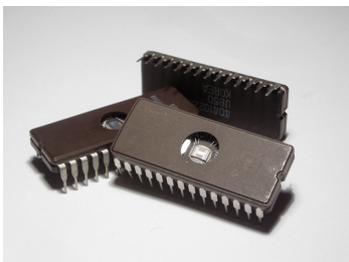
Properties

- Improves properties over its replacement.
- Relatively expensive.

Examples

- Metallic foams
- Inter-metallic compounds
- Multi-component alloys
- Magnetic alloys
- Special ceramics

Applications



Integrated circuits



Rocket capsule



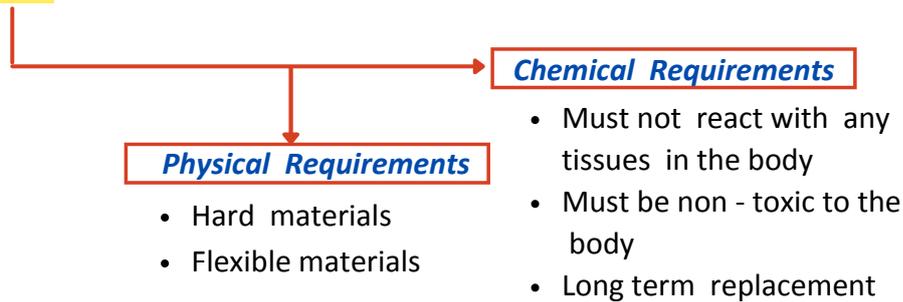
Fiber optics

1.2.5 Advanced Materials : Biomaterial

General

- Biomaterials are used in the replacement of diseased or damaged body parts that are **implanted into the human body**.
- These materials must be non-toxic and compatible with body tissues.
- Low friction, wear, density, and cost; ability to support forces.

Properties



Examples

- All of the materials.
(metals, ceramics, polymers, composites and semiconductors)

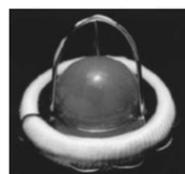
Applications



Dental implants



Lenses



Heart valve



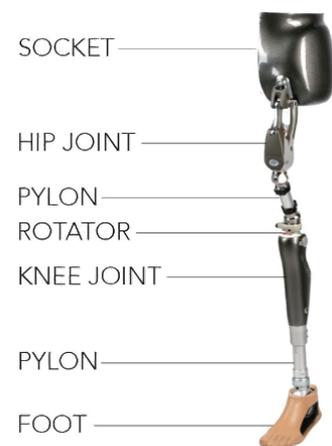
Hip joint



Knee joint



Skin



1.2.5 Advanced Materials : Semiconductor

General

- Semiconductors have electrical properties that are intermediate between those of conductors and those of insulators.

Properties

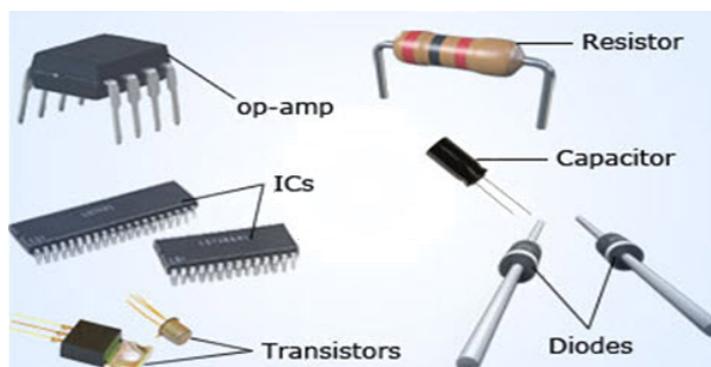
- Intermediate between electrical conductors and insulators.

Examples

- Elements such as silicon, Si or germanium, Ge.
- Compounds such as gallium arsenide, GaAs or cadmium selenide, CdSe.

Applications

- **Transistor**
To amplify and switch electronic signals.
- **A wafer in photovoltaic cells**
To convert light energy to electric energy.
- **Semiconductor memory uses**
- **Silicon**
Used in electronic circuit fabrication and gallium arsenide is used in solar cells, laser diodes, etc.



1.2.5 Advanced Materials : Nanoengineered

General

- Metals, ceramics, polymers, and composites are the four primary categories of nanomaterials.
- The nano prefix indicates that these structural entities have dimensions on the order of a nanometer (10^{-9} m); unlike other materials, they are differentiated by their size rather than their chemistry.

Properties

- Ability to create mechanical, electrical, magnetic, and other qualities that would otherwise be impossible to achieve.

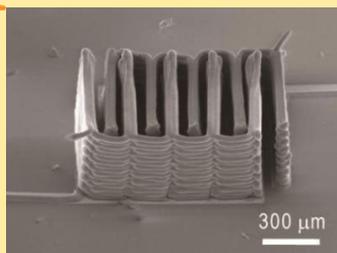
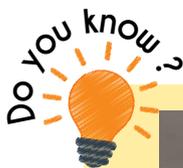
Examples

- Carbon nanotube.

Applications



- **Nano-engineered materials**
-automotive products
- **High-power rechargeable battery systems**
- **Thermoelectric materials**
-temperature control
- **Thin-film smart solar panels**
- **Fuel additives and improved catalytic converters**
-cleaner exhaust and extended range



This image depicts an interlaced stack of electrodes that are printed layer by layer to form the microbattery's functional anode and cathode. (Photo courtesy of Harvard's Wyss Institute for Biologically Inspired Engineering)

1.2.5 Advanced Materials : Smart Materials

General

- A new generation of cutting-edge materials is currently being developed that will have a substantial impact on many technologies.

Properties

- Capable of detecting changes in their surroundings and reacting to them in specified ways.
- Components include :
 - type of sensor (detects an input signal)
 - actuator (performs a responsive and adaptive function)
- Temperature, electric fields, and magnetic fields cause changes in shape, location, natural frequency, and mechanical qualities.

Examples

There are four various kinds of materials that are regularly used :

Magneto Strictive Materials

Shape-memory Alloys

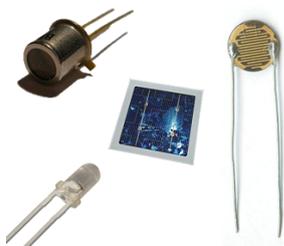
Piezoelectric Ceramics

Electrorheological / Magnetorheological Fluids.

Applications

Photochromic material – Color changes in response to light

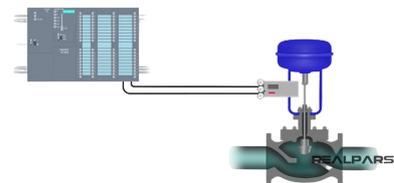
Example : When exposed to harsh sunshine, sunglasses darken.



Sensor



Switches



Actuator

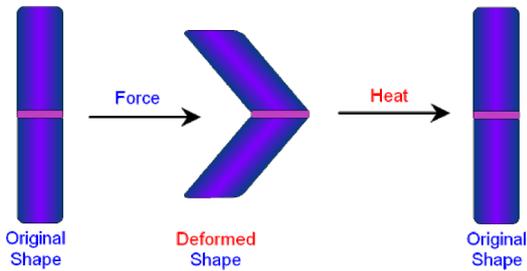


<https://www.youtube.com/watch?v=X1MXHkubYlg>

1.2.5 Advanced Materials : Smart Materials

A) Shape-memory Alloys

Metals that after having been deformed, revert to their original shape when the temperature is changed.



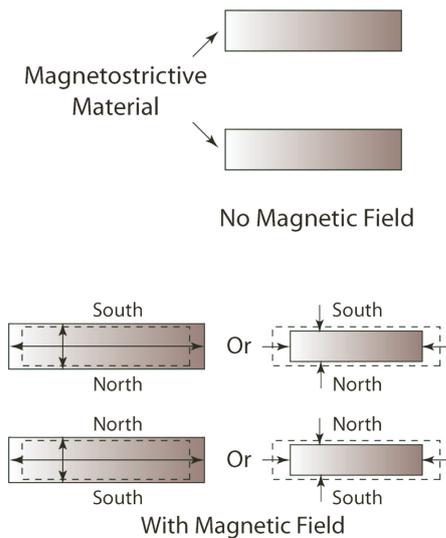
B) Piezoelectric Ceramics

In reaction to an applied electric field (or voltage), they expand and shrink in opposite directions.

It also generates an electric field when its dimensions are altered.

C) Magneto Strictive Materials

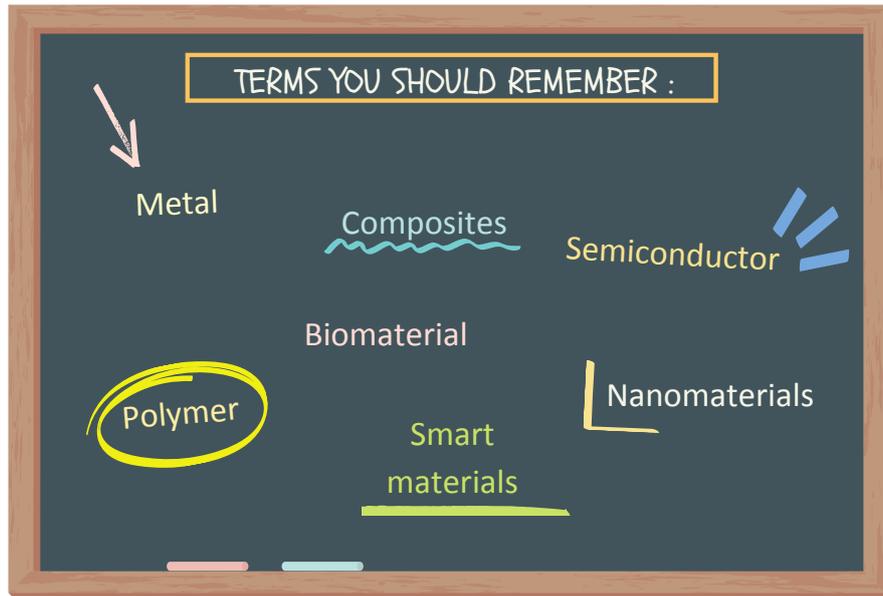
Material that changes its shape when exposed in a magnetic field. Utilised in switches and sensors.



D) Electrorheological/ Magnetorheological Fluids

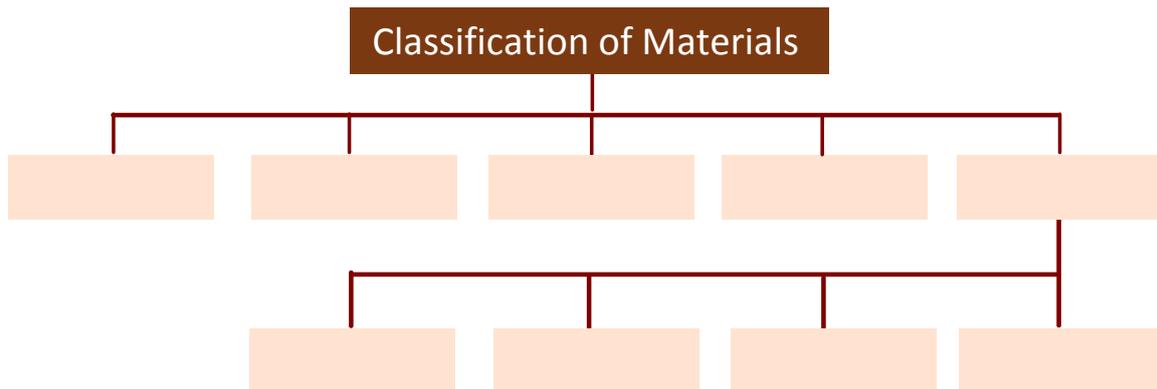
The viscosity of liquids changes dramatically when electric and magnetic fields are applied to them.





Checkpoint 2

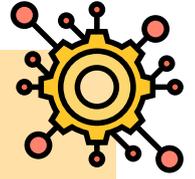
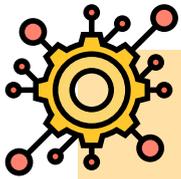
1. Classify the classification of material as shown in the figure below by filling up the blanks. *(Sec.1.2/pg.8)*



2. List the three basic classifications of solid materials. *(Sec.1.2/pg.7)*
3. Define :
 - i. Metal *(Sec.1.2.1/pg.9)*
 - ii. Ceramic *(Sec.1.2.2/pg.10)*
 - iii. Polymer *(Sec.1.2.3/pg.11)*
4. Identify two consumer items made from composites. *(Sec.1.2.4/pg.13)*
5. Briefly define advanced materials. *(Sec.1.2.5/pg.14)*



Let's summarize !

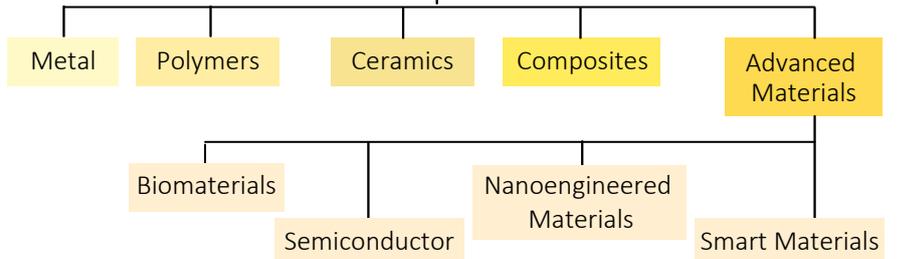


Chapter 1 : Introduction to Material Science and Engineering

4 Components of The Discipline of Material Science

- 1) Structure
- 2) Processing
- 3) Properties
- 4) Performance

Classification of Materials



Properties of Metals

1. Ductile.
2. Stiff and strong.
3. Good conductor of heat and electricity.
4. Polished metal surface has good appearance.

Properties of Polymers

1. Dissimilar to the metallic and ceramic materials.
2. Low densities, lightweight, low thermal and electrical conductivity.
3. Extremely ductile and pliable.

Properties of Composites

1. Increased strength, stiffness, and corrosion resistance are all possible and limitless.
2. The constituents of a material, their physical shapes, and how they are mixed to generate the final product determine its qualities.

Properties of Ceramics

- Relatively stiff and strong
- They are often exceedingly hard, brittle (poor ductility), and easily fractured.
- They are more resistant to high temperatures and harsh environments because they are insulated against the flow of heat and electricity.

Properties of Advanced Materials

- Improves properties over its replacement
- Relatively expensive

**Exercise****Multiple Choice Questions**

1. How does materials science relate to technology?
 - All materials are a form of technology.
 - It has no relationship with technology.
 - It helps to develop technology, by choosing the right material for the job and man-made materials are a form of technology themselves.
 - All technology is made out of materials.
2. Which of the following classifications of materials includes things like silk and rubber?
 - Composites
 - Ceramics
 - Polymers
 - Metals
3. What is materials science?
 - None of the other answers is correct.
 - The study of materials and how they're useful.
 - The part of engineering that involves discovering and designing new materials, and analysing their properties and structure.
 - The study of the chemicals and structure of materials, with no reference to their properties.
4. In which of the following categories would you find steel?
 - Polymers
 - Composites
 - Metals
 - Ceramics

**Exercise****Multiple Choice Questions**

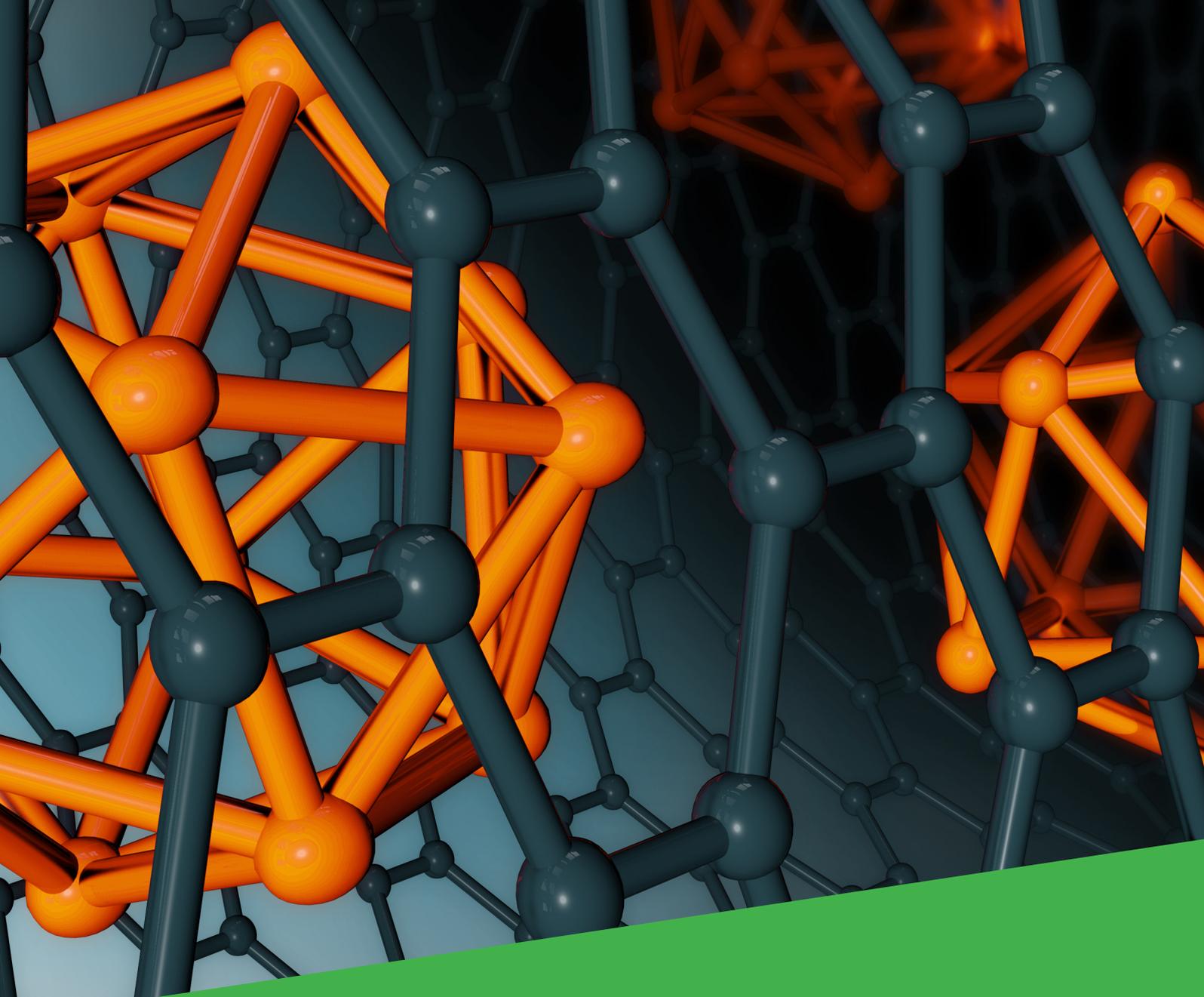
5. Which of the following is not a classification of materials commonly used in material science?
- Polymers
 - Ceramics
 - Gemstones
 - Composites
6. GFRP is an important composite. It stands for
- Gelatin Fibre Reinforced Polymer
 - Graphite Fibre Reinforced Polymer
 - Germanium Fibre Reinforced Polymer
 - Glass Fibre Reinforced Polymer

