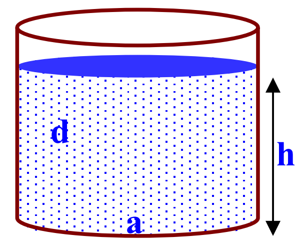
1. Properties of liquids

Thrust and pressure:



- Consider a liquid of density "**d**" in a beaker of cross-section area "**a**", up to a height "**h**".
- The force acting on the surface of solid by liquid is called **thrust**. Thrust has the same unit as force, i.e: Newton.

- Total thrust produce by liquid = weight of the liquid
  = (Mass of liquid) x (**g**)
  = (Volume of liquid) x (density of liquid) x (**g**)
  = **ahdg**

Thrust per unit area is called **pressure** of the liquid. Its unit is Newton/m^2

Pressure = (thrust) /(area)
= (**ahdg**) / (**a**)
P = **hdg**

Density:

- It is the mass per unit volume of substance.
- Its unit is gm/cc or kg/m^3
- Its value is different in the two different system of measurement.

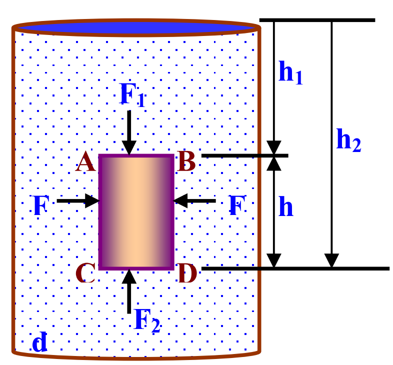
Specific gravity:

- It is a ratio of the density of substance to the density of water.
- It has no unit.
- Its value remain unchanged whatever be the system of units is used.

Laws of liquid pressure:

- The pressure at any point in the liquid is proportional to the density of the liquid.
- The pressure at any point in the liquid is proportional to the depth of the point below the free surface of the liquid.
- Liquid transmit pressure equally in all directions. (**Pascal's Law**)
- Pressure at equal depth is the same.
- Pressure dose not depend on the shape of the containing vessel.

Uptrust on a solid immersed in a liquid.



Let
- **ABCD** be the solid of height '**h**' and base area '**a**'
- It immersed in a liquid of density'**d**'.
- Force '**F1**' acts on face **AB** in downward direction.
- Force '**F2**' acts on face **CD** in upward direction.
- The lateral forces '**F**' are equal and balance each other, thus net resultant force become zero.

Now
- The force 'F_1' on face **AB** = (area of **AB**) x (pressure at depth 'h_1')
  = $\mathbf{a\ h_1\ d\ g}$

- The force 'F_2' on face **CD** = (area of **CD**) x (pressure at depth 'h_2')
  = $\mathbf{a\ h_2\ d\ g}$

- Here, $F_2 > F_1$ as $h_2 > h_1$,

  Therefore, the resultant upthrust exerted by liquid on a solid

  $= F_2 - F_1$

  $= a\,h_2\,d\,g - a\,h_1\,d\,g$

  $= a\,(h_2 - h_1)\,d\,g$

  $= (ah)dg$

  = (Volume of solid) x (density of liquid) x (**g**)

  = (Vol. of liquid displaced by solid) x (density of liquid) x (**g**)

  = (Mass of liquid displaced by solid) x (**g**)

  = Weight of the liquid displaced by immersed part of solid.

Principle of Archimedes:

- It says that when a solid is partly or wholly immersed in a liquid, it apparently loses its weight, which is equal to the weight of the liquid displaced by immersed part of solid.

Law of floatation:

- When a body is partially or completely immersed in a liquid, it experiences two forces:-
  1. Its own weight '**W**' acting in vertically downwards
  2. The resultant upthrust '**w**' that is equal to weight of the liquid displaced by immersed part of the body.
- If,
  a. $W > w$, the body sinks in the liquid
  b. $W = w$, the body remains in equilibrium at any depth.
  c. $W < w$, the body floats on the surface of liquid.

"When the weight of a body is equal to the weight of the liquid displaced by the immersed part of the body, the body floats on the surface of liquid." This statement is known as the **law of floatation.**

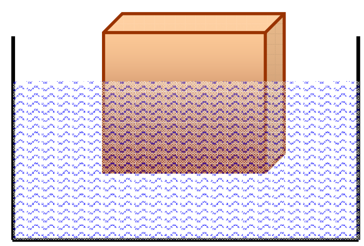
- Consider a body of density d_1 floating in liquid of density d_2.

  Let

  V_1 = Total volume of the body

  V_2 = Volume of immersed part of the body in liquid

  According to Law of floatation, the body floats on the surface of liquid when



  Weight of the body in air '**W**' = Upthrust '**w**' (Weight of the liquid displaced by immersed part of the body)

$$V_1 \times d_1 \times g = V_2 \times d_2 \times g$$

$$V_1 \times d_1 = V_2 \times d_2$$

Specific gravity = (Weight of substance in air) / (Loss of weight of substance in water).

= Weight of a substance / Weight of water displaced by substance

= Mass of substance x g / Mass of water displaced by substance x g

= [(Mass of a substance) / (volume of a substance)] / [(Mass of displaced water) / (volume of water displaced by substance)]

= (Density of substance) / (Density of water displaced by substance).

Specific gravity of solids heavier than water (insoluble in water):

Let Weight of solid in air = W_1
Weight of solid in water = W_2
Loss of weight of solid in water = (W_1-W_2)

Specific gravity of solids = $(W_1) / (W_1-W_2)$

Specific gravity of solids lighter than water (insoluble in water):

Let Weight of solid in air = W_1
Weight of sinker (solid heavier than water) in water = W_2
Weight of (solid + sinker) in water = W_3
Weight of lighter solid in water = (W_3-W_2)
Loss of weight of lighter solid in water = $\{ W_1 - (W_3-W_2)\}$

Specific gravity of lighter solids = $(W_1) / \{ W_1 - (W_3-W_2)\}$

Surface tension

Surface tension is the property of liquid by virtue of which, the free surface of liquid at rest behave like elastic stretched membrane with a tendency to contract so as to occupy minimum surface area.

