

PHYMP401

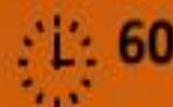
Apply mechanics and properties of matter

Competence

REQF Level: 4

Credits: 6

Learning hours



Sector: Construction and building services, Agriculture and food processing, Art and craft, Manufacturing and mining, Transport and logistics, ICT, Energy, Technical services, Media and Farm Making.

Sub-sector: Carpentry, Masonry, Plumbing, Road construction, Interior design, Land surveying, Animal health, Food processing, Irrigation, Agrimechanization, Graphic art, Production Technology, Welding, Mining, Auto-Electricity and Electronics systems, Auto-Transmission System Technology, Software Engineering, Networking, Software development, Renewable energy, Industrial electricity, Solar energy, Hydropower energy, Electronic services, Telecommunication, Multimedia.

Issue date: September, 2020

Purpose statement

The current module describes skills, knowledge and attitudes required apply concepts of mechanics and properties of matter. At the end of the module the trainee should be able to apply static equilibrium and elasticity, thermodynamics, analyze fluid mechanics, describe laws of motion and their applications, describe optical instrument and examine effects of electric current flow in dc electric circuit. In a nutshell, the features depicted on above helps trainees identify the essential steps in solving problems and increases their skills as problem solvers.

Learning assumed to be in place

Not applicable

Elements of competence and performance criteria

Learning units describe the essential outcomes of a competence.

Performance criteria describe the required performance needed to demonstrate achievement of the learning unit.

By the end of the module, the trainee will be able to:

Elements of competence	Performance criteria
1. Describe laws of motion and their applications	1.1 Clear interpretation of the concept of force based on types of forces 1.2 Clear interpretation of Newton's laws of motion 1.3 Correct application of Newton's laws based on the free body diagram
2. Apply static equilibrium and elasticity	2.1 Correct application of the conditions of equilibrium for rigid bodies 2.2 Clear description of examples of rigid objects in static equilibrium 2.3 Proper application of elastic properties of solids
3. Analyze fluid mechanics	3.1 Correct description of pressure and its variation with depth 3.2 Proper application of Archimedes' principle-based on Buoyant forces 3.3 Effective analysis of fluid dynamics based on Model of ideal fluid flow
4. Apply thermodynamics	4.1 Clear description of the measurement of temperature of a body according to zeroth law of thermodynamics. 4.2 Effective application of heat measurement, transfer and effects on a body in line with thermal properties of matter 4.3 Effective application of gas laws based on physical properties of gases 4.4 Effective application of thermodynamic processes on a system in line with thermodynamics laws
5. Examine effects of electric current flow in DC electric circuit	5.1 Proper description of a simple electric circuit based on Ohm's law. 5.2 Analytical determination of electric current, resistances and voltages in DC electric circuits based on Kirchhoff's laws. 5.3 Correct determination of electric energy, work and power in DC electric circuit in accordance with the law of conservation of energy.
6. Apply Geometric instruments	6.1 Effective description optical instruments based on its corresponding types 6.2 Correct determination of magnification of optical instrument in use 6.3 Effective correction of optical aberrations based on the type of aberration

LU1. DESCRIBE LAWS OF MOTION AND THEIR APPLICATIONS

LO1. Describe the concept of the force

1.1.1 Contact force and field forces

- **Force** is a pull or push upon an object resulting from the object's **interaction** with another object.
 - ✓ Whenever there is an interaction between two objects, there is a force upon each object.
 - ✓ When the interaction ceases or stops, the two objects no longer experience the force.
 - ✓ Force exist only as a result of an interaction.
- **Contact force** exists when two objects are in contact with each other. It is a direct force and requires a contact.

For example, pushing a car up on a hill, or kicking a ball across a room.

Examples of contact forces **are friction force, tensional forces, normal force, air resistance force, applied forces, spring forces**, etc.

- **Field force** is a force which does not require direct contact between the bodies. In this case, the objects interact without touching each other.

Examples of field forces are **magnetic forces, gravitational forces**, and **electrical forces**.

1.1.2. Fundamental forces and their characteristics

- **Fundamental forces** are the interactions that do not appear to be reducible to more basic interactions.
 - There are four (4) fundamental forces:
 1. Gravitational forces
 2. Electromagnetic forces
 3. Weak forces, and
 4. Strong forces
 - These forces govern everything that happens in the universe.
- Fundamental forces are characterized on the basis of the following four criteria:
 1. Types of particles that experience the force
 2. Relative strength of the force
 3. Range over which the force is effective, and
 4. Nature of the particles that mediate the force.

1.1.3. Internal and external forces

- **Internal forces** are produced from the external forces acting on structure members such as poled, beamed or columned. Generally, we have three types of internal forces: **axial, shear**, and **moment**.

1. Axial force: sometimes is called normal force, is compression or tension force acting aligned with expression of structure member.

2. Shear force: is force acting in a direction perpendicular to alignment of member.

3. Moment force: lastly, is turning result of force multiplied by distance from its acting location to turning point.

- **External force:** it is acting on a system from outside the system as opposed to internal forces which act between components within the system.

- In our everyday life, we are exposed to many external physical forces as we perform our activities.
 - These forces vary in magnitude and direction and hence, vary in their effects.
- Simply, **external forces** are forces applied to the structure from outside of the structure. Examples of external forces includes **applied force, normal force, friction force, and air resistance force.**

LO1.2. Interpret Newton's laws

1.2.1 First law of Newton (law of Inertia)

Newton's first law states that if a body is at rest or moving at constant speed in straight line, it will remain at rest or keep moving in a straight line at constant speed unless it is acted upon by a force.

Examples of Newton's first law

1. An object placed on a plane surface
2. A ball rolling on ground
3. Shaking a tree

Motion at constant velocity.

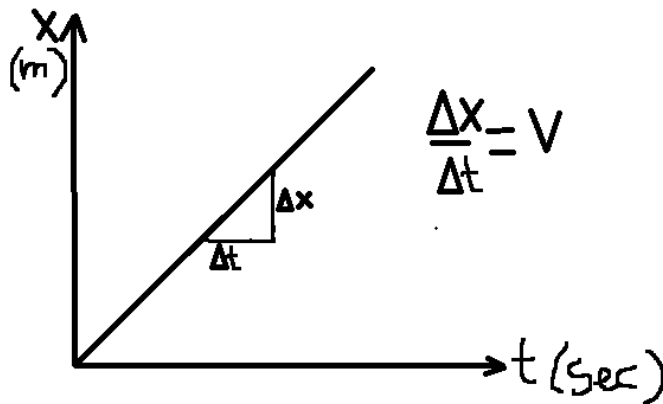
- Motion with constant velocity is one of simplest forms of motion. This type of motion occurs when an object is moving or sliding in presence of little or negligible friction force.
- To have constant velocity, an object must have a constant speed in constant direction.
- Constant direction constrains the object to motion to straight path.
- This means that the acceleration is zero. In mathematical expression,

$$a = \frac{dv}{dt} = 0$$

- If the object is moving at constant velocity, the graph of distance Vs time (X Vs t) shows as the same change in position over each interval of time.

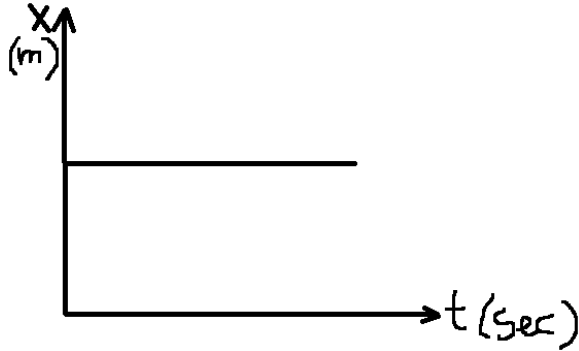
$$x = x_0 + Vt$$

Where x_0 is displacement when $t=0$



Body at rest

For a body at rest, displacement-time graph is a straight line parallel to the time axis.



1.2.2. Second Newton's law

Newton's second law says that when a constant force acts on a massive body, it causes it to accelerate. i.e to change its velocity, at constant rate.

In simple case, a force applied to an object at rest cause it to accelerate in the direction of force.

$$\sum F = m \cdot a$$

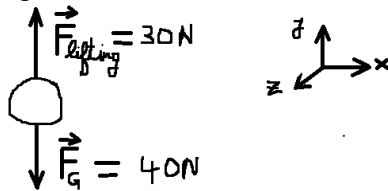
Where F is net force, m is mass of object, a is acceleration, \sum is vector sum of forces.

Net external forces and Vectors

The vector sum of external forces acting on an object or system is called the net external force (F_{net}) and is also represented as $\sum F$.

By Newton's second law of motion, the net force produces an acceleration on the body it acts on as long as its value is not zero.

Eg: Calculate the net force of the following system.



Ans: $\sum F_{net} = F_{lifting} + F_G$

$$\sum F_{net} = 30N - 40N = -10N$$

1.2.3. Newton's third law of motion

Newton's 3rd law state that when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction.

- The 3rd law of Newton is also known as the law of action and reaction.
- Law of action and reaction states that for every action force, there is an opposed and equal reaction force.

Examples: 1. A book resting on a table applies a downward force equal to its weight on the table.

2. A person pushes against a wall (action force), and the wall exerts an equal and opposite force (reaction force) against the person.

Mathematically, if a body A exerts a force F on a body B, then B simultaneously exerts a force – F on A, or in vector equation form,

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

LO1.3. Apply Newton's laws**1.3.1. Motion on a plane**

Motion on a plane is the point where we consider motion in two dimensions as only two dimensions make a plane. In this case we consider both directions (X-axis and y-axis).

Equations of motion in a plane

Apply equations of motion in straight line separately in both directions, X and y.

$$\begin{aligned} V_x &= U_x + a_x t & V_y &= U_y + a_y t \\ S_x &= U_x t + \frac{1}{2} a_x t^2 & S_y &= U_y t + \frac{1}{2} a_y t^2 \\ V_x^2 &= U_x^2 + 2a_x s & V_y^2 &= U_y^2 + 2a_y s \end{aligned}$$

Example: A motorboat of 40kg starting from rest on a lake accelerates in straight line. It travels a distance of 96m in 8sec.

- i) Calculate its acceleration.
- ii) By applying Newton's 2nd law of motion, calculate the force of the motorboat.

➤ **Static friction**

Static friction is a friction present between two or more objects that are not moving with respect to other. EX: A book on a table.

Laws of static friction

There are two laws of static friction:

- ✓ First law: The maximum force of static friction is not dependent on the area of contact.
- ✓ Second law: The maximum force of friction is comparative to the normal force. I.e. if normal force increases, the maximum external force that can endure without moving, also increases.

Note that, static friction force, F_s is directly proportional to the normal force, N

$$\begin{aligned} F_s &\propto N \\ F_s &= \mu_s N \end{aligned}$$

Where F_s is static friction force, μ_s is coefficient of static friction force, N is normal force and is given by $N = mg$, m is mass and g is acceleration due to gravity.

- ✓ **Coefficient of friction** is a ratio of friction force and normal force. Therefore, coefficient of static friction force, μ_s is given by: $\mu_s = \frac{F_s}{N}$
- ✓ Coefficient of friction is **dimensionless**.
- ✓ Coefficient of friction helps an object to lie on a surface.

➤ **Kinetic friction/Dynamic friction**

- ✓ **Kinetic friction** is a friction force that acts between moving surfaces and it is denoted as F_k .
- ✓ A body moving on a surface experiences a force in the opposite direction of its movement.

Laws of kinetic friction

There are four (4) laws of kinetic friction:

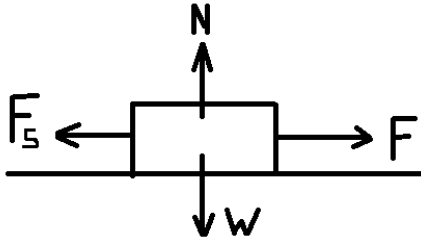
1st law: the force of kinetic, F_k is directly proportional to the normal reaction, N between two surfaces in contact where μ_k is constant called coefficient of kinetic friction.

$$\begin{aligned} F_k &\propto N \\ F_k &= \mu_k N \end{aligned}$$

2nd law: Force of kinetic friction is independent of shape and apparent area of the surfaces in contact.

3rd law: Force of kinetic friction depends upon nature and material of surface in contact.

4th law: Force of kinetic friction is independent of the velocity of object in contact provided the relative velocity and surface is not too long.



Difference between static and kinetic friction force

Static friction	Kinetic friction
Static friction is a friction present between two or more objects that do not moving respect to each other.	Kinetic friction is the friction present between two or more objects that are in motion with respect each other.
The magnitude of static friction is greater than due to the greater value of its coefficient.	The magnitude of kinetic friction is comparatively lesser due to the low value of its coefficient.
The equation representing static friction is given by: $F_s = \mu_s N$	The equation representing kinetic friction is given by: $F_k = \mu_k N$

Examples

1. An object having a mass of 10kg is placed on smooth surface. Static friction between these two surfaces is given as 15N. Find the coefficient of static friction.
2. the normal force and static frictional force of an object are 50N and 80N respectively. Find the coefficient of static friction.
3. What is the relationship between static and kinetic friction?

Ans: The force of static friction keeps a stationary object at rest. Once the force of static friction is overcome, the force of kinetic friction is what slows down a moving object.

4. A fridge weighs 1619N and the static friction coefficient is 0.50. what is the least force used to move the fridge?
5. A worker exerts a force of 400N on a large cardboard of mass 75.0kg with a coefficient of kinetic friction of 0.520.
 - a) Find the magnitude of force of friction.
 - b) Calculate the net force moving the cardboard.

➤ Free body diagram on a plane

- ✓ **Free body diagrams** are diagrams used to show the relative magnitude and direction of all forces upon an object in a given situation.

Rules of drawing free diagram

1. Draw circle or square around the object of interest to be sure you focus on labeling the forces acting on an object.

If you are treating object as particle (no size or shape and no rotation), represent the object as **point**.

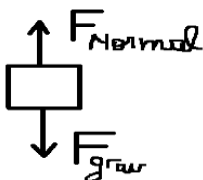
2. Include all forces that act on the object, representing these force as vectors. Consider the types of forces (normal force, friction, tension, and spring forces as well as weight and applied force). Do not include net force on the object. Also do not include action and reaction pair.

3. Convert the free body diagram into more detailed diagram showing the X- and y- component of a given force. This helps to solve a problem using 1st or 2nd law of Newton.

4. If there are two or more objects or bodies in the problem, draw a separate free body diagram for each object.

Example: A book is at rest on tabletop. Draw the forces acting on the book.

Ans:



1.3.2. Motion of suspended object

Suspended object/body is an object/body hung so as to be free on all side except at the point of support.

➤ Weight of suspended body

Suspended body is not in motion, its weight is due to the gravitational acceleration, **g**. so weight of suspended body/hanging body is product of its mass and gravitational acceleration.

$$W = mg$$

Where m is mass, g is gravitational acceleration ($g=9.8\text{m/s}^2$), and W is weight.

The SI unit of weight is **Newton (N)** or **kgm/s²**.

Ex: A hanging spring balance whose 50kg was measuring the sack of 100kg. Find the weight of spring balance and sack.

Ans: let m_t be total mass of balance and sack and W be weight of sack and balance

$$m_t = 50\text{kg} + 100\text{kg} = 150\text{kg}$$

$$\text{Then, } W = m_t g$$

$$W = 150\text{kg} \times 9.8\text{m/s}^2$$

$$W = 1470\text{N}$$

➤ Tension forces

✓ **Tension force** is the force generated when a load is applied at one or more ends of material in directional away.

✓ It is often given as pulling force.

Examples:

✓ Pulling a block with the help of a rope

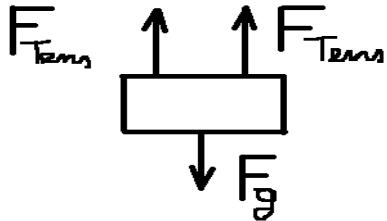
✓ Crane machine

✓ Gym equipment

➤ Free diagram on a suspended body

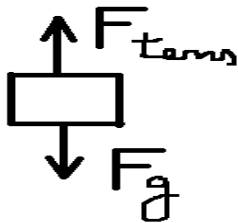
Example1: A gymnast holding onto a bar is suspended motionless in mid-air. The bar is supported by two ropes that attach to ceiling. Diagram the forces acting on the combination of gymnast and bar.

Ans: A free diagram for this situation looks like this:



Example2: a college student rests a backpack upon his shoulder. The pack is suspended motionless by one strap from one shoulder. Draw a free diagram for this situation.

Ans: A free diagram for this situation looks like this:



➤ Rocket motion

Rocket motion is based on Newton's 3rd law which states that for every action there is an equal and opposite reaction.



u: exhaust velocity, V: Rocket velocity.

❖ Thrust

- ✓ **Thrust** is a force which moves the rocket through the air and through space.
- ✓ It is given by:

$$T = v_e \frac{\Delta m}{\Delta t}$$

Where T is thrust force, v_e is escape velocity or exhaust velocity, $\frac{\Delta m}{\Delta t}$ is fuel burn rate.

- ✓ Acceleration of rocket is given by:

$$a = \frac{v_e \Delta m}{m \Delta t} - g$$

Where a is acceleration of rocket, m is mass of rocket, v_e is escape velocity or exhaust velocity, $\frac{\Delta m}{\Delta t}$ is fuel burn rate and g is acceleration due to gravity.

Example: A Saturn V's mass at liftoff was $2.8 \times 10^6 \text{ kg}$, its fuel burn rate was $1.4 \times 10^4 \text{ kg/s}$ and the exhaust velocity was $2.4 \times 10^3 \text{ m/s}$. Calculate its initial acceleration.

Ans: Given: $m = 2.8 \times 10^6 \text{ kg}$, $\frac{\Delta m}{\Delta t} = 1.4 \times 10^4 \text{ kg/s}$, $v_e = 2.4 \times 10^3 \text{ m/s}$ and $g = 9.8 \text{ m/s}^2$

Formula:

$$a = \frac{v_e \Delta m}{m \Delta t} - g$$

$$a = \left(\frac{2.4 \times 10^3 \text{ m/s}}{2.8 \times 10^6 \text{ kg}} \times 1.4 \times 10^4 \text{ kg/s} \right) - 9.8 \text{ m/s}^2$$

$$a = 2.20 \text{ m/s}^2$$

✓ Rocket velocity, V is given by:

$$V = v_e \ln \frac{m_0}{m_f}$$

Where V is rocket velocity, v_e is exhaust velocity, m_0 is initial mass of rocket, m_f is final mass of rocket.

Factors affecting rocket acceleration

- ✓ The greater exhaust velocity, v_e of gases relative to the rocket, the greater acceleration.
- ✓ The faster the rocket burns its fuel, the greater its acceleration.
- ✓ The smaller the rocket's mass, the greater acceleration.

❖ Air resistance

- ✓ **Air resistance** is a force acting opposite to relative motion of any object moving with respect to surrounding fluid.
- ✓ It is a frictional force air exerts against a moving body.
- ✓ As an object moves, air resistance slows it down.

Air resistance is also known as **drag force**, F_D and it is given by:

$$F_D = \frac{1}{2} \rho V^2 C_D A$$

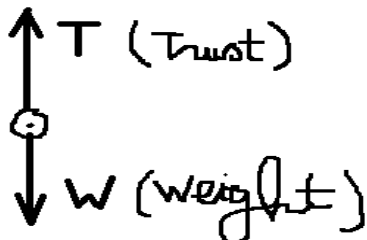
Where F_D is drag force or air resistance force, ρ is density of air, V is speed of rocket, C_D is drag coefficient, and A is cross sectional area.

❖ Free body diagram on a rocket

A rocket is experienced by:

- ✓ **Trust force:** Force pushing up the rocket, and
- ✓ **Weight:** force pulling down the rocket

Then, the free diagram for the rocket looks like this;



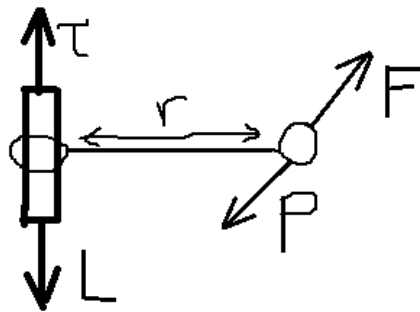
LU2. APPLY STATIC EQUILIBRIUM AND ELASTICITY

LO2.1: Apply conditions of static equilibrium

- ✓ **Static equilibrium** is a state in which a system is stable and at rest.
- ✓ To achieve static equilibrium, a system must have both **rotational equilibrium** and **translational equilibrium**.
- ✓ Translational equilibrium is a state in which net force is equal to zero, while an object is in rotational equilibrium if the velocity of its rotation is constant.
- ✓ To be in rotational equilibrium, the net torque acting on the object must be **zero**.