Answer

1. It helps to develop technology, by choosing the right material for the job and man-made materials are a form of technology themselves.
2. Polymers
3. The part of engineering that involves discovering and designing new materials, and analysing their properties and structure.
4. Metals
5. Gemstones
6. Glass Fibre Reinforced Polymer

Past Year Questions

1. Differentiate between the terms of material science and material engineering. *(Sec.1.1/pg.4)*
2. Name a metal that you consider suitable for a food/drink container.
Write the best reasons why the metal you named is suitable for the manufacture of the food/drink container. *(Sec.1.2.1/pg.9)*
3. Below are the following examples that are regularly used in our daily life.
 - i. Copper is made from metal and is suitable for electrical wiring. *(Sec.1.2.1/pg.9)*
 - ii. Vase is made from ceramic. *(Sec.1.2.2/pg.10)*Specify THREE(3) properties for each, to make it suitable for use. *(Sec.1.2.1/Sec.1.2.2)*
4. Explain the purpose of biomaterial in our body. *(Sec.1.2.4/pg.15)*
5. Describe the following Smart Material:
 - a) Piezoelectric *(Sec.1.2.5/pg.19)*
 - b) Photochromic *(Sec.1.2.5/pg.18)*
 - c) Shape Memory *(Sec.1.2.5/pg.19)*
6. Material Y is ductile, has a high melting point, as well as thermally and electrically conductive. Based on the features given,
 - i. Write TWO (2) examples of material Y. *(Sec.1.2.1/pg.9)*
 - ii. Write the type of material produced if material Y is combined with other materials. *(Sec.1.2/pg.7)*



CHAPTER

2

MATERIAL STRUCTURE AND INTERATOMIC BONDING

By the end of this lesson, you should be able to:

- Explain the fundamental atomic structure
- Interpret the Periodic Table
- Draw the atomic bonding in solids
- Construct the metallic crystal structures

- 27** INTRODUCTION
- 28** FUNDAMENTAL OF ATOMIC STRUCTURE
- a. Terminology
 - i. Atom
 - ii. Element
 - iii. Mixture
 - iv. Compound
- 31** PERIODIC TABLE
- 41** ATOMIC BONDING IN SOLIDS
- a. Covalent
 - b. Ionic
 - c. Metallic
- 47** METALLIC CRYSTAL STRUCTURE
- a. Fundamental concepts
 - b. Unit cells
 - c. Metallic crystal structures
 - i. Simple cubic
 - ii. Body-centered cubic
 - iii. Face-centered cubic
 - iv. Hexagonal close-packed

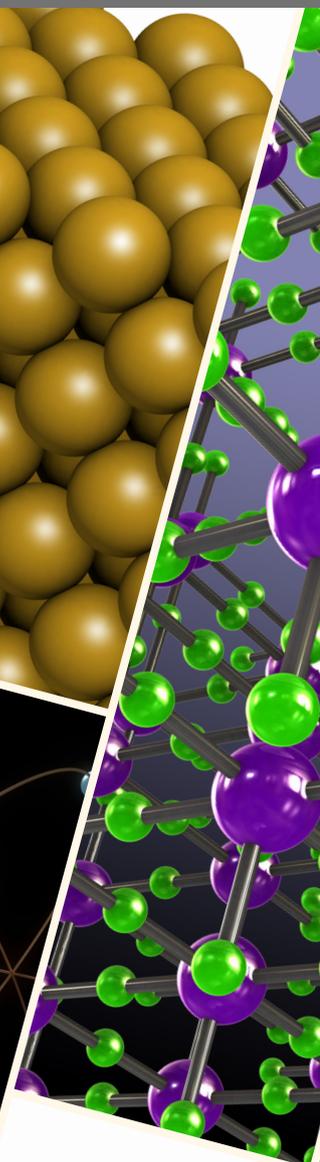
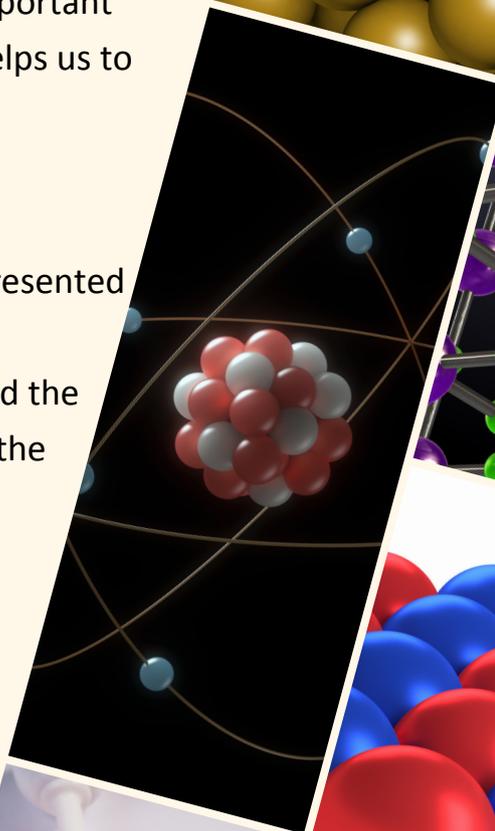
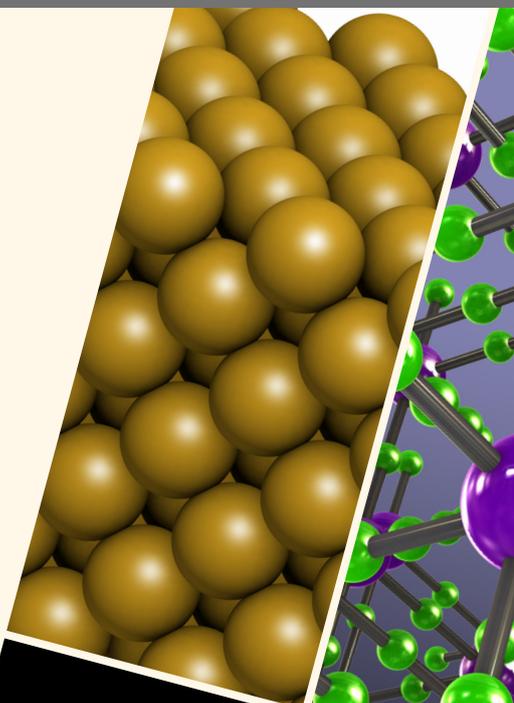
INTRODUCTION

Why Study Atomic Structural and Interatomic Bonding?

Understanding interatomic bonding in solids is important because, in some cases, the type of connection helps us to explain a material's properties.

Several fundamental and significant ideas were presented in this lesson, including atomic structure, electron configurations in atoms and the periodic table, and the numerous forms of inter-atomic bonds that keep the atoms that compose a solid together.

Some of the most essential features of solid materials are dictated by the numerous types of atomic bonding, which is determined by the electron configurations of individual atoms, as well as geometric atomic groupings.



2.1 FUNDAMENTAL OF ATOMIC STRUCTURE

Physical Structure of Atoms

All materials are made from atoms. Figure 2.1 shows the **nucleus** of an atom, which is made up of **protons** and **neutrons**.

- The nucleus is surrounded by **electrons**.
- Protons and electrons are oppositely charged.
- Neutrons have no charge.
- Atomic Number = Number of protons
- Atomic Mass = Number of protons + Number of neutrons

Protons are Positive (+VE)
Neutrons are Neutral (NEUTRAL)
Electrons are Negative (-VE)

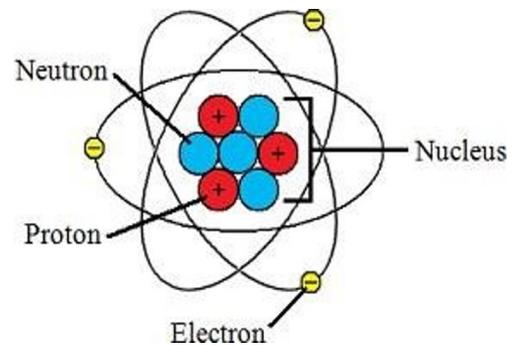
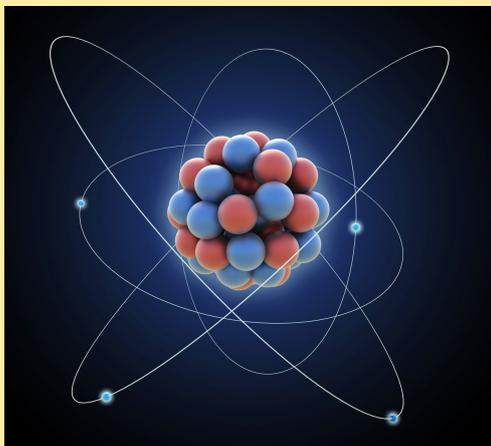
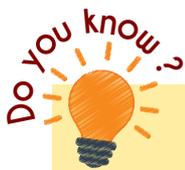


Figure 2.1 : The position of electron nucleus and orbit in an atom.



Atoms are the fundamental building blocks of matter, and they can't be separated using chemicals. Chemical reactions that shift electrons can change how atoms connect to one another, but they can't be utilised to divide them. Most of the mass of the atom is located in the nucleus, with the mass of the proton roughly equal to the larger neutron, but 1840 times the mass of the electron. The majority of an atom's volume, on the other hand, is occupied by electrons.

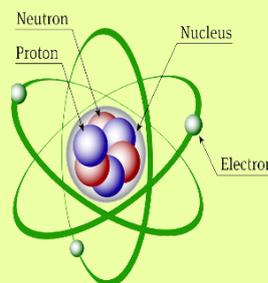


<https://www.youtube.com/watch?v=03iWCjxjCdA>

Terminology of :

ATOM

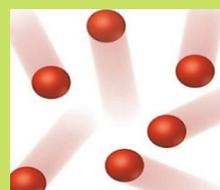
- Smallest unit / the basic unit of an element.
- 3 basic particles of atoms are **proton, neutron and electron**.
- Formed whether in solid, gas or liquid.

**ELEMENT**

- A combination of two or more of one kind of atoms bonding together / consist of either atoms or molecules.
- Chemically, the substance **cannot be broken down**.

Example :

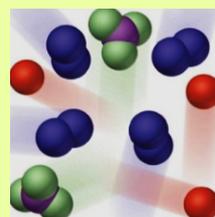
Hydrogen is made up of atom containing 1 proton and 1 electron.

**MIXTURE**

- Various kinds of atoms combined together but **not chemically combined**.
- Mixtures can be heterogeneous or homogenous forms of matter.
- Components of mixture **easily separated**.

Examples:

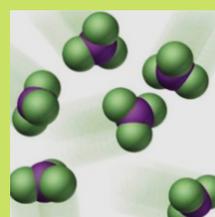
sea water - water and salt; steel – iron and carbon; brass – copper and zinc.

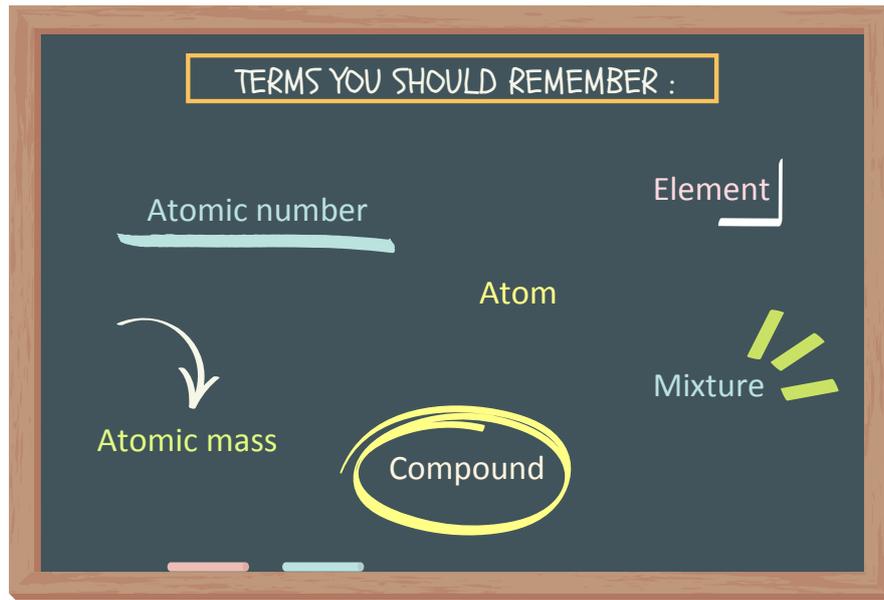
**COMPOUND**

- A combination of different types of atoms that are **chemically joined** together.
- It **takes energy to separate** the components.

Examples:

water (H₂O), CO₂, NaCl.





<https://www.youtube.com/watch?v=14BEh2EKrM0>



Checkpoint 1

1. Define atom and element. *(Sec.2.1/pg.29)*
2. List THREE (3) basic particles found in one unit of atomic element and state the charges that exist on each of the particles. *(Sec.2.1/pg.28)*
3. Fill in Table 1. Categorize items list below in their correct group. *(Sec.2.1/pg.29)*

Salt Syrup Lithium Copper Methane Sand

Element	Mixture	Compound

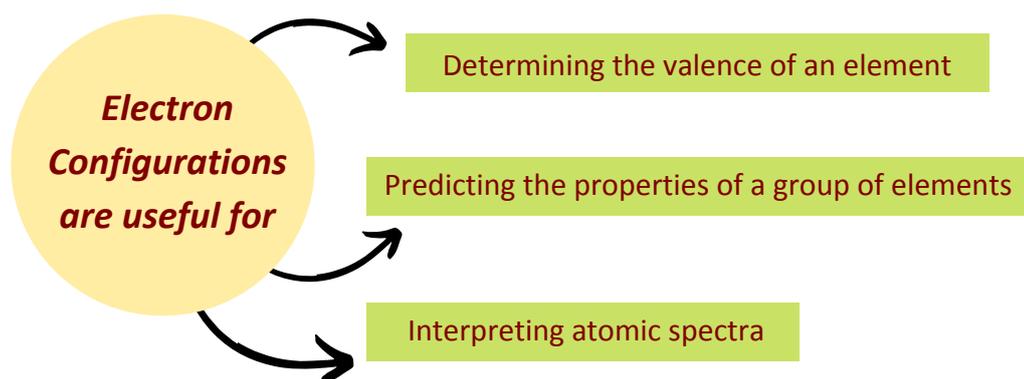
4. Define the terminology of
 - i. Mixture *(Sec.2.1/pg.29)*
 - ii. Compound *(Sec.2.1/pg.29)*
5. What is the difference between an element and a compound? *(Sec.2.1/pg.29)*



2.2 ELEMENT PERIODIC TABLE (EPT)

Electron Configuration

- Electrons are arranged in energy level (electrons are assumed to revolve around the atomic nucleus in discrete orbitals)
- Each electron in an atom must occupy the lowest shell available nearest the nucleus.
- When the lower level is full, the next electron goes to the highest net level available.



- The symbols used to write the electron configuration are the shell number (n), followed by the kind of orbital, and finally the superscript, which indicates the number of electrons in the orbital. (Figure 2.2).

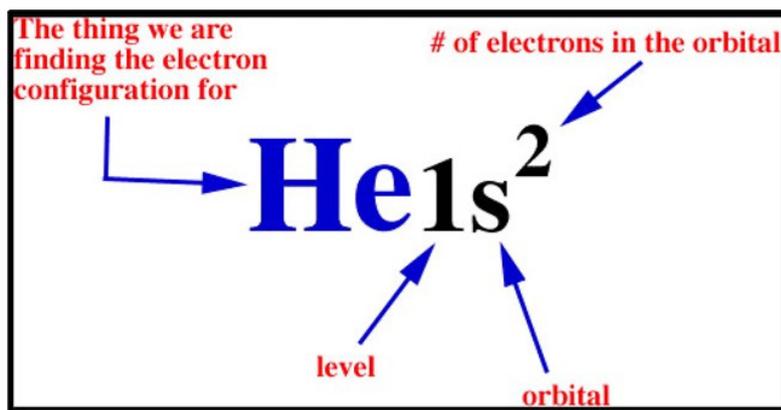
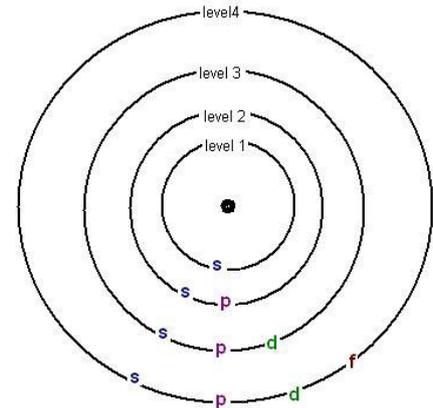
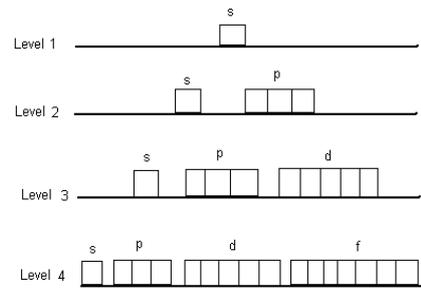
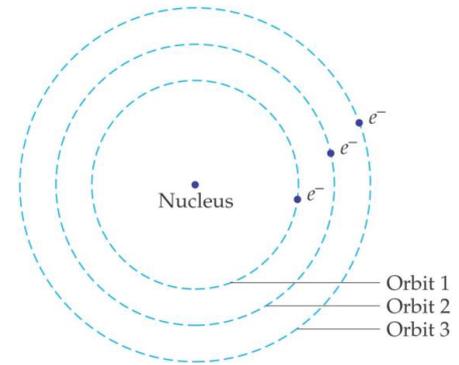


Figure 2.2 : Symbol used for writing the electron configuration

Electron Configuration

- The location of electrons around a nucleus is summarised by electron configurations.
- As previously stated, each neutral atom has the same number of protons as electrons.
- Electrons reside in discrete, precise orbits around the nucleus of an atom. These orbits are called levels. The levels can be broken down into sublevels -s, p, d, and f sublevels.
- Level one has one sublevel – an s. Level 2 has 2 sublevels - s and p. Level 3 has 3 sublevels - s, p, and d. Level 4 has 4 sublevels - s, p, d, and f.
- There can be **two electrons in one orbital maximum**. Figure 2.3 is a list of the different types of orbitals and how many electrons each one can hold. By using this chart :
 - 2 electrons to fill an s orbital;
 - 6 electrons to fill a p orbital;
 - 10 electrons to fill a d orbital and;
 - 14 electrons to fill the f orbital.



Orbitals and Electron Capacity of the First Four Principle Energy Levels				
Principle energy level (n)	Type of sublevel	Number of orbitals per type	Number of orbitals per level(n ²)	Maximum number of electrons (2n ²)
1	s	1	1	2
2	s	1	4	8
	p	3		
3	s	1	9	18
	p	3		
	d	5		
4	s	1	16	32
	p	3		
	d	5		
	f	7		

Figure 2.3 : Type of orbitals

Electron Configuration

Example : Find out the configuration electron for Oxygen.