Molecular forces:

- The forces of attraction between different molecules are known as molecular forces. There are two types of molecular forces:
  1. **Adhesive force**: - Force of attraction between molecules of different substances.
  2. **Cohesive force**: - Force of attraction between molecules of same substances.

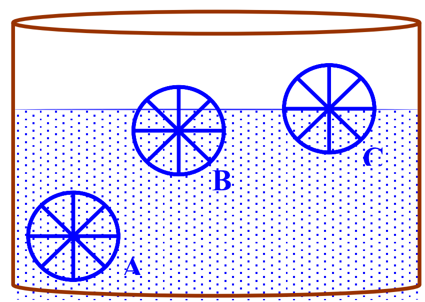
Molecular range:

- The maximum distance up to which the molecular force can act.

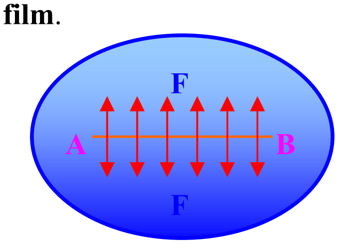
Sphere of influence:

- An imaginary sphere drawn with radius equal to molecular range and having a liquid molecule at its center is called sphere of influence.

Molecular theory of surface tension:



- Consider a container filled up with some liquid.
- Consider three molecules **A**, **B**, and **C**, with its sphere of influence; such that **A** is completely inside the liquid, **B** is just below the surface of the liquid and **C** is at the surface of the liquid.
- In case of molecule **A**, the sphere of influence is completely inside the liquid. Thus it is attracted equally in all directions by the other molecules lying within its sphere. Hence there is no resultant cohesive force acting on molecule **A**.
- In case of molecule **B**, the sphere of influence is partly outside the liquid. There are more molecules in lower hemisphere in comparison of upper hemisphere. Hence there is net resultant cohesive force acting on molecule **B** is in downward direction.
- In case of molecule **C**, the sphere of influence is exactly half outside and half inside the liquid. There are all molecules in lower hemisphere. Hence there is net resultant cohesive force acting on molecule **C** is in downward direction and its magnitude is maximum
- As a result, the molecules at the surface of the liquid are attracted sideways and the tension or pull in the surface is called **surface tension**. The layer of the liquid at surface of thickness equal to the molecular range is known as **surface film**.



- If '**F**' is the total tangential force acting on either side of an imaginary line AB of length '**L**'.

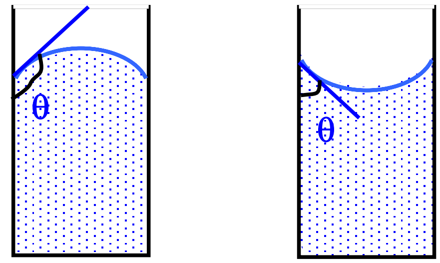
  Surface tension '**T**' = (Force) / (length)

  = F/L Newton/meter

Angle of contact:

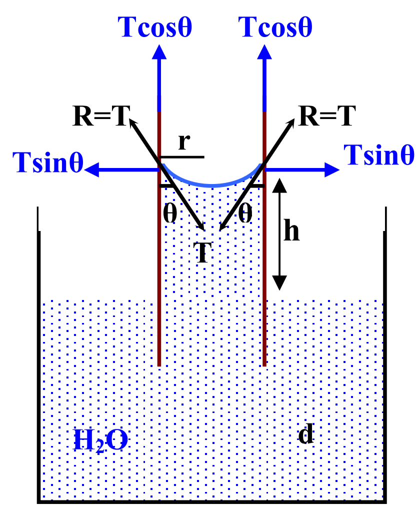
- It is the angle between the tangent to the liquid surface and the solid surface inside the liquid at the point contact. It is denoted by **θ** and measured in degrees**.**
- The angle of contact between water and glass surface; mercury and glass surface is shown in figure.
- The angle of contact between water and glass is very small and taken to be zero.

- The angle of contact between mercury and glass is 140^0.



Derivation of surface tension formula:

- If capillary tube is immersed in a liquid, the liquid rises or depress in the capillary tube. This phenomenon is due to the surface tension and is known as capillarity
- Consider a capillary tube of radius **'r'** dipped in to a liquid of density 'd'.
- Let,
  - **h** = Height to which liquid rises in tube.
  - **θ** = Angle of contact.
  - **T** = Surface tension force of liquid.
  - **R** = Reaction force due to '**T**'



- Surface tension force '**T**' acts along the circumference of the tube and is resolved into two components; Horizontal component **Tsinθ** and Vertical component **Tcosθ** as shown in figure.
- All the horizontal components **Tsinθ** are equal and opposite. Therefore they cancel out effect of each other whereas all vertical components **Tcosθ** add up. The vertical components **Tcosθ** are only effective.
- The total upward force due to the surface tension, acts along the circumference of the tube is given by

$$\text{Total upward force} = \left\{ \begin{array}{c} \text{The vertical} \\ \text{component} \\ \mathbf{T\cos\theta} \text{ at a} \\ \text{point.} \end{array} \right\} \times \left\{ \begin{array}{c} \text{The circumference} \\ \text{of the tube of} \\ \text{radius 'r'} \end{array} \right\}$$

$$= (T\cos\theta) \times 2\pi r$$

- This total upward force is balanced by the weight of liquid in the capillary tube that rises above the liquid surface in beaker.