2.1.1. Moment of the force

- ✓ A **moment of force** is the turning effect of force.
- ✓ Moments act about a pivot in clockwise or anticlockwise direction.



$$\tau = r \times F$$

$$L = r \times P$$

- ✓ To calculate magnitude of torque, τ , firstly determine the lever arm and multiply applied force.
- ✓ **Lever arm** is a perpendicular distance from axis of rotation to the line of force.

2.1.2. Necessary conditions for equilibrium of an object

➤ First condition for equilibrium

- ✓ The sum of all external forces acting on the body is zero,

$$\sum F = 0$$

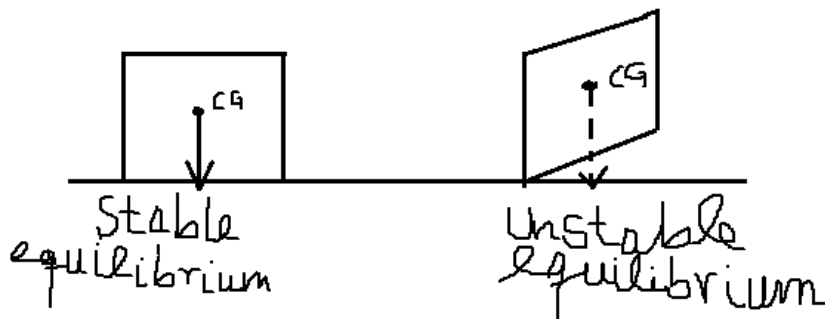
➤ Second condition for equilibrium

- ✓ The sum of all external torques from external forces is zero.

$$\sum \tau = 0$$

2.1.3. Center of gravity

- ✓ **Center of gravity** is the average location of weight of an object.
- ✓ It is also a geometric property of an object.
- ✓ It is also an important concept in determining stability of an object.



2..1.4. Determination of center of gravity

- ✓ The center of gravity of an object is calculated by taking of its moments divided by overall weight of the object.
- ✓ The moment is the product of weight and its location as measured from set point called the origin.

$$CG = \frac{W_1d_1 + W_2d_2 + W_3d_3 + \dots}{W}$$

Where $W_1, W_2,$ and W_3 are weight of object 1, 2, 3, respectively, $d_1, d_2,$ and d_3 are distance from origin to object 1, 2, 3 respectively, and W is total weight.

Examples:

1. A long rod of length 20m has a mass of 100kg. there is 25kg mass at the left end. Where is the center of gravity relative to the left end?
2. Where would you place a 50kg mass on 75kg, 14m rod so that its center of mass is 10meter to the left of physical center of the rod?

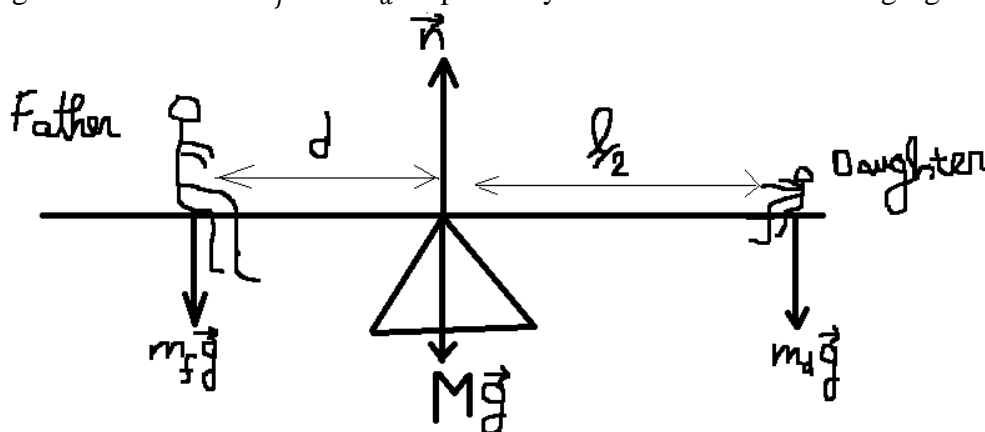
LO 2.2: Describe examples of rigid objects in static equilibrium

- ✓ **Static equilibrium** refers to any system where the sum of all forces and torques on every particle of the system happens to be zero.
- ✓ In simple words, static equilibrium is the equilibrium of the whose parts acts are at rest.
- ✓ In physics, a **rigid body/ rigid object** is a solid body in which deformation is zero or small it can be neglected.
- ✓ In other words, the distance between any two given points of a rigid body remains constant in time regardless of external forces exerted on it.

2.2.1. The seesaw revisited

➤ Determine magnitude of the upward force

A seesaw consisting of uniform board of mass M , and length l , supports at rest a father and daughter with masses m_f and m_d respectively as shown in the following figure.



The support (called fulcrum) is under the center of gravity of board, the father is a distance d , from the center and daughter is distance $l/2$ from the center.

- a) Determine the magnitude of the upward force \vec{n} exerted by the support on the board.
- b) Determine where the father should sit to balance the system at rest.

Ans:

a) Apply the 1st condition for equilibrium, $\sum F_{ext} = 0$

$$\vec{n} - m_f \vec{g} - M \vec{g} - m_d \vec{g} = 0$$

$$\vec{n} = m_f \vec{g} + M \vec{g} + m_d \vec{g}$$

$$\vec{n} = (m_f + M + m_d) \vec{g}$$

b) Apply 2nd condition for equilibrium, $\sum \tau_{ext} = 0$

$$(m_f \vec{g})d - (m_d \vec{g}) \frac{l}{2} = 0$$

$$(m_f \vec{g})d = (m_d \vec{g}) \frac{l}{2}$$

$$d = \left(\frac{m_d \vec{g}}{m_f \vec{g}} \right) \frac{l}{2}$$

$$d = \left(\frac{m_d}{m_f} \right) \frac{l}{2}$$

2.2.2. A weighted hand

➤ Upward and downward forces

✓ **Upward force** is any force that counteracts the force of gravity.

Eg: Buoyancy is a good example of an upward force because it pushes an object away from the earth's center of mass.

✓ In fact, every object that sits on surface of the earth is not only experiencing gravity, but it is always experiencing an upward force as well.

✓ Example, a book sitting on table stays on table due to gravity, however, the table is also equally pushing up on the book in reactive force which keeps the book sitting on the table. If there is no upward force the book, the book would fall right through the table.

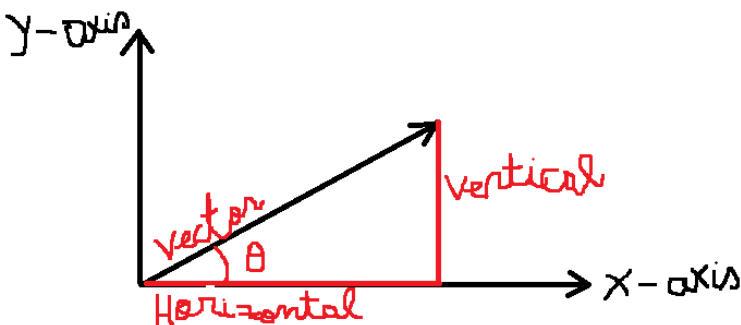
2.2.3. Standing on horizontal beam.

➤ Determination of horizontal and vertical component

✓ By taking a vector to be analyzed as the hypotenuse, the horizontal and vertical components can be found by completing a right triangle.

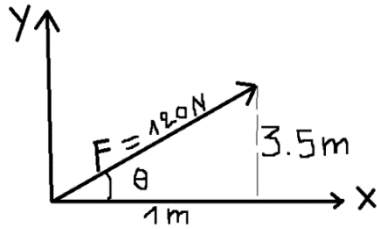
✓ The bottom edge of the triangle is the horizontal component and the side opposite the angle is the vertical component.

✓ The angle that the vector makes the horizontal can be used to calculate the length of the two components.



Examples:

1. The force of 120N form an angle θ with an x-axis as sown in the following figure:



- i. Calculate the angle θ .
- ii. Calculate vertical and horizontal components (F_x and F_y)

Ans:

Data: $F=120\text{N}$, Opposite side of $\theta=3.5\text{m}$, Adjacent side of $\theta=1\text{m}$

Asked: $\theta = ?$

$$\sin \theta = \frac{\text{Opposite side of } \theta}{F}$$

$$\sin \theta = \frac{3.5\text{m}}{F}$$

$$\cos \theta = \frac{\text{Adjacent side of } \theta}{F}$$

$$\cos \theta = \frac{1\text{m}}{F}$$

$$\tan \theta = \frac{\sin \theta}{\cos \theta} = \frac{3.5\text{m}/F}{1\text{m}/F}$$

$$\tan \theta = \frac{3.5\text{m}}{F} \times \frac{F}{1\text{m}}$$

$$\tan \theta = 3.5$$

$$\theta = \tan^{-1} 3.5$$

$$\theta = 74^\circ$$

ii) Asked: F_x and F_y

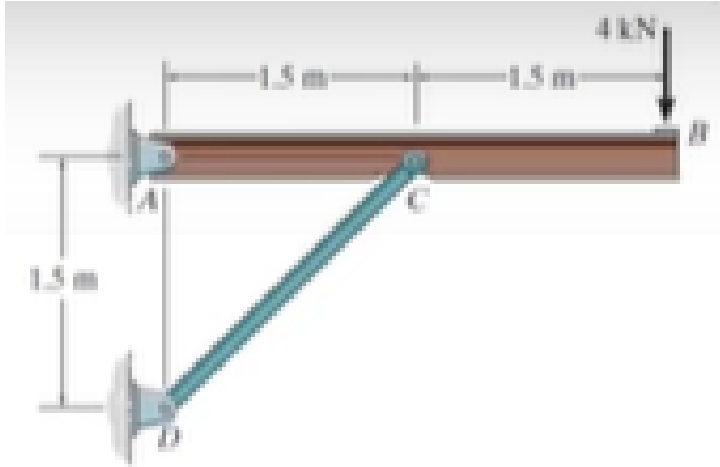
$$F_x = F \cos \theta = 120\text{N} \cos 74$$

$$F_x = 33\text{N}$$

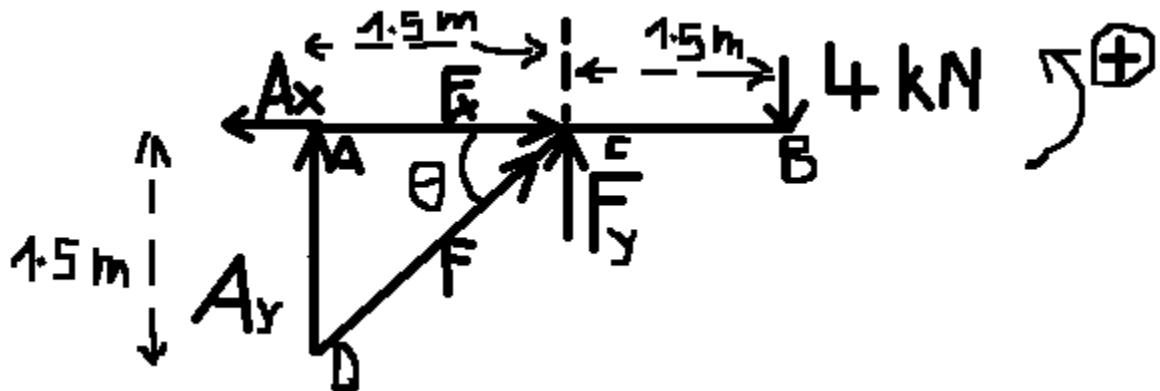
$$F_y = F \sin \theta = 120\text{N} \sin 74$$

$$F_y = 115.35\text{N}$$

2. Determine the horizontal and vertical components of reaction at the pair A and reaction on the beam at C.



Ans:



$$+\sum \tau_A = 0$$

$$-F_y \times 1.5m + 4kN \times 3m = 0$$

$$F_y = 8kN$$

$$\sum F_x = 0$$

$$-A_x + F_x = 0$$

$$A_x = 8kN$$

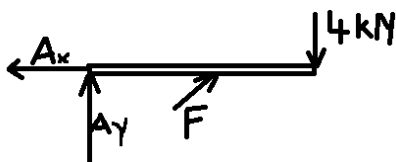
$$\sum F_y = 0$$

$$A_y + F_y - 4kN = 0$$

$$A_y + 8kN - 4kN = 0$$

$$A_y = -4kN$$

$$A_y = 4kN \downarrow$$



$$F \sin \theta = F_y$$

$$F \cos \theta = F_x$$

From $F \sin \theta = F_y$, calculate F

$$F = \frac{F_y}{\sin \theta}$$

$$F = \frac{8kN}{\sin \theta}$$

$$\theta = \tan^{-1} \frac{1.5m}{1.5m}$$

$$\theta = 45^\circ$$

$$F = \frac{8kN}{\sin 45}$$

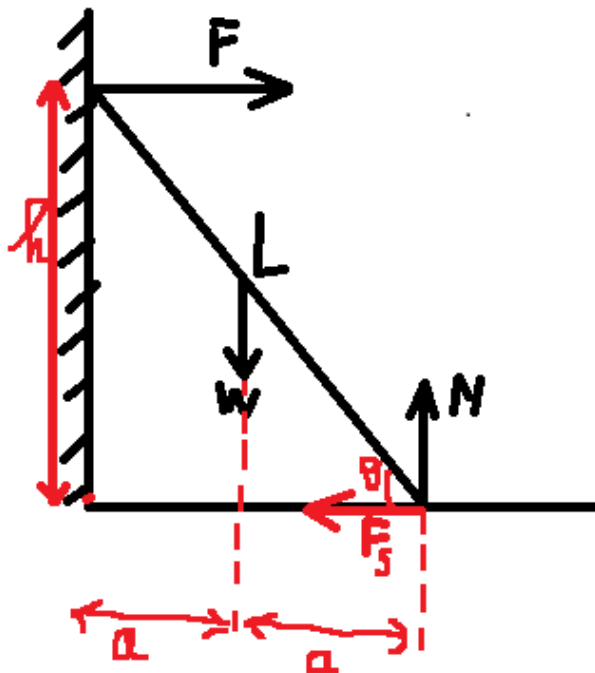
$$F = 11.3kN$$

2.2.4. The learning ladder

A **ladder** is a structure of wood, metal, or rope, commonly consisting of two sidepieces between which a series of bar or rungs are set at suitable distances, forming a means of climbing up or down.

➤ A uniform ladder at rest

- ✓ Uniform ladder rests against vertical wall where there is negligible friction.
- ✓ The bottom of ladder rests on rough ground where there is a friction.
- ✓ The top of ladder is at a height h , above the ground and foot of ladder is at a distance $2a$ from the wall.
- ✓ The diagram shows forces which act on the ladder.

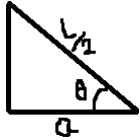


Apply the condition of equilibrium,

$$\sum F_x = 0 \qquad F - F_s = 0$$

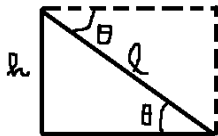
$$\begin{aligned} \sum F_y = 0 & & N - W = 0 \\ \sum \tau = 0 & & -wa + Fh = 0 \end{aligned}$$

For small triangle,



$$\begin{aligned} \cos \theta &= \frac{a}{l/2} \\ a &= \frac{l}{2} \cos \theta \end{aligned}$$

For big triangle



$$\begin{aligned} \sin \theta &= \frac{h}{l} \\ h &= l \sin \theta \end{aligned}$$

then, $h = l \sin \theta$

$$\sum \tau = -w \frac{l}{2} \cos \theta + Fl \sin \theta = 0$$

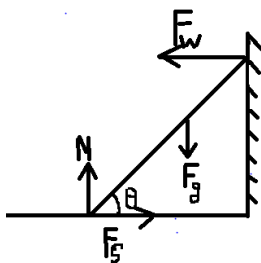
Example: A 20kg uniform ladder 2.5meters long rest against a smooth wall at an angle of 53 degrees with the horizontal.

- Diagram a free body diagram of this system /5marks
- Calculate the forces on the ladder exerted by the floor and wall. /8marks

Solution

a) **Learning ladder: structure of wood, metal, or rope, commonly consisting of two sidepieces between which a series of bars or rungs are set at suitable distances, forming a means of climbing up or down.**

b) i) Free diagram of uniform learning ladder looks like this,



ii) To answer this question, we apply the conditions for equilibrium.

1st condition

$$\sum F_x = 0, F_s - F_w = 0 \leftrightarrow F_s = F_w$$

$$\sum F_Y = 0, F_N - F_g = 0 \leftrightarrow F_N = F_g$$

$$F_N = 20 \times 9.8$$

$$F_N = 196N \text{ where } F_g = mg$$

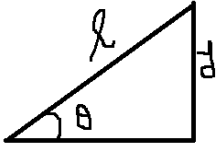
then, F_g is also equal to 196N ($F_g = 196N$)

For small triangle,



$$\cos \theta = \frac{X}{l/2} \leftrightarrow X = \frac{l}{2} \cos \theta$$

For big triangle,



$$\sin \theta = \frac{y}{l} \leftrightarrow y = l \sin \theta$$

$$\text{As } \sum \tau = -F_g X + F_W y = 0$$

$$\text{Then, } \sum \tau = -F_g \left(\frac{l}{2} \cos \theta \right) + F_W (l \sin \theta) = 0$$

$$F_W (l \sin \theta) = F_g \left(\frac{l}{2} \cos \theta \right)$$

$$F_W = F_g \left(\frac{l \cos \theta}{2l \sin \theta} \right)$$

$$F_W = F_g \left(\frac{\cos \theta}{2 \sin \theta} \right)$$

$$F_W = \frac{196N}{2} \times \left(\frac{\cos 53}{\sin 53} \right)$$

$$F_W = 73.8N$$

As $F_W = F_s$, therefore $F_s = 73.8N$

LO2.3. Apply elastic properties of solids

2.3.1. Deformation of solids in terms of the concepts of stress and strain

- ✓ **Stress** is a quantity that describes the magnitude of forces that cause deformation.
- ✓ Stress is generally defined as **force per unit area**.

$$\text{Stress} = \frac{F}{A}$$

- ✓ The SI unit of stress is **Pascal (Pa)**.
- ✓ **Strain** is the change in length divided by original length of object.

$$\text{Strain} = \frac{\Delta L}{L_0}$$

- ✓ Strain is dimensionless.

There are three (3) types of stress and strain,

1. **Tensile stress:** Deformation/ change in length. Then, the strain under tensile stress is called **tensile strain**.
2. **Bulk stress:** Deformation/ change in volume. Then, the strain under bulk stress is called **bulk strain/ volume strain**.
3. **Shear stress:** Deformation/ change in geometry. Then, the strain under shear stress is called **shear strain**.

Note that,

- ✓ **Strain** is dimensionless while the SI unit of **stress** is **Pascal (Pa)**.
- ✓ The ratio of **stress** and **strain** is called **elastic modulus** and SI unit is the same as stress, **(Pa)**.

$$\text{Elastic modulus} = \frac{\text{stress}}{\text{strain}}$$

2.3.2. Three types of deformation and elastic modulus for each.

1. **Young's modulus:** is the elastic modulus for tensile stress. It is denoted as **Y**.
Young's modulus is a ratio of tensile stress to tensile strain.

$$Y = \frac{\text{Tensile stress}}{\text{Tensile strain}} = \frac{F_{\perp}/A}{\Delta L/L_0} = \frac{F_{\perp}}{A} \times \frac{L_0}{\Delta L}$$

Where **A** is area, ΔL is change in length, F_{\perp} is deforming force, L_0 is initial length.