Solution :

- Electron number = 8 (refer Figure 2.2).
- Writing electron configuration for Oxygen (refer Figure 2.7):
 - Row 1s – 2 electron
 - Row 2s – 2 electron
 - Row 2p – 4 electron



- $1s^2 2s^2 2p^4$ (2:6).



<https://www.youtube.com/watch?v=iFN9agJVea4>

Element of Periodic Table (EPT)

- EPT is a dictionary that contains the names and chemical symbols for the elements that make up all engineering materials.
- As illustrated in Figure 2.5, all elements in the periodic table have been classified according to electron configuration.
- From left to right, the elements are arranged from most active to least active.
- The lightest is at the top of the EPT; the atomic masses increase toward the bottom of the chart.
- The vertical groupings are based on similarities in valence electron configurations and similarities in the chemical and physical properties of the elements.

Element of Periodic Table (EPT)

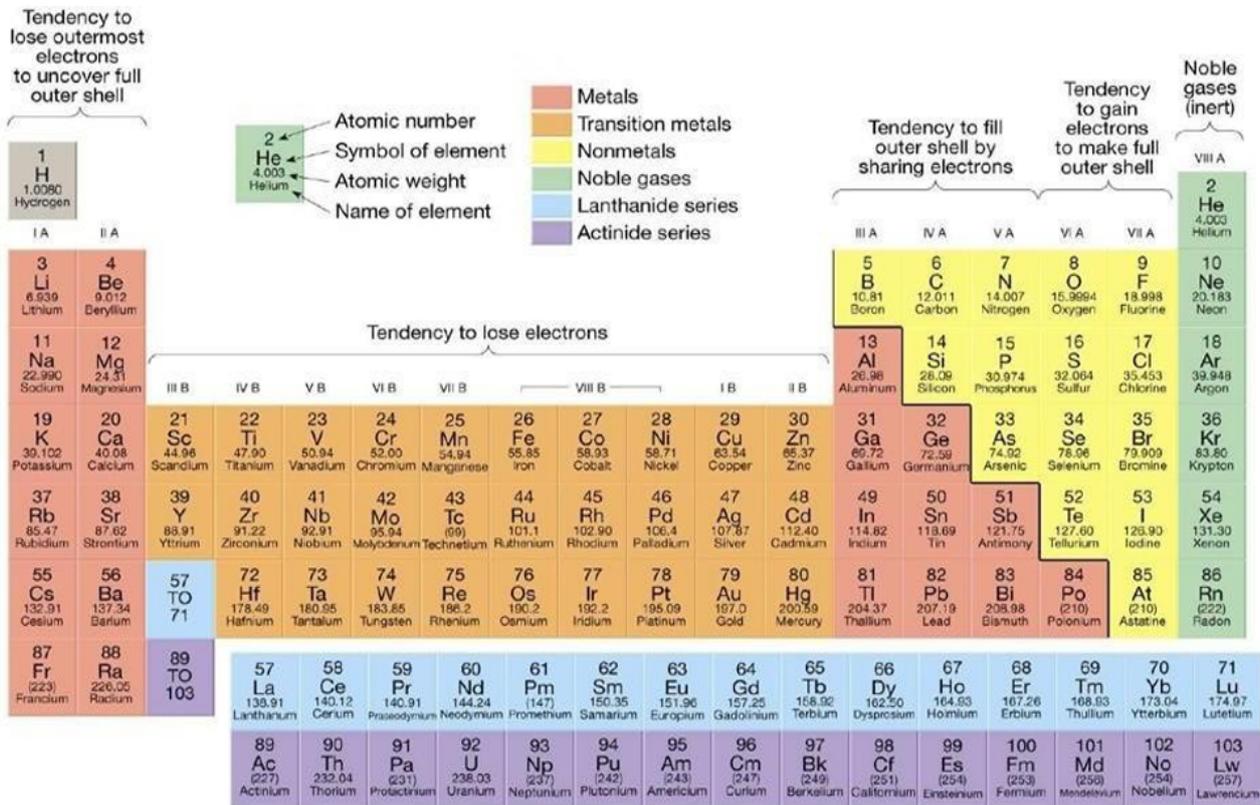
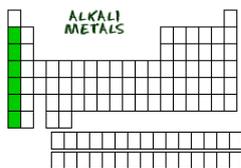


Figure 2.5 : Element Periodic Table (EPT)

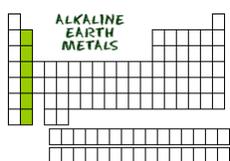
Source : Pearson Prentice Hall, Inc.

- The elements in group IA and IIA are called alkali metals and alkali earth metals (Li, Na, K, Be, Mg, Ca, etc.).
- The groups listed as transition elements are metals with a particular electron subshell configuration (incomplete subshell).
- Groups IIIA, IVA, VA, VIA, and VIIA are mostly nonmetals (as shown by the heavy line in Figure 2.5).
- Inert gases are found in the last vertical grouping.

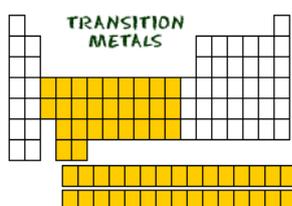
FAMILY CHARACTERISTICS AND PROPERTIES

**ALKALI METALS**

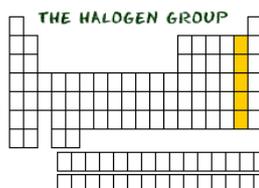
- Group 1.
- Most reactive metals.
- Low boiling point and melting point.
- Less dense than most other elements.
- All are found naturally in nature but not in pure forms.

**ALKALINE EARTH METALS**

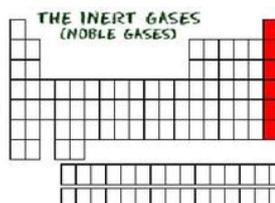
- Group 2.
- Have 2 electrons in valence shell having an oxidation state of plus 2.
- Easily lose electrons.
- Pure forms are shiny and silvery.
- Exist with an 2 plus charge most of the time.

**TRANSITION METALS**

- Very hard.
- The largest group of elements.
- Positive oxidation states.
- High electrical conductivity.
- Malleable.
- 5 d-orbitals become more filled, from left to right on the table.
- High melting and boiling points

**HALOGENS**

- Group 17 (VIIA).
- Have 7 valence electrons requiring only one other electron to form a full octet.
- More reactive than other non-metal groups.
- Melting and boiling points increase down the group.
- Very reactive especially with groups 1 and 2 where they form ionic compounds

**NOBLE GASES**

- Group 18 of the table located on the far right
- Extremely non-reactive
- Have filled valence electrons
- Atomic mass & boiling point increase down a group
- Increase in density down the group
- Stable and tending not to form bonds
- Noble gases are colourless, odourless, tasteless, and non-flammable gases under standard conditions
- Low boiling and melting points

The Element Sequence in EPT

The horizontal rows of elements on the periodic table are called

PERIODS.

hydrogen	1	H	helium	2	He																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
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cesium	55	Cs	barium	56	Ba	lanthanum	57-70	* Lu	hafnium	72	Hf	tantalum	73	Ta	tungsten	74	W	rhenium	75	Re	osmium	76	Os	iridium	77	Ir	platinum	78	Pt	gold	79	Au	mercury	80	Hg	thallium	81	Tl	lead	82	Pb	bismuth	83	Bi	polonium	84	Po	astatine	85	At	radon	86	Rn																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
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How To Read Each Element

- To guide you identify the elements, each box on the table has an atomic number, element symbol, element name, and atomic mass.
- Figures 2.6 and 2.7 show how to read and information by each element.

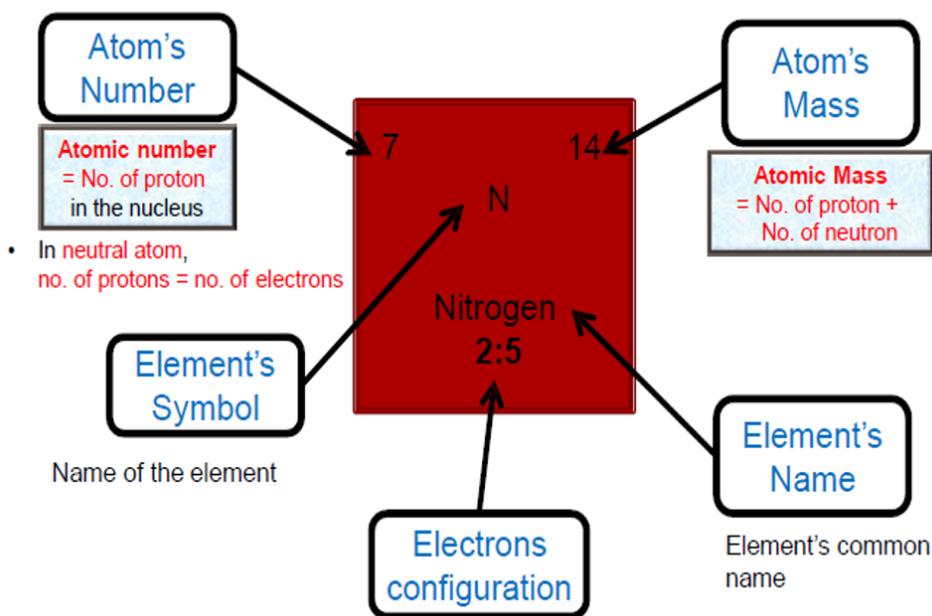


Figure 2.6 : Reading the element information in periodic table

Atomic Number And Atomic Mass

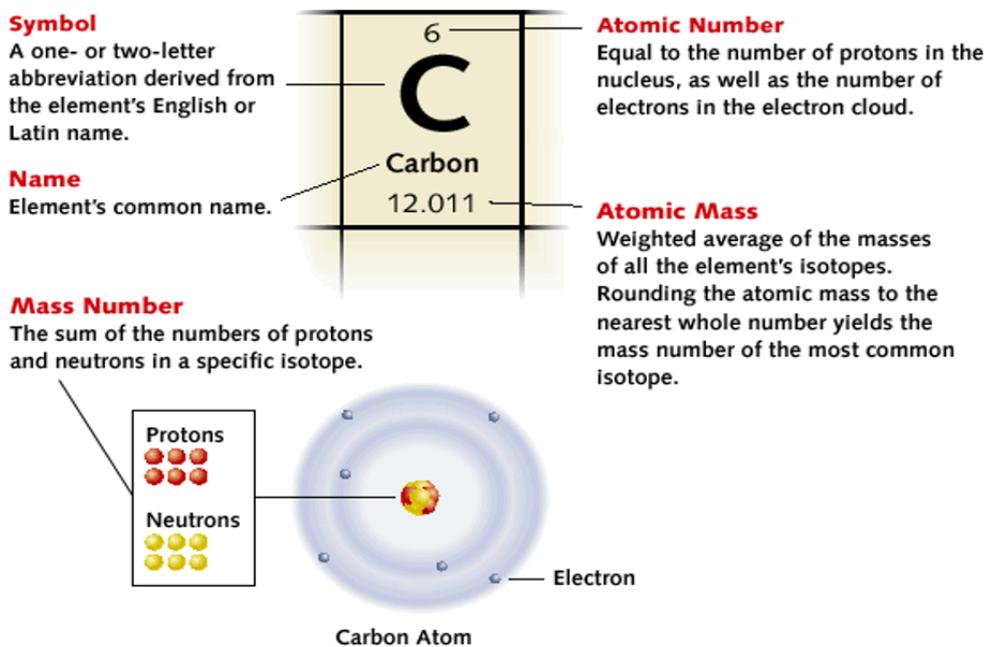
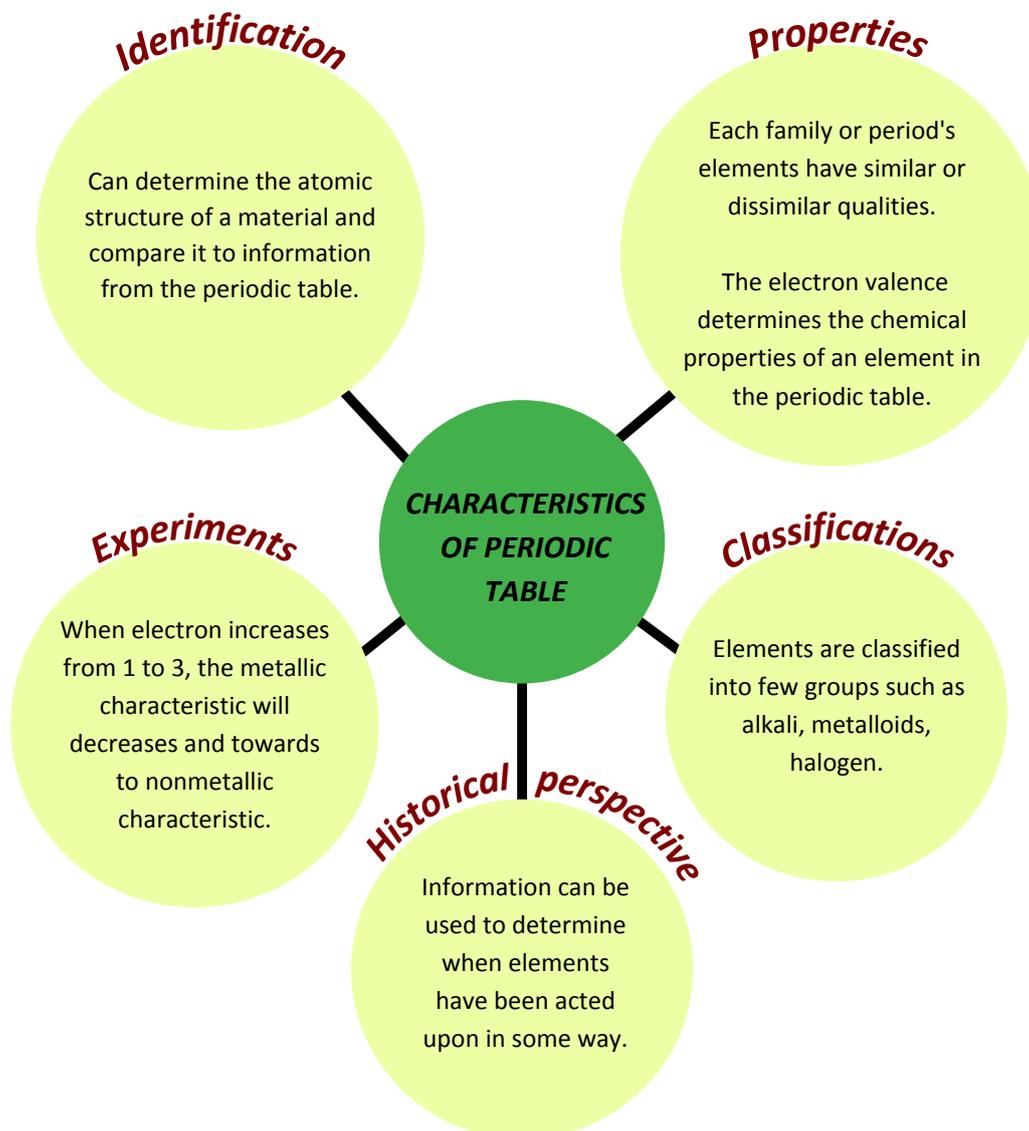


Figure 2.7 : Element information in periodic table
Source from <https://www.classzone.com>

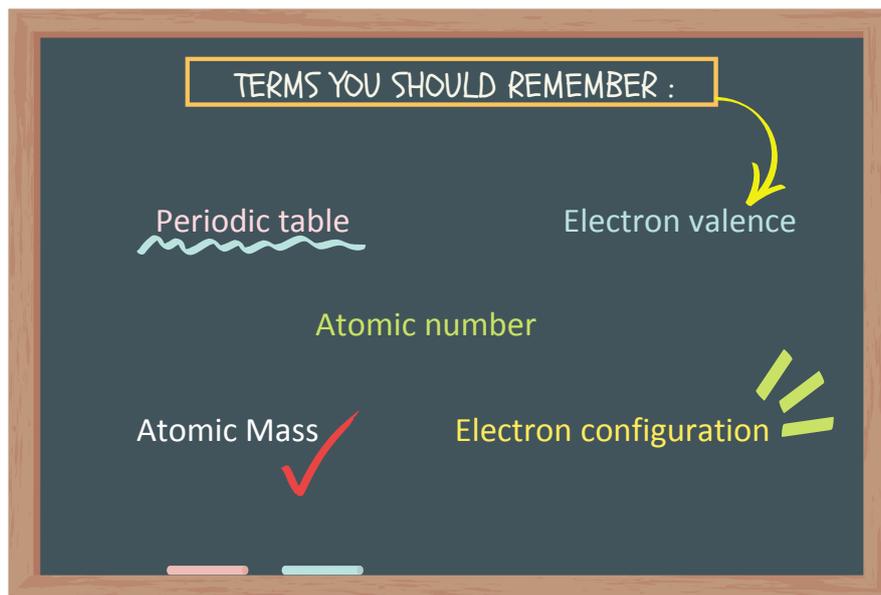
Characteristics of EPT



The Importance Of Element Periodic Table

To recap, the periodic table is important because of the following:

- It is **organised** to provide a lot of information about elements and how they relate to one another in one easy-to-use reference.
- The table can be used to **expect / predict** a new element which still in research as well as its characteristics (mechanical properties, electrical and thermal conductivity, etc.)
- To **analyze and understand** the reaction between elements (reactivity, corrode, etc.).



<https://www.youtube.com/watch?v=P6DMEgE8CK8>



Checkpoint 2

- The diagram below shows an atom in an element periodic table. By referring to the diagram below,

Aluminium
13
Al
26.982

- Explain the meaning of the numbers 13, 26.982, and the letters Al. *(Sec.2.2/pg.38)*
 - Write the electron configuration for the atom. *(Sec.2.2/pg.33)*
 - State the group and period for Al. *(Sec.2.2/pg.34)*
- How many electrons and protons are there in the element Natrium? *(Sec.2.2/pg.37)*
 - Refer to Element Periodic Table, list FIVE (5) elements that are metals and FIVE (5) that are non-metals.

2.3 ATOMIC BONDING

- Atomic bonding can be categorized as primary and secondary bonds as shown in Figure 2.8.
- Atomic bonding is the interatomic forces that bind the atoms together.
- Characterize by strong atom-to-atom interactions involving the exchange of valence electrons

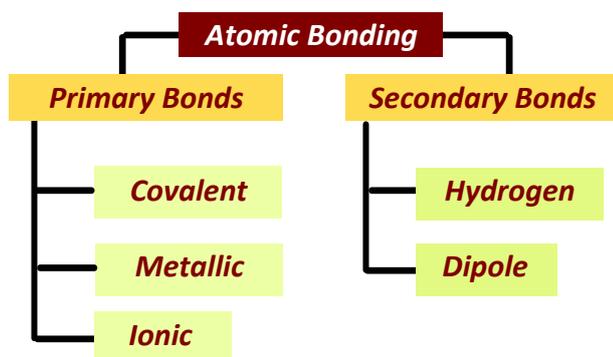


Figure 2.8 : Types of Atomic Bonding

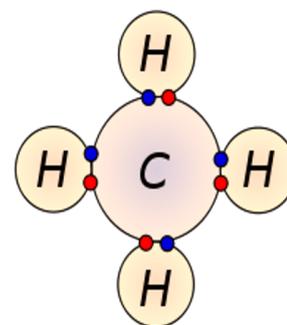
Secondary Bonds, a.k.a van der Waals, are weak in comparison to the primary.