The total upward force = The weight of liquid in the capillary tube that rises above the liquid surface in beaker.

$$(T\cos\theta) \times 2\pi r = \left(\begin{array}{c} \text{Mass of liquid in the capillary tube that} \\ \text{rises above the liquid surface in beaker.} \end{array} \right) \times (g)$$

$$(T\cos\theta) \times 2\pi r = \begin{pmatrix}\text{Density}\\ \text{of liquid}\end{pmatrix} \times \begin{pmatrix}\text{Volume}\\ \text{of liquid}\end{pmatrix} \times (g)$$

$$(T\cos\theta) \times 2\pi r = d\,[\pi r^2 h]\,g$$

$$T = \frac{r\,h\,g\,d}{2\cos\theta}$$

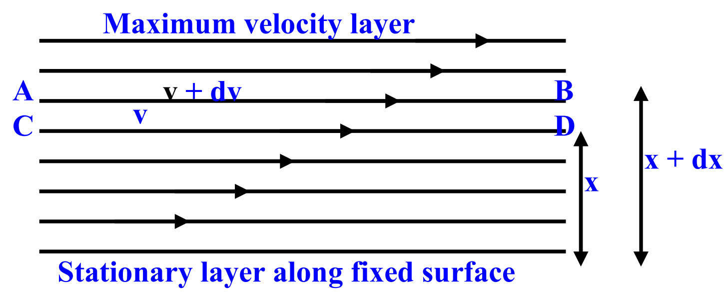
Application of surface tension:

- The plants get their water supply by the capillary action at roots
- The rise of oil in the oil lamp and rise of melted wax in a candle.
- Blotting paper sucks the ink.
- In ink-pen a pen is split at the tip to provide the narrow capillary and the ink is drawn up to the point continuously.
- The pores in the earth act as capillary and because of this rain water are soaked by the earth.

Viscosity

Viscosity is the property of liquids by virtue of which it opposes relative motion between the adjacent layers of the liquid. It is also known as fluid friction.

Explanation of viscosity:



- Figure shows a liquid flowing steadily over a horizontal surface.
- The liquid column is made up of different horizontal layers. The layer which is in contact with the solid surface is at rest due to adhesive forces.
- The velocities of layers go on increasing as we move up from the solid surface. The top most layer of the liquid has maximum velocity.
- Thus different layers of the liquid move with different velocities. Any two adjacent layers are therefore in relative motion.
- The upper layer tries to accelerate on the lower layer.
- Due to this a force tangential to the surface of the layer acts in such a way that the relative motion between different layers is reduced.
- This is called viscous force and the property of the liquid is called as **viscosity**.

Velocity gradient:

- Consider a layer **CD** of a liquid moving with a velocity **v** at a distance **x** and a parallel layer **AB**, moving with a velocity **(v+dv),** at a distance of **(x+dx)** from fixed surface.
- Velocity gradient is defined as the ratio of change of velocity (**dv**) with respect to the change in the distance (**dx**) measured perpendicular to the layer of the flow of liquid. It is denoted by (**dv/dx**). Its unit is **second**$^{-1}$.

Newton's law of viscosity:

- Newton found that the viscous force **F** acting tangentially on a layer of a liquid is directly proportional to:
    1. Velocity gradient (**dv/dx**); and
    2. The surface area '**A**' of the layer.

i.e : $F \propto A\,(dv/dx)$

$$F = -\eta A(dv/dx)$$

$$\therefore \eta = (F) / A(dv/dx)$$

- η is constant, known as co-efficient of viscosity, depends upon the nature and temperature of liquid.
- **-ve** sign indicate that 'F' is in backward dragging force.
- Unit of 'η' in M.K.S. is **N-sec/m^2.**

- Unit of 'η' in C.G.S. is **dyne-sec/cm^2** or **Poise.**
- The co-efficient of viscosity of a liquid is defined as the tangential viscous force (**F**) per unit area (**A**) per unit velocity gradient.

Streamline and turbulent flow:

- In streamline flow, a liquid flows steadily, such that each particle passing a certain point follows exactly the same path and has the same velocity as its preceding particle.
- In turbulent flow, a liquid flows with large velocity and there is a free mixing of the fluid particles of the various shells.
- The velocity at which the steady or streamline flow changes into turbulent flow is called critical velocity.

Reynold's number:

- Reynold studied the motion of fluids in detail and observed that the critical velocity V_c of a liquid is directly proportional to its Co-efficient of viscosity 'η' and inversely proportional to density '**d**' of the liquid and radius '**r**' of the tube.
- Mathematically, $$V_C \propto \frac{\eta}{d\,r}$$
$$V_C = \frac{R\,\eta}{d\,r}$$
- Where '**R**' is constant and known as Reynolds number. On the basis of experiments it is observed that for tube of radius 1 cm flow is streamline if $R \leq 2000$, whereas flow is turbulent if $R \geq 3000$
- If the value of Reynolds number lies between 2000 and 3000 then the flow of liquid is of intermediate type.

Stoke's law and terminal velocity:

- According to stoke's law, when a small spherical body moves in a viscous liquid, the viscous force '**F**' acting on a small spherical body is directly proportional to
  1. Radius '**r**' of the spherical body.
  2. Co-efficient of viscosity 'η'
  3. Terminal velocity '**v**'

$$\therefore\ F = 6\pi\eta r\, v$$

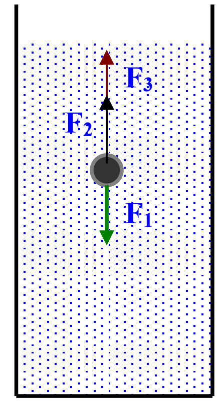
- When a small spherical body moves in a viscous liquid, liquid offers resistance to its motion, which increases with the increase in velocity of the spherical body.
- A stage is reached when the resultant downward force due to weight of the body acts vertically in downward direction, become equal to the viscous force acts vertically upward. The resultant force at this stage becomes zero and the body moves with a constant velocity called the **terminal velocity**.

Determination of 'η' by falling sphere method (stocke's law method)

- Suppose spherical ball of radius '**r**' and density 'd_1' is falling freely in a liquid of density 'd_2' and coefficient of viscosity 'η'.
- After covering small distance, the sphere attains a constant terminal velocity '**v**'.
- Three forces acting on the sphere are
  - (i) F_1 = Weight of the sphere in the downward direction,
  - (ii) F_2 = Upthrust acting in upward direction and
  - (iii) F_3 = Force of viscosity in upward direction.