2. **Bulk modulus:** is the elastic modulus for bulk stress. It is denoted by **B**.
It is a ratio of bulk stress to bulk strain.

$$\text{Bulk strain} = \frac{\Delta V}{V_0}$$

The bulk strain results from stress which is a force F_{\perp} normal to the surface that pressures on unit surface area **A** of submerged object. This kind of physical quantity, or pressure **P** is defined as,

$$\text{Pressure, } P = \frac{F_{\perp}}{A}$$

Then,

$$B = \frac{\text{Bulk stress}}{\text{Bulk strain}} = -\frac{\Delta P}{\Delta V/V_0} = -\Delta P \frac{V_0}{\Delta V}$$

Note: The minus sign (-) in this equation is for consistency, to ensure that **B** is positive quantity.

- ✓ Note that minus sign (-) is necessary because an increase ΔP in pressure (positive quantity) always causes a decrease ΔV in volume, and decrease in volume is a negative quantity.
- ✓ The reciprocal of the bulk modulus is called compressibility, **K** or,

$$K = \frac{1}{B} = -\frac{\Delta V/V_0}{\Delta P} = -\frac{\Delta V}{\Delta P V_0}$$

- ✓ The term compressibility is used in relation to fluids (gas and liquid).
 - ✓ **Compressibility** is the change in volume of fluid per unit increase in pressure.
3. **Shear modulus:** It is a ratio of shear stress to shear strain and is denoted as **S**.

$$\text{Shear strain} = \frac{\Delta X}{L_0}$$

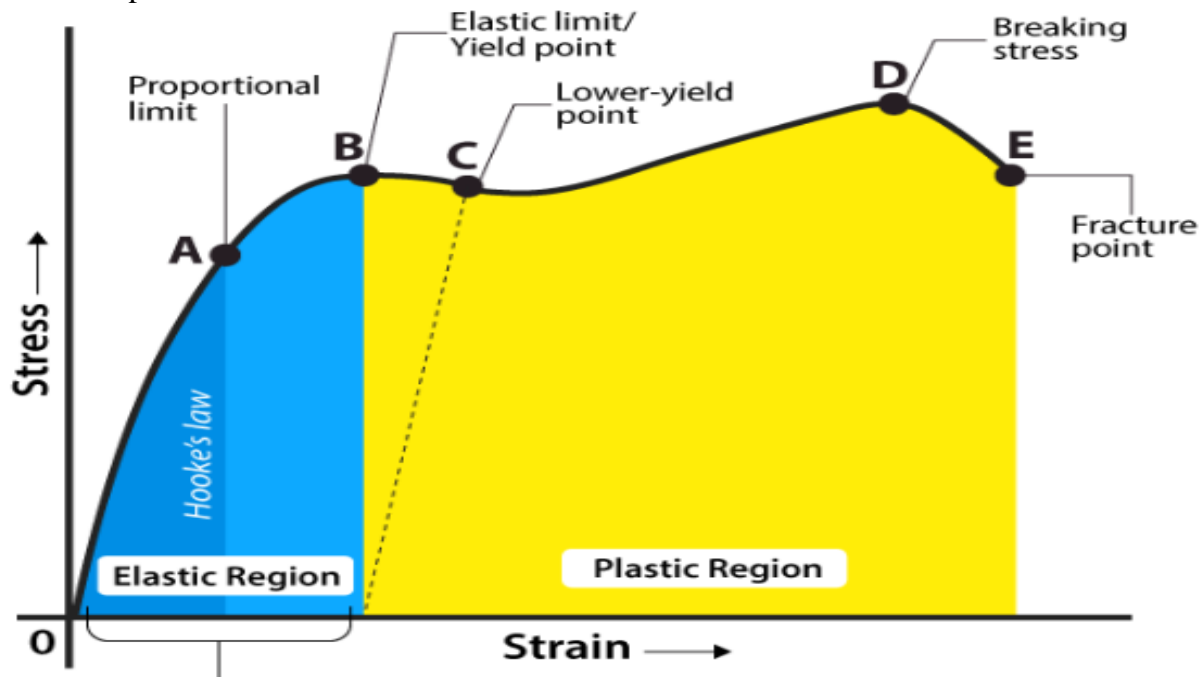
$$\text{Shear stress} = \frac{F_{\parallel}}{A}$$

The shear stress is due to the force parallel to the surface F_{\parallel} .

$$S = \frac{F_{\parallel}/A}{\Delta X/L_0} = \frac{F_{\parallel}}{A} \times \frac{L_0}{\Delta X}$$

➤ **Stress versus strain curve for an elastic solid.**

- ✓ When we study solids and their mechanical properties, information regarding their **elastic properties** is most important.
- ✓ We can learn about the elastic properties of materials by studying the stress-strain relationships under different loads in these materials.
- ✓ The material's stress-strain curve gives its stress-strain relationship.
- ✓ In stress-strain curve, the stress and its corresponding strain values are plotted.
- ✓ Example of a stress-strain curve is



1. Proportional limit: It is a region in stress-strain curve that obey Hook's law.

In this limit, the stress-strain curve ratio gives us proportionality constant known as **Young's modulus**. The point OA in the graph represent proportional limit.

2. Elastic limit: It is the point in the graph up to which the material returns to its original position when the load acting on it is completely removed.

Beyond this limit, the material does not return to its original position and plastic deformation starts to appear in it.

3. Yield point: It is defined as the point at which material starts to deform plastically.

- ✓ After yield point is passed, permanent plastic deformation occurs.

✓ There are two yield point: **Upper yield point** and **Lower yield point**.

4. Ultimate stress point: It is a point that represents the maximum stress that material can endure before failure. Beyond this this point failure occurs.

5. Fracture or Breaking point: It is a point in the stress-strain curve at which the failure of the material takes place.

➤ **Hooke's law**

Hooke's law states that "the strain of material is proportional to the applied stress within the elastic limit of that material".

Mathematically, Hooke's law is commonly expressed as:

$$F = -KX$$

Where **F** is a force, **X** is extension length, **K** is constant of proportionality known as spring constant in N/m .

Example: A spring is displaced by 5cm and held in place with a force of 500N. What is the spring constant of the spring?

Ans: Given $F = 500N$, $X = 5cm = 0.05m$

Asked: $K = ?$

Formula: $F = -KX$, then $K = \frac{F}{X}$

$$K = \frac{500N}{0.05m} = 10000 N/m$$

Elastic Moduli of Materials

The following table lists Young's modulus, shear modulus and bulk modulus for common materials.

Material	Young's modulus (E) in GPa	Shear modulus (G) in GPa	Bulk modulus (K) in GPa
Glass	55	23	37
Steel	200	84	160
Iron	91	70	100
Lead	16	5.6	7.7
Aluminium	70	24	70

Note: GPa is gigapascal and $1 \text{ GPa} = 1,00,00,00,000 \text{ Pa}$.

LU3. ANALYZE FLUID MECHANICS

LO3.1. Describe pressure and its variation with depth.

3.1.1. Pressure

- ✓ **Pressure** is perpendicular force per unit area.
- ✓ It is a stress at point within confined fluid.
- ✓ The SI unit of pressure is Pascal (Pa).
 - **Pressure in fluid**
- ✓ **Fluids:** are substances that have no fixed shape and yield easily to external pressure.
 - Examples** are **gas** and **liquids**.
- ✓ Pressure in fluids is given by,

$$P = P_0 + \rho hg$$

Where P is pressure, P_0 is atmospheric pressure, ρ is density of fluids, h is height or depth and g is acceleration due to gravity.

- ✓ **If the atmospheric pressure, $P_0 \lllll 1$, pressure will be,**

$$P = \rho hg$$

- **Force and pressure**
- ✓ **Force:** is the pull or push action resulting in acceleration of an object.
- ✓ **Pressure:** is a force acting upon a certain area and acted upon something perpendicular to its surface.

$$P = \frac{F}{A}$$

Where P is pressure, F is force, and A is area.

❖ Difference between force and pressure

Force	Pressure
Force is a pull or push action resulting in acceleration of an object.	Pressure is a force acting upon a certain area and acted upon something perpendicular to its surface
Its SI unit is Newton (N)	Its SI unit is Pascal (Pa)
Instrument used to measure force is called Dynamometer	Instrument used to measure force is called Manometer
Force is a vector quantity which means that has direction	Pressure is scalar quantity which means that no direction
Force can be acted upon the face, side, edges or vertices of the objects	Pressure only acts on surface or face of object.
Force change the speed and direction of an object.	Pressure cannot change the speed and direction of an object

- **A simple device for measuring the pressure exerted by a fluid**
- ✓ The instrument used to measure the pressure in fluid is called **Manometer**.
- ✓ Manometer is a U-tube device used to measure pressure

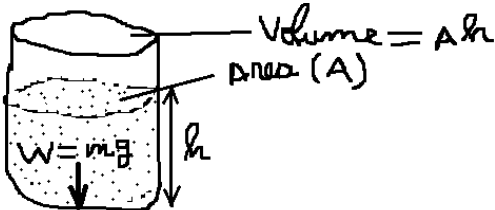
3.1.2. Variation of pressure with depth

- **Variation of atmospheric pressure against altitude**
- ✓ Altitude is related to air pressure.

- ✓ As altitude increases, the amount of gas molecules in the air decreases, the air becomes less dense than nearer to sea level.
- ✓ This means that, atmospheric pressure is lower at higher altitude and it becomes higher at lower altitude.

➤ **Water pressure against depth**

- ✓ The pressure increases as depth increases.
- ✓ This is due to the weight of water above the object in water and air above the water.



- ✓ Pressure exerted on the bottom by weight of fluid

$$P = \frac{W}{A} \quad \leftrightarrow \quad P = \frac{mg}{A}$$

- ✓ Mass of fluid from its volume and density,

$$\rho = \frac{m}{V} \quad \leftrightarrow \quad m = \rho V$$

- ✓ Volume of fluid is related to dimension of container,

$$V = Ah$$

Where **A** is cross sectional Area, **h** is depth

- ✓ **Combining the last two equations gives,**

$$m = \rho Ah$$

- ✓ Replace the value of mass, **m** in equation of pressure, **P**, we get,

$$P = \frac{\rho Ahg}{A}$$

A cancels, and rearranging the variables yields,

$$P = \rho gh$$

- ✓ This value is pressure due to the weight of fluid.

Example1: The dam is 500m wide, and the water is 40,0m deep at the dam.

- What the average pressure on the dam due to the water?
- Calculate the force exerted against the dam and compare it with the weight of water in the dam. (weight of water in dam, $W = 1.96 \times 10^{13} N$, density of water, $\rho = 10^3 kg/m^3$)

Ans: Given: $l = 500m$, $h = 40m$, $\rho_w = 10^3 kg/m^3$, $g = 9.8 m/s^2$, $W_w = 1.96 \times 10^{13} N$

Asked: a) $\rho = ?$, b) $F = ?$ and compare it with the weight of water

Formula: a) $P = \rho gh$ b) $P = \frac{F}{A} \leftrightarrow F = PA$

$$a) P = \rho gh = 10^3 kg/m^3 \times 9.8 m/s^2 \times 40m = 3.92 \times 10^5 N/m^2 = 392KPa$$

$$b) P = \frac{F}{A} \leftrightarrow F = PA$$

$$\bullet A = l \times h = 500m \times 40m = 20000m^2$$

$$\text{Then, } F = 3.92 \times 10^5 N/m^2 \times 20000m^2 = 7.84 \times 10^9 N$$

F is smaller than weight.

Example2: Calculate the depth below the surface of water at which the pressure due to the weight of water equals 1atm and density of water, ρ_w is 10^3 kg/m^3 .

Ans: Given: $P = 1\text{atm} = 1.01 \times 10^5 \text{ N/m}^2$, $\rho_w = 10^3 \text{ kg/m}^3$, $g = 9.8 \text{ m/s}^2$

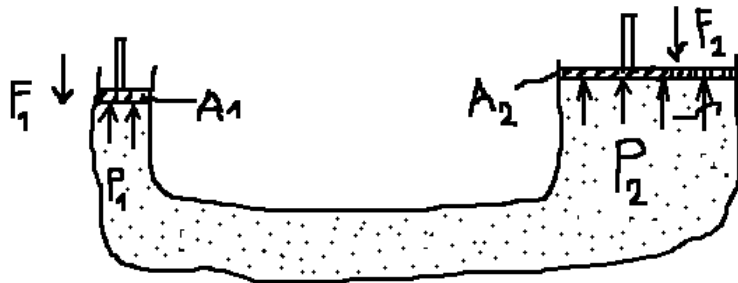
Asked: $h = ?$

Formula: Pressure in fluid, $P = \rho gh$,

Then, $h = \frac{P}{\rho g} = \frac{1.01 \times 10^5 \text{ N/m}^2}{10^3 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2} = 10.3 \text{ m}$

➤ Pascal's Principle

- ✓ Pascal's Principle is also known as Pascal's law
- ✓ According to Pascal's law, "Pressure or intensity of pressure at point in a static fluid will be equal in all directions".
- ✓ Or, "The external static pressure applied on a confined liquid is distributed or transmitted evenly throughout the liquid in all directions".



$$\text{As } P = \frac{F}{A}, \quad \text{then } F = PA \text{ (Pascal's law)}$$

$$P_1 = P_2$$

$$P_1 = \frac{F_1}{A_1}, \quad P_2 = \frac{F_2}{A_2}$$

$$\text{Then, } \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

Example1: Two pistons of a hydraulic lift have diameters of 60 cm and 5 cm. What is the force exerted by the larger piston when 50 N is placed on the smaller piston?

Solution

Since, the diameter of the pistons is given, we can calculate the radius of the piston.

$$r = \frac{D}{2}$$

$$\text{Area of smaller piston, } A_1 = \pi \left(\frac{5}{2}\right)^2 = \pi(2.5)^2$$

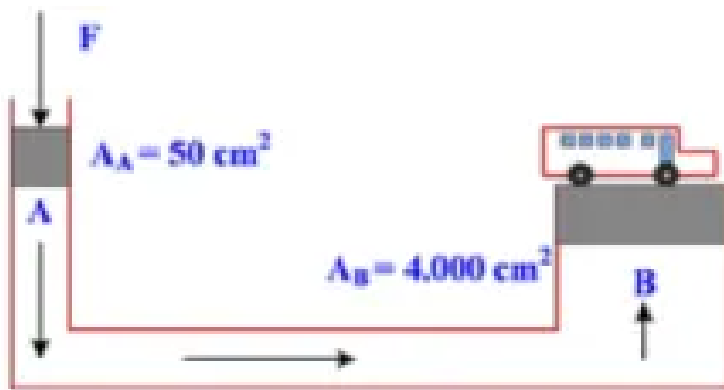
$$\text{Area of smaller piston, } A_2 = \pi \left(\frac{60}{2}\right)^2 = \pi(30)^2$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$F_2 = \frac{A_2}{A_1} \times F_1 = (50N) \times \left(\frac{30}{2.5}\right)^2 = 7200N$$

This means, with the force of 50 N, the force of 7200 N can be lifted.

Example2: Car's weight is 1600N. What is the external force input force F?



Solution: Given: $W = 1600N$, $A_A = 0.005m^2$, $A_B = 0.4m^2$

Asked: $F = ?$

$$\frac{W}{A_A} = \frac{F}{A_B}$$

$$F = \frac{W \times A_B}{A_A}$$

$$F = \frac{1600N \times 0.005m^2}{0.4m^2} = 200N$$

➤ Applications of Pascal's Principle

1. Hydraulic Lift: It works based on the principle of equal pressure transmission throughout a liquid.

2. Hydraulic Brakes

Example: A pressure of 2000Pa is transmitted throughout a liquid column due to a force being applied on a piston. If the piston the area of $0.1m^2$, what force is applied?

Ans: $F = PA = 2000 N/m^2 \times 0.1m^2 = 200N$

3.1.3. Pressure measurements

➤ Measurement of atmospheric pressure

Atmospheric pressure is measured in:

1. Atmosphere (atm)
2. Bar (bar)
3. Millimeters of mercury (mmHg)
4. Torr

$$1\text{atm} = 760\text{torr} = 760\text{mmHg} = 1.01325\text{bar} = 101325\text{Pa}$$

Note that:

- ✓ **Barometer** is an advice used to measure atmospheric pressure at a place.
- ✓ In a barometer, there is mercury column in which mercury moves up or down depending on the atmospheric pressure at a place.
- ✓ It is graduated in millimeter and the unit used for measurements from a Barometer is **mmHg**.

$$1\text{mmHg} = 133.3224\text{Pa}$$

$$1\text{atm} = 760\text{mmHg}$$

- ✓ Pressure measured by a Barometer is also known as **Barometric pressure (atmospheric pressure)**.

➤ Absolute pressure and Gauge pressure

- **Absolute pressure**
- ✓ It is a pressure of having no matter inside a space or perfect vacuum.
- ✓ The measurement of barometric pressure is example of absolute referenced pressure.

$$P_a = P_g + P_{atm}$$

- **Gauge pressure:** It is measured in relation to ambient atmospheric pressure.

$$P_g = P_a - P_{atm}$$

- **Atmospheric pressure:** Pressure measured by a **Barometer**.

$$P_{atm} = P_a - P_g$$

➤ Difference between atmospheric pressure and gauge pressure

- ✓ Atmospheric pressure is a measure of absolute pressure and is due to the weight of air molecules above the certain height relative to sea. It is increasing with decreasing altitude and decreasing with increasing altitude.
- ✓ Gauge pressure is additional pressure in a system relative to atmospheric pressure.

LO3.2. Apply Archimedes' Principle

3.2.1. Buoyant force

- ✓ **Buoyant force** is an upward force exerted by any fluid upon a body placed in it.
- ✓ It is an ability of something to float or rise in fluid.

Buoyant force = Weight of object in empty space – Weight of object immersed in fluid

$$F_B = \rho gV$$

Where F_B is Buoyant force applied on submerged object, ρ is density of fluid, V is volume of displaced fluid, g is acceleration of gravity.

Weight of displaced fluid = Weight of object in vacuum – Weight of object in fluid

Weight of displaced fluid = Buoyant force

3.2.2. Archimedes' Principle

“The volume of displaced fluid is equivalent to the volume of an object fully immersed in fluid or to that fraction of volume below the surface for an object partially submerged in liquid”.

Examples

1. A ship that is launched sinks into the ocean until the weight of water it displaces is just equal to its own weight.
2. A stone sink in the basin full of water, the weight of water displaced by stone is equal to the weight of the stone.



$$F_B = m_f g$$

m_f : mass of fluid

$$W = F_B$$

LO3.3. Analyze fluid dynamics

3.3.1. Viscosity

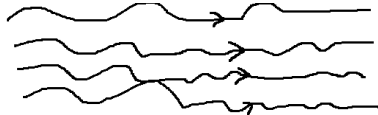
- ✓ **Viscosity** is a measure of fluid's resistance to flow
- ✓ It is a resistance of fluid (liquid or gas) to change in shape or movement of neighboring portions relative to one another.

➤ Four assumptions of model of ideal fluid flow

1. Steady flow/ laminar flow: the velocity of fluid at each point remains constant in time. The particles move in straight line.



2. Unsteady flow/ Turbulent flow: Particles unlike straight line in their motion. It is irregular flow of particle.



3. Incompressible flow: Density of fluid remains constant

4. Irrotational flow: The motion of particles is in circular path but the rotation is not about the axis. There is no turbulence.

Turbulence: instability or disturbance

5. Non-viscous flow: No fluid friction.

➤ Equation of continuity for fluids

Equation of continuity states that in the case of steady flow, the amount of fluid flowing past one point must be the same as the amount of fluid flowing past another, or mass flow rate is constant.

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

Where ρ is density, A is cross sectional area, V is flow velocity of fluid, **1** and **2** indicate two different region.

Example1: Suppose water is flowing through the pipe of diameter 1cm with flow velocity of 2 m/s. If the pipe widens to a diameter of 3cm, what is the new flow rate?