Secondary bonding exists between virtually all atoms or molecules

Primary Bond

COVALENT

- Bonding is formed when electrons are **shared between atoms**.
- In Figure 2.9, Hydrogens and Carbon share electrons so that both of them can have a stable octet (8 electron valence).
- More **stable and stronger** than ionic bonds.
- Bonds are between :
 - Non-metals and non-metals**
example : H^2 , Cl^2 , F^2
 - Hydrogen and non- metals**
example : CH^4 , H_2O , HNQ_3
- Characteristics : Varies
 - Diamond (strong, hard, high melting point)
 - Bismuth (very weak, low melting point)



● Electron from hydrogen
● Electron from carbon

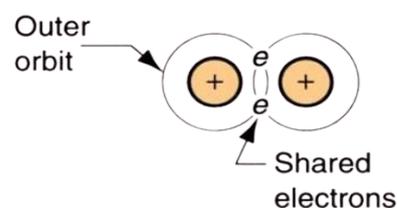


Figure 2.9 : Covalent bonding

IONIC BOND

- The force of attraction between the **opposite charges of an ion** is known as ionic bonding.
- It occurs between nonmetallic and metallic elements by **transferring the electrons** from an atom that has a positive charge to the atom that has a negative charge as in **Figure 2.10**.
- In an ionic bond, one of the elements **loses electrons**. Electrons **must be gained** by another element.
- To make the outer energy levels more stable, certain atoms lose electrons.
- Its **melting and boiling points** are **markedly higher** than those of covalent compounds.
- Materials bonded this way are usually **brittle with poor electrical conductivity**.
- **Figure 2.11** shows the example for Sodium Chloride (NaCl) where Na donates/ transfers its one electron valence to Cl so they both could have a stable octet.

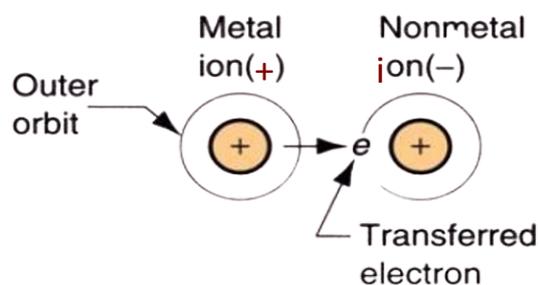


Figure 2.10 : Transferring electrons between nonmetallic and metallic elements

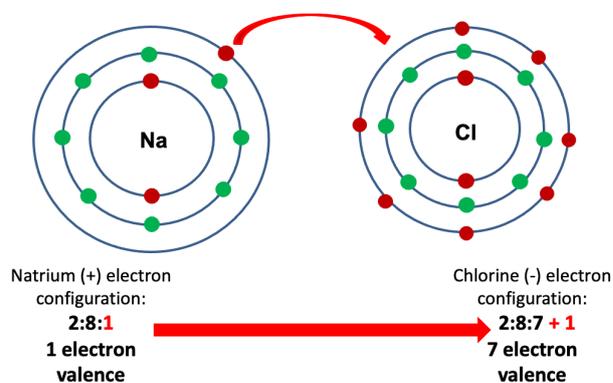


Figure 2.11 : Ionic Bonding NaCl

METALLIC BONDING

- Metallic bonding is the electromagnetic interaction between delocalized electrons, known as conduction electrons, that have accumulated in an "electron sea," and metallic nuclei within the metal.
- Delocalized means "not fixed in one spot" or "free to move".
- As seen in Figure 2.12, all atoms share outer shell electrons, forming an electron cloud.
- **Good electrical and thermal conductors** are due to their free valence electrons.
- Example: Fe (iron), W (tungsten)

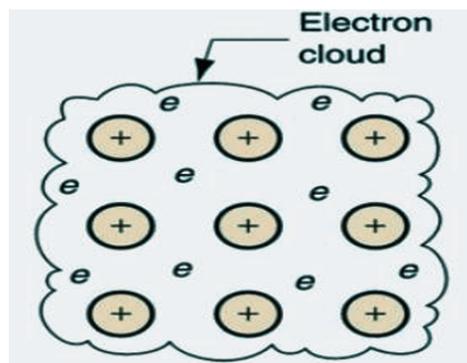
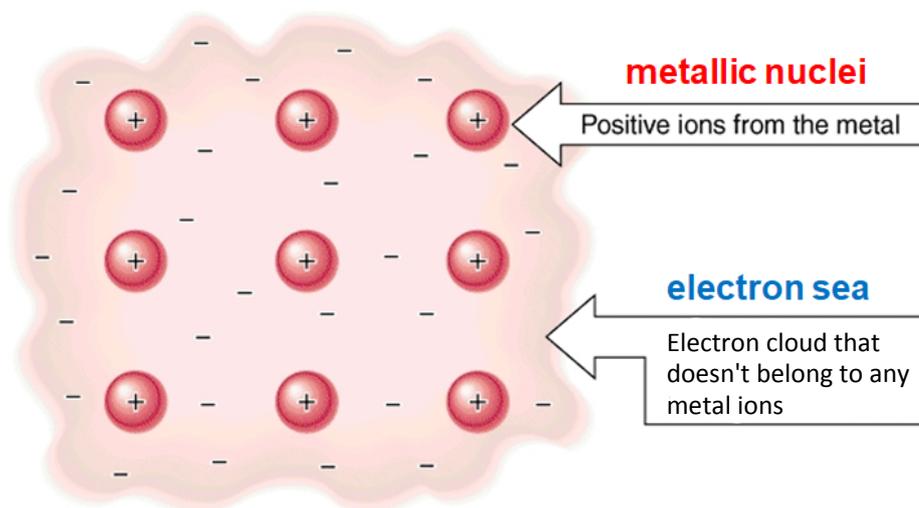


Figure 2.12 : Metallic Bonding by Metal Element



<https://www.youtube.com/watch?v=g-tE6MN-wrE>

Secondary Bond

- Secondary bonds are known as **Van Der Waals** or physical bonds.
- Generally associated with the **attraction between molecules**.
- No transfer or sharing of electrons.
- Bonds are **weaker than primary bonds**.

DIPOLE BOND

- When a partial charge forms within a molecule due to an unequal distribution of electrons, **dipole-dipole interactions** occur.
- Polar molecules align so that the positive ends of one molecule interact with the negative ends of another, as seen in **Figure 2.13**.
- Dipole-dipole interactions, unlike covalent bonds between atoms within a molecule (intramolecular bonding), generate attraction between molecules of a material (**intermolecular attractions**).

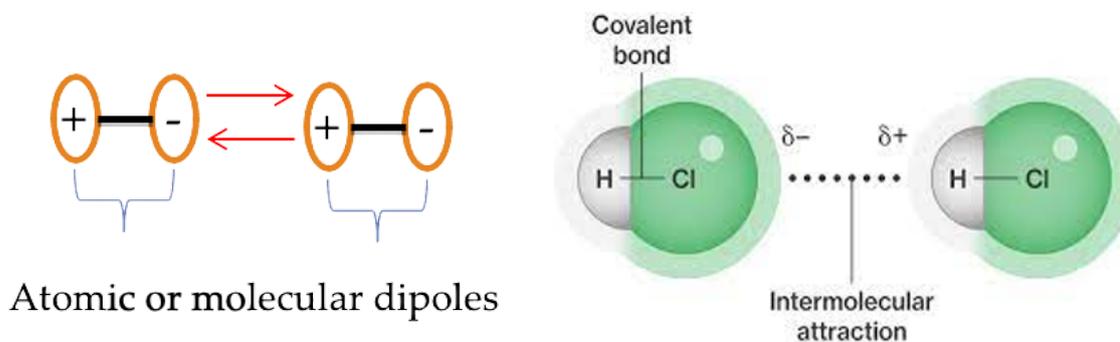
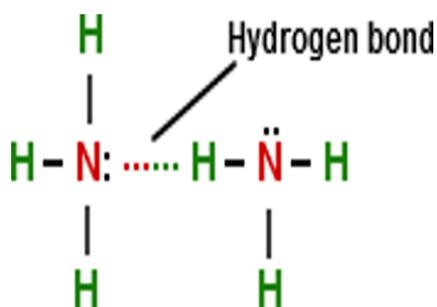


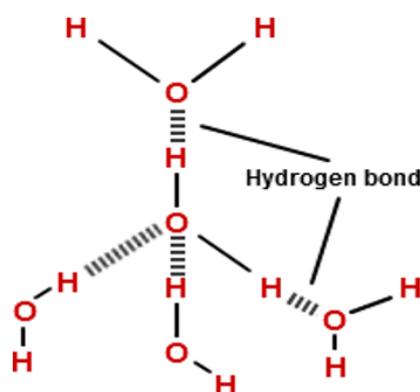
Figure 2.13 : Dipole Bonding

HYDROGEN BOND

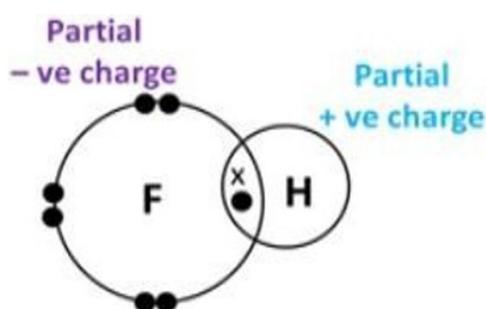
- Some molecules with **hydrogen as one of their constituents** have been discovered to have hydrogen bonding.
- For the hydrogen bond, highly polar molecules form when hydrogen covalently bonds to a **non-metallic element** such as oxygen (O), nitrogen (N), or fluorine (F) as shown in **Figure 2.14**.
- The weak bond between water molecules makes the vaporising of water very easy.



Ammonia, NH_3



Water, H_2O

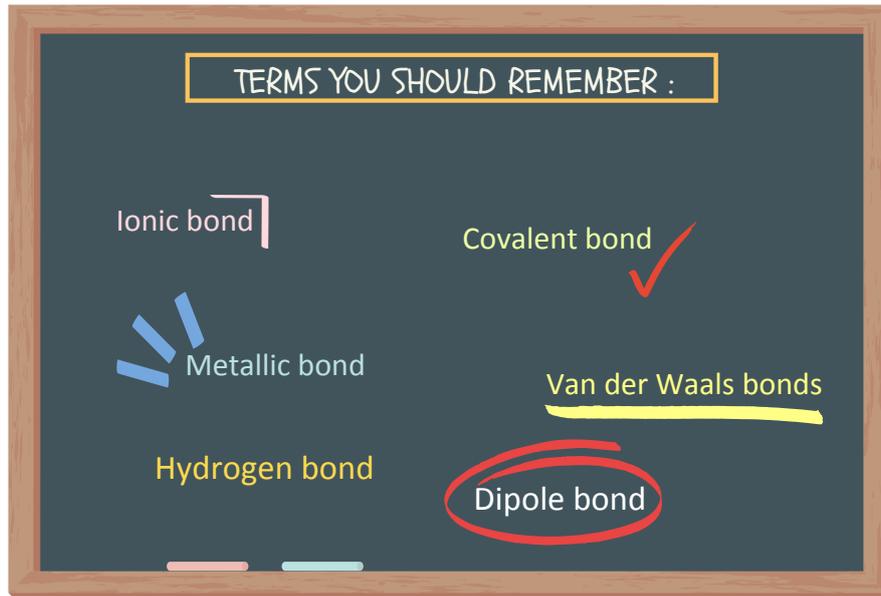


Hydrogen Fluoride, HF

Figure 2.14 : Hydrogen bond for Hydrogen Fluoride, Ammonia and water.



<https://www.youtube.com/watch?v=m-v5G8C70pc>



Checkpoint 3

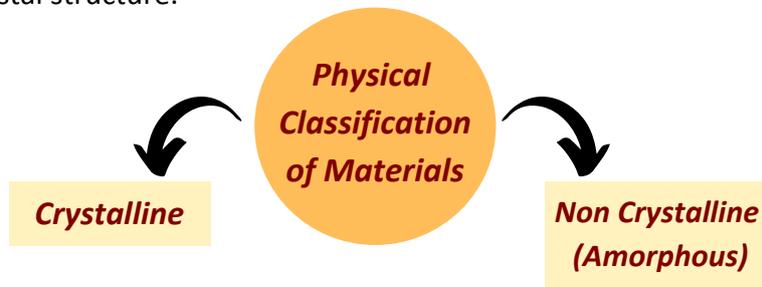
1. List the types of primary bonds. *(Sec.2.3/pg.41)*
2. What type of chemical bonds shares electrons between atoms? *(Sec.2.3/pg.41)*
3. What type of chemical bond is formed when one atom donates an electron to another atom? *(Sec.2.3/pg.42)*
4. State the bonding that occurs on the following compounds. *(Sec.2.3/pg.41-42)*
 - i. NaCl (Na=11, Cl=17)
 - ii. H₂O (H=1, O=8)
 - iii. MgO (Mg = 12, O = 8)
 - iv. CO₂ (C = 6, O = 8)

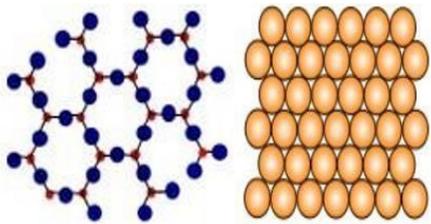
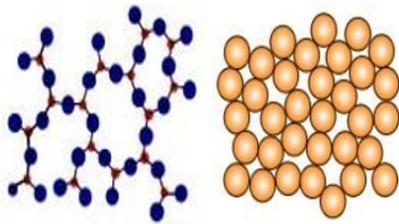


METALLIC CRYSTAL STRUCTURES

Fundamental Concept

- The properties of some materials are directly related to their crystal structures.
- A crystal structure is made up of unit cells, which are groups of atoms arranged in a specific pattern and repeated in three dimensions on a lattice.
- **Unit cells** are the smallest repeating unit of the crystal lattice ([Figure 2.13](#))
- Example: pure magnesium is much more brittle than pure gold because it possesses a different crystal structure.



ATOMIC ARRANGEMENT	
CRYSTALLINE	NON CRYSTALLINE (AMORPHOUS)
Have a regular arrangement of particles.	Have a random particles of arrangement.
Highly ordered 3-D arrangements / pack in periodic.	No periodic materials / complex structures.
Have a high melting point and a high boiling point.	Melts at a variety of temperatures.
Example : diamond, salt, sugar, NaCl.	Example : glass, plastic, rubber.
 <p>Quartz</p>	 <p>Glass</p>

Unit Cell

- The simplest repeating unit of a crystalline solid, whether metal or not, is referred to as its unit cell, and this is the best way to characterise its structure.
- As shown in [Figure 2.13](#), the unit cell consists of lattice points that indicate the positions of atoms or ions.
- In the same figure, the entire structure is made up of this unit cell repeating in three dimensions.

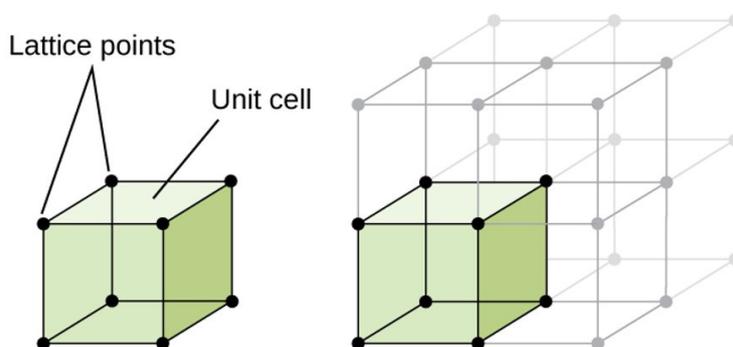


Figure 2.13 : The placements of lattice points repeat in all directions can be seen in a unit cell.

Source : [BC Campus / chemistry](#)

Metallic Crystal Structure

- The properties of these type of materials depend on the crystal structure. [Figure 2.14](#) depicts the most frequent crystal forms seen in metal.

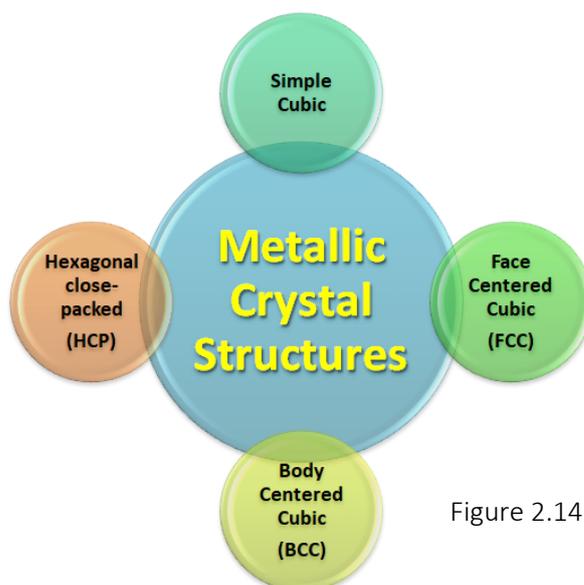
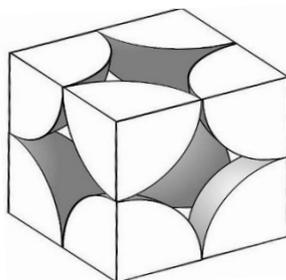
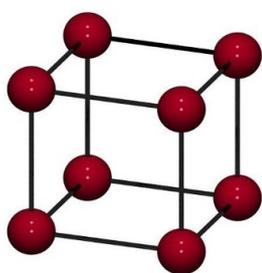


Figure 2.14 : Common crystal structure in metal

SIMPLE CUBIC

- As shown in Figure 2.15, it is a **cube** with an atom **at each corner** of the unit cell (all sides have the same length and all faces are perpendicular to each other).
- Contains only **one atom per unit cell**
- Example: Sodium chloride (salt), Phosphorus

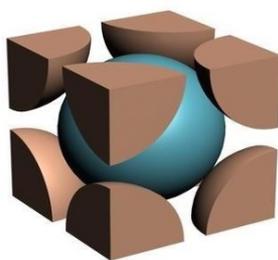
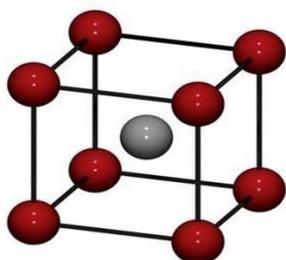


No of atoms:
 8 corner atom \times $1/8$
Total atom = 1 atom

Figure 2.15 : Simple Cubic

BODY CENTERED CUBIC (BCC)

- As seen in Figure 2.16, it has atoms at each of the eight corners of a cube (similar to the cubic unit cell) plus **one atom in the cube's centre**.
- The net total of **two atoms**.
- Example: Molybdenum, Fe.
- Properties: less ductile and stronger compared to FCC metals.