- Now,

$$F_1 = \begin{pmatrix}\text{Volume} \\ \text{of sphere}\end{pmatrix} \times \begin{pmatrix}\text{Density of} \\ \text{sphere}\end{pmatrix} \times \begin{pmatrix}\text{Acceleration due to} \\ \text{gravity 'g'}\end{pmatrix}$$



$$\therefore F_1 = (4/3)\,\pi\, r^3\, d_1\, g \text{ -------------------------(1)}$$

F_2 = Upthrust = Weight of liquid displaced by sphere

$$\therefore F_2 = \begin{pmatrix}\text{Volume} \\ \text{of liquid} \\ \text{displaced} \\ \text{by sphere}\end{pmatrix} \times \begin{pmatrix}\text{Density} \\ \text{of} \\ \text{liquid}\end{pmatrix} \times (g)$$

$$\therefore F_2 = (4/3)\,\pi\, r^3\, d_2\, g \text{ -----------------(2)}$$

Viscous force $F_3 = 6\pi\eta rv$-------------(3)

When sphere attains constant terminal velocity **v**,

Downward force = Resultant upward force

$$F_1 = F_2 + F_3$$

$$(4/3)\,\pi\, r^3\, d_1\, g = (4/3)\,\pi\, r^3\, d_2\, g + 6\pi\eta rv$$

$$6\pi\eta rv = (4/3)\,\pi\, r^3\, (d_1 - d_2)\, g$$

$$\therefore\ \boldsymbol{\eta = \frac{2}{9}\frac{r^2 g(d_1 - d_2)}{v}}$$

Application of viscosity:

- The bodies of ships, airplanes, cars and sport cars, are made streamlined to minimize the air resistance and to make them travel with high speed.
- For lubricating various parts of machines in order to reduce the friction between different parts low viscosity liquid is used.

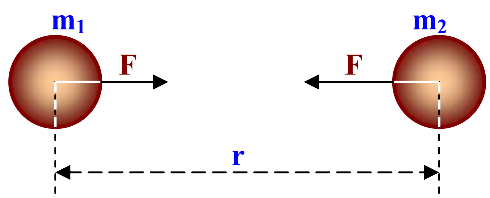
Problems :-

1) Calculate the height of a column of water that gives a pressure of 1 atmosphere at the bottom. 1 atmospheric pressure = 1.01 x 10^5N/m^2.
2) A swimming pool has dimensions 24m x 9m x 2m. When it is filled with water, what is the force on the bottom ?
3) Weight of a body in air is 100N. What is its weight in water if it displaces 400cc of water?
4) A fish weigh 348gm in air and 23gm in pure water. Calculate the relative density of fish.
5) A piece of wood of relative density 0.32 floats in oil of relative density 0.80. What fraction of the volume of piece is above the surface of oil?
6) Specific gravity of ice is 0.90 and that of sea water is 1.125. What fraction of the whole volume of a floating iceberg appears above the surface of water ?
7) A capillary tube of diameter 1.5mm is dipped in a liquid of density 8gm/cc. The liquid rises through 7.2mm. Calculate the surface tension of liquid . The angle of contact is 28^0.
8) A capillary tube of inner radius 0.5mm is dipped in water of surface tension 75 dyne/cm. To what height will water rise? Calculate the weight of water raised.
9) A liquid rises to a height of 2.8cm in a capillary tube of diameter 0.25mm. How far will it rise in a tube of diameter 0.55 mm ?
10) A capillary tube of inner diameter 0.5mm is dipped in a liquid of specific gravity 13.6, surface tension 545 dyne/cm and angle of contact 130^0. Find the depression or elevation of the liquid in the tube.
11) Calculate the horizontal force required to move a metal plate of area 200cm^2 with a velocity of 4.5 cm/s when it rests on a layer of oil 1.5mm thick.
12) Calculate the viscous force on a rain drop of diameter 4mm falling with constant velocity of 4m/s through air. Coefficient of viscosity of air is 1.8x10^{-5} N-s/m^2.
13) Calculate the radius of drop of water falling through air if the terminal velocity of drop is 1.2cm/sec, coefficient of viscosity for air is 1.8x10^{-5} N-s/m^2, density of water is 1000 Kg/m^3 and the density of air is 1.21Kg/m^3.
14) Calculate the terminal velocity of an air bubble of radius 5x10^{-4}m rising in a liquid of viscosity 0.15 N-s/m^2 and density 900 Kg/m^3 and density of air is 1.21 Kg/m^3.
15) Two drops of water of the same size are falling through air with terminal velocity 10cm/sec. If two drops combine to form a single drop, what will be the new terminal velocity?

2. Gravitation

Universal law of gravitation

- According to Newton's law of gravitation, "every body in the universe attrect every other body with a force which is directly proportional to the product of their mases and inversely propotional to the square of the distance between them."
- This force is known as force of gravitation.



- Consider two bodies of masses $\mathbf{m_1}$ and $\mathbf{m_2}$ separated by distance **r**. The force (**F**) of gravitationnal attraction between them is

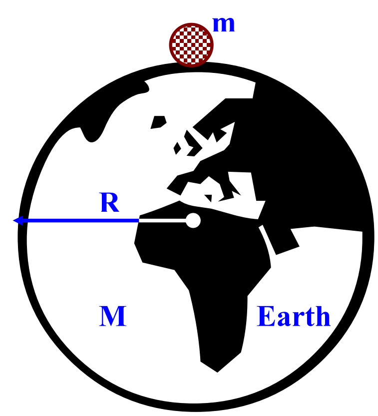
$$F \,\alpha\, m_1 m_2 \quad \text{and} \quad F \,\alpha\, \frac{1}{r^2}$$

$$\therefore F \,\alpha\, \frac{m_1 m_2}{r^2} \quad \text{or} \quad \therefore F = G\frac{m_1 m_2}{r^2} \text{ --------------------- (1)}$$

- Where **G** = universal constant of gravitation = 6.67 x 10^{-11} N-m^2/Kg^2.
- If $\mathbf{m_1} = \mathbf{m_2}$ **=1 unit** and **r = 1 unit,** then from equation (1), **F = G.**
- Thus, the universel gravitational constant **G** is numerically equal to the force of attraction between two bodies, each of unit mass separated by unit distance.