Ans: $\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

The density of water in this pipe is constant and can be canceled from both sides of continuity equation, we get,

$$A_1 V_1 = A_2 V_2$$

We know that, $A = \pi r^2$ and $r = \frac{d}{2}$

Then, $A = \pi \left(\frac{d}{2}\right)^2$

The equation of continuity becomes, $\pi \left(\frac{d_1}{2}\right)^2 V_1 = \pi \left(\frac{d_2}{2}\right)^2 V_2$

π cancelled in both sides, we get, $\frac{d_1^2}{4} V_1 = \frac{d_2^2}{4} V_2$

4 cancelled and we get, $d_1^2 V_1 = d_2^2 V_2$

$$\text{Then, } V_2 = \frac{d_1^2 V_1}{d_2^2} = \left(\frac{d_1}{d_2}\right)^2 V_1$$

$$V_2 = \left(\frac{1\text{cm}}{3\text{cm}}\right)^2 \times 2\text{ m/s} = 0.22\text{ m/s}$$

Example2: suppose that a compressible gas is flowing through a pipe. In a region of the pipe with a cross sectional area of 0.02m^2 , it has a flow rate of 4 m/s and density of 2 kg/m^3 . What is its density as it flows through another region of the same pipe with cross sectional area of 0.03m^2 at velocity 1 m/s ?

Ans: continuity equation:

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

$$\rho_2 = \frac{\rho_1 A_1 V_1}{A_2 V_2}$$

$$\rho_2 = \frac{2\text{ kg/m}^3 \times 0.02\text{m}^2 \times 4\text{ m/s}}{0.03\text{m}^2 \times 1\text{ m/s}} = 5.33\text{ kg/m}^3$$

Note that:

1. The volume flow rate (Q) is given by:

$$Q = AV$$

Where Q is volume flow rate, A is cross sectional area, and V is average velocity.

The IS unit of volume flow rate is l/s or ml/min .

2. Mass flow rate (\dot{m}), is given by:

$$\dot{m} = \rho AV$$

➤ **Volume flow rate problem solving**

Example: The pipe with radius of 0.1m is used to drain water cylindrical tank with height of 3m and a diameter of 5m in less than one hour. How fast will the stream of water need to move through the pipe in m/s in order to fill of tank?

Ans: Volume of cylinder , $V = \pi r^2 h$

$$r = \frac{d}{2} = \frac{5\text{m}}{2} = 2.5\text{m}$$

$$V = 3.14 \times (2.5\text{m})^2 \times 3\text{m} = 58.9\text{m}^3$$

Volume flow rate, $Q = AV$

Asked: To find the average velocity (V) of the pipe,

$$V = \frac{Q}{A}$$

Volume flow rate (Q), $Q = \frac{\text{Volume}}{\text{Time}}$

$$\text{Time} = 1\text{h} = 3600\text{sec}$$

$$Q = \frac{58.9\text{m}^3}{3600\text{s}} = 0.01636\text{ m}^3/\text{s}$$

Area of drainage pipe (A), $A = \pi r^2$

$$A = 3.14 \times (0.1\text{m})^2 = 0.0314\text{m}^2$$

Average velocity (V), $V = \frac{Q}{A}$

$$V = \frac{0.01636\text{ m}^3/\text{s}}{0.0314\text{m}^2} = 0.52\text{ m/s} = 52\text{ cm/s}$$

Water must be forced through the pipe quick but plausible speed of about half meter per second to properly drain the tank.

3.3.3. Bernoulli's principle and its application

➤ Bernoulli's principle

“The total mechanical energy of the moving fluid comprising the gravitational potential energy of elevation, the energy associated with the fluid pressure and the kinetic energy of fluid motion, remains constant”.

➤ Bernoulli's principle formula

Bernoulli's principle formula is a relation between pressure, kinetic energy and gravitational potential energy of fluid in a container.

$$P + \frac{1}{2}\rho V^2 + \rho gh = \text{constant}$$

Where P is pressure exerted by fluid, V is velocity of fluid, ρ is density of fluid, h height of container.

At any point of pipe, the constant is the same,

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho gh_2$$

➤ Bernoulli's equation at constant depth (h)

$$h_1 = h_2$$

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

Example: Calculate the pressure in the hose whose absolute pressure is $1.01 \times 10^5\text{ N/m}^2$ if the speed of water in the hose increases from 1.96 m/s to 25.5 m/s . assume the flow is frictionless and the density is 10^3 kg/m^3 .

Ans: Pressure at point 2, $P_2 = 1.01 \times 10^5\text{ N/m}^2$

Density of fluid, $\rho = 10^3\text{ kg/m}^3$

Velocity of fluid at point 1, $V_1 = 1.96\text{ m/s}$

Velocity of fluid at point 2, $V_2 = 25.5\text{ m/s}$

Asked: $P_1 = ?$

Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

$$P_1 = P_2 + \frac{1}{2}\rho V_2^2 - \frac{1}{2}\rho V_1^2$$

$$P_1 = P_2 + \frac{1}{2}\rho(V_2^2 - V_1^2)$$

$$P_1 = (1.01 \times 10^5) + \left(\frac{1}{2} \times 10^3 \times ((25.5)^2 - (1.96)^2) \right)$$

$$P_1 = 4.24 \times 10^5 \text{ N/m}^2$$

➤ **Application of Bernoulli's principle**

1. Airflight:

- ✓ To manufacture the wings of plane, you use Bernoulli's Principle
- ✓ The top of wings is somewhat curved, while the bottom of wing is totally flat
- ✓ While in the sky, air travels across both top and bottom concurrently.
- ✓ Because both top part and bottom part of plane are designed differently this allows for the air on bottom to move slower, which creates more pressure on bottom and allows for the air on the top to move faster which creates less pressure.
- ✓ This is what creates lift which allows planes to fly.

2. Lift: As you see on airplane, the wing moves up and down a little bit as it flies through the air.

3. Baseball

4. Draft

5. Sailing

➤ **Other applications of fluid dynamics**

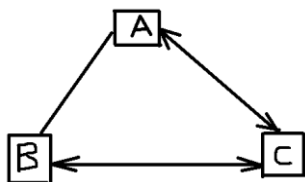
- ✓ Streamline flow around a moving airplane wing
- ✓ Newton's third law about the airstream.

LU4. APPLY THERMODYNAMICS

LO4.1: Describe measurement of temperature of a body

4.1.1. Key terms

- ✓ **Heat:** is a form of energy that is transferred between systems or objects with different temperatures.
It flows from high temperature system to lower temperature system.
- ✓ **Temperature:** It is a physical quantity that express hotness and coldness of the object.
It is expressed in several scales including **Fahrenheit, Celsius, kelvin.**
- ✓ **Internal energy:** It is also known as **intrinsic energy.**
 - It is defined as the total energy of closed system.
 - It is the sum of potential energy of system and system's kinetic energy.
- ✓ **Zerorth law of thermodynamics:** it states that if two systems A and B are in thermal equilibrium with each other, and B is in thermal equilibrium with third system C, then A is also in thermal equilibrium with C.
This statement may seem obvious, because all three system have the same temperature, but it is basic to thermodynamics.



4.1.2. Temperature measurement

1. Thermocouple: Two different metals or alloys connected at the end to form simple electrical circuit (current loop).

Temperature different between two ends of the circuit produces a voltage called electromotive force (emf) that is proportional to the temperature difference.

2. Liquid-in-glass thermometer: consist of mercury as a liquid filled in glass tube.

On the body of glass tube, carbureted marks are provided which facilitates the reading of temperature.

3. Digital thermometer: use mercury to measure temperature. They show the number. It calculates and give number.

4. Infrared thermometer: It is thermometer which infers temperature from portion of thermal radiation sometimes called black-body radiation emitted by object being measured. It does not need contact.

➤ Calibration of thermometer

The thermometers should be calibrated regularly to make sure the readings are correct. The ice-point method is most widely used method to calibrate a thermometer.

Calibration of thermometer using ice-point method

1. Fill a large container with crushed ice. Add clean tap water until the container is full. Stir the mixture well.
2. Put the thermometer stem or probe into the ice water. Make sure the sensing area is under water. Wait 30 seconds or until the reading stays steady.

3. Adjust the thermometer so it reads 32°F (0°C). Hold the calibration nut securely with a wrench or other tool and rotate the head of thermometer until it reads 32°F (0°C).

➤ **Measuring a body's temperature**

To measure body's temperature, depends on the types of thermometer. You can use thermometer needs contact (liquid-in-glass thermometer, digital thermometer), or do not require contact (Infrared thermometer).

For those need contact

The probe of thermometer can be placed in **mouth**, **rectum**, or **armpit**.

➤ **Mouth**

- Place the probe under the tongue and close the mouth.
- Hold the thermometer tightly in place using lips
- Leave thermometer in the mouth for 3 minutes or until the device beeps

➤ **Rectum**

- This method is for infants and small children
- Insert the probe in anal canal
- Remove thermometer after 3 minutes or device beeps

➤ **Armpit**

- Place thermometer in the armpit
- Press the arm against the body
- Wait for 5 minutes before leading

For those do not need contact

- Hold sensing area (NCIT) perpendicular to forehead
- The distance between (NCIT) and forehead is specific to each NCIT
- Do not touch the sensing area of NCIT and keep sensor clean and dry

4.1.3. Conversion of temperature scales (Celsius, kelvin, and Fahrenheit)

- ✓ These common temperature scales are **Celsius, kelvin, and Fahrenheit**.
- ✓ Each scale has its uses, so it has likely you will encounter them and need to convert between them.
- ✓ The formula to convert these scales are follow:

Conversion	Formula
Celsius to Fahrenheit	$^{\circ}\text{F} = \frac{9}{5} (^{\circ}\text{C}) + 32$
Kelvin to Fahrenheit	$^{\circ}\text{F} = \frac{9}{5} (K - 273) + 32$
Fahrenheit to Kelvin	$K = \frac{5}{9} (^{\circ}\text{F} - 32) + 273$
Fahrenheit to Celsius	$^{\circ}\text{C} = \frac{5}{9} (^{\circ}\text{F} - 32)$
Celsius to Kelvin	$K = ^{\circ}\text{C} + 273$
Kelvin to Celsius	$^{\circ}\text{C} = K - 273$

Note: When you are counting the temperature in:

1. Celsius, you start from zero (0°C)

2. Fahrenheit, you start from 32°F

3. Kelvin, you start from 273K

i.e. 0°C = 32°F = 273K

Exercises:

1) Convert 100°C and 0°C into °F and K

2) Convert 98.6°F into °C

LO 4.2. Apply heat measurement, transfer and effects on a body

4.2.1. Thermal properties of matter

➤ Thermal conductivity (K)

- ✓ The thermal conductivity is the rate at which heat is transferred by conduction through a unit cross-section area of material when the temperature gradient exists perpendicular to the area.

$$K = \frac{Q \cdot d}{A\Delta T}$$

Where K is thermal conductivity, Q is amount of heat transferred, d is distance between two isothermal planes, A is area of surface, ΔT is difference in temperature.

- ✓ The SI unit of thermal conductivity is W/mk

➤ Thermal diffusivity (α)

- ✓ Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure.
- ✓ It measures the ability of material to conduct thermal energy relative to its ability to store thermal energy.
- ✓ High diffusivity means heat transfer rapidly.

$$\alpha = \frac{K}{\rho C_p}$$

Where α is thermal diffusivity, K is thermal conductivity, C_p is specific heat, ρ is density.

- ✓ The SI unit of thermal diffusivity is m^2/s

➤ Specific heat (C_p)

- ✓ **Specific heat** is the quantity of heat required to raise the temperature of one gram of substance by one Celsius degree.

$$C_p = \frac{Q}{m\Delta T}$$

Where C_p is specific heat, Q is heat energy, m is mass, ΔT is change in temperature

- ✓ The SI unit of specific heat is $J/g^\circ C$ or J/kgK

➤ Melting point

- ✓ **Melting point** is temperature at which solid and liquid forms of pure substance can exist in equilibrium.
- ✓ Simply, **melting point** is maximum temperature required to change solid state to liquid state.

➤ **Boiling point**

- ✓ Boiling point is a temperature at which pressure exerted by surrounding up on a liquid is equaled by the pressure exerted by the vapor of liquid.
- ✓ Simply, boiling point is maximum temperature required to change the liquid state to gaseous state.

4.2.2. Heat quantities

- **Heat loss or gain due to temperature change**
 - **Principal of heat exchange**

This principal of heat exchange states that the heat energy lost by hot object is always equal to heat gained by cold object provided that system of both the objects is isolated.

$$Q_{loss} = Q_{gain}$$

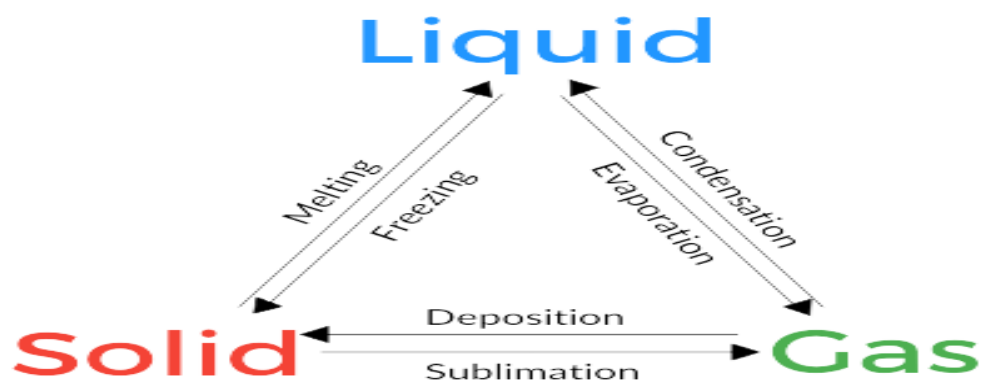
$$\text{where } Q = mc\Delta T$$

$$\text{then, } m_1c_1(T_f - T_i) = m_2c_2(T_f - T_i)$$

➤ **Latent heat**

- ✓ **Latent heat:** is energy absorbed or released by a substance during a change in physical state (phase) that occurs without changing its temperature.
- ✓ It is normally expressed as the amount of heat per mole or unit mass of substance undergoing a change of state.
- ✓ It is a heat required to convert a solid into liquid or vapor or a liquid to vapor without change of temperature.

➤ **Transition of physical states**



- **Melting:** change from solid state to liquid state.
- **Freezing:** change from liquid state to solid state.
- **Condensation:** change from gas state to liquid state.
- **Evaporation:** change from liquid state to gas state.
- **Sublimation:** change from solid state to gas state.

- **Deposition:** change from gas state to solid state.
- ✓ **Heat of fusion:** Amount of heat required to convert one-unit amount of substance from solid to liquid phase.

$$\Delta H_f = \frac{Q}{m}$$

Where ΔH_f is heat of fusion, m is mass, Q is heat.

- ✓ **Heat of vaporization:** Amount of heat needed to turn 1g of liquid into vapor without a rise in temperature of liquid.

$$\Delta H_v = \frac{Q}{m}$$

- ✓ **Heat of sublimation:** Heat absorbed by one gram or unit mass of substance in process of changing at constant temperature and pressure from solid to gaseous state.
- ✓ It is heat required to change one mole of substance from solid state to gaseous state at a given combination of temperature and pressure.

$$\Delta H_{sub} = \Delta H_f + \Delta H_v$$

➤ Thermal equilibrium

- ✓ It is a state of system in which all parts are at the same temperature
- ✓ Thermal equilibrium exists when two objects in thermal contact no longer affect each other's temperature.

4.2.3. Modes of heat transfer

1. Conduction: Heat or energy is transferred by direct contact like when any heated object you touch with your hand; the conduction process takes place.

Note: When we heat iron at one side, other side automatically gets heated because the molecules present in it travels to another side and heated that area too. So, conduction is equal to direct contact.

➤ Fourier's law

Fourier's law states that the negative gradient of temperature and the time rate of heat transfer is proportional to the area at right angles of that gradient through which the heat flows.

$$q = -k\nabla T$$

Where q is local heat flux density in $W.m^2$, k is conductivity of material in $W.m^{-1}K^{-1}$, ∇T is temperature gradient in $K.m^{-1}$

➤ Coefficient of thermal conductivity

- ✓ The coefficient of thermal conductivity of material is the quantity of heat that conducts per unit time through a cube of material when its opposite faces are kept at temperature difference of one degree.

$$K = \frac{QL}{A\Delta T}$$

Where Q is heat transferred through material in J/s or W (**watts**), K is thermal conductivity in $W/m.K$, L is distance between two isothermal planes, A is area of surface in m^2 , ΔT is difference in temperature

- ✓ Its SI unit is $J/s.cm.^{\circ}C$ or $W/m.K$

➤ Thermal resistance

- ✓ **Thermal resistance** is a ratio of temperature difference between two faces of material to the rate of heat flow per unit area.

$$R_o = \frac{\Delta X}{KA}$$

Where R_o is absolute thermal resistance in K/W across the thickness of sample, ΔX is thickness in m of sample, K is thermal conductivity in $W/m.K$, A is cross-sectional area in m^2 perpendicular to the path of heat flow.

- ✓ **Conductors:** Materials that permit electrons to flow freely from the particle. They allow for charge transfer through the free movement of electrons.

Examples: metals, aqueous solutions of salts, graphite, and human body.

- ✓ **Insulators:** Materials that impede the free flow of electrons from the atom and molecule to molecule.

Examples: plastics, Styrofoam, paper, rubber, glass, dry woods.

2. Convection: Process by which heat is transferred by movement of a heated fluid such as air or water.

Example: Boiling water: Burner heats water at bottom. Hot water rises and cooler water moves down to replace it.



- ✓ **Convection current:** It is the result of differential heating.
- ✓ Lighter (less denser), warm materials rise while heavier (more denser), cool materials sink.

➤ Newton's law of cooling

"The rate of cooling of body is directly proportional to difference in temperatures of the body (T) and surrounding (T_0)".

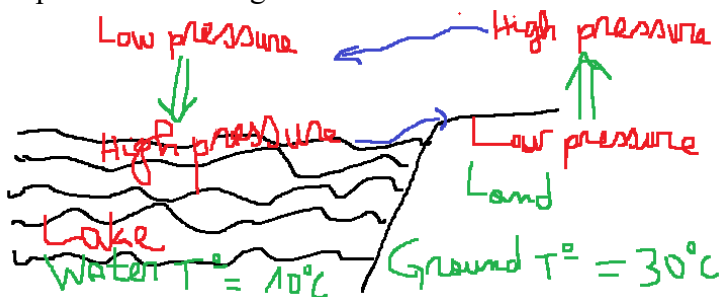
$$Q = h.A(T_t - T_{env})$$

Where Q is rate of heat transfer out of the body, h is heat transfer coefficient, A is heat transfer of surface area, T_t is time dependent temperature, T_{env} is temperature of environment.

➤ Theory of wind formation

- ✓ **Wind** is the air in motion.
- ✓ Wind forms when the sun heat one part of atmosphere differently than other part.
- ✓ This causes expansion of warmer air, making less pressure where it is warm than where it is cooler.
- ✓ Air always moves from higher pressure to lower pressure and this movement of air is wind.

- ✓ During the day, the sun heats air above the land more quickly than air above water. Warm air above the land expands and rises. Cooler air from the ocean moves toward the land to take place of the rising air and makes “sea breeze”.



3. Thermal radiation: It is a process by which energy in form of electromagnetic radiation is emitted by heated surface in all direction and travels directly to its point of absorption at the speed of light.

- ✓ **Emissivity:** It is the ratio of energy radiated from material’s surface to that radiated from perfect emitter, known as black body, at the same temperature and wave length and under the same viewing condition.
- ✓ **View factor:** Degree to which heat carried by radiation can be passed between two surfaces.
- ✓ **Black body:** It is a surface that absorbs all radiant energy falling on it.
- ✓ **Black body radiation:** refers to the spectrum of light emitted by any heated object.
- ✓ **Stefan Boltzmann law:** It is also known as Stefan’s law.

It states that “the total energy radiator per unit surface area of black body in unit time is directly proportional to the fourth power of black body’s thermodynamic temperature, T (also called absolute temperature)”.

$$P = e\sigma AT^4$$

Where P is power radiated (Watts, W), e is emissivity (no unit), σ is Stefan’s Boltzmann constant, $5.67 \times 10^{-8} Wm^{-2}K^{-2}$, A is surface area (m^2), T is temperature (kelvin, K).

$$e = \frac{\text{Emissive power of body at temperature, } T}{\text{Emissive power of black body at same temperature, } T} = \frac{E}{E_0}$$

Note: Emissivity, e for ideal radiator is equal to 1.