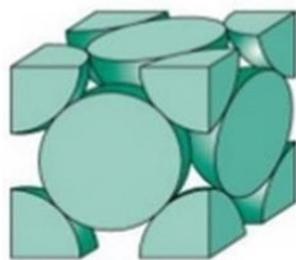
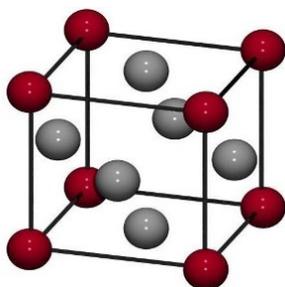


No of atoms:
 8 corner atom \times $1/8$ = 1 atom
 Center = 1 atom
Total atom = 2 atoms

Figure 2.16 : Body Centered Cubic (BCC)

FACE CENTERED CUBIC (FCC)

- As seen in **Figure 2.17**, atoms are positioned at each of the cubic's corners and centres.
- A total of **four atoms** make up the FCC unit cell.
- Example: Copper, aluminium, silver, and gold
- Properties: soft, ductile

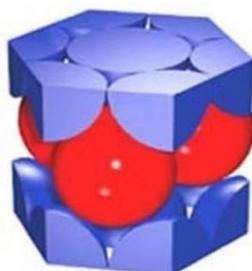
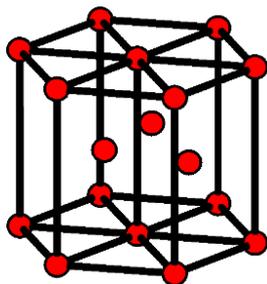


No of atoms:
 8 corner atom $\times 1/8 = 1$ atom
 6 face corner $\times 1/2 = 3$ atoms
Total atom = 4 atoms

Figure 2.17 : Face Centered Cubic (FCC)

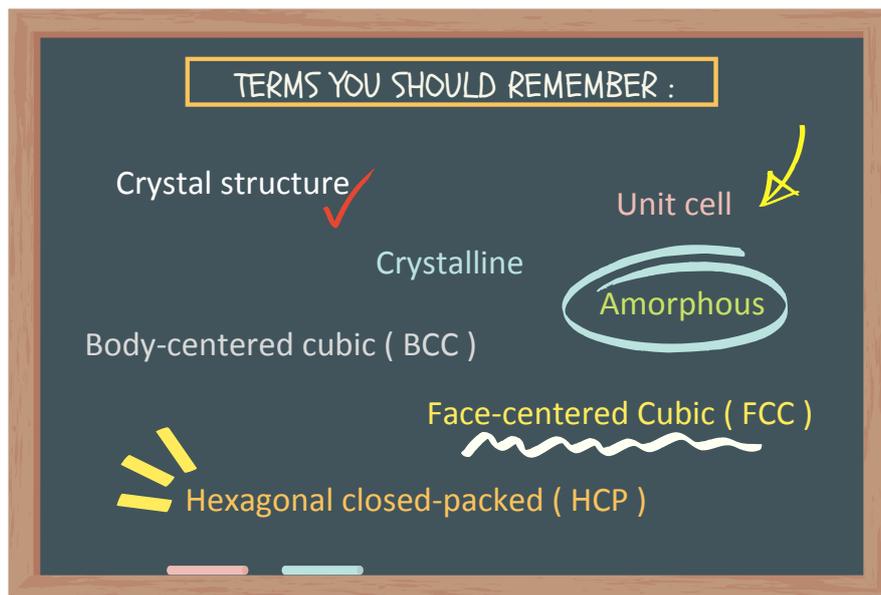
HEXAGONAL CLOSED PACKED (HCP)

- It is a unit cell with an atomic packing arrangement in which **12 atoms** surround a central identical atom.
- Another plane consists of **3 additional atoms** which are situated in the middle and **2** atoms in the **centre**.
- The total net is **6 atoms**.
- Example: Cadmium, Titanium, and Zinc.
- Properties: brittle



No. of atoms:
 12 corner atom $\times 1/6 = 2$ atoms
 2 centre atom $\times 1/2 = 1$ atom
 3 centre atom = 3 atoms
Total atom = 6 atoms

Figure 2.1 : Face Centered Cubic (FCC)



Showtime !



<https://www.youtube.com/watch?v=Rm-i1c7zr6Q>



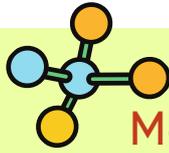
Checkpoint 4

1. The crystal lattice has a _____ arrangement. *(Sec.2.4/pg.47)*
2. Give the number of atom/s in simple cubic (SC). *(Sec.2.4/pg.49)*
3. Give the number of atom/s in BCC. *(Sec.2.4/pg.49)*
4. Give the number of atom/s in FCC. *(Sec.2.4/pg.50)*
5. What is meant by unit cell? *(Sec.2.4/pg.47)*

MATERIAL STRUCTURE AND INTERATOMIC BONDING

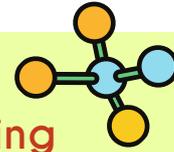


Let's summarize !



Chapter 2 :

Material and Structure Bonding



Definition

Atom: the basic unit of an element formed for all material whether for solid, gas, liquid.

Element: the combination of two or more of one liquid of one atom bending together.

Mixture: various types of atoms are combined together, but not chemically.

Compound: various kinds of atoms, are combined chemically with proportion.

Atomic Structure

Has a concentrated nucleus containing the protons and neutrons surrounded by a cloud representing where the electrons are likely to be found.

Protons in the nucleus
(+ ve charge)

Neutrons in the nucleus
(are natural, have no charge)

Electrons move in energy level outside of the nucleus
(- ve charge)

Types of Primary bonds :

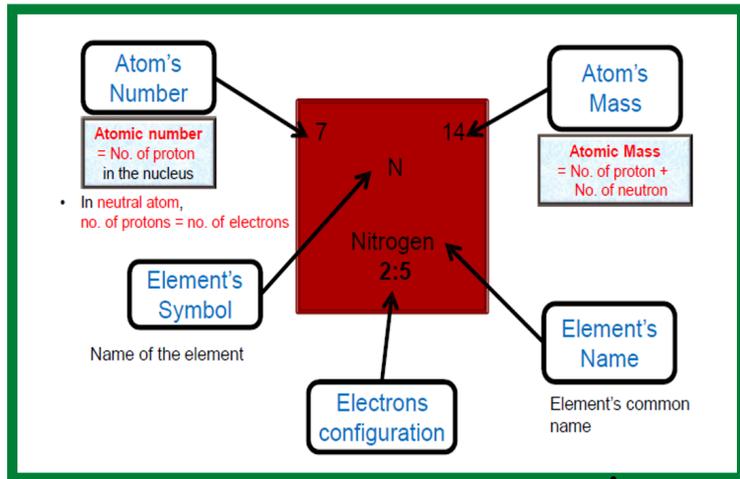
- covalent bonding
- ionic bonding
- metallic bonding

Types of Secondary bonds:

- Dipole
- Hydrogen

Type of crystal structure :

- Simple Cubic
- BCC
- FCC
- HCP



The Periodic Table

- The electron configuration of atoms. Chemical reactivity, outer shell or valence electrons
- Elements are arranged into rows are known as groups (+) or periods (-)

Importance of the Periodic Table

- Classification any element
- Information of an element (arrangement)
- Analyse and understand the reaction between element

**Exercise****Multiple Choice Questions**

1. The atomic number of an atom is the number of _____ in the atom's nucleus.
 - Electrons
 - Neutrons
 - Protons
 - Valence electrons
2. Electrons orbit around the nucleus of an atom in layers. What are these layers called?
 - Valences
 - Covalent
 - Bonds
 - Shells/orbit
3. Which of the following is true of ionic bonds?
 - Electrons are completely transferred during bonding
 - Electrons are shared during bonding
 - Electrons are not involved with bonding
 - All of the above
4. Which of the following describes covalent bonds?
 - Bonds form because of opposite charges
 - Bonds form to fill outer electron shells
 - Electrons are transferred between atoms
 - Covalent bonds are magical
5. Covalent bonds are formed between two metallic elements.
 - TRUE
 - FALSE

**Exercise****Multiple Choice Questions**

6. Amorphous solids have _____ structure.
- Regular
 - Linear
 - Irregular
 - Dendritic
7. What is a crystal?
- A pure material that can't be changed.
 - Material with a regular, repeating arrangement of atoms.
 - A foggy like material.
 - All of the above
8. Which of the following is a secondary bond?
- Metallic bond
 - Hydrogen bond
 - Covalent bond
 - Ionic bond
9. Elements in the same column of the periodic table have:
- Similar valence shell electron configuration
 - Same value of highest principal quantum number
 - Same number of nucleons
 - All of the mentioned
10. Which is true about an atom that has 6 of 8 electrons in its outer shell?
- It will want to give up 2 electrons
 - It will want to gain 2 electrons
 - It will want to give up 6 electrons
 - It is considered stable and will not react with other elements

**Exercise****Multiple Choice Questions**

11. What group of elements have a naturally full outer shell of electrons?
- Metals
 - Transition metals
 - Halogens
 - Noble gases
12. The horizontal rows of the periodic table are known as
- groups
 - series
 - periods
13. The transition elements are located
- on the left side of the periodic table.
 - on the right side of the periodic table.
 - in central section of the periodic table.
14. The atomic weight of phosphorus (P) is
- 16.00
 - 15
 - 30.97
15. The element with atomic number 12 is
- carbon
 - magnesium
 - manganese
16. The alkali metals are located of the periodic table.
- in the far right column
 - in the middle
 - in the far left column

**Exercise****Multiple Choice Questions**

17. Configuration electron for oxygen is _____
- 2:8
 - 2:8:2
 - 2:6
18. The number of atom/s for HCP is _____
- 1 atom
 - 4 atoms
 - 6 atoms
 - 8 atoms
19. Which of the following is metallic crystal structure for aluminum?
- BCC
 - FCC
 - HCP
20. A sample of an unknown element is found in a laboratory cabinet. Upon inspection, it is observed that the element has a dull surface, shatters into many pieces when hit with a hammer, and is a poor conductor of both heat and electricity. It is concluded that this element would be classified as a _____
- metal
 - metalloid
 - nonmetal

Answer

1. Protons
2. Shells/orbit
3. Electrons are completely transferred during bonding
4. Bonds form to fill outer electron shells
5. FALSE
6. Irregular
7. Material with a regular, repeating arrangement of atoms
8. Hydrogen bond
9. Similar valence shell electron configuration
10. It is considered stable and will not react with other elements
11. Metals
12. periods
13. in central section of the periodic table
14. 30.97
15. magnesium
16. in the far left column
17. 2:6
18. 6 atoms
19. FCC
20. nonmetal



Exercise

Past Year Questions

1. Define atom, mixture and compound. (Sec.2.1/pg.29)
2. Explain the characteristics of the Element Periodic Table. (Sec.2.2/pg.34)
3. Give an example of a primary bond and a secondary bond. (Sec.2.3/pg.41)
4. A molecule or compound is made when two or more atoms form a chemical bond, linking them together. Sketch and write about the Covalent Bonding and Ionic Bonding. (Sec.2.4/pg.41-42)
5. Sketch and state the numbers of atoms for the structure below:
 - i. Face Centre Cubic (FCC) (Sec.2.4/pg.50)
 - ii. Body Centre Cubic (BCC) (Sec.2.3/pg.49)
 - iii. Simple Cube (Sec.2.3/pg.49)
 - iv. Hexagonal close-packed (HCP) (Sec.2.3/pg.50)
6. The Figure S1 below represents an electron configuration for 2 types of element.

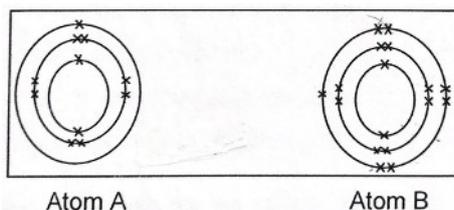


Figure S1

- i. Determine the group number in the element periodic table for atom A and atom B. (Sec.2.2/pg.37)
 - ii. Identify the most suitable chemical bonding between atom A and atom B. (Sec.2.3/pg.42)
 - iii. Based on your answer in (ii), explain how the chemical bonding occurred between atom A and atom B. (Sec.2.3/pg.42)
7. Describe the following types of metallic crystal structures:
 - i. Simple cubic (Sec.2.4/pg.49)
 - ii. Body centred cubic (Sec.2.4/pg.49)
 - iii. Face centred cubic (Sec.2.4/pg.50)
 - iv. Hexagonal close-packed (Sec.2.4/pg.50)



CHAPTER

3

MECHANICAL PROPERTIES OF METALS AND FAILURE

By the end of this lesson, you should be able to:

- Construct the concepts of stress-strain
- Describe the elastic and plastic deformation from the stress-strain curve
- Analyse the failure in engineering materials

61 INTRODUCTION

62 CONCEPTS OF STRESS-STRAIN

- a. Tension
- b. Compression
- c. Shear and torsional test

67 ELASTIC AND PLASTIC DEFORMATION

- a. Stress - strain behaviour for elastic deformation
- b. Tensile properties for plastic deformation
 - i. Yielding and yield strength
 - ii. Tensile strength
 - iii. Ductility
 - iv. Resilience
 - v. Toughness
 - vi. Brittleness

76 FAILURE IN ENGINEERING MATERIAL

- a. Fundamental of failure
 - i. Ductile fracture
 - ii. Brittle fracture
- b. Fatigue
- c. Creep

INTRODUCTION

Why is it important for you to understand materials properties?

Many materials are vulnerable to stresses or loads when in use. In such circumstances, knowing the material's properties and designing the member to avoid failure during the material's expected life and service environment is crucial.

Stiffness, strength, hardness, ductility, and toughness are important mechanical design properties. The kind of the imposed load and its duration, as well as the ambient circumstances are all factors to consider.

The applied loads might be tensile, compressive, or shear and their magnitudes could remain constant with time or change over time.

It could take a fraction of a second to apply, or it could take years. Service temperature may be an important factor.

In this lesson, we will introduce how the various mechanical properties and what these properties represent.



3.1 CONCEPTS OF STRESS-STRAIN

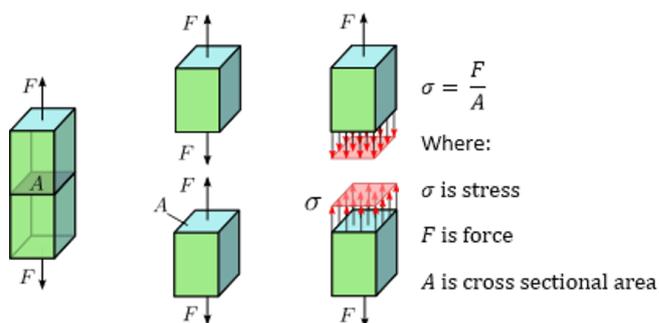


Figure 3.1

When describing the properties of materials, as shown in Figure 3.1, a variety of materials terminologies are utilised. The above terms will be defined in this lesson. Many of the terms listed above turn out to be connected to a material's stress-strain curve. What is the difference between stress and strain, and how are they related?

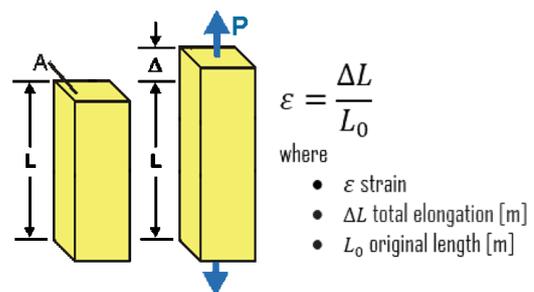
Stress

- Defined as the force applied to an object which causes a change in the object.
- Force per unit area of material



Strain

- Defined as the amount of deformation experienced by the body in the direction of applied force, divided by the body's original dimensions.



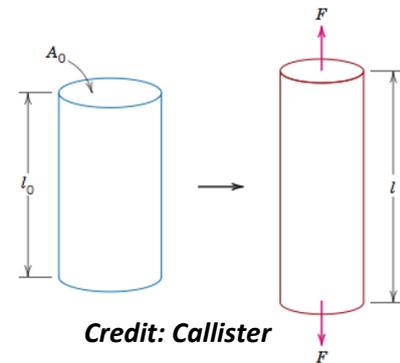
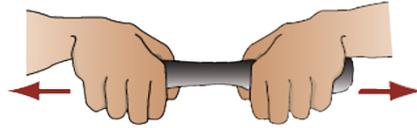
A load can be applied in three different ways:

- Tension
- Compression
- Shear and torsion

Types of Loading Stress

Tension

Is the stress that resists a force that tends to pull something apart.



Credit: Callister

The original length of the cylinder was l_0 , and the surface area was A_0 . The cylinder will lengthen when pulled with force F , and the resulting length will be l .

Definition of engineering stress
(for tension and compression)

The force is divided by the initial surface area to define stress, σ .

$$\sigma = F / A_0.$$

Tensile stress is the term for this pulling stress.

Definition of engineering strain
(for tension and compression)

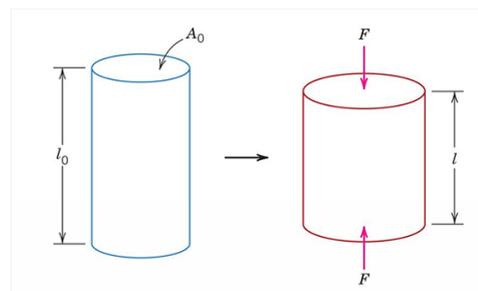
The change in length divided by the original length is defined as strain, ϵ .

$$\epsilon = \Delta l / l_0.$$

No unit for strain.

Compression

Is the stress that resists a crushing force.



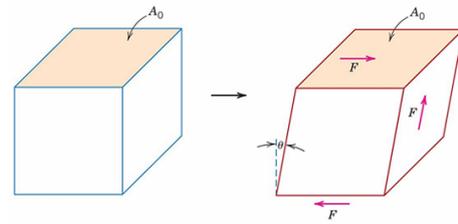
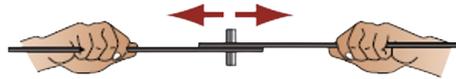
Credit: Callister

When it is pushed or compressed, the cylinder is introducing compressive stress.

When a material's behaviour under large and persistent strains is required, or when the material is brittle in tension, compressive tests are utilised.

Shear

Is the stress that opposes a force that would cause one layer of a material to slide over another.



Credit: WD. Callister

Stress related to shear is torsional stress. The object's height decreases while its cross-sectional area increases as it is compressed.

Definition of shear stress

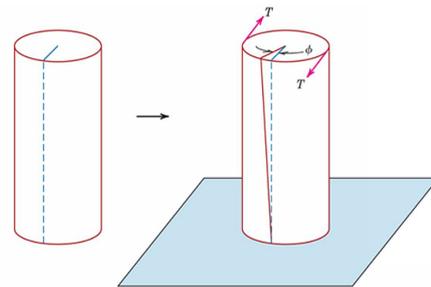
Pure shear stress, $\tau = \frac{F}{A_0}$

Pure shear strain, $\gamma = \tan \theta$

A shear stress is a function of the applied torque, whereas shear strain is related to the angle of twist.

Torsion

Is the stress that produces twisting. Torsion is a variation of pure shear.