Acceleration due to gravity (g):

- When a body falls freely, it is attracted by the earth with a force given by Newton's law of gravitation. This force is known as gravity. The effect of force on the body is to produce acceleration in a body. Thus the force of gravity produces an acceleration in a freely falling body. This acceleration is called acceleration due to gravity. It is denoted by '**g**'. The value of '**g**' on the surface of earth is 9.81 m/sec^2.



- If M is the mass of earth, m is the mass of the body placed on the surface of earth and R is the radius of earth, then according to Newton's law of gravitation

$$F = G\frac{Mm}{R^2} \text{ ----------(1)}$$

- According to Newton's second law of motion,

$$F = mg \text{ --------- (2)}$$

From equation (1) and (2),

$$mg = G\frac{Mm}{R^2}$$

$$\therefore \mathbf{g} = \frac{\mathbf{GM}}{\mathbf{R}^2} \qquad \text{-------------} \ (3)$$

- **Mass of the earth**: From equation (3), we have $M = \dfrac{g\,R^2}{G}$

  By putting the value of Acceleration due to gravity 'g' = 9.81 m/sec^2.
  Radius of the earth 'R' = 6.4 x 10^6 m.
  Gravitational constant 'R' = 6.67 x 10^{-11} N-m^2/Kg^2
  We can get mass of the earth **M = 6.02 x 10^{24} Kg**

- **Mean density of the earth:**

$$\text{Mean density of the earth } (\rho) = \frac{\text{Mass of the earth}}{\text{Volume of the earth}} = \frac{\left(gR^2/G\right)}{\left(\frac{4}{3}\right)\pi\ R^3} = \frac{3g}{4\pi\ R\,G}$$

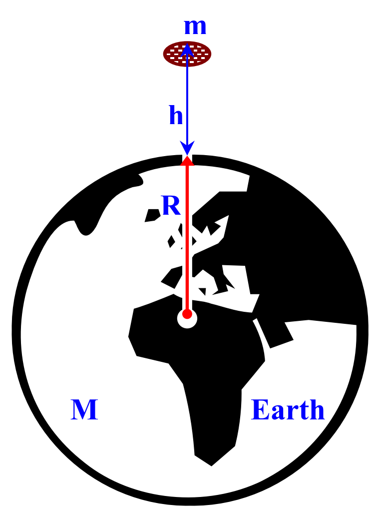
Variation of Acceleration due to Gravity 'g':

- The value of acceleration due to gravity 'g' varies with,
  1. Altitude (Height above the surface of the earth).
  2. Depth from the surface of the earth.
  3. Latitude.

Variation of 'g' with altitude:

- Let us assume that the earth is a perfect sphere of mass **M** nad radius **R**. Consider a body of mass **m** lying on the surface of earth.
- Now the value of '**g**' on the surface of the earthis given by,

$$g = \frac{GM}{R^2} \ \text{---------} \ (1)$$



- Suppose the body is taken to a height '**h**' above the surface of the earth. Then, acceleration due to gravity at height '**h**' is

$$g_h = \frac{GM}{(R+h)^2} \ \text{---------} \ (2)$$

From equation (1) and (2), we get

$$\frac{g_h}{g} = \frac{\left(\frac{GM}{(R+h)^2}\right)}{\left(\frac{GM}{R^2}\right)} = \frac{R^2}{(R+h)^2} = \frac{R^2}{R^2\left(1+\frac{h}{R}\right)^2} = \left(1+\frac{h}{R}\right)^{-2}$$

- since h < < R,therefore **h/R** is very small, and expanding the right hand side of the above equation by Binomial theorem and neglecting squares and higher power of h/R, we get

$$\frac{g_h}{g} = \left(1+\frac{h}{R}\right)^{-2} = \left(1-\frac{2h}{R}\right)$$

$$g_h = g\left(1-\frac{2h}{R}\right) = g - g\left(\frac{2h}{R}\right)$$

Thus the value of 'g' decreases with increase in altitude.

Loss in weight at height 'h':

$$g_h = g - g\left(\frac{2h}{R}\right)$$

$$mg_h = mg - mg\left(\frac{2h}{R}\right)$$

$$(Wt)_h = (Wt) - \left(\frac{2mgh}{R}\right)$$

$$\text{Loss in weight at height } h = (Wt) - (Wt)_h = \left(\frac{2mgh}{R}\right)$$

Variation of 'g' with depth:

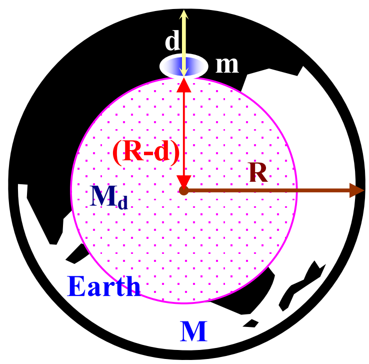
- Let us assume that the earth is a perfect sphere of mass **M** and radius **R**. Consider a body of mass **m** lying at depth '**d**' from the surface of earth.
- Now the value of '**g**' on the surface of the earthis given by,

$$\mathbf{g} = \frac{\mathbf{GM}}{\mathbf{R^2}}$$

If ρ is the mean density of the earth, then

Mass of the Earth **M** = 4/3 π R^3 ρ

$$\therefore g = \frac{G((4/3)\,\pi\, R^3 \times \rho)}{R^2} = G(4/3)\,\pi\, R\rho \text{ ----- (1)}$$



- The body at depth '**d**' will only be attracted by the mass of earth, which is enclosed in a sphere of radius (R-d).

∴The mass $\mathbf{M_d}$ of this portion of the earth is $\mathbf{M_d}$ = 4/3 π $(R-d)^3$ ρ

$$\therefore g_d = \frac{GM_d}{(R-d)^2} = \frac{G((4/3)\,\pi\,(R-d)^3 \times \rho)}{(R-d)^2} = G(4/3)\,\pi\,(R-d)\rho \text{ --------- (2)}$$

From equation (1) and (2), we get

$$\frac{g_d}{g} = \frac{G\,(4/3)\,\pi\,(R-d)\rho}{G\,(4/3)\,\pi\, R\,\rho} = \frac{(R-d)}{R} = \left(1-\frac{d}{R}\right)$$

$$g_d = g\left(1-\frac{d}{R}\right) = g - g\left(\frac{d}{R}\right) \text{ ------------------------------------(3)}$$

Above equation indicate that the value of acceleration due to gravity 'g' decreases with depth from the surface of the earth. At the center of the earth, **d = R**, so the value of acceleration due to gravity 'g' is zero.