4.2.4. Heat effects

1. Chemical effect

- ✓ Since heat is a form of energy, it plays a major role in chemical changes.
- ✓ In some cases, chemical reactions need heat to begin and also heat determines the speed at which reactions occur.

Example: When we cook food, we light the wood and it catches fire and the food particles become soft because of heat energy.

- ✓ These are all chemical changes taking place due to heat.

2. Change of physical states

- ✓ When you heat ice cubes, they become water and water further heating changes into vapor.
- ✓ So, solid becomes liquid and liquid becomes gas when heat is added.
- ✓ The reverse takes place when heat is removed.

3. Expansion and contraction

- ✓ When heat is added to surface, the molecules gain energy and vibrate and force other molecules apart. As result, **expansion** takes place.
- ✓ Inversely, when heat is removed to substance, the molecules loss energy and molecules attract each other and as result, **contraction** takes place.

Note: Expansion is greater for liquids than for solids and maximum in case of gases.

- ✓ There are three types of expansion:

1. **Linear expansion**
2. **Areal expansion**
3. **Volume expansion**

1. Linear expansion

- ✓ Linear expansion is the change in length due to heat.
- ✓ Linear expansion formula is given as:

$$\frac{\Delta L}{L_0} = \alpha_L \Delta T$$

Where L_0 is original length, L is expanded length, α_L is length expansion coefficient, ΔL is change in length, ΔT is change in temperature.

2. Areal expansion

- ✓ Areal expansion is the change in area due to temperature change.
- ✓ Areal expansion formula is given as,

$$\frac{\Delta A}{A_0} = \alpha_A \Delta T$$

Where A is expanded area, A_0 is original area, ΔA is change in area, ΔT is change in temperature, α_A is area expansion coefficient.

Note that; $\alpha_A = 2\alpha_L$

3. Volume expansion

- ✓ Volume expansion is the change in volume due to temperature
- ✓ Volume expansion formula is given as,

$$\frac{\Delta V}{V_0} = \alpha_V \Delta T$$

Where V_0 is original volume, V is expanded volume, ΔV is change in volume, ΔT is change in temperature, α_V is volume expansion coefficient.

Note that, $\alpha_V = 2\alpha_A = 3\alpha_L$

Example1. A rod of length 5m heated to 40°C. If the length increases to 7m after some time, find the expansion coefficient. Room temperature is 30°C.

Ans: Given; Initial length, $L_0 = 5m$, Expanded length, $L = 7m$,

Change in length, $\Delta L = 7m - 5m = 2m$,

Temperature difference, $\Delta T = 40^\circ\text{C} - 30^\circ\text{C} = 10^\circ\text{C}$

Absolute temperature, $T = (10 + 273)K = 283K$

Asked: $\alpha_L = ?$

Formula:
$$\frac{\Delta L}{L_0} = \alpha_L \Delta T$$

$$\text{Then, } \alpha_L = \frac{\Delta L}{\Delta T L_0}$$

$$\alpha_L = \frac{2m}{5m \times 283K} = 14 \times 10^{-4} K^{-1}$$

Example2: A sheet of steel at 20°C has size as shown in the figure below. If the coefficient of linear expansion for steel is $10^{-5}/^{\circ}\text{C}$, then what is the change in the area at 60°C?



Ans: Given:

Length of steel, $l = 40\text{ cm}$

Width of steel, $w = 20\text{ cm}$

Initial area of steel, $A_0 = l \times w = 40\text{ cm} \times 20\text{ cm} = 800\text{ cm}^2$

Coefficient of linear expansion, $\alpha_L = 10^{-5}/^{\circ}\text{C}$

Coefficient of area expansion, $\alpha_A = 2\alpha_L = 2 \times 10^{-5}/^{\circ}\text{C}$

Change in temperature, $\Delta T = 60^{\circ}\text{C} - 20^{\circ}\text{C} = 40^{\circ}\text{C}$

Asked: Change in area of steel at 60°C, $\Delta A = ?$

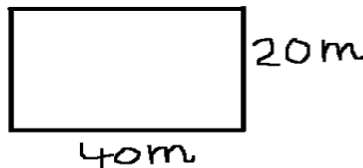
$$\text{Equation of areal expansion: } \frac{\Delta A}{A_0} = \alpha_A \Delta T$$

$$\text{Then, } \Delta A = \alpha_A A_0 \Delta T$$

$$\Delta A = 2 \times 10^{-5}/^{\circ}\text{C} \times 800\text{ cm}^2 \times 40^{\circ}\text{C}$$

$$\Delta A = 0.64\text{ cm}^2$$

Example 3: A bronze plate with coefficient of linear expansion, $\alpha_L = 18 \times 10^{-6}/^{\circ}\text{C}$ has size shown in figure below. If the plate heated at 80°C, then what is the increase in area. /7marks



Ans: Data: Length of bronze: 40m

Width of bronze: 20m

Initial area of bronze (A_0) = $L \times W$

$$A_0 = L \times W$$

$$A_0 = 40\text{ m} \times 20\text{ m} = 800\text{ m}^2$$

Coefficient of linear expansion of bronze, $\alpha_L = 18 \times 10^{-6}/^{\circ}\text{C}^{-1}$

Coefficient of area expansion of bronze, $\alpha_A = 2 \times \alpha_L = 2 \times 18 \times 10^{-6}/^{\circ}\text{C}^{-1} = 36 \times 10^{-6}/^{\circ}\text{C}^{-1}$

Change in temperature, $\Delta T = 80^{\circ}\text{C} - 0^{\circ}\text{C} = 80^{\circ}\text{C}$

Asked: Increase of area for bronze, $\Delta A = ?$

$$\text{Equation of area expansion: } \frac{\Delta A}{A_0} = \alpha_A \Delta T \leftrightarrow \Delta A = \alpha_A A_0 \Delta T$$

$$\Delta A = 36 \times 10^{-6}/^{\circ}\text{C}^{-1} \times 800\text{ m}^2 \times 80^{\circ}\text{C} = 2.304\text{ m}^2$$

Example 4: A glass container with volume of 4liters filled with water, then heated until the increase in temperature is 20°C , some water spilled. The coefficient of linear expansion for glass is $9 \times 10^{-6}/^{\circ}\text{C}$, the coefficient of volume expansion for water is $2.1 \times 10^{-4}/^{\circ}\text{C}$. Determine the volume of spilled water.

Ans: Given: $V_0 = 4\text{l}$, $\Delta T = 20^{\circ}\text{C}$, $\alpha_L \text{ for glass} = 9 \times 10^{-6}/^{\circ}\text{C}$,
 $\alpha_V \text{ for glass} = 3\alpha_L = 3 \times 9 \times 10^{-6}/^{\circ}\text{C} = 27 \times 10^{-6}/^{\circ}\text{C}$
 $\alpha_V \text{ for water} = 2.1 \times 10^{-4}/^{\circ}\text{C}$

Asked: Volume of spilled water=?

Equation for volume expansion,

$$\frac{\Delta V}{V_0} = \alpha_V \Delta T$$

$$\text{Then, } \Delta V = \alpha_V V_0 \Delta T$$

Change in volume of glass container:

$$\Delta V = 27 \times 10^{-6}/^{\circ}\text{C} \times 4\text{l} \times 20^{\circ}\text{C} = 2.16 \times 10^{-3}\text{l} = 0.00216\text{l}$$

Change in volume of water:

$$\Delta V = 2.1 \times 10^{-4}/^{\circ}\text{C} \times 4\text{l} \times 20^{\circ}\text{C} = 168 \times 10^{-4}\text{l} = 0.0168\text{l}$$

The change in volume of water is greater than the glass container, so some water spilled.

The volume of spilled water is $0.0168\text{l} - 0.00216 = 0.01464\text{l} \cong 0.015\text{l}$

Example 5: A plate of iron has shown in figure below. If the temperature is raised to 100°C and the coefficient of linear expansion of iron is $1.1 \times 10^{-7}/^{\circ}\text{C}$, then what is final area of plate?



Ans: Given: Length of plate, $l = 2\text{m}$, Width of plate, $w = 1\text{m}$

Initial area of plate, $A_0 = l \times w = 2\text{m} \times 1\text{m} = 2\text{m}^2$

$$\Delta T = 100^{\circ}\text{C} - 20^{\circ}\text{C} = 80^{\circ}\text{C}$$

Coefficient of linear expansion, $\alpha_L = 1.1 \times 10^{-7}/^{\circ}\text{C}$

Coefficient of area expansion, $\alpha_A = 2\alpha_L = 2 \times 1.1 \times 10^{-7}/^{\circ}\text{C} = 2.2 \times 10^{-7}/^{\circ}\text{C}$

Asked: Final area of plate, $A = ?$

$$\text{Formula: } A = \Delta A + A_0$$

$$\frac{\Delta A}{A_0} = \alpha_A \Delta T$$

$$\Delta A = \alpha_A A_0 \Delta T$$

$$\Delta A = 2.2 \times 10^{-7}/^{\circ}\text{C} \times 2\text{m}^2 \times 80^{\circ}\text{C} = 3.52 \times 10^{-5}\text{m}^2 = 0.0000352\text{m}^2$$

Final area of plate, $A = 2\text{m}^2 + 0.0000352\text{m}^2 = 2.0000352\text{m}^2$

Example 6: A steel container (Coefficient of linear expansion= $10^{-5}/^{\circ}\text{C}$) with volume of 6liters filled with acetone (the coefficient of volume expansion= $1.5 \times 10^{-3}/^{\circ}\text{C}$). If the container and acetone are heated from 0°C to 40°C , what is the volume of spilled acetone?

Ans: $V_0 = 6\text{l}$, $\Delta T = 40^{\circ}\text{C} - 0^{\circ}\text{C} = 40^{\circ}\text{C}$

Coefficient of linear expansion of steel, $\alpha_L = 10^{-5}/^{\circ}\text{C}$

Coefficient of volume expansion of steel container, $\alpha_V = 3\alpha_L = 3 \times 10^{-5}/^{\circ}\text{C}$

Coefficient of volume expansion of acetone, $\alpha_V = 1.5 \times 10^{-3}/^\circ\text{C}$

Asked: Volume of spilled water=?

Equation of expansion of volume;

$$\frac{\Delta V}{V_0} = \alpha_V \Delta T$$

$$\Delta V = \alpha_V V_0 \Delta T$$

Change in volume of steel container,

$$\Delta V = 3 \times 10^{-5}/^\circ\text{C} \times 6l \times 40^\circ\text{C} = 0.0072l$$

Change in volume of acetone,

$$\Delta V = 1.5 \times 10^{-3}/^\circ\text{C} \times 6l \times 40^\circ\text{C} = 360 \times 10^{-3}l = 0.36l$$

The change in volume of acetone is greater than that of steel container, so some acetone spills.

The volume of acetone spilled = $0.36l - 0.0072l = 0.3528l \cong 0.35l$

LO4.3. Apply gas laws

4.3.1. Physical properties of gases

1. Low density

- ✓ Gases contain scattered molecules that are dispersed across volume and are therefore less dense than in their solid or liquid states.
- ✓ Their low density gives fluidity, which allows gas particle to move rapidly and randomly past to one another, expanding or contracting with no fixed positions.

2. Indefinite shape or volume

- ✓ Gases have no definite shape or volume.
- ✓ The random movement of gas molecules allows them to expand or contract to assume that the volume of container holding them.
- ✓ Therefore, a gas's volume refers to the space of container in which its molecules have range to move.
- ✓ This property results in gases occupying more space than they would in their liquid or solid state.
- ✓ Gases also contract and expand by predictable amount depending upon changes in temperature and pressure.
- ✓ The freedom of gas molecules causes them to take the shape of any container in which they are placed. Filling container's volume.

3. compressibility and expandability

- ✓ Low density of gases makes them compressible since their molecules can be positioned far apart from one another.
- ✓ This allows them to move freely to fit into the gaps of space between them.
- ✓ Just as the gases are compressible, they are also expandable.

4. Pressure

- ✓ Gas molecules are constant motion.
- ✓ They exert pressure or force per unity area on the interior surface of container.
- ✓ The pressure varies according to the movement of gas confined to a given container's volume, the temperature and volume.

4.3.2. Force and energy of a gas system

➤ **Intermolecular force**

- ✓ It is the forces of interaction between atoms, molecules and ions when they are placed closer to each other.
- ✓ For gas, the intermolecular forces are extremely weak.
- ✓ They are negligible and the constituent particles are free to move. As a result, gases occupy any space available to them.

➤ **Molecular kinetic energy**

- ✓ It is energy produced when molecules are in motion.
- ✓ It is given by:

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

Where K is molecular kinetic energy, m is mass of molecule particle, v is velocity of molecule.

4.3.3. Gas laws

1. Boyle-Marriot law

- ✓ Boyle's law states the relation between volume and pressure at constant temperature and mass.
- ✓ **Statement:** "Under constant temperature, when pressure of gas increases, its volume decreases".
- ✓ In other words, according to Boyle's law, volume is inversely proportional to pressure when temperature and number of molecules are constant.

$$P \propto \frac{1}{V} \quad \leftrightarrow \quad P = \frac{k_1}{V}$$

Where k_1 is proportionality constant, V is volume, P is pressure.

- ✓ On rearranging,

$$k_1 = PV$$

- ✓ If a fixed mass of gas undergoes an expansion at constant temperature, then the final volume and pressure shall be P_2 and V_2 . The initial pressure and volume here are P_1 and V_1 .
- ✓ Then, according to Boyle's law;

$$P_1V_1 = P_2V_2 = \text{constant } (k_1)$$

$$\frac{P_1}{P_2} = \frac{V_2}{V_1}$$

2. Charles law

- ✓ He describes the effect of temperature on volume of gaseous substance at constant pressure.
- ✓ **Statement:** "At constant pressure and for constant mass, the volume of a gas is directly proportional to the temperature".

$$V \propto T \quad \leftrightarrow \quad V = k_2T \quad \leftrightarrow \quad k_2 = \frac{V}{T}$$

- ✓ If a fixed mass of gas undergoes expansion, final volume and final temperature are V_2 and T_2 respectively. Initial volume and initial pressure are V_1 and T_1 respectively.
- ✓ According to Charles;

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \text{constant } (k_2)$$

$$V_1T_2 = V_2T_1$$

3. Gay-Lussac law

- ✓ This law describes the effect of temperature on pressure at constant volume and mass of gas.
- ✓ **Statement:** “At constant volume and mass of gas, the pressure of that gas is directly proportional to the temperature”.

$$P \propto T \quad \leftrightarrow \quad P = k_3 T \quad \leftrightarrow \quad k_3 = \frac{P}{T}$$

- ✓ If a fixed mass of gas undergoes expansion, the final pressure and final temperature are P_2 and T_2 respectively. Initial pressure and initial temperature are P_1 and T_1 respectively.
- ✓ According to Gay-Lussac;

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} = \text{constant } (k_3)$$

$$P_1 T_2 = P_2 T_1$$

4. Avogadro's law

- ✓ This law describes the number of molecules on volume of gas at constant pressure and temperature.
- ✓ **Statement:** “At constant pressure and temperature, the volume of any gases is directly proportional to the number of molecules of that gas”.

$$V \propto n \quad \leftrightarrow \quad V = k_4 n \quad \leftrightarrow \quad k_4 = \frac{V}{n}$$

Where n is number of molecule of gas.

Note:

- The number of molecules in mole of any gas is known as Avogadro's constant and is equal to 6.022×10^{23}
- At standard temperature and pressure (STP), (1bar or $10^5 Pa$ and 273K),

$$n = \frac{m}{M}$$

- ✓ According to Avogadro's equation,

$$V = k_4 \frac{m}{M}$$

$$M = k_4 \frac{m}{V}$$

$$\frac{m}{V} = \text{density}(\rho) \quad \text{therefore, } M = k_4 \rho$$

$$k_4 = \frac{M}{\rho}$$

Where M is Molar mass.

For expansion of gas at constant pressure and temperature.

$$\frac{V_1}{n_1} = \frac{V_2}{n_2} = \text{constant } (k_4)$$

$$\frac{M_1}{\rho_1} = \frac{M_2}{\rho_2} = \text{constant } (k_4)$$

➤ Combined gas law

- ✓ Describes relationship between P, V, and T at constant mass of gas.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

5. Equation of state of Ideal gas

$$PV = nRT$$

Where P is pressure in Pascal (Pa) of gas, V is volume of gas m^3 , n is number of moles of gas in mol, T is temperature in kelvin, K , R is universal gas constant ($R = 8.3145 \text{ J/mol K}$).

Example: A jar whose volume is exactly 1liter which contains 1mole of air at temperature 20°C , assuming the air behaves as an ideal gas. So what is the pressure inside the jar in Pa?

Ans: Data: $V = 1\text{l} = 1\text{dm}^3 = 0.001\text{m}^3$, $n = 1\text{mol}$, $T = 20^\circ\text{C} = (20 + 273)\text{K} = 293\text{K}$

Asked: $P=?$

Ideal gas law: $PV = nRT$

$$\text{Then, } P = \frac{nRT}{V}$$

$$P = \frac{1\text{mol} \times 8.3145 \text{ J/mol K} \times 293\text{K}}{0.001\text{m}^3} = 2437249\text{Pa} = 2.437 \times 10^6\text{Pa}$$

LO4.4. Apply thermodynamic processes on a system

4.4.1. Key concept

✓ **Thermodynamic:** study of relations between heat, work, temperature and energy.

✓ There are three (3) types of thermodynamic system:

1. **Open system:** system exchange both energy and matter with its surroundings.

Examples: stove, automobile engine, human body, etc.

2. **Closed system:** system exchange only energy with its surroundings, not matter.

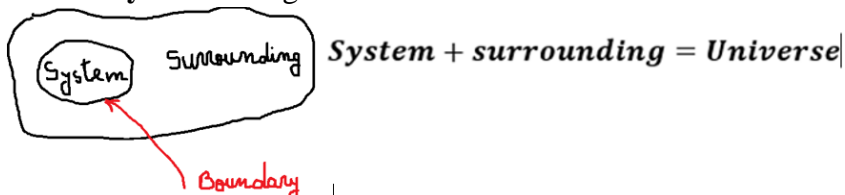
Examples: cup of water with lid on it.

3. **Isolated system:** Systems do not exchange either matter nor energy with its surroundings.

Examples: closed thermos bottle, combustion of glucose in bomb calorimeter, Universe, etc.

✓ **Surroundings:** Things and conditions around a person or thing.

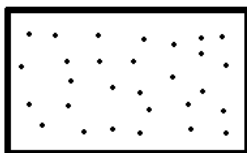
✓ **Boundary:** Something that indicates or fixes a limit or extent.



4.4.2. First law of thermodynamics

“The energy can neither be converted nor be destroyed in a chemical reaction, it is always conserved or the sum total energy of universe is conserved”.

✓ Let consider a system,



Internal energy: U_1

Heat absorbed: q

Work done on a system: W

Change in internal energy: U_2

$$U_2 = U_1 + q + W$$

$$U_2 - U_1 = q + W$$

$$\Delta U = q + W$$

We know that $W = -P\Delta V$

So, the above question can be written as:

$$\Delta U = q - P\Delta V$$

Where q is heat, P is pressure, V is volume.

✓ Internal energy: is total amount of kinetic energy and potential energy of all particles in system.

$$U = K_E + P_E$$

✓ **Energy:** ability of body to do a work.

4.4.2. Thermodynamic processes

✓ The state of a given thermodynamic system can be expressed by various parameters such as pressure (P), temperature (T), volume (V), and internal energy (U).

✓ Work of a given thermodynamic system is given by:

$$W = \int P dV$$

✓ The state of system can be changed by different processes. In thermodynamics, types of processes include (thermodynamic processes are):

1. Adiabatic process

✓ The process in which heat transfer is zero ($Q=0$)

✓ No heat is exchanged with system in an adiabatic process ($Q=0$).

$$PV = k \quad \leftrightarrow \quad P = \frac{k}{V}$$

We know that, $W = \int P dV$

Replace the value of P in W value, we get; $W = k \int \frac{dV}{V}$

From 1st law of thermodynamic, $Q = \Delta U + W \quad \leftrightarrow \quad \Delta U = -W \quad \text{as } Q = 0$

✓ Thus, the internal energy will increase if work done is negative and vice versa.

2. Isothermal process

✓ Process in which temperature (T) is kept constant, $\Delta T = 0$

✓ Temperature of system remains constant in an isothermal process.