Credit: WD. Callister

Examples of Materials Under Stress

Figure 3.2 depicts the various types of stress :

- **Tensile stress** is present in the cable highlighted in **box A**.
- **Torsion stress** is present on the driveshaft, which is highlighted in **box B**.
- **Compressional stress** is applied to the support pillar shown in **box C**.

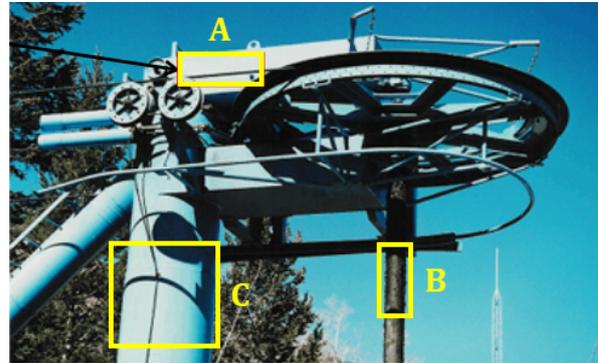


Figure 3.2 : Ski lift.
Credit: P.M. Anderson

A wrench is typically used to tighten or loosen a nut and bolt combination, as shown in **Figure 3.3**.

- The top of the wrench is shaped in such a way that it fits the nut firmly.
- When a rotational motion is applied to the wrench, it is also applied to the nut, allowing the user to loosen or tighten the combination - **torsion force**.



Figure 3.3 : Wrench.

Figure 3.4 shows :

- compressive stress is being applied to the rock that is supporting the boulder.
- while supporting the bridge's top structure, the bridge's metal struts are subjected to compression stress.

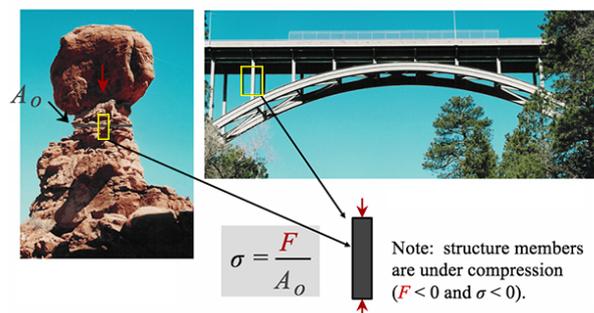
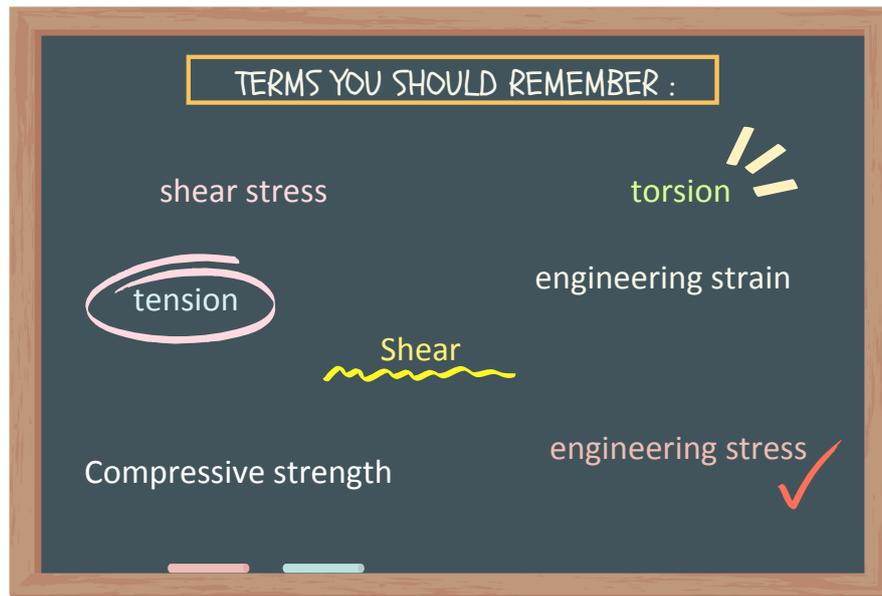
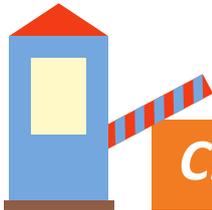


Figure 3.4 : Boulders and bridge.
Credit: P.M. Anderson



<https://www.youtube.com/watch?v=AnwrltEvqh4>



Checkpoint 1

1. Define engineering stress and engineering strain. *(Sec.3.1/pg.62)*
2. What are the different types of stress? *(Sec.3.1/pg.63,64)*
3. What is compressive stress? *(Sec.3.1/pg.63)*
4. What is shear stress? *(Sec.3.1/pg.64)*
5. Based on the picture below, state the type of stress used to do the work. *(Sec.3.1/pg.65)*



3.2 ELASTIC AND PLASTIC DEFORMATION

Stress – Strain Test (Tensile Test)

- The stress-strain diagram depicts the **material's strength and elasticity graphically**. Furthermore, the stress-strain diagram can be used to investigate **material behaviour**, which makes it easy with the application of these materials.
- Mechanical properties are those characteristics of the material that describe its behaviour under the action of external forces
- The Stress-Strain diagram is determined by the tensile test. Tensile tests are conducted in tensile test machines, providing controlled uniformly increasing tension force, applied to the specimen.
- **Figure 3.5** depicts a typical stress-strain testing apparatus, as well as a diagram of the apparatus and the typical geometry of a tensile test specimen.
- The sample is slowly pulled during a tensile test, and the length change and applied force are both recorded. A stress-strain diagram can be created using the original length and surface area.

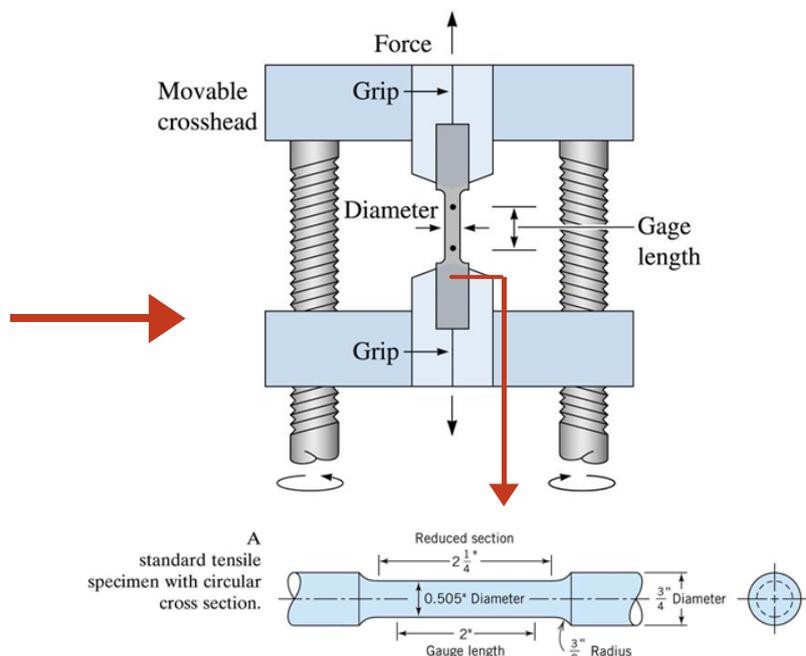


Figure 3.5 : The apparatus used to conduct tensile stress-strain test.

Credit: Callister & Rethwisch 5e.

Stress – Strain Curve

- A stress-strain curve is a graphical description of a **material's behaviour** when it is subjected to a load or force. As seen in **Figure 3.6**, the two characteristics plotted are stress on the y-axis and strain on the x-axis.
- The ratio of a load or force to the cross-sectional area of the material to which it is applied is known as stress. The standard units of measure for stress are pounds per square inch or Newtons per square meter squared (N/m^2).

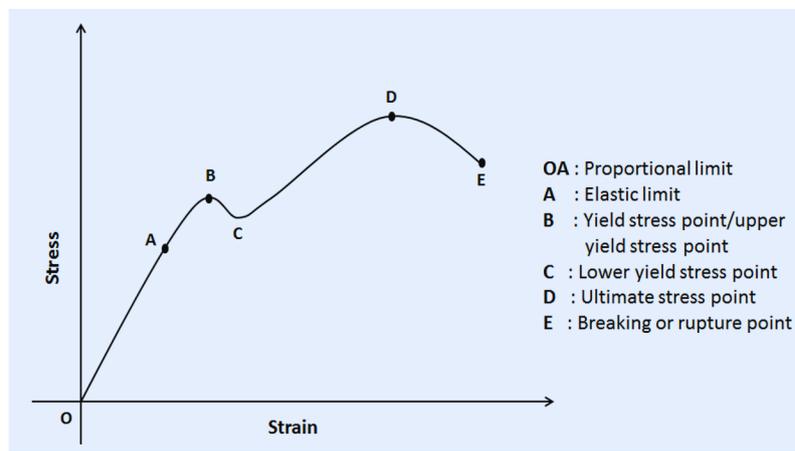
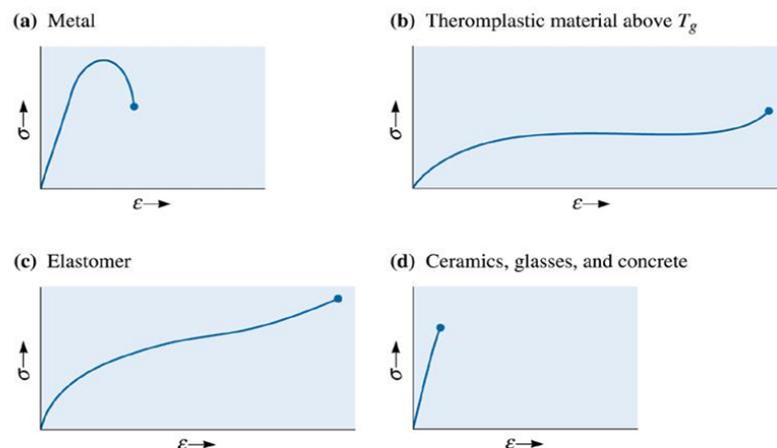


Figure 3.6 : Tensile stress-strain curves

- **Brittle materials and ductile materials** are the two basic categories of materials.
- When a large enough force is applied to brittle materials like glass, they will break or fracture without bending (**Figure 3.7 (d)**).
- When a force is applied to ductile materials like steel or aluminium, they bend. The material will permanently distort and not return to its original shape if the force is significant enough (**Figure 3.7 (a)**).

Figure 3.7 : Tensile stress-strain curves for different materials.



Stress – Strain Behavior

Elastic Deformation

Definition Elastic deformation is a **non-permanent deformation** in which the material returns to its original state after the applied tension is released.

Deformation in which stress and strain are proportional.

The stress-strain curve for a ductile material is shown in **Figure 3.8**. Consider the metal copper. The elastic region shows the extent to which the elastic deformation takes place.

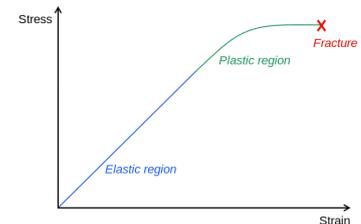


Figure 3.8 : A Stress Strain Curve for a Ductile Material

Hooke's Law This can be written as $\sigma = E\epsilon$, and more generally is known as a form of **Hooke's law**. Where ;

E is the proportionality constant and is called the modulus of elasticity or Young's modulus.

The modulus of elasticity is shown in **Figure 3.9** as the slope of the curve. The higher the modulus of elasticity value, the stiffer the material is, and the more resistant it is to bend.

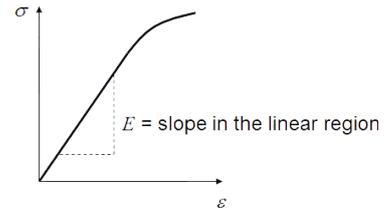


Figure 3.9 : Elastic region

Elasticity Elasticity refers to an object's or material's ability to return to its original shape after being stretched or crushed.

The materials that show a high degree of elasticity are known as elastics.

Elastic means reversible As an example (**Figure 3.10**), elastomers are polymer materials that show a high degree of elasticity.



Figure 3.10 : Elastic material

Stress – Strain Behavior

Plastic Deformation

Definition Plastic deformation is the **permanent deformation** or change in the shape of a solid body without fracture caused by a sustained force.

Plasticity Plasticity is permanent deformations in which are materials do not return to their original shape when applied force is released.

Plasticity is the quality of being easily shaped or moulded permanently

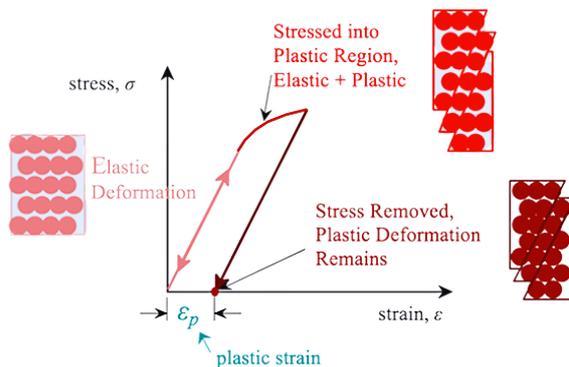


Figure 3.11 : Stress-strain curve.

Credit: Callister & Rethwisch 5e.

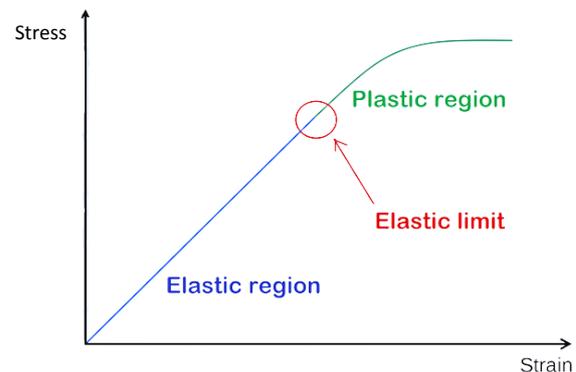


Figure 3.12 : The Elastic Limit shown in a Stress-Strain Curve

Plastic deformation is caused by the breaking of a small number of chemical bonds between the atoms that make up the substance.

During plastic deformation as in **Figure 3.11**, atoms may slip past on each other. This causes **dislocations** of atoms; thus, the material stays still after removing the applied stress.

Elastic Limit

The elastic limit is the beginning point of plastic deformation for ductile materials, as shown in **Figure 3.12**. The elastic limit of a solid refers to the maximum extent to which it may be stretched without permanently changing its size or shape.

If the stress is applied beyond the elastic limit, then the material will undergo plastic deformation.

Elastic Deformation



Plastic Deformation

<p>Elastic deformation is a non-permanent deformation in which the material returns to its original state after the applied tension is released.</p>	<p>Definition</p>	<p>The permanent deformation or change in the shape of a solid body without fracture under the action of a sustained force</p>
<p>Stretching and bending</p>	<p>Causes the chemical bonds of the substance to undergo</p>	<p>Breakage</p>
	<p>Reversible</p>	
	<p>Permanent</p>	
	<p>Atoms collide and pass through each other.</p>	

As a conclusion

Deformation of a substance can occur due to the application of stress. This deformation can be elastic or plastic, depending on the type of substance and the amount of force applied. The main difference between elastic and plastic deformation is that elastic deformation is reversible, whereas plastic deformation is not.

Tensile Properties

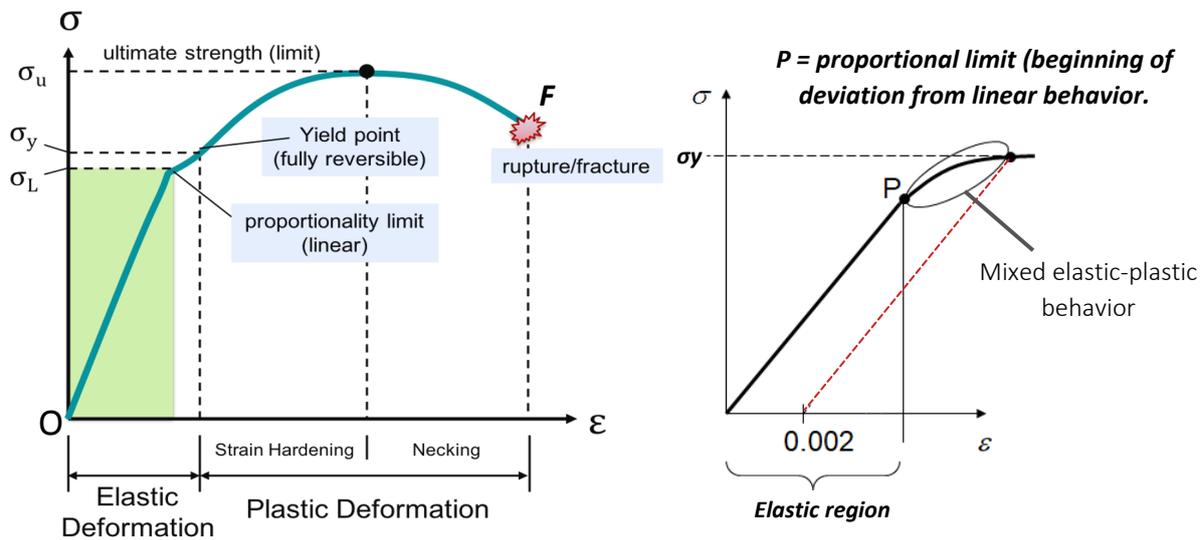


Figure 3.13 : (a) Tensile properties for plastic deformation (b) Stress-strain curve - 0.2% offset yield strength

Yielding

- Plastic deformation begins.

Yield point

- The transition point between elastic and plastic deformation (Figure 3.13 (a)).
- When the yield point is reached, some part of the deformation becomes permanent and irreversible.

Proportional limit

- From the origin O to the point called proportional limit, the stress-strain curve is a straight line (Figure 3.13 (a)).

Yield Strength

- The stress corresponds to the yield point at which the material **begins to deform plastically**.
- The strength is required to produce a very slight yet specified amount of plastic deformation.
- Strain offset method as in Figure 3.12 (b) :

What is the specified amount of strain?

- Start at 0.002 (0.2%) strain (for most metals).
- Draw a line parallel to the linear region.
- σ_y = where the dotted line crosses the stress-strain curve.
- For most engineering materials, strength should be specified by yield strength.

Tensile Properties

Tensile Strength

- In **Figure 3.13(a)** the curve proceeds to a maximum at which point the curves downward toward the fracture point. The maximum corresponds to the tensile strength σ_u .

Ultimate Tensile Strength (UTS)

- The ability of plastic material to withstand the maximum amount of tensile stress without failing when being pushed or stretched.
- At this point, a small constriction or neck begins.

Fracture point

- In **Figure 3.13(a)**, the point at which the material ultimately breaks, indicated by F.

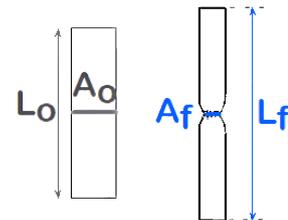
Ductility

- For metals, ductility is the ability of a metal to **receive permanent deformation** without fracturing.