- **Loss in weight with depth 'd':**

We know that $$g_d = g - g\left(\frac{d}{R}\right)$$

$$mg_d = mg - mg\left(\frac{d}{R}\right)$$

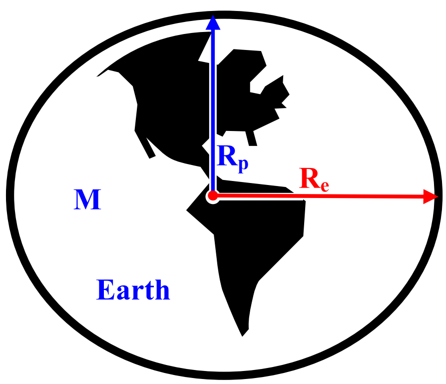
$$(Wt)_d = (Wt) - \left(\frac{mgd}{R}\right)$$

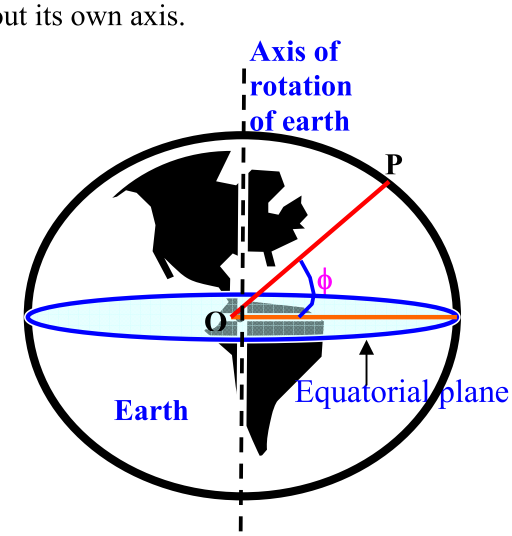
$$\text{Loss in weight with depth 'd'} = (Wt) - (Wt)_d = \left(\frac{mgd}{R}\right)$$

Variation of 'g' with latitude:

- The earth rotates about an axis passing through its North Pole and South Pole. A plane passing through the center of the earth and perpendicular to the axis of rotation of earth is called **equatorial plane**. The **latitude** of a point **P** on the surface of earth is given by the angle 'ϕ' which the radial line **OP** makes with the equatorial plane [shown in figure below].

- The value of acceleration due to gravity changes with latitude due to:
  1. Shape of the earth and
  2. Rotation of the earth about its own axis.





- **Shape of the earth:**

  The earth is not a perfect sphere. It is flattened at the poles and bulges out at the equator. The equatorial radius $\mathbf{R_e}$ is greater than the polar radius $\mathbf{R_P}$ by nearly **21** kilometer.

  We know that $g = \frac{GM}{R^2}$ or $g \, \alpha \frac{1}{R^2}$ as **G** and **M** are constant.

  Since the value of $\mathbf{R_e}$ is maximum at the equator, therefore, the value of **g** is minimum at the equator. Also, the value of $\mathbf{R_P}$ is minimum at the poles and hence the value of **g** is maximum at the poles.

- **Rotation of the earth:**

  The earth is spins on its own axis completing one revolution each day as well as orbiting round the sun in one year. The body of mass '**m**' at the pole turns through **360**^{0} on the

same spot in one day, while the body of mass '**m**' at equator covers a distance of **2πR** in one day.
At equator, the centripetal force **(mv^2/R)** is needed to keep the body of mass '**m**' in its circular orbit. Where **v** is the speed of the body of mass in its orbit. The total gravitational force '**F**' at equator has to do two jobs:

1. Provide the force to keep the mass in circular motion,
2. Use the remaining force to accelerate the mass towards the earth.

Thus $F = (mv^2/R) + mg_e$ at equator while $F = mg_P$ at the pole.
This means $mg_e < mg_P$ i.e. $g_e < g_P$.

Gravitational field:

- The gravitational field is the space round about a material body in which its gravitational force of attraction is experienced by other material body.

Escape velocity:

- "**Escape velocity** is defined as the least velocity with which a body must be thrown vertically upwards in order that it may just escape the gravitational pull of earth".
- When we throw a body vertically upwards with certain velocity, the body returns to the earth's surface after some time. However when a body is thrown with a velocity equal to the escape velocity, the body overcomes the earth's gravitational pull and also the resistance of earth's atmosphere. This body never returns to the surface of the earth.

Kepler's laws of planetary motion:

To understand the solar system, Kepler found three laws concerning the motion of the planets round the sun.

Kepler's first law (law of orbit):

Each planet moves in an elliptical orbit with the sun at one focus.

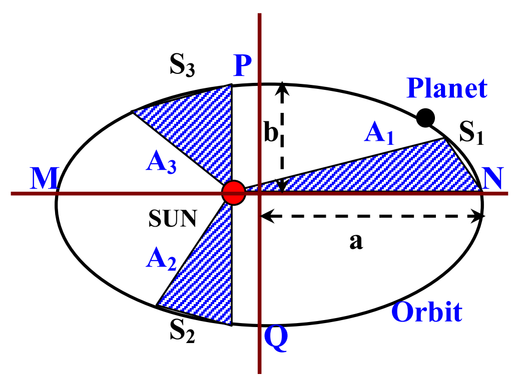
Kepler's second law (law of Areas):

The area swept by a line joining the sun to a planet, per unit time is constant.

Or

The areal velocity (area swept by the radius vector in unit time) of the planet is constant.

The areas A_1, A_2, and A_3 are swept by the radius vector in equal time. So according to kepler law, $A_1 = A_2 = A_3$. Also, the planet cover unequal distances S_1, S_2, and S_3 in equal times.