✓ We know that,

$$W = \int P dV$$

From the gas law, $PV = nRT \quad \leftrightarrow \quad P = \frac{nRT}{V}$

Replace P in value of W, we get,

$$W = \int \frac{nRT}{V} dV \quad \leftrightarrow \quad W = \int nRT \frac{dV}{V}$$

$$W = nRT \int_{V_1}^{V_2} \frac{dV}{V}$$

$$W = nRT \ln \frac{V_2}{V_1}$$

- ✓ Since the internal energy is temperature-dependent, $\Delta U = 0$ because temperature is constant and thus from 1st law of thermodynamics ($Q = \Delta U + W$), we will get $Q = W$

3. Isobaric process

- ✓ Process in which pressure, P is kept constant ($\Delta P = 0$)
- ✓ Since pressure, P is constant in this process, the volume of system changes.

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

- ✓ If ΔV is positive, W is positive.
- ✓ If ΔV is negative, W is negative.

4. Isochoric process

- ✓ Process in which volume, V is kept constant ($\Delta V = 0$).
- ✓ Therefore, the system do not any work (since $\Delta V = 0$, $P\Delta V$ or W is zero).

Exercises

1. A 0,5 moles of gas at temperature 300K expands isothermally from an initial volume of 2l to 6l.

- a) What is the work done by the gas?
- b) Estimate the heat added to the gas?
- c) What is the final pressure of gas? (the volume of gas constant, $R = 8.314 J/mol K$)

Ans: Data $n = 0.5 mol$, $T = 300K$ (constant), $V_f = 6l$, $V_i = 2l$

Asked: a) $W = ?$, b) $Q = ?$, c) $P_f = ?$

$$a) W = nRT \ln \frac{V_f}{V_i} = 0.5 mol \times 8.314 J mol^{-1} K^{-1} \times 300K \times \ln \frac{6}{2} = 1370.07J$$

$$W = 1.37kJ$$

b) From 1st law of thermodynamic,

$$Q = \Delta U + W \quad \text{and} \quad \Delta U = 0$$

$$\text{Then, } Q = W = 1.37kJ$$

c) For isothermal process,

$$P_f V_f = nRT$$

$$P_f = \frac{nRT}{V_f}$$

$$P_f = \frac{0.5 mol \times 8.314 J mol^{-1} K^{-1} \times 300K}{6 \times 10^{-3} m^3} = 207750 Pa = 207.75 kPa$$

2. A gas has a volume of $0.02 m^3$ at pressure of $2 \times 10^5 Pa$ and a temperature of $27^\circ C$. It is heated at constant pressure until its volume increases to $0.03 m^3$. Calculate the:

- i) External work done
- ii) New temperature of the gas.
- iii) Increase in internal energy of the gas if its mass is 16g, its molar heat capacity at constant volume is $0.8 J mol^{-1} K^{-1}$ and the molar mass is 32g.

Ans: Data:

$$V_1 = 0.02\text{m}^3, V_2 = 0.03\text{m}^3, P_1 = P_2 = 2 \times 10^5\text{Pa}, C_V = 0.8\text{Jmol}^{-1}\text{K}^{-1},$$

$$T = 27^\circ\text{C} = (27 + 273)\text{K} = 300\text{K}, m = 16\text{g}, M_m = 32\text{g}$$

i) External work done

$$W = P\Delta V = 2 \times 10^5\text{Pa}(0.03\text{m}^3 - 0.02\text{m}^3) = 2 \times 10^3\text{J}$$

ii) From,

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

$$\frac{0.02}{300} = \frac{0.03}{T_2}$$

$$T_2 = 450\text{K}$$

iii) Increase in internal energy,

$$\Delta U = nC_V\Delta T$$

$$n = \frac{m}{M_m} = \frac{16\text{g}}{32\text{g/mol}} = 0.05\text{mol}$$

$$\Delta U = 0.05\text{mol} \times 0.8\text{Jmol}^{-1}\text{K}^{-1}(450\text{K} - 300\text{K}) = 60\text{J}$$

3. An ideal gas at 17°C has a pressure of 760mmHg is compressed (i) isothermally, (ii) adiabatically, until its volume is halved.

Calculate in each case the final temperature and pressure of the gas. Assume that $C_p = 2100\text{Jmol}^{-1}\text{K}^{-1}$ and $C_v = 1500\text{Jmol}^{-1}\text{K}^{-1}$.

LU5. EXAMINE CURRENT FLOW EFFECTS IN DC ELECTRIC CIRCUIT

LO5.1: Describe a simple electric circuit.

5.1.1. Simple DC electric circuit

- ✓ **Simple DC electric circuit** is a circuit that contains the three basic components needed for an electric circuit to function.
- ✓ Three basic components are
 1. **Source of voltage**
 2. **Conductor**
 3. **Resistor**
- ✓ **Electric current** is movement of electrons or ions through an electrical conductor or space.
- ✓ It is measured in **Ampere (A)**.
- ✓ **Electrical resistance** is the electrical quantity that measures how device or material reduces the electric current flow through it.
- ✓ It is a ratio between the voltage applied to the current flowing through it.

$$R = \frac{V}{I}$$

- ✓ It is measured in **Ohms (Ω)**
- ✓ **Voltage** is difference in electric potential between two points.
- ✓ It is measured in **Volt (V)**

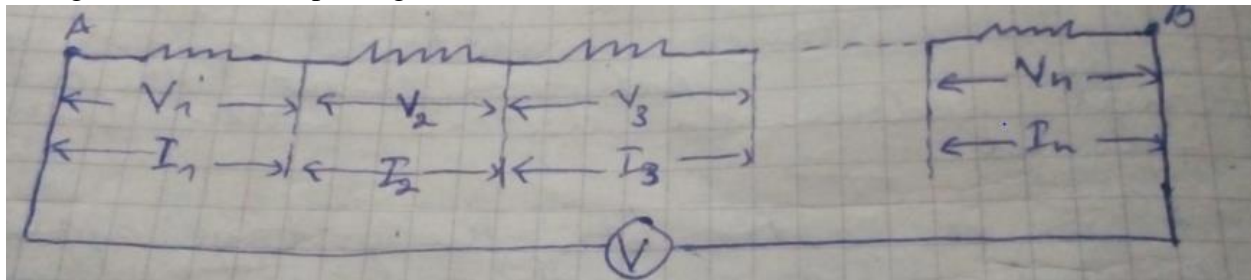
5.1.2. Measuring instruments used in simple DC electric circuit

1. **Ammeter:** Instrument used to measure current in circuit.
2. **Voltmeter:** Instrument used to measure potential difference or voltage between two points in electrical circuit.
3. **Ohmmeter:** Electrical instrument used to measure resistance.
4. **Multimeter:** Electrical instrument used to measure more than one parameters like potential difference, current, resistance, frequency, capacitance, etc.

5.1.3. Combination of resistors

➤ In series

Let $R_1, R_2, R_3, \dots, R_n$ be the individual resistance which are connected in series, V is applied voltage and I is current passing in the circuit.



- ✓ The current flow, I in this circuit is the same.
i.e. $I = I_1 = I_2 = I_3 = \dots = I_n$
- ✓ The voltage in each resistor is different. Then, total voltage, V is given by:

$$V_T = V_1 + V_2 + V_3 + \dots + V_n$$

- ✓ According to Ohm's law, $V_T = IR_T$

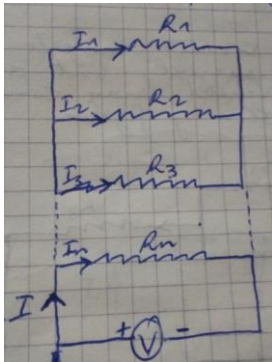
$$V_1 = IR_1$$

$$V_3 = IR_3$$

- $V_2 = IR_2$ $V_n = IR_n$
 ✓ Then, $V_T = V_1 + V_2 + V_3 + \dots + V_n$ becomes
 $IR_T = IR_1 + IR_2 + IR_3 + \dots + IR_n$
 $IR_T = I(R_1 + R_2 + R_3 + \dots + R_n)$
 $R_T = \frac{I}{I}(R_1 + R_2 + R_3 + \dots + R_n)$
 $R_T = R_1 + R_2 + R_3 + \dots + R_n$
 (**Total resistance in series**)

2. In parallel

Let $R_1, R_2, R_3, \dots, R_n$ be the individual resistance which are connected in parallel, V is applied voltage and I is current passing through the circuit.



- ✓ The voltage across to each resistor is the same in parallel connection.
 i.e. $V = V_1 = V_2 = V_3 = \dots = V_n$
 ✓ The current across to each resistor in parallel connection is different.
 i.e. $I_T = I_1 + I_2 + I_3 + \dots + I_n$ where I_T is total current.
 ✓ According to Ohm's law, $I_T = \frac{V}{R_T}$

$$I_1 = \frac{V}{R_1} \qquad I_3 = \frac{V}{R_3}$$

$$I_2 = \frac{V}{R_2} \qquad I_n = \frac{V}{R_n}$$

Then, $I_T = I_1 + I_2 + I_3 + \dots + I_n$ will be,

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \dots + \frac{V}{R_n}$$

$$\frac{V}{R_T} = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \right)$$

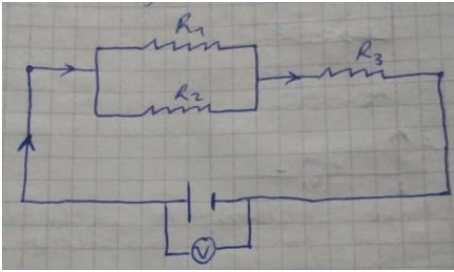
$$\frac{1}{R_T} = \frac{V}{V} \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \right)$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

(**Total resistance in parallel**)

3. In mixed

- ✓ Sometimes, the circuit may be neither pure series nor pure parallel, but a combination of series and parallel may come across as shown in the following figure:

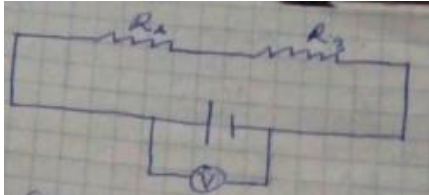


- ✓ R_1 and R_2 are connected in parallel.
Let R_A be total resistance connected in parallel. Then,

$$\frac{1}{R_A} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_A = \frac{R_1 R_2}{R_1 + R_2}$$

- ✓ After finding R_A , R_1 and R_2 is replaced by R_A

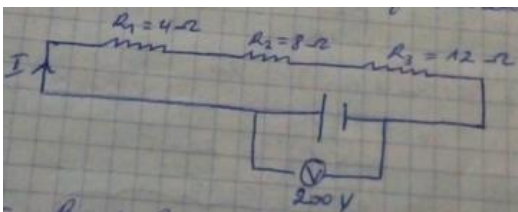


- ✓ R_A and R_3 are connected in series. Then, total resistance will be, $R_T = R_A + R_3$

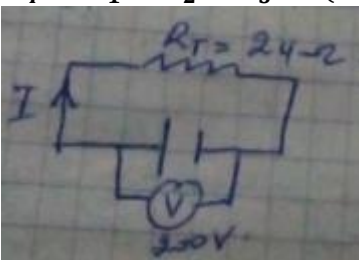
Example 1. Three resistances 4Ω , 8Ω and 12Ω are connected in series across a generator, which maintains a potential of $200V$.

- Draw this circuit.
- What is the resistance of circuit?
- What is the value of current?

Ans:



-
- $R_T = R_1 + R_2 + R_3 = (4 + 8 + 12)\Omega = 24\Omega$



-
-
-

$$V_T = IR_T \quad \leftrightarrow \quad I = \frac{V_T}{R_T}$$

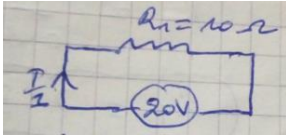
$$I = \frac{200V}{24\Omega} = 8.33A$$

Example2: A circuit has 20V battery across resistance $R_1 = 10\Omega$,

a) How many currents will flow in the circuit?

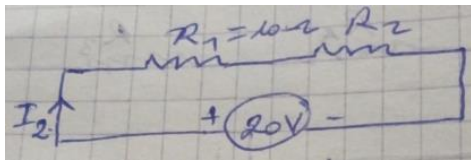
b) How much resistance R_2 should be added in series with R_1 to reduce the current to one fourth?

Ans:



a)

$$I_1 = \frac{V}{R_1} = \frac{20V}{10\Omega} = 2A$$



b)

$$I_1 = 2A$$

$$I_2 = \frac{1}{4}I_1 = \frac{2A}{4} = 0.5A$$

$$R_T = R_1 + R_2, \quad R_1 = 10\Omega$$

$$R_T = 10 + R_2$$

$$I_2 = \frac{V}{R_T}$$

$$0.5 = \frac{20}{10 + R_2}$$

$$0.5(10 + R_2) = 20$$

$$5 + 0.5R_2 = 20$$

$$0.5R_2 = 20 - 5$$

$$0.5R_2 = 15$$

$$R_2 = \frac{15}{0.5}$$

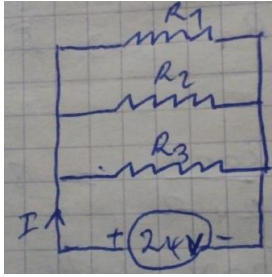
$$R_2 = 30\Omega$$

Example3: Three resistances of 15Ω , 25Ω and 35Ω are connected in parallel across a 24V battery. Calculate the current supplied by battery.

Ans: Data: $R_1 = 15\Omega$, $R_2 = 25\Omega$, $R_3 = 35\Omega$ connected in parallel.

Asked: $I = ?$

Formula: $I = \frac{V}{R_T}$



In parallel circuit;

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

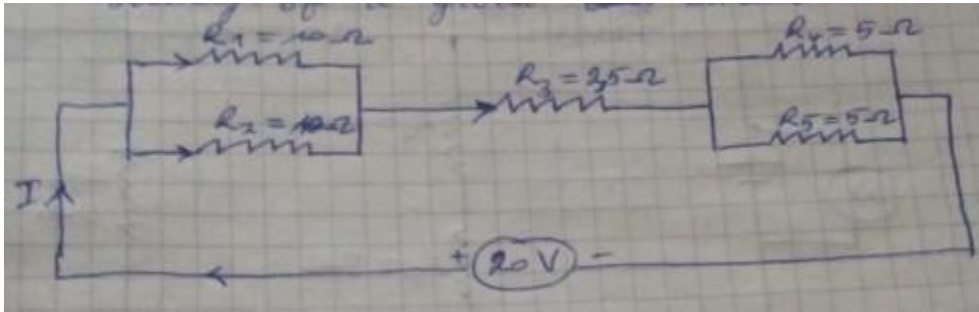
$$\frac{1}{R_T} = \frac{1}{15} + \frac{1}{25} + \frac{1}{35}$$

$$\frac{1}{R_T} = 0.13523$$

$$R_T = \frac{1}{0.13523} \quad \leftrightarrow \quad R_T = 7.39\Omega$$

$$\text{Then, } I = \frac{24V}{7.39\Omega} = 3.247A$$

Example4: Find equivalent resistance and current supplied by the battery of a given circuit.



Ans: Asked: $R_{eq} = ?$ And $I = ?$

✓ R_1 and R_2 are connected in parallel.

Let R_A be total resistance to this connection.

$$\frac{1}{R_A} = \frac{1}{R_1} + \frac{1}{R_2}$$

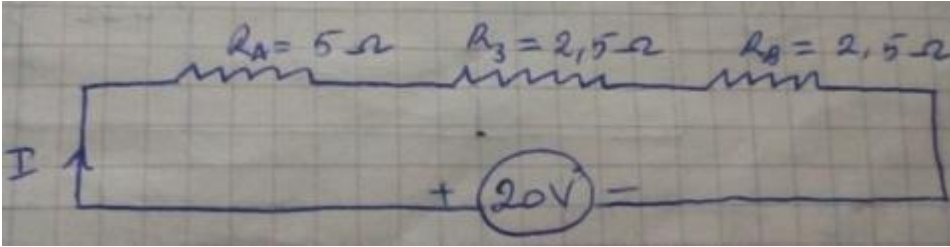
$$R_A = \frac{R_1 R_2}{R_1 + R_2} = \frac{10\Omega \times 10\Omega}{10\Omega + 10\Omega} = \frac{100\Omega^2}{20\Omega} = 5\Omega$$

✓ R_4 and R_5 are connected in parallel and let R_B be total resistance for this connection.

$$\frac{1}{R_B} = \frac{1}{R_4} + \frac{1}{R_5}$$

$$R_B = \frac{R_4 R_5}{R_4 + R_5} = \frac{5\Omega \times 5\Omega}{5\Omega + 5\Omega} = \frac{25\Omega^2}{10\Omega} = 2.5\Omega$$

✓ Then, R_A , R_3 and R_B are connected in series



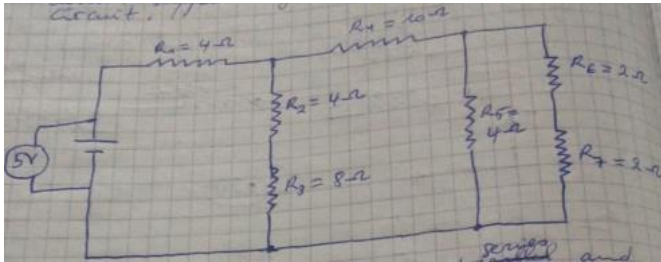
$$R_{eq} = R_A + R_B + R_C$$

$$R_{eq} = 5\Omega + 2.5\Omega + 2.5\Omega = 10\Omega$$

Current supplied by battery, $I = \frac{V}{R_{eq}}$

$$I = \frac{20V}{10\Omega} = 2A$$

Example5: Calculate equivalent resistance and current supplied by battery for the following circuit.



5.1.4. Ohm's law

Ohm's law states that "the current through a conductor between two points is directly proportional to the voltage across two points".

$$I \propto V \quad \leftrightarrow \quad V = IR$$

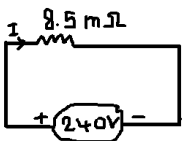
Where **R**: Resistance is constant

$$R = \frac{V}{I}$$

The SI unit of resistance is **Ohm (Ω)**

Example: An accidental short circuit to 240V supply is caused by the connection of component of $8.5m\Omega$ across the supply terminals. What will be the short circuit current?

Ans:



By Ohm's law, $V = IR$

$$I = \frac{V}{R} = \frac{240V}{8.5 \times 10^{-3}\Omega} = 28.23 \times 10^3 A$$

Short circuit current is **28.23 kA** (**kA**: Kiloampere)

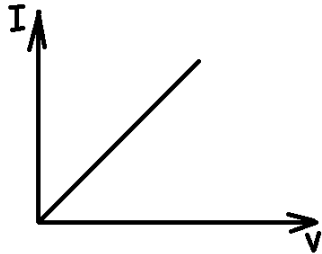
❖ Voltage-Current characteristic of resistor

➤ Ohmic resistors

✓ I-V graph for Ohmic resistor is straight line.

- ✓ The curve passes through the origin, which means that for zero potential difference, we have zero current.
- ✓ The current is directly proportional to potential difference. The proportionality constant is **resistance**.

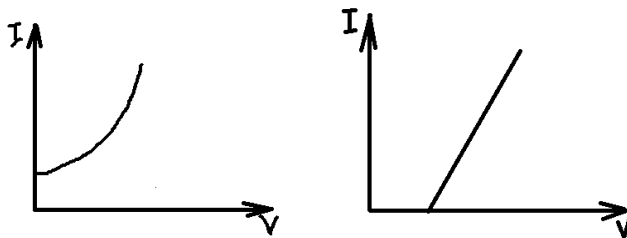
Eg: Resistors made of Margarine



➤ **Non- Ohmic resistors**

- ✓ I-V graph for non-Ohmic material is a straight non-linear curve.
- ✓ The curve does not pass through the origin.
- ✓ Current is not proportional to the voltage.

Eg: Junction chide or electrolyte.