How to Measure Ductility?

$$\% \text{ elongation} = \frac{l_f - l_o}{l_o} \times 100\%$$

$$\% \text{ reduction in area} = \frac{A_o - A_f}{A_o} \times 100\%$$



A_o and l_o are initial.
 A_f and l_f are at fracture.

Resilience

- A material's ability to absorb energy during elastic deformation.
- The **amount of energy a material can absorb** and still **return to its original state** is known as resilience.
- Modulus of resilience is calculated as the area under the stress strain curve
- That area has been highlighted in **Figure 3.14**, which is the area under the curve from the origin to the yield strength.

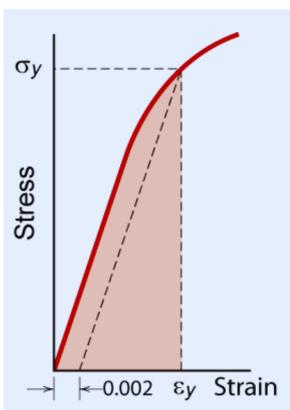


Figure 3.14 : Energy of elasticity shown under the curve of the stress-strain curve.

Credit: WD.Callister

Tensile Properties

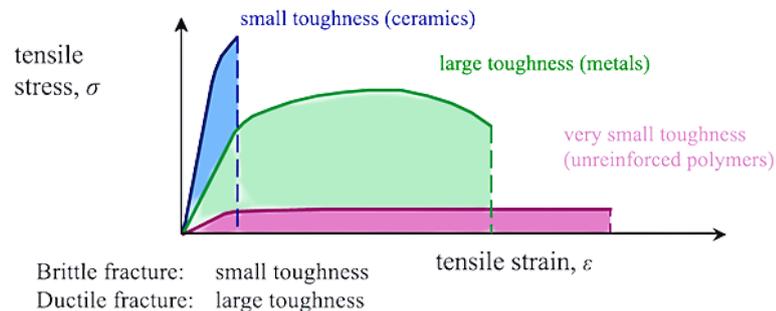
Toughness

- The ability of a material to **absorb energy** in plastic deformation or fracture point.

Fracture toughness

- It is a property indicative of a **material's resistance to fracture** when a crack is present.
- Toughness is calculated as an **area under the stress-strain curve** up to the fracture point.
- Figure 3.15** shows how a material with high tensile strength (ceramics) can have a low toughness. Furthermore, materials might be quite ductile (unreinforced polymers) and have a low toughness. As a result, having high tensile strength and ductility results in a high toughness (metals).

Figure 3.15 : Stress-strain curve for a material with high tensile strength (ceramics) and small toughness.

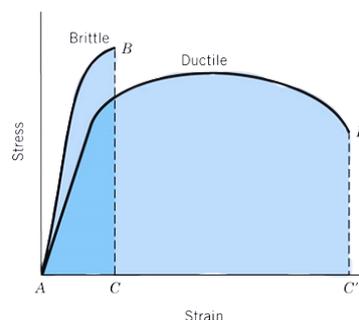


Brittleness

- This is a mechanical property of a material manifested by failure **without undergoing any deformation** on the application of stress.
- A material that exhibits a linear stress-strain relationship up until the point of failure.
- It is the tendency of metals or materials to fracture or shatter even when subjected to minor impact, force, or stress.
- Figure 3.16** shows little plastic deformation and low energy absorption before fracture at B point for brittle materials.
- Ceramics, glass, and cold metals are usually the materials that are brittle.

Example of brittle materials

Figure 3.16 : Tensile stress-strain behaviour for brittle and ductile materials





<https://www.youtube.com/watch?v=WSRqJdT2COE>



Checkpoint 2

1. What is meant by the mechanical properties of materials? *(Sec.3.1/pg.67)*
2. What is the use of the stress-strain diagram? *(Sec.3.1/pg.67)*
3. What is meant by ductility? *(Sec.3.1/pg.73)*
4. Sketch the stress-strain curve for a typical metal alloy to the point of fracture. *(Sec.3.1/pg.69)*
5. State Hooke's law and the conditions under which it is valid. *(Sec.3.1/pg.69)*
6. Define tensile strength and yield strength of the material. *(Sec.3.1/pg.72,73)*
7. Distinguish between elasticity and plasticity and give an example of each. *(Sec.3.1/pg.69,70)*
8. Differentiate between ductility and brittleness. *(Sec.3.1/pg.73,74)*
9. List the main parameters which may be determined in a tensile test. *(Sec.3.1/pg.67)*

3.3 FAILURE IN ENGINEERING MATERIAL

Fundamentals of Fracture

Definition

- Is the **separation of a body** into 2 or more parts as a result of static load at low temperature.
- Two types of fracture mode for engineering materials: ductile and brittle.
- Classification is based on the ability of the material to experience plastic deformation
- Fracture is initiated by a microscopic crack. The fracture process involves the crack formation and propagation



https://www.youtube.com/watch?v=07Gf_TdCSyM

Brittle Fracture

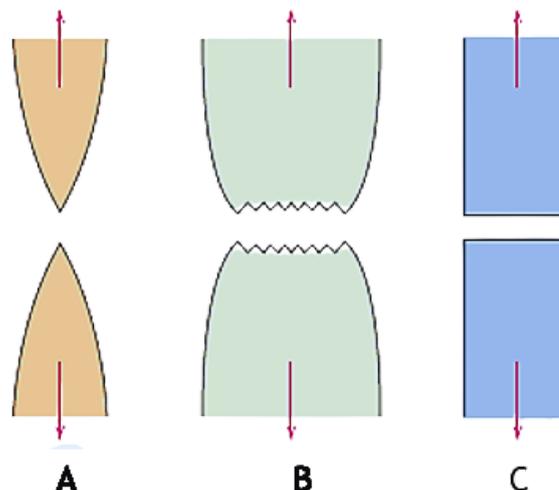
- Brittle Fracture involves fracture without any appreciable plastic deformation (i.e. energy absorption).

Ductile Fracture

- Ductile Fracture in the converse and involves large plastic deformation before separation.
- The most common type of tensile fracture for ductile metal is represented in **Figure 3.17(b)** - only a moderate amount of necking.

Figure 3.17 :

- (a) Very ductile: soft metals
- (b) Moderately ductile fracture typical for metals
- (c) Brittle fracture: ceramics, cold metals

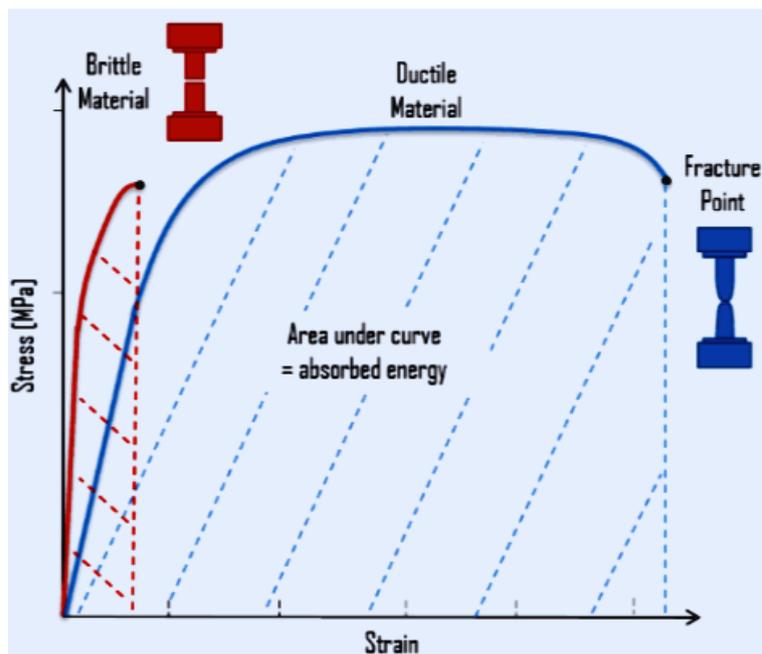


VS

Ductile Fracture

Brittle fracture

After plastic deformation and slow propagation of crack	Material fracture	With very little or no plastic deformation.
Rough, dull or fibrous in appearance	Surface obtained at the fracture	Smooth, shining and crystalline appearance
The material is in plastic condition	Occurs when	The material is in elastic condition
The formation of cup and cone	Characterized by	Separation of normal to tensile stress
Dislocations and other defects in metals	Tendency of fracture is increased by	Decreasing temperature, and increasing strain rate.
Undergo reduction	Cross - sectional area	No change



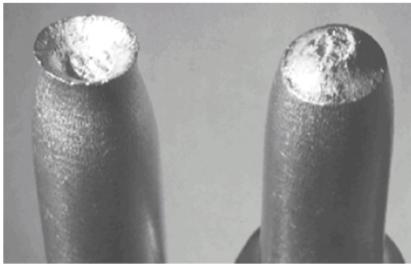
Stages in Brittle Fracture



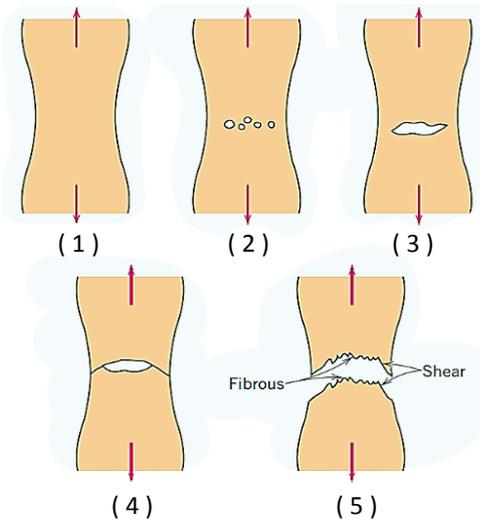
Flat Surface

- 1 Initiation of crack
- 2 Spontaneous and rapid crack propagation , with very little plastic deformation.
- 3 Brittle fracture happen quickly and catastrophically without any warning.

Stages in Ductile Fracture



Cup-and-cone surface



- 1 Initial necking
- 2 Formation of small cavity
- 3 Crack formation by coalescence of cavities
- 4 Crack Propagation
- 5 Fracture

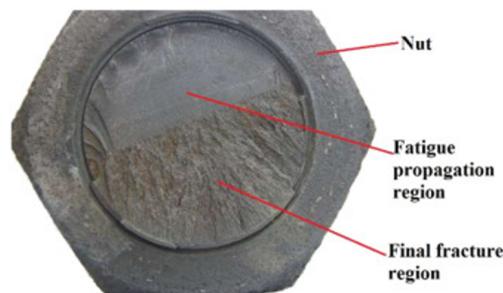
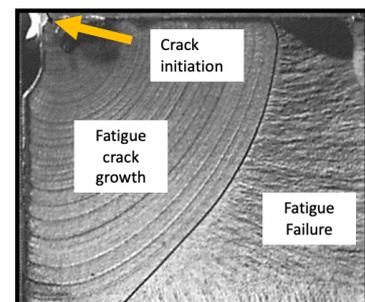
Fatigue

Definition

- Failure under **dynamic fluctuating** stress/cyclic loading.
- For a static load, failure occurs after a long period of repeated stress at a lower stress than tensile or yield strength.

Examples

- One of the major causes of structural failure in bridges, aeroplanes, machine components, rotating shafts and automobile parts, etc.
- Without any warning or signs of failure, brittle in nature. The single largest cause of failure in metals (80-90%).

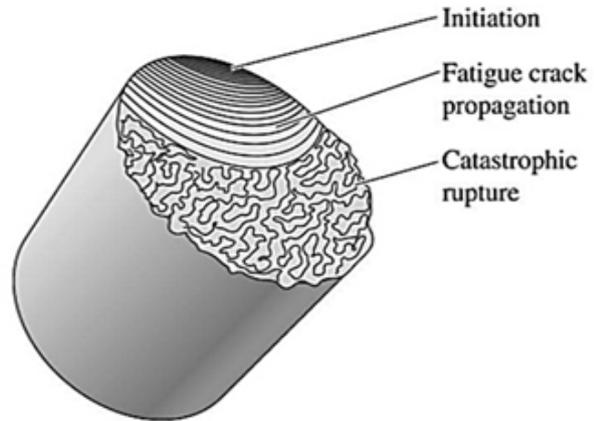


Fatigue Process

- The process of fatigue failure:
 - i. **crack initiation**: at high stress concentrated point.
 - ii. **crack propagation**: where the crack advances incrementally in each cycle
 - iii. **final failure**: which occurs very rapidly once the advancing crack has reached a critical size.

Fatigue Behavior

Figure 3.18 : Schematic of fatigue fracture surface showing the initiation region, the propagation crack and rupture.

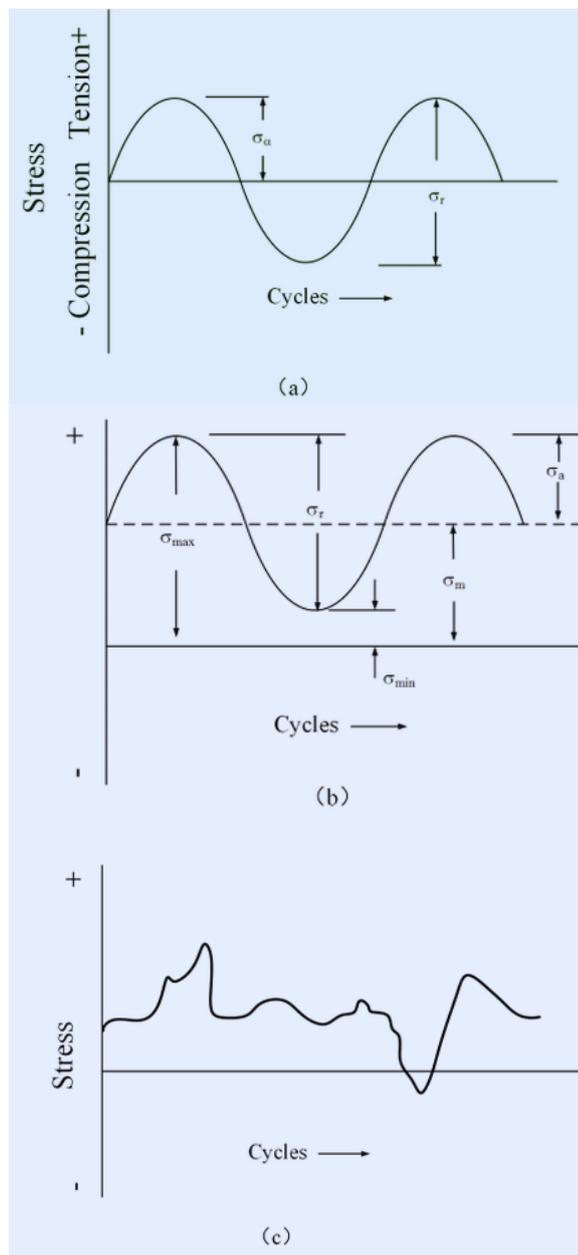


Cyclic Stresses.

Figure 3.19 depicts the variation of stress over time that accounts for fatigue failure.

Figure 3.19 : Examples of typical fatigue stress cycles.
 a) reversed stress;
 b) repeated stress;
 c) irregular or random stress cycle.

Credit : McGraw-Hill Education

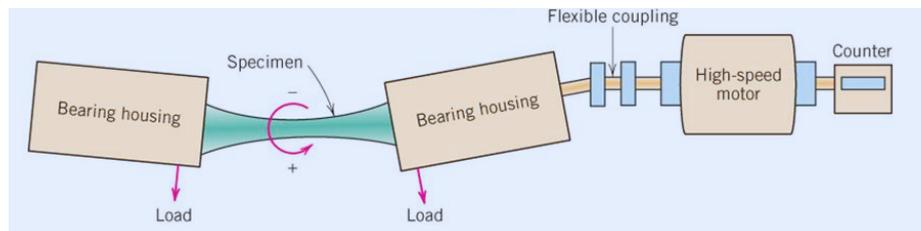


Fatigue Behavior

The S-N Curve

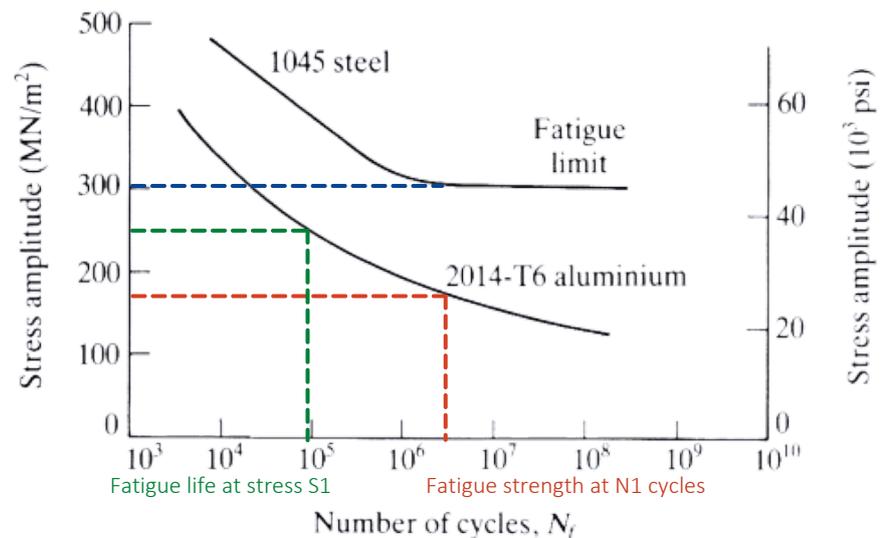
- The Stress Life Method is a **basic method that depicts fatigue failure** in high cycles, which implies the stress level is relatively low and the deformation is in the elastic range.
- The fatigue properties can be determined by the rotating bending test (**Figure 3.20**).

Figure 3.20 : Apparatus for making rotating bending test.
Credit : Pearson Education, Inc.



- S-N behaviour is observed for 1045 steel and 2014-T6 aluminium, which is represented in **Figure 3.21**. The smaller the number of cycles the material can withstand before failing, the higher the magnitude of stress.

Figure 3.21 : S-N curve for 1045 steel and 2014-T6 aluminium



Fatigue/Endurance limit

- The largest value of fluctuating stress will not cause failure for an infinite number of cycles.

Fatigue strength

- **The stress level** at which failure is likely to occur for some given number of cycles.

Fatigue life

- **The number of cycles** to cause failure at a specified stress level.



Factors affecting Fatigue

- Surface irregularities like scratches, machining marks.
- Presence of stress concentration points – notches, keyways, screw threads, etc.
- Rate of cycling.
- The environment in which the component is functioning.
- Temperature.
- Stress gradient.
- Size of the component.



Protection against fatigue

- By preventing or delaying the initiation of cracks at the surface.
- Methods :
- Surface treatments
 - a) Shot peening.
 - b) Surface rolling.
 - c) Carburising followed by hardening and nitriding.
 - d) Polishing the surface.
 - e) Preventing decarburisation during heat treatment.
 - Grain refinement.
 - Proper design.

Environmental Effect

Thermal Fatigue

- It is a type of fatigue failure mechanism caused by **cyclic stress (thermal expansion and contraction)** from repetitive fluctuations in the temperature (heating and cooling) of equipment.
- This type of fatigue is very important especially in power engineering, aeronautics and automotive engineering.
- The degree of damage is affected by the magnitude and frequency of the temperature swings.