Kepler's third law (law of Periods):

The square of the periodic time (time taken to complete one revolution) of a planet around the sun is proportional to the cube of the semi-major axis of its elliptical orbit.

In the figure, **MN** is the major axis, **PQ** is the minor axis, '**a**' is the semi-major axis, and '**b**' is the semi-minor axis.

Let, **T** = 'period of one revolution' or 'time taken to complete one revolution'.

According to kepler's third law, $T^2 \propto a^3$

Satellites:

- A **satellite** is a body, which is continuously revolving around a planet.
- Satellites are classified as : (1) **natural satellites** and (2) **artificial satellites**
  The earth is a natural **satellite** of the sun. Similarly moon is a natural satellite of the earth. The man-made satellites are known as **artificial satellites**.

Orbital velocity:

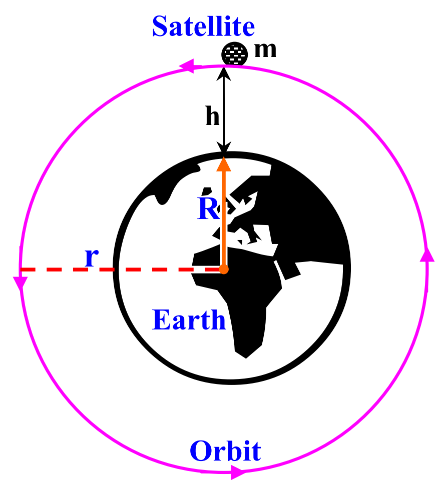
Let, **m** = mass of satellite

r = (**R**+**h**) = Radius of the circular orbit of satellite

R = Radius of earth

M = Mass of earth

$\mathbf{v_0}$ = Orbital velocity of satellite



The gravitational force $F = G\frac{Mm}{r^2}$ between the satellite and the earth provides the centripetal force ($\mathbf{mv_0^2/r}$) required by the satellite to keep moving in a circular orbit.

Then, $$\frac{mv_0^2}{r} = G\frac{Mm}{r^2} \quad \text{-------------(1)}$$

$$\therefore v_0^2 = \frac{GM}{r}$$

$$\therefore \mathbf{v_0} = \sqrt{\frac{\mathbf{GM}}{\mathbf{r}}} = \sqrt{\frac{\mathbf{GM}}{\mathbf{(R+h)}}} \quad \text{-------}$$

(2)

Since the distance travelled by a satellite during one revolution (i.e. periodic time T) is $2\pi r$.

$$\therefore v_0 = \frac{2\pi r}{T} \quad \text{-----------------(3)}$$

Comparing equations (2) and (3)

$$\therefore \sqrt{\frac{GM}{r}} = \frac{2\pi r}{T}$$

$$\therefore \frac{GM}{r} = \frac{4\pi^2 r^2}{T^2}$$

$$\therefore T^2 = \left(\frac{4\pi^2}{GM}\right) r^3 \quad ------(4)$$

$$\therefore T^2 \propto r^3$$

Thus, "The square of the period of a planet is directly proportional to the cube of its orbital radius". Which is Kepler's third law.

Geo-stationary or **Synchronous satellite:**

A satellite of the earth having orbital time period of 24 hours is called a Geo-stationary or Synchronous satellite. It is so named because it appears stationary as viewed from the earth.

Geo-stationary satellites orbit the earth in equatorial plane. The orbital period of such satellites coincides with the rotational period of the earth.

Putting $G = 6.67 \times 10^{-11}$ N-m^2/kg^2, Mass of the earth $M = 6 \times 10^{24}$ kg, T = 24 x 3600 s in eq.(4) , we get

r = 42260 km

$\therefore$ The height of geo-stationary satellite is

h = r - R = 42260 – 6400 = 35860 km.

Polar Satellite :-

The polar satellites orbit in a north-south direction as the earth spins below it in an east-west direction. As a result, the satellite can eventually scan the entire surface of the earth.

Satellites which monitor the weather, environment and the spy satellites are almost always in low flying polar orbits.

Uses of artificial satellites:

- To study the various phenomena in the outer regions of the earth's atmosphere.
- To study the various phenomena connected with sea.
- For communication purposes.
- For weather forecasting.

Problems :-

1. A sphere of mass 40Kg is attracted by another sphere of mass 15Kg with a force of 1/10 mg wt. Find the value of constant of gravitation if centers of spheres are 20cm apart. [Given 1kg wt = 9.8 N]
2. Calculate the force of attraction between two bodies each of mass 100Kg and 1m apart on the surface of earth. Will the force of attraction be different if the same bodies are taken on the moon, their separation remaining constant? Given: $G = 6.67 \times 10^{-11}$ N-m^2/kg^2
3. A spherical mass of 20kg lying on the surface of earth is attracted by another spherical mass of 150Kg with a force equal to 0.25mg wt. The centers of two masses are 30cm apart. Calculate the mass of earth. [Given: Radius of earth = 6×10^8 cm]
4. The acceleration due to gravity on the surface of moon is 1.67m/s^2. If the radius of moon is 1.74×10^6 m, calculate the mass of the moon. Use the known value of G.
5. If the radius of earth were increased by a factor of 3, by what factor would its density have to be changed to keep 'g' same?
6. The Mount Everest is 8848m above the sea level. Estimate the acceleration due to gravity at this height. Given: 'g' on the surface of earth is 9.8 m/s^2 and radius of earth is 6.37×10^6m.
7. Calculate the height above the surface of earth at which the value of acceleration due to gravity reduces to half of its value on the surface of earth. Assume the earth to be a sphere of radius 6400 Km.
8. A body weighs 63N on the surface of earth. What is the gravitational force due to earth at a height equal to half the radius of earth?
9. Assuming the earth to be a sphere of uniform density, how much would a body weigh half way down the center of earth if it weighs 250N on the surface of earth?
10. An earth's satellite has a time period of 90 min. Assuming the orbit to be circular, calculate its height. Given : $G = 6.67 \times 10^{-11}$ N-m^2/kg^2, $M = 6.02 \times 10^{24}$kg and radius of the earth is 6400km.
11. If the radius of the earth suddenly decreases to 60% of the present value, the mass of the earth remaining same, what will be the change in the magnitude of gravitational acceleration on the surface of earth ?
12. If both, the mass and the radius of the earth decrease by 1% , what will be the % change in the gravitational acceleration ?
13. The distance of an object of mass 1kg lying on the surface of the earth, from the center of the moon is 0.38×10^9 m. The mass of the moon is 7.36×10^{22} kg. Estimate the gravitational force exerted on the object by the moon. Use known value of G.
14. A spacecraft goes directly from the earth to the Sun. How far from the center of the earth the gravitational force exerted on it by the earth and the sun would be the same? The distance between the earth and the sun is 1.49×10^8 km, masses of the earth and the sun are 2×10^{30} kg and 6×10^{24} kg respectively.
15. If the earth were made completely of gold, what would have been the magnitude of gravitational acceleration on its surface ? The radius of the earth is 6400km, density of gold is 19.3×10^3 kg/m^3 and $G = 6.67 \times 10^{-11}$ N-m^2/kg^2.
16. The radius of the circular orbit of the earth, revolving round the sun, is 1.5×10^8 km. The orbital speed of the earth is 30 km/s. Calculate the mass of the sun from these data. $G = 6.67 \times 10^{-11}$ N-m^2/kg^2.
17. A satellite revolves round the earth at a height equal to radius of the earth. Calculate its (i) orbital speed and (ii) period. Take $G = 6.67 \times 10^{-11}$ N-m^2/kg^2. The radius of the earth = 6400 km and the mass of the earth = 6×10^{24} kg.