5.1.5. Electric cells

- ✓ Electric cell is electrical power supply.
- ✓ It converts stored chemical energy into electrical potential energy, allowing positive charges to flow from positive terminal to negative terminal one through external circuit.
- ✓ Electromotive force, emf: energy supplied by battery or cell per Coulomb (Q) of charge passing through it.

$$emf = \frac{E}{Q} \quad or \quad e = \frac{E}{Q}$$

Where e is electromotive force (V), E is energy (J), Q is charge (Coulomb, C)

- ✓ emf formula can also be written as,

$$e = IR + Ir \quad or \quad e = V + Ir$$

Where e is electromotive force (V), I is current (A), R is load resistance (Ω), r is internal resistance of cell (Ω).

$$e = I(R + r)$$

Example: Find the terminal potential difference of cell when it is connected to a 9Ω load with cell $emf = 2V$ and internal resistance 1Ω .

Ans: Data: $e = 2V$, $r_{ext} = 9\Omega$, $r_{int} = 1\Omega$

Asked: $V = ?$

$$As, \quad I = \frac{V}{R}$$

$R = \text{Internal resistance} + \text{External resistance}$

$$R = r_{int} + r_{ext} = 1\Omega + 9\Omega = 10\Omega$$

$$\text{then, } I = \frac{2V}{10\Omega} = 0.2A$$

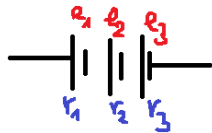
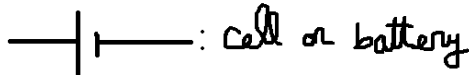
$$e = V + Ir_{int}$$

$$V = e - Ir_{int}$$

$$V = 2V - (0.2A \times 1\Omega) = 2V - 0.2V = 1.8V$$

❖ Cells network

➤ Cells in series connection

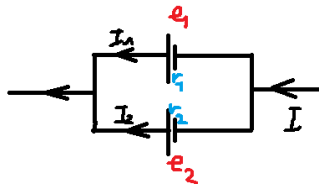


Let $e_1, e_2, e_3, \dots, e_n$ be emf of individual cell and $r_1, r_2, r_3, \dots, r_n$ be internal resistance of individual cell.

$$e_T = e_1 + e_2 + e_3 + \dots + e_n$$

$$r_T = r_1 + r_2 + r_3 + \dots + r_n$$

➤ Cell in parallel connection

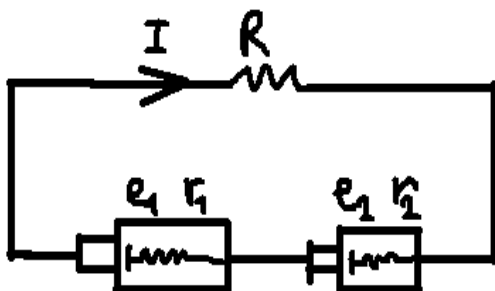


$$\frac{e_T}{r_T} = \frac{e_1}{r_1} + \frac{e_2}{r_2} + \frac{e_3}{r_3} + \dots + \frac{e_n}{r_n}$$

$$\frac{1}{r_T} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots + \frac{1}{r_n}$$

And, $I = I_1 + I_2$

Example: Two cells of emf, e_1 , and e_2 and resistance, r_1 and r_2 respectively are connected in series across a resistor, $R = 7\Omega$.



$$e_1 = 8.0V$$

$$e_2 = 2.0V$$

$$r_1 = 2.0\Omega$$

$$r_2 = 1.0\Omega$$

What is the current, I in this circuit?

Ans:

$$I = \frac{e_T}{r_T}$$

$$e_T = e_1 + e_2 = 8V + 2V = 10V$$

$$r_T = R + r_1 + r_2 = 7\Omega + 2\Omega + 1\Omega = 10\Omega$$

then, $I = \frac{10V}{10\Omega} = 1A$

LO5.2. Determine electric current, resistance and voltage in DC electric circuit

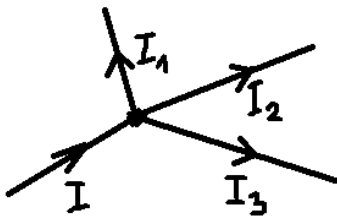
5.2.1. Key concepts

- ✓ **Junction:** Point at which at least three circuit paths meet
- ✓ **Branch:** It is a path connecting two junctions.
- ✓ **Path:** It is a continuous and closed loop. Path consists of conductors or wires and battery.
- ✓ **Voltage supply:** Voltage obtained from power source for operation of a circuit or device.
- ✓ **Voltage drop:** Reduction in an electrical circuit between the source and the load.
- ✓ **Voltage gain:** Difference between output signal voltage level in decibels and input signal voltage level in decibels.

5.2.2 Kirchhoff's laws

1st law of Kirchhoff: It is also known as **Kirchhoff's current law (KCL)**.

“The current flowing into a node (or junction) must be equal to the current flowing out of it”.



$$I = I_1 + I_2 + I_3$$

Or, “The algebraic sum of currents meeting at electric junction in network is equal to zero”.

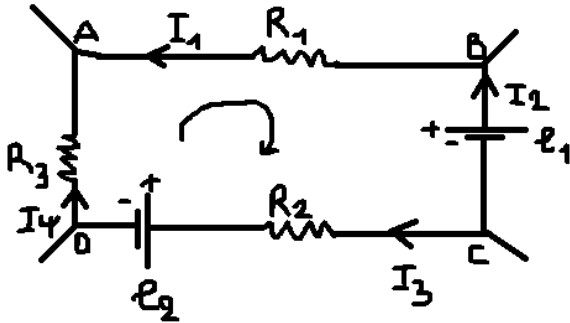
Assuming that currents entering in junction be positive and current out the junction be negative.

$$I + (-I_1) + (-I_2) + (-I_3) = 0$$

2nd law of Kirchhoff: It is also known as **Kirchhoff's law of voltage (KLV)**.

“In any closed mesh or path, the algebraic sum of the products of current and resistance in each of the conductor plus the algebraic sum of the emf's in that path is equals to zero”.

- ✓ We sign **positive sign to voltage rise**. i.e. if we start from the **negative terminal** of the battery to its **positive terminal**.
- ✓ We sign **negative sign to voltage drop**. i.e. if we start from the **positive terminal** of the battery to its **negative terminal**.
- ✓ Consider a closed mesh ABCDA as shown in the following figure.



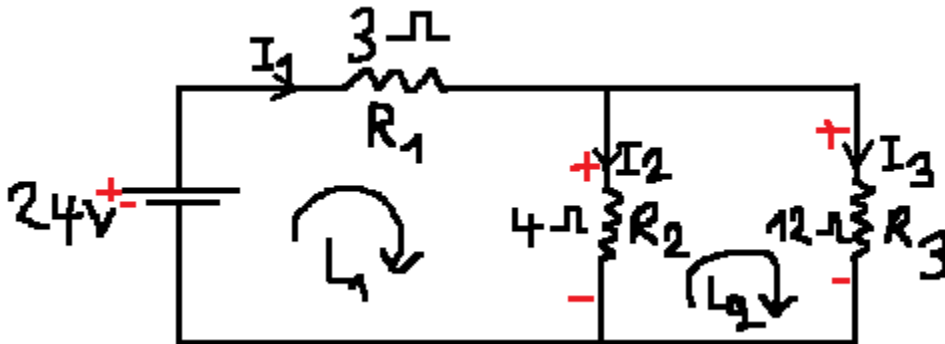
- ✓ Starting from point A and traveling through B to C to D to A.
- ✓ Signs or different voltage sources and voltage drops are as flows
- ✓ Let $I_1, I_2, I_3,$ and I_4 are assumed direction through A-B, B-C, C-D, and D-A.
- ✓ I_1R_1 is a rise in voltage, so, **positive**.
- ✓ I_3R_2 is a voltage drop, so **negative**.
- ✓ I_4R_3 is a voltage drop, so **negative**.
- ✓ e_1 is a decrease in potential, so **negative**.
- ✓ e_2 is a rise in potential, so **positive**.

Now, apply KVL to mesh ABCDA

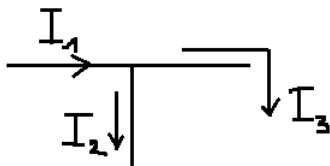
$$I_1R_1 - e_1 - I_3R_2 + e_2 - I_4R_3 = 0$$

$$\text{Or } I_1R_1 - I_3R_2 - I_4R_3 = e_1 - e_2$$

Example: Using Kirchhoff's laws calculate the current in each branch of the circuit shown in the following figure.



Ans: Using 1st law of Kirchhoff (or KLC)



$$\sum I_{in} = \sum I_{out}$$

$$I_1 = I_2 + I_3 \quad (1)$$

Using KLV (2nd law)

$$\sum V = 0 \quad \text{and we know that } V = IR$$

$$\sum V = 0$$

$$i.e. \quad V + V_1 + V_2 + V_3 = 0$$

$$V_1 = I_1 R_1 = 3I_1$$

$$V_2 = I_2 R_2 = 4I_2$$

$$V_3 = I_3 R_3 = 12I_3$$

$$\text{For } L_1 : \quad +24 - 3I_1 - 4I_2 = 0$$

$$\text{Then,} \quad 3I_1 + 4I_2 = 24 \quad (2)$$

$$\text{For } L_2 : \quad +4I_2 - 12I_3 = 0$$

$$\text{Then,} \quad 4I_2 - 12I_3 = 0 \quad (3)$$

Solve the system of three equations;

$$\begin{cases} I_1 = I_2 + I_3 & (1) \\ 3I_1 + 4I_2 = 24 & (2) \\ 4I_2 - 12I_3 = 0 & (3) \end{cases}$$

Replace equation (1) in equation (2), we get,

$$24 = 3(I_2 + I_3) + 4I_2$$

$$24 = 3I_2 + 3I_3 + 4I_2$$

$$24 = 7I_2 + 3I_3$$

$$7I_2 + 3I_3 = 24 \quad (4)$$

Solve equations (3) and (4),

$$\begin{cases} 4I_2 - 12I_3 = 0 & (3) \\ 7I_2 + 3I_3 = 24 & (4) \end{cases}$$

$$\begin{cases} 4I_2 - 12I_3 = 0 & (3) \\ 7I_2 + 3I_3 = 24 & (4) \end{cases}$$

Multiply 4 on the equation (4), we get,

$$\begin{cases} 4I_2 - 12I_3 = 0 \\ 28I_2 + 12I_3 = 96 \end{cases}$$

$$32I_2 = 96$$

$$I_2 = \frac{96}{32} \quad \leftrightarrow \quad I_2 = 3A$$

$$\text{As} \quad 4I_2 - 12I_3 = 0$$

$$4I_2 = 12I_3$$

$$I_3 = \frac{1}{3}I_2$$

$$I_3 = \frac{1}{3} \times 3A \quad \leftrightarrow \quad I_3 = 1A$$

$$\text{As} \quad I_1 = I_2 + I_3$$

$$I_1 = 3A + 1A = 4A \quad \leftrightarrow \quad I_1 = 4A$$

LO5.3. Determine electric energy, work and power in DC electric circuit

5.3.1. Law of conservation of energy

“Energy can neither be created nor destroyed only converted from one form of energy to another”.

$$K_E + P_E = \text{Constant}$$

- ✓ **Electric power:** Type of kinetic energy caused by moving electric charges.
- ✓ It is energy derived as a result of movement of electrically charged particle.
- ✓ **Electric power:** Amount of energy produced per second.

- ✓ It is the rate at which electric energy is transferred.
- ✓ It is commonly expressed in megawatts (MW).

5.3.2. Calculations of energy and power in DC electric circuit

- ✓ **Electrical energy:** It is capacity to do work and unit of work or energy in **Joule (J)**.

$$\text{Electrical energy} = \text{Power (W)} \times \text{Time (s)}$$

$$1W = 1J/s$$

From this equation, we can find power.

$$\text{Power} = \frac{\text{Electrical energy (E)}}{\text{Time (t)}}$$

➤ **Electrical power**

$$\text{Power} = \text{Voltage} \times \text{Current}$$

$$P = VI \quad (1)$$

We know that $I = \frac{V}{R}$ (2), Ohm's law

Replace (2) in (1),

$$P = V \cdot \frac{V}{R}$$

$$P = \frac{V^2}{R}$$

Again, $V = RI$, $P = RI \cdot I$

$$P = RI^2$$

$$\text{Hence, } P = \frac{V^2}{R} \quad \text{or} \quad P = RI^2$$

Where **R** is resistance

Example1: A 100W bulb normally takes 0.833A and 200W bulb takes 1.666A from the 120V power line. If these two bulbs were connected in series across a 240V power line prove that the current would be 1.111A in both bulbs assuming the resistance remain constant.

Ans: We know that bulbs are connected in series and

$$P = VI \quad \text{or} \quad P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P}$$

At normal conditions,

- Resistance of 100W bulb, $R_1 = \frac{(120V)^2}{100J/s} = 144\Omega$
- Resistance of 200W bulb, $R_2 = \frac{(120V)^2}{200J/s} = 72\Omega$
- Total resistance in circuit, $R_T = R_1 + R_2$
 $R_T = 144\Omega + 72\Omega = 216\Omega$
- Current in circuit,

$$I = \frac{V_{\text{applied}}}{R_T}$$

$$I = \frac{240V}{216\Omega} = 1.111A$$

The current in the circuit is 1.111A, hence proved.

Example2: A 220V – 5A electrical lamp is used for 30min. How much energy does it require?

Ans: Data: Voltage, $V = 220V$, current, $I = 5A$,

time, $t = 30min = (30 \times 60)sec = 1800sec$

Electric power, $P = VI$

$$P = VI$$

$$P = 220V \times 5A = 1100W = 1100 J/s$$

Then, *Electrical energy = Electrical power \times Time*

$$E = P \times t$$

$$E = 1100 J/s \times 1800s = 1980000J = 1980kJ$$

Example3: A 220V – 60W solder is used for 4min. How much energy does it require?

Ans: $P = 60W = 60 J/s$

Time $t = 40min = (40 \times 60)sec = 240sec$

Voltage, $V = 220V$

Asked: Electrical energy, $E = ?$

$$P = \frac{E}{t}$$

$$E = P \times t$$

$$E = 60 J/s \times 240s = 14400J$$

Example4: The energy used by the iron for 1min is 33kJ, at a voltage of 220V. How large the current is in the iron?

Ans: Data:

Time interval, $t = 1min = 60sec$

Energy, $E = 33kJ = 33000J$

Voltage, $V = 220v$

Asked: Current, $I = ?$

Power, $P = \frac{\text{Energy}}{\text{Time}}$

$$P = \frac{33000J}{60sec} = 550 J/s$$

$$P = VI \quad \leftrightarrow \quad I = \frac{P}{V}$$

$$I = \frac{P}{V} = \frac{550 J/s}{220V} = 2.5A$$

5.3.3. Effects associated with electric current in a circuit

1. Heating effect or Joule's effect

✓ The electrons moving in conductor cause the conductor to heat up.

✓ The amount of heat generated depends up on:

1. The amount of current flowing
2. Dimensions of the conductors

3. Type of conductor material used.

- ✓ Practical applications of heating effect on electric current are:
 1. Radiant heating which heat rooms
 2. Circuit protection fuses and MCB_s which cut off supply when an over current flows

2. Magnetic effect

- ✓ Whenever current flows in a conductor a magnetic field is set up around the conductor like an extension of the insulation more about this later
- ✓ Increasing current increases the magnetic field.
- ✓ Switching the current off causes the magnetic field to collapse
- ✓ Practical applications of magnetic effect are:
 1. Electrical motors which rotate because of magnetic flux generated by electrical supply
 2. Door chimes and buzzers which ding dong or buzz because of the magnetic flux generated by the electrical supply

3. Chemical effect

- ✓ When an electric current flows through a conducting liquid, the liquid separates into its chemical parts a process called electrolysis.
- ✓ Alternatively, if two metals are placed in conducting liquid they react chemically and produce voltage.
- ✓ Practical applications of chemical effect are:
 1. Processes such as electroplating which is used to silver plate sports trophies and cutlery.
 2. Motor car batteries which store electrical energy.

LU6. APPLY GEOMETRIC INSTRUMENT

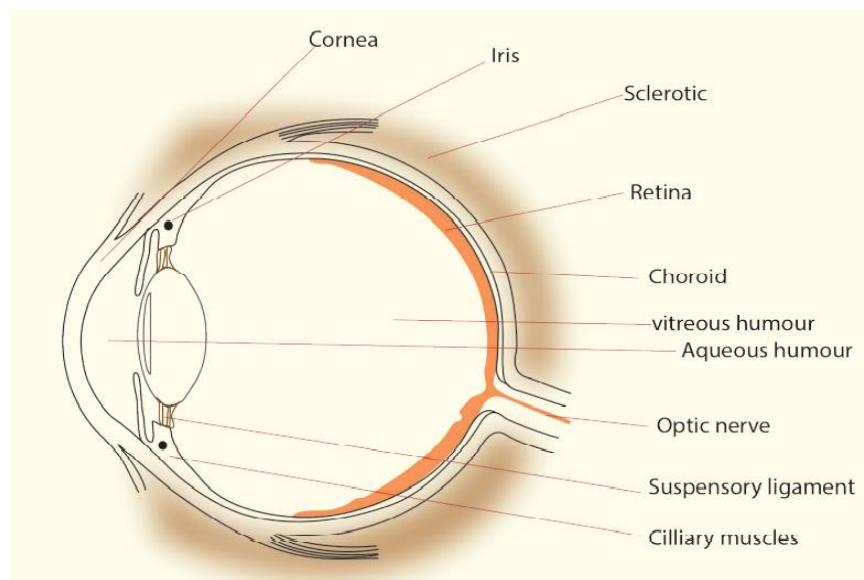
LO6.1. Describe types of optical instruments

- ✓ **Optical instruments** are all instruments used to aid vision.
- ✓ They are devices which process light wave to enhance an image for more clear view.

6.1.1. Single lens optical instruments

1. Human eyes

- ✓ **Eye** is biological instrument used to see objects at different distances.
- ✓ It uses a **convex lens** system to form **small, inverted**, and **real image** of an object in front of it.



➤ Functions of the parts of the eye

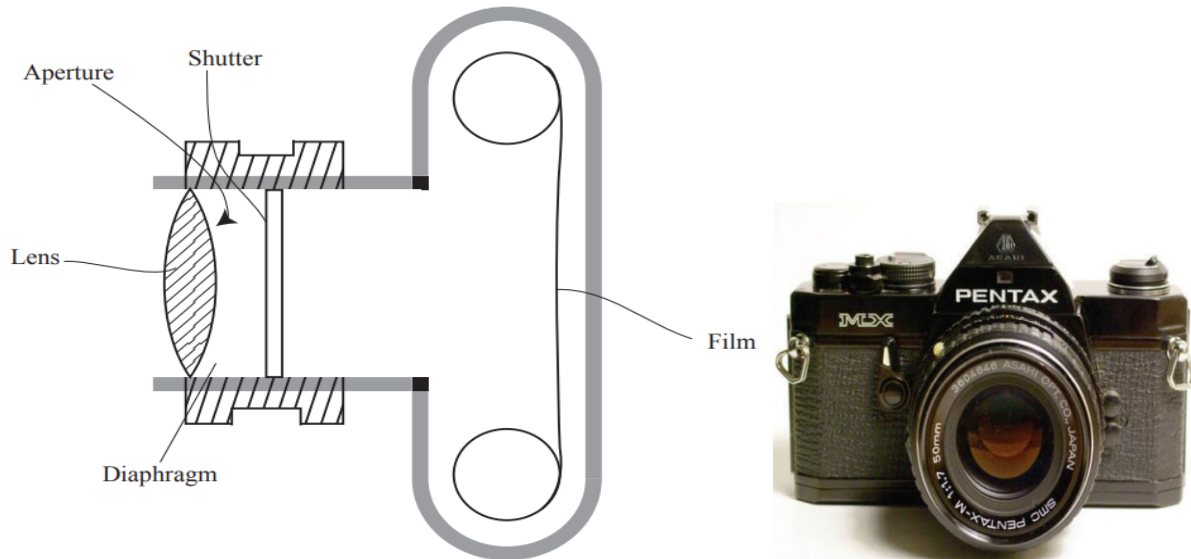
- ✓ **The cornea:** It is made out of a fairly dense, jelly like material which provides protection for the eye, and seals in the aqueous humour. It also provides most of the power of the eye (59 Dioptres), having about 46 Dioptres. So it provides most of the bending of light rays.
- ✓ **The aqueous humour:** This is a watery liquid that helps to keep the cornea in a rounded shape, similar to that of a lens.
- ✓ **The iris:** This controls the amount of light entering the eye.
- ✓ **The lens:** This is used to focus an image on the retina. It controls the bending of light rays by change of its shape, a process called accommodation, which is done by the ciliary muscles.
- ✓ **The ciliary muscles:** These control the thickness of the lens during focusing.
- ✓ **The retina:** This is the light sensitive part of the eye and it is where images are formed.
- ✓ **The vitreous humour:** This is a jelly like substance that helps the eye to keep its round shape.
- ✓ **The yellow spot:** This is a small area on the retina where the sharpest image, that is, the finest detail can be seen.
- ✓ **The optic nerve:** This is the nerve that transmits images received by the retina to the brain for interpretation.