Examples

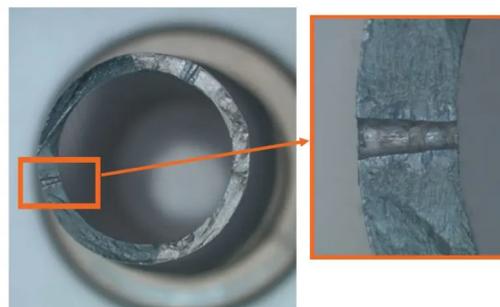
- **Figure 3.22** shows the fracture surface of the Thermal Mechanical Fatigue crack(s) starting from the holes in the cylindrical specimens under a mechanical strain range of 0.5%, and a temperature range of 800 to 2100 °F.
- Thermal fatigue can impact all materials of construction and several types of units and equipment. Here are a few examples:
 - Areas where condensate and steam systems contact each other.
 - Steam generating equipment.
 - High-temperature superheater and reheated tubes.

Prevention

- The best way to prevent failure due to thermal fatigue :
 - To minimize thermal stresses and cycling in the design and operating of equipment.
 - Reducing stress raisers, controlling temperature fluctuations (especially during shutdown and start-up), and reducing thermal gradients can help prevent thermal fatigue.
- Unfortunately, thermal fatigue cannot always be prevented. As a result, inspection and mitigation must be done.

Figure 3.22 : The Fracture surface of the Thermal Mechanical Fatigue crack(s).

Credits : aerodefensetech.com



Environmental Effect

Corrosion Fatigue

- It refers to the fatigue fracture of a metal aggravated by a corrosive environment or stress corrosion cracking (SCC) of a metal aggravated by cyclic stress (Figure 3.23).
- It is a special case of stress corrosion cracking in that it combines a corrosion process and applied stress on the materials.
- Fatigue corrosion is similar to stress corrosion cracking, except the stresses are cyclic, and it can happen in any environment.

Examples

- Fatigue corrosion can affect a wide range of metal products, from heavy machinery to metal panels used in construction and shipbuilding.

Factor affecting

- Fatigue corrosion, like stress corrosion cracking, is influenced by a number of variables, including:
 - Loading
 - Environmental
 - Metallurgical

Prevention

- Fatigue corrosion can be prevented by reducing:
 - Fatigue: minimising vibration and pressure fluctuation
 - Corrosion: using high-performance alloys resistant to corrosion fatigue
 - Corrosion: using coatings and inhibitors to delay the initiation of corrosion fatigue cracks

Figure 3.23 : Corrosion fatigue.
Credits:
lbrumf2/Shutterstock.
com



Creep

- Creep is caused by prolonged exposure to applied forces that are below the receiving metal's yield strength. Figure 3.24 shows the example of creep failure under the condition of static strain.

Importance of creep

- Creep becomes important in the following cases:
 - Soft metals employed at about room temperature such as lead pipes and white metal bearings.
 - Steam and chemical plants operating at 450 — 550°C.
 - Gas turbines work at high temperatures.
 - Rockets and missiles, supersonic jets.
 - Nuclear reactor field.

Definition

- It is time-dependent and permanent deformation under constant load or stress.

Creep Behavior

- Thermal creep is most common at high temperatures, although it can also happen at room temperatures in some materials (e.g. lead or glass).
- As a result, the material's length increases in a time-dependent manner, which could be hazardous while in use.



Figure 3.24: Creep rupture failure under condition of static strain

Creep Behavior

Creep Curve

- In the **Figure 3.25**, creep is time-dependent and it goes through numerous stages:
 - **Primary Creep** : Starts at a rapid rate and slows with time. The strain rate is relatively high at the initial stage, but it decreases with increasing time and strain due to the material's increased creep resistance or strain hardening.
 - **Secondary Creep** : Uniform rate (steady-state creep) The plot becomes nearly linear. As the secondary stage begins, the strain rate decreases to a minimum and becomes nearly constant. This is because the work hardening and annealing processes are balanced (thermal softening). The slope of the secondary component of the creep curve (E/t) is arguably the most relevant parameter from a creep test in materials engineering. For long-term applications, it is the engineering design parameter that is taken into account.
 - **Tertiary Creep** : Acceleration of the rate and possibly ultimate failure.

Because of necking events or internal cracks, cavities, or voids that reduce the effective area of the specimen, the strain rate increases exponentially with stress. All of these factors contribute to a reduction in effective cross-sectional area and an increase in strain rate. In the tertiary stage, the acceleration of creep deformation leads to failure.

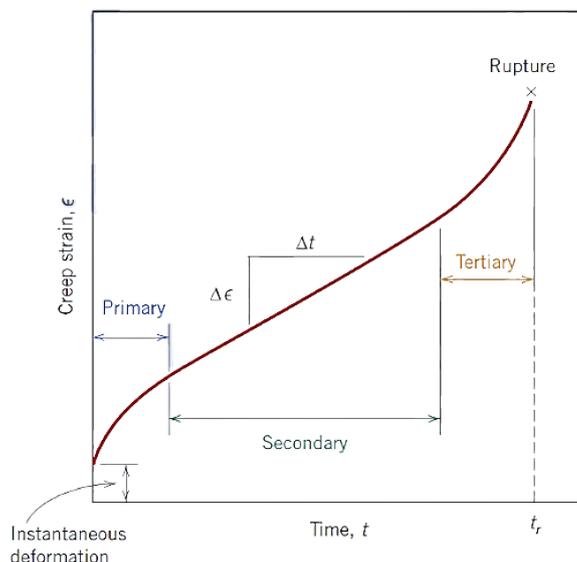
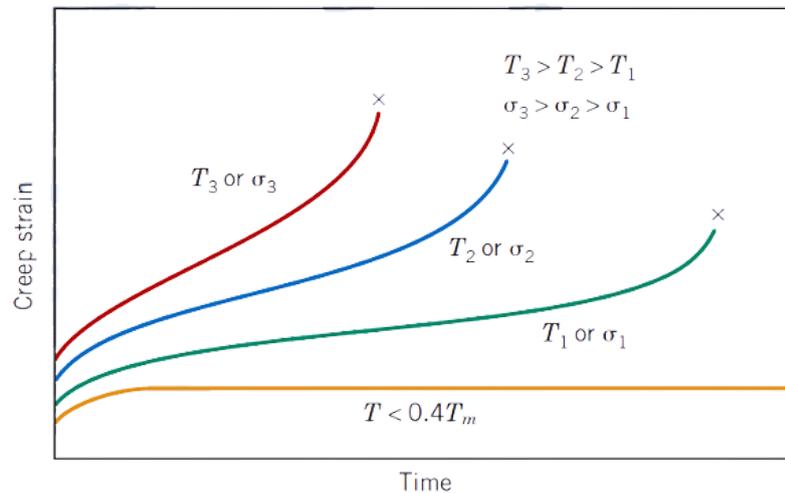


Figure 3.25 : Typical creep curve of strain versus time at constant stress

Creep Behavior

- In Figure 3.26, with either increasing stress or temperature :
 - Instantaneous strain increases.
 - Steady-state creep rate increased.
 - Rupture time is diminished.

Figure 3.26 : Influence of stress and temperature on creep behaviour.
Source : WD. Callister



Creep strength

- The continuous nominal stress that will generate a particular creep extension at a given time and temperature is known as creep strength.

Factor affecting

- Grain size, microstructure, and previous strain history, such as cold work, all have a significant impact on creep.

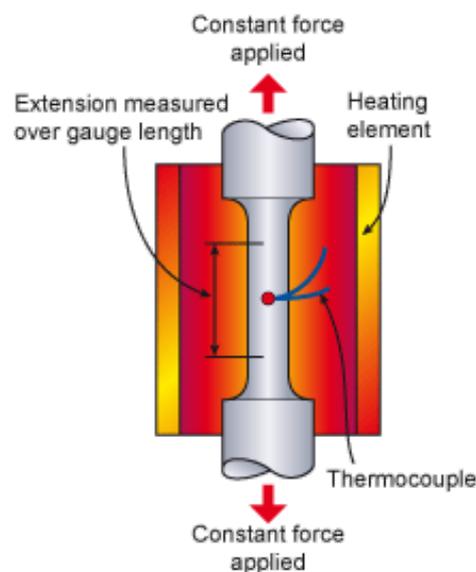
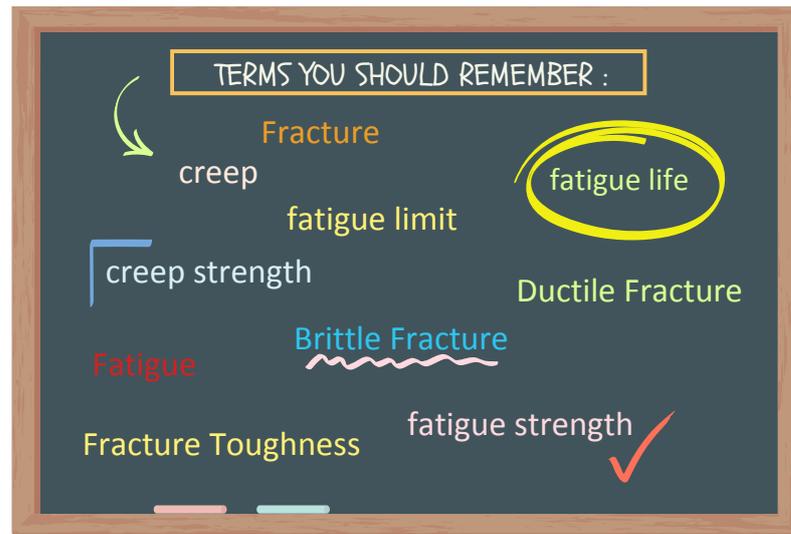


Figure 3.27 :
Schematic of a Creep Test.
Source : TWI-Global

- The creep test is conducted using a tensile specimen to which constant stress is applied, often by the simple method of suspending weights from it.
- Surrounding the specimen is a thermostatically controlled furnace, the temperature being controlled by a thermocouple attached to the gauge length of the specimen (Figure 3.27).



Checkpoint 3

1. Define fracture. *(Sec.3.1/pg.76)*
2. List the different types of fracture in a material. *(Sec.3.1/pg.76)*
3. Define fatigue and specify the conditions under which it occurs. *(Sec.3.1/pg.79)*
4. What are the factors affecting fatigue. *(Sec.3.1/pg.82)*
5. How can you prevent fatigue fracture? *(Sec.3.1/pg.82)*
6. Define creep and specify the conditions under which it occurs. *(Sec.3.1/pg.85)*
7. What is an S-N diagram? What is the significance of it? *(Sec.3.1/pg.81)*
8. Explain the following material behaviour with the aid of the appropriate diagram:
 - a) Creep *(Sec.3.1/pg.76)*
 - b) Fatigue *(Sec.3.1/pg.79)*
 - c) Fracture *(Sec.3.1/pg.85)*
9. Explain the term Endurance Limit. *(Sec.3.1/pg.81)*
10. Draw the creep curve and show the different stages of creep on the creep curve. *(Sec.3.1/pg.86)*
11. Describe the mechanism of crack propagation for both ductile and brittle fracture. *(Sec.3.1/pg.78)*
12. Explain the following terms.
 - a) Fatigue life *(Sec.3.1/pg.81)*
 - b) Fatigue strength *(Sec.3.1/pg.81)*
13. Draw a neat sketch of the S-N curve for mild steel. *(Sec.3.1/pg.81)*
14. Explain fatigue crack propagation. *(Sec.3.1/pg.79)*
15. Define creep strength. *(Sec.3.1/pg.87)*



Let's summarize !

Chapter 3 : Mechanical Properties of Metals and Failure

Mechanical Properties

- **Strength** : Resistance offered by a material when subjected to external loading
- **Toughness** : the ability of a material to absorb energy
- **Elasticity** : return to its original size and shape when the load is removed
- **Plasticity** : deform permanently under the application of a load
- **Ductility** : stretch under the application of tensile load
- **Hardness** : withstand indentation and surface abrasion by another hard object
- **Brittleness** : breaking without much permanent distortion

The S-N Curve

Stress Life Method, is the basic method presenting fatigue failure

Stages in Fracture

- **Brittle Fracture** : Initiation of crack - spontaneous and rapid crack propagation - Brittle fracture occurs suddenly.
- **Ductile Fracture** : Initial necking - Formation of small cavity - Crack formation by coalescence of cavities - Crack Propagation - Fracture

Material behaviour & Failure

Creep

- It is time-dependent and permanent deformation under constant load or stress.
- Constant stress and high temperature below the elastic limit

Three stages of creep

1st : The material elongates rapidly but at a decreasing rate

2nd : The rate of elongation is constant

3rd : The rate of elongation increases rapidly until the material fails

Fatigue

- The fatigue of a material is the maximum stress at which failure a certain number of cyclic load applications.
- Subjected to repeated alternating stresses.
- **Endurance limit** - The largest value of fluctuating stress which will not cause failure for the infinite number of cycles.
- **Fatigue strength** - Stress level at which failure is likely to occur for some given number of cycles.
- **Fatigue life** - Number of cycles to cause failure at a specified stress level

Fracture

A fracture is the separation of an object or material into two or more pieces under the action of stress

Types of Fracture

- **Brittle Fracture** : Brittle Fracture involves fracture without any appreciable plastic deformation.
- **Ductile Fracture** : Ductile Fracture in the converse and involves large plastic deformation before separation.

**Exercise****Multiple Choice Questions**

1. The ability of the material to withstand tensile force, without breaking, is known as
 - Yield strength
 - Tensile strength
 - Compressive strength
 - Creep strength
2. The ability of a material to undergo plastic deformation without fracture when subjected to a uniaxial tensile force is
 - Ductility
 - Malleability
 - Tensile Strength
 - Yield Strength
3. _____ occurs when metal is subjected to a constant tensile load at an elevated temperature?
 - Fatigue
 - Creep
 - Impact
 - Wear
4. The property of a material that enables it to absorb energy and deform plastically without fracture is _____
 - Stiffness
 - Toughness
 - Hardness
 - Resilience
5. Creep is a ____ dependent phenomenon.
 - Temperature
 - Time
 - Load
 - Stress cycle

**Exercise****Multiple Choice Questions**

6. The ability of a material to return to its original form after a load has been applied and removed
- Elasticity
 - Plasticity
 - Tensile strength
 - Toughness
7. The ability of a material to resist plastic deformation known as _____
- Tensile strength
 - Yield strength
 - Modulus of elasticity
 - Impact strength
8. The ability to withstand pushing or squeezing forces
- Compressive strength
 - Tensile strength
 - Stability
 - Brittleness
9. In which of the stages do we observe a constant deformation rate?
- Transient creep stage
 - Constant creep stage
 - Fracture stage
 - Steady stage creep stage
10. In _____ fracture, the crack grows at a slow pace and a lot of plastic deformation occurs.
- Ductile
 - Brittle
 - Fatigue
 - De-cohesive

**Exercise****Multiple Choice Questions**

11. What appearance does ductile fracture under microscope give?

- Irregular and rough
- Smooth
- Plate like
- Shiny

12. Cup and cone type fracture is a _____ fracture.

- Brittle
- Ductile
- Creep
- Fatigue

13. Ceramics generally undergo ductile fracture.

- True
- False

14. Which of the following is not a stage of ductile fracture?

- Nucleation of crack
- Growth of crack
- Coalescence of cracks
- Development of tensile stresses

15. Which material fails by a brittle fracture?

- White cast iron
- Steel
- Aluminium
- Copper

**Exercise****Multiple Choice Questions**

16. Which of the following materials don't give brittle fracture?
- White cast iron
 - Grey cast iron
 - Aluminium
 - Ceramics
17. What is the characteristic of brittle fracture?
- Prior warning
 - High speed
 - Necking
 - Ductile rupture
18. Brittle fracture is a break in a brittle piece of metal that failed because stress exceeds
- Cohesion
 - Adhesion
 - Yield stress
 - Tensile stress
19. Automobile crankshaft is likely to undergo _____ fracture.
- Ductile
 - Brittle
 - Intergranular
 - Fatigue
20. How does fracture surface appear in brittle fracture?
- Rough and dull
 - Smooth and bright
 - Cup and cone
 - Fibrous

**Exercise****Multiple Choice Questions**

21. In terms of which of the following properties, metals are better than ceramics?

- Hardness
- Ductility
- Toughness
- Yield Strength

22. Up to which point on the stress-strain curve is Hooke's law valid?

- Elastic limit
- Yield point
- Proportionality limit
- Fracture point

23. What is the unit for stress?

- N/m²
- Nm²
- N/m
- Nm

24. Strain is a dimensionless quantity.

- True
- False

25. Which of the following is found out by calculating the area under the stress strain graph?

- Toughness
- Hardness
- Endurance
- Strength

**Exercise****Multiple Choice Questions**

26. Up till which point will a body regain its original shape?
- Yield point
 - Elastic limit
 - Fracture limit
 - Ultimate tensile strength point
27. Which of the following is not a factor affecting fracture?
- Stress concentration
 - Temperature
 - Pressure
 - Speed of loading
28. Necking occurs in which of the following fractures?
- Ductile fractures
 - Brittle fracture
 - Fatigue
 - It doesn't occur during fracture
29. Ductile fracture happens after extensive plastic deformations.
- True
 - False
30. Which of the following is associated with minimum plastic deformation?
- Ductile fractures
 - Brittle fracture
 - Fatigue
 - It doesn't occur during fracture

**Exercise****Multiple Choice Questions**

31. Below which point does brittle fracture occur?

- Ultimate tensile strength
- Fracture point
- Elastic limit
- Yield point

32. Which of the statement is true?

- Energy consumed is less in ductile fracture than brittle fracture
- Energy consumed is more in ductile fracture than brittle fracture
- Energy consumed is same in brittle fracture than ductile fracture
- Energy consumed is more in brittle fracture than ductile fracture

33. Which of the following relation is stated by Hooke's law?

- Stress is directly proportional to strain
- Stress is inversely proportional to strain
- Stress is directly proportional to square of stress
- Stress is inversely proportional to square of stress

34. _____ of material can be defined as its ability to resist a fluctuating or repetitive stress.

- Creep strength
- Fatigue strength
- Impact strength
- Tensile strength

35. Most often machine components fail by

- Fatigue
- Buckling
- Creep
- All

**Exercise****Past Year Questions**

1. List FOUR (4) types of material properties and state the importance of material properties for engineers. *(Intro/pg.61)*
2. List THREE (3) types of material failure. Then, briefly describe any ONE(1) of those three failures. *(Sec.3.1/pg.74,77,83)*
3. Explain briefly the characteristics of ductile fracture and brittle e fracture. *(Sec.3.1/pg.76,77)*
4. Define brittleness and ductility. *(Sec.3.1/pg.73,74)*
5. Compare between creep and fatigue. *(Sec.3.1/pg.79,85)*
6. Compare TWO (2) differences between yield strength and tensile strength. *(Sec.3.1/pg.72,73)*
7. Fracture is the separation of an object or material into two or more pieces under the action of stress. Explain the characteristics of each ductile fracture and brittle fracture. *(Sec.3.1/pg.77)*

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