3. Heat

Heat is a form of energy, which gives us the sensation of warmth or hotness. A body becomes hotter when it gains heat energy and become colder when it gives out heat energy. The degree of hotness or coldness of a body is known as **temperature**. A device used to measure temperature is called thermometer. Various temperature scales are as follows:

Scales of temperature

In order that temperature readings have the same meaning wherever they are taken, it is necessary to have a fixed scale of temperature.

- **The Kelvin scale:** This is the scale used for all scientific work. The lower fixed point on the Kelvin scale is the temperature of pure melting ice. Its value is 273.15 K. The upper fixed point is the temperature of dry steam and its value is 373.15 K.

- **The Celsius scale** also known as the Centigrade scale: On this scale the lower fixed point is 0° C which is freezing point of water and upper fixed point is 100^0 C which is boiling point of water.
  It is given by $t\,^0C = T\,^OK - 273.15$

- **The Fahrenheit scale**: The Fahrenheit scale, used in English-speaking countries for purposes other than scientific work and based on the mercury thermometer, the freezing point of water is defined as 32° F and the boiling point as 212° F.
  It is given by $t\,^0F = 32 + 9/5\ t\,^0C$

Units of heat energy

- Heat is measured in the units of calorie and kilocalories. The amount of heat required to raise the temperature of 1 kg of pure water at a pressure of 1 atmosphere from 15° to 16° C is 1 kilocalorie. 1 Kilocalorie = 1000 calorie.
- In S. I. system, heat is measure in Joule **(J).** , 1 Joule = 10^7 ergs

Specific Heat

- The amount of heat required to raise the temperature of 1 gm of a substance by 1°C is called **specific heat** and is denoted by **S**.
- If a body of mass **m** is allowed to gain or lose quantity of heat **Q** and as a result change in the temperature is **Δt** °C, then $\mathbf{S = Q/m\Delta t}$

System	**Unit Specific Heat**
C. G. S.	Cal/gm/°C
M. K. S.	Kcal/Kg/°K
S. I.	Joule/Kg/°K

Heat gained or heat lost by a body

The amount of heat **Q** lost or gained by a **m** gram of body having specific heat **S** of material, during the change in temperature **Δt** is given by $\mathbf{Q = mS\ \Delta t}$.

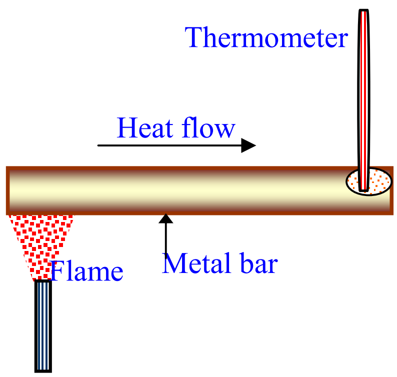
Principle of calorimetry or mixtures

- Whenever a hot substance and a cold substance are mixed together, heat is lost by the hot substance and gained by the cold substance. If the heat is not lost or gained by an external source the amount of heat lost by the hot body will be equal to amount of heat gained by the cold body. This is the principle of calorimetry. i.e. **Heat lost = Heat gained**

Modes of transmission of heat

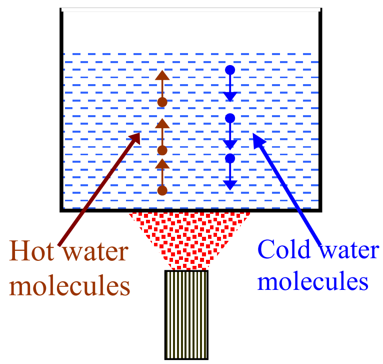
- The transfer of heat takes place from a region of higher temperature to a region of lower temperature. The transmission of heat from one body to another can take place by the following three processes: **conduction, convection and radiation**.

Conduction



- When a metallic rod is heated at one end, opposite end also gets heated after some time. This indicates that the heat has traveled through the material of the rod from one end to the other.
- The molecules of every solid are vibrating about their mean positions. These vibrations increase with increase in temperature.
- The molecules of the metal rod near the source of heat are the first to receive heat. As soon as they receive heat, they begin to vibrate vigorously. These molecules collide with the molecules in the neighboring layer and transfer some of their vibrating energy.
- As a result of this the neighboring molecules also start vibrating energetically. In this way, heat travels along the rod.
- This is the process in which heat is transferred along a body, from the part of the body at a higher temperature to the part at a lower temperature without actual movement of the particles of the medium. This mode of transference of heat is called **conduction** it occurs in solid materials.

Convection