2. Magnifying glass

- ✓ **Magnifying glass** is convex lens that is used to produce a magnified image of an object.
- ✓ A magnifying glass forms a **virtual, upright, magnified image** of an object placed between the lens and its principal focus.

3. Single lens camera

- ✓ Camera that typically uses a mirror and prism system that permits the photographer to view through the lens and see exactly what we will be captured.
- ✓ It uses the **convex lens** to form a **small, inverted, real image** on the film at the back.



- ✓ **The lens** focuses light from the object onto a light sensitive film. It is moved to and fro so that a sharp image is formed on the film.
- ✓ **The diaphragm** is a set of sliding plates between the lens and the film. It controls the aperture (diameter) of a hole through which light passes.
- ✓ **The aperture** controls the depth of field of the lens camera.
- ✓ **The shutter** controls the exposure time of the film. It opens and closes quickly to let a small amount of light into the camera.
- ✓ **The exposure time** affects the sharpness of the image. When the exposure time is short, the image is clear (sharp) but when it is long the image becomes blurred.
- ✓ **The film:** This is where the image is formed. It is kept in darkness until the shutter is opened. It is coated with light sensitive chemicals which are changed by the different shades and colours in the image.

✓

6.1.2. Multi-lens optical instruments

- ✓ **Multiple lenses** are devices like telescopes and microscopes which use multiple lenses to create images.

1. Telescope

- ✓ It is an optical instrument using lenses, curved mirrors, or combination of both to observe distant objects.
- ✓ It is also defined as various devices used to observe distant object by emission, absorption, or reflection of electromagnetic radiation.

2. Projector

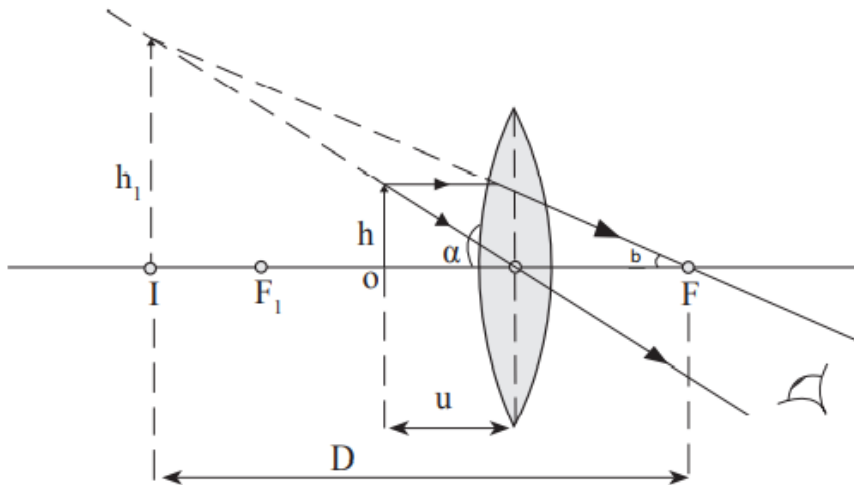
- ✓ It consists of illumination system and projection lens.
- ✓ Illumination system consists of lamp, concave reflector and the condenser.

- ✓ Illuminant is either a carbon electric arc or quartz lamp to give small but very high intensity source of light in order to make image brighter.

LO6.2. Determine the magnification of optical instruments

6.2.1. Magnification of microscope

➤ Magnification of microscope in normal adjustment



- ✓ Consider an object of height h placed at a given distance from the lens.
- ✓ Let β be the angle subtended by the image I to the lens.
- ✓ From the figure, $\tan \beta = \frac{h_i}{D}$
- ✓ Assuming that rays are paraxial and that the eye is very close to the lens.
- ✓ It implies that β is very small and $\tan \beta \approx \beta$.

$$\text{Thus, } \beta = \frac{h_i}{D} \quad (1)$$

- ✓ Now suppose that the object is viewed at the near point by the unaided eye and that it subtends an angle of α at the eye.

$$\text{Now, } \tan \alpha = \frac{h}{D}$$

- ✓ For small α , $\tan \alpha \approx \alpha$

$$\text{Thus, } \alpha = \frac{h}{D} \quad (2)$$

- ✓ It follows that the magnifying power (angular magnification) M is given by

$$M = \frac{\frac{h_i}{D}}{\frac{h}{D}} \quad \Leftrightarrow \quad M = \frac{h_i}{h}$$

- ✓ But $\frac{h_i}{h}$ = linear magnification produced by a lens or magnifying glass,

$$M = \frac{v}{f} - 1$$

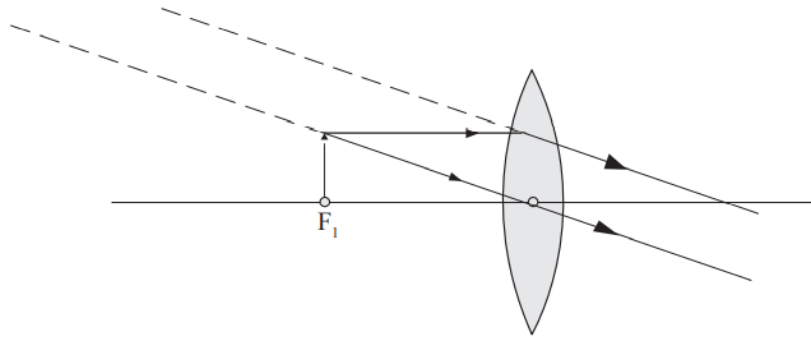
Hence the magnifying power, $M = \frac{v}{f} - 1$

- ✓ Since the image is at the near point (least distance of distinct vision), the image distance v is equal to $-D$, (negative for a virtual image).

$$M = \frac{-D}{f} - 1$$

- ✓ This gives the maximum magnifying power of a simple microscope.
- ✓ **Note that:**
 - ❖ In calculations, the value of the magnifying power is negative.
 - ❖ The negative sign can always be neglected since magnification cannot be negative.

➤ **Magnifying power of a simple microscope when it is not in normal adjustment**



- ✓ Angular magnification, $M = \frac{\beta}{\alpha}$
- ✓ From the figure, $\tan \beta = \frac{h}{f}$
- ✓ For β small, $\tan \beta \approx \beta$.

$$\text{Thus, } \beta = \frac{h}{f}$$

- ✓ From the figure, $\tan \alpha = \frac{h}{D}$
- ✓ For small α , $\tan \alpha \approx \alpha$

$$\text{Thus, } \alpha = \frac{h}{D}$$

- ✓ It follows that, angular magnification,

$$M = \frac{\frac{h}{f}}{\frac{h}{D}} = \frac{D}{f} \quad \leftrightarrow \quad M = \frac{D}{f}$$

Where f is focal length, D is distinct vision

- ✓ This is the minimum magnifying power of the simple microscope.

Example1: A magnifying glass has a focal length of 5cm. Find the angular magnification and the position of an object if the image is formed at the position of least distinct vision of 25cm.

Ans:

Since the image is formed at the position of least distinct vision, the magnifying glass is in normal adjustment. $f = 5\text{cm}$, $D = 25\text{cm}$

$$M = \frac{D}{f} + 1$$

$$M = \frac{25\text{cm}}{5\text{cm}} + 1 = 6$$

Thus, the maximum angular magnification is 6

But since angular magnification for a magnifying glass = linear magnification

As the image is formed at the least distance of distinct vision from the lens then: $v = -D$

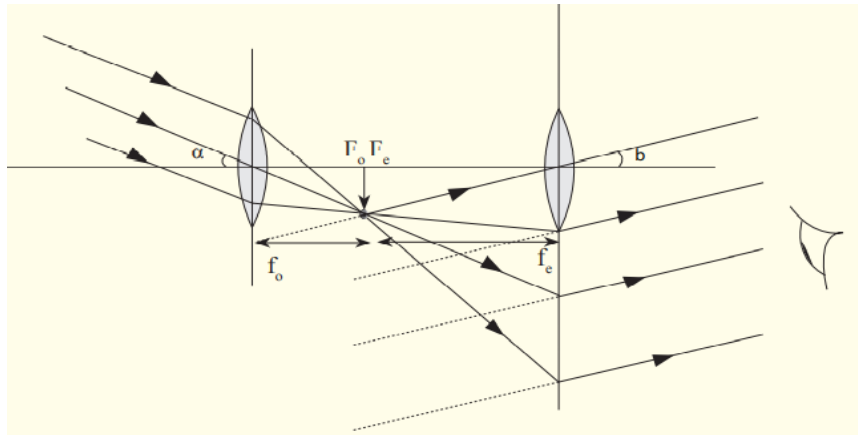
$$\text{It follows that } 6 = \frac{v}{u} = \frac{25}{u}$$

$$\text{Thus, } 6u = 25$$

$$\text{Hence, } u = 4.2\text{cm}$$

6.2.2. Magnification of telescope

➤ Magnification of telescope in normal adjustment



- ✓ In normal adjustment, the magnifying power (angular magnification) of an astronomical telescope is given by:

$$M = \frac{\text{Angle subtended at the eye by the final image at infinity}}{\text{Angle subtended at the objective by the object}}$$

$$M = \frac{\beta}{\alpha} \quad (1)$$

Where β is angle subtended by final image at eye, α is angle subtended by object at objective.

$$\beta = \frac{h_i}{f_e} \quad (2) \quad \alpha = \frac{h_i}{f_o} \quad (3)$$

Where h_i is image height, f_e is eye focal length, f_o objective focal length.

- ✓ Then, replace (2), and (3) into (1), we get,

$$M = \frac{\frac{h_i}{f_e}}{\frac{h_i}{f_o}} = \frac{f_o}{f_e} \quad \leftrightarrow \quad M = \frac{f_o}{f_e}$$

- ✓ **Note that**

- ❖ From the above expression, M is high when eye piece focal length, f_e is short and the objective focal length, f_o is long. This explains the fact why the objective lens of long

focal length and the eye piece lens of short focal length are used during the construction of the astronomical telescope.

- ❖ For a telescope in normal adjustment, the separation(L) of the objective and the eye piece is:

$$L = f_e + f_o$$

Example: An astronomical telescope has an objective lens of focal length 120 cm and an eye piece of focal length 5 cm. If the telescope is in normal adjustment, what is;

- The angular magnification (magnifying power)
- The separation of the two lenses?

Ans: $f_o = 120\text{cm}$, $f_e = 5\text{cm}$

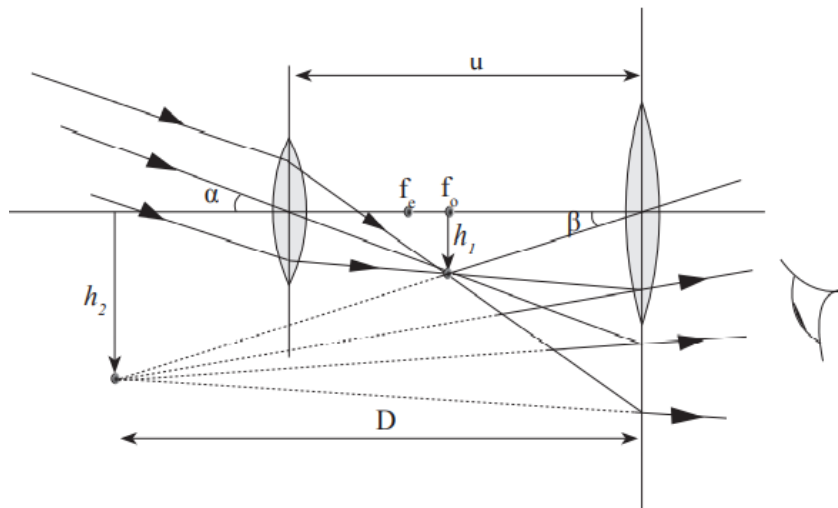
Asked: i) $M = ?$ ii) $L = ?$

Formula: i) $M = \frac{f_o}{f_e}$ ii) $L = f_e + f_o$

$$\text{i) } M = \frac{f_o}{f_e} = \frac{120\text{cm}}{5\text{cm}} = 24$$

$$\text{ii) } L = 120\text{cm} + 5\text{cm} = 125\text{cm}$$

➤ Magnification of telescope not in normal adjustment



$$\tan \alpha \approx \alpha = \frac{h_1}{f_o}$$

$$\tan \beta \approx \beta = \frac{h_2}{D}$$

$$M = \frac{\beta}{\alpha}$$

$$M = \frac{\frac{h_2}{D}}{\frac{h_1}{f_o}}$$

↔

$$M = \frac{h_2}{D} \times \frac{f_o}{h_1}$$

$$M = \frac{f_o}{D} \left(\frac{h_2}{h_1} \right)$$

But $\frac{h_2}{h_1}$ = linear magnification due to eye piece, $m_e = \frac{v_e}{f_e} - 1$

$$M = \frac{f_o}{D} \left(\frac{v_e}{f_e} - 1 \right) \quad \text{and} \quad v_e = D$$

$$\text{Then, } M = \frac{f_o}{D} \left(\frac{D}{f_e} - 1 \right) = \frac{f_o}{D} \times \frac{D}{f_e} - \frac{f_o}{D} = \frac{f_o}{f_e} - \frac{f_o}{D} = \frac{f_o}{f_e} \left(1 - \frac{f_e}{D} \right)$$

$$\text{Thus, } M = \frac{f_o}{f_e} \left(1 - \frac{f_e}{D} \right)$$

- ✓ As the final image is virtual, in calculation, D is negative, and note that separation of the lenses, L is

$$L = f_o + u_e$$

Example: Magnification produced by astronomical telescope for normal adjustment is 10 and length of telescope is 1.1m. Calculate the magnification when the image is formed at least distance of distinct vision, D equals to 25cm? ($D = 25\text{cm}$)

Ans:

Magnification for normal adjustment, $m = 10$

Length of telescope, $L = 1.1\text{m} = 110\text{cm}$

Distinct vision, $D = 25\text{cm}$

We know that, $m = \frac{f_o}{f_e} = 10$

$$\frac{f_o}{f_e} = 10 \quad \leftrightarrow \quad f_o = 10f_e \quad (1)$$

$$L = f_o + f_e = 110 \quad (2)$$

Replace (1) into (2), we get,

$$\begin{aligned} f_o + f_e &= 110 \\ 10f_e + f_e &= 110 \\ 11f_e &= 110 \quad \leftrightarrow \quad f_e = 10 \\ \text{Then, } f_o &= 10f_e \quad \leftrightarrow \quad f_o = 10 \times 10 = 100 \\ f_o &= 100 \end{aligned}$$

Then, magnification when image is formed at least distance of distinct vision ($D = 25\text{cm}$).

$$M = \frac{f_o}{f_e} \left(1 + \frac{f_e}{D} \right)$$

$$M = \frac{100}{10} \left(1 + \frac{10}{25} \right) = 14$$

6.2.3. Use of optical instruments

1. Uses of microscopes

- ✓ Microscopes used to observe smallest object that are at cellular level.
- ✓ Microscope allows scientists to see the shape of cell, its nucleus, mitochondria, and other organelles.

2. Use of telescope

- ✓ It is used to form magnified images of distinct objects.

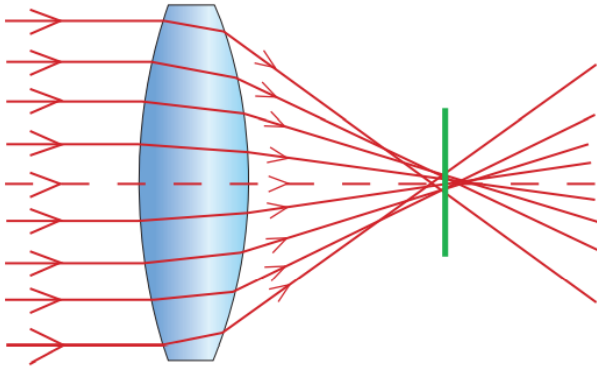
LO6.3. Correct optical aberrations

1. Spherical aberration

- ✓ This arises in lenses of large aperture when a wide beam of light incident on the lens, not all rays are brought to one focus.
- ✓ As a result, the image of object becomes distorted.

- ✓ The defect is due to the fact that the focal length of lens for rays far from the principal axis are less than for rays closer to property of spherical surface and as result, they converge to a point closer to the lens.

➤ **Lens cannot focus a single color of light**

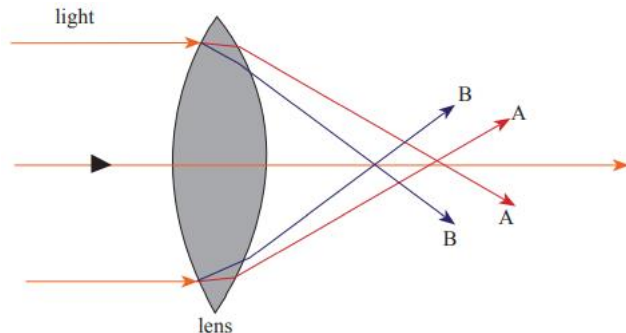


Correction: This defect can be minimized (reduced) by surrounding the lens with an aperture disc having a hole in the middle so that rays fall on the lens at a point closer to its principal axis.

➤ **Simply use mirror or lens with different shape.**

2. Chromatic aberration

- ✓ It occurs when white light from object falls on a lens and splits it into its component colors.
- ✓ These colors separate and converge to different foci, and this results into an image with colored edges.



- ✓ **Simply, lens do not focus the various color at single point.**

Correction: Chromatic aberration can be minimized by using an achromatic lens called an **achromatic doublet**.

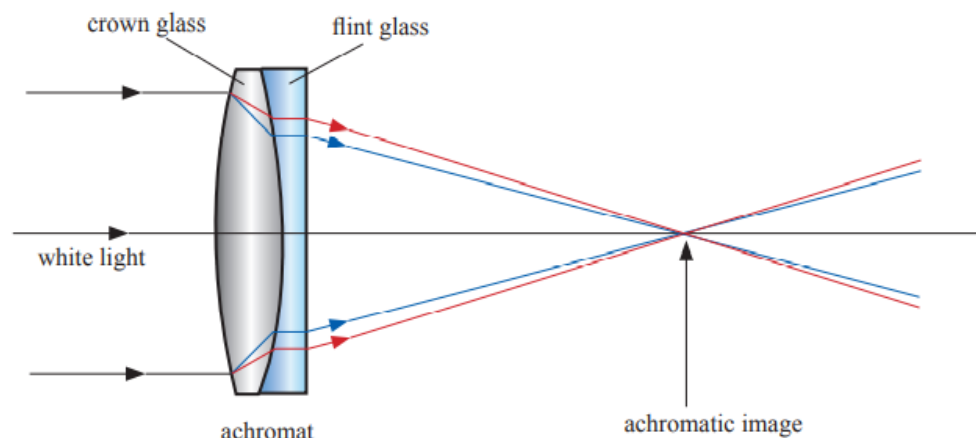


Figure 1: An Achromatic doublet

3. Astigmatism aberration

- ✓ This is the defect that occurs if the curvature of the cornea varies in different directions so that rays in different planes from an object are focused in different positions by the eye and the image is distorted.
- ✓ A person suffering from astigmatism sees one set of lines more sharply than others.

Correction: This defect is corrected by wearing corrected lenses. These help to bend the incoming rays to correct for irregular refraction.

Exercises

1. Find the angular magnification produced by a simple microscope of focal length 5cm when used not in normal adjustment.
2. Explain why angular magnification of a simple microscope is high for a lens of short local length.
3. Why the image formed by magnifying glass is free from chromatic aberration.

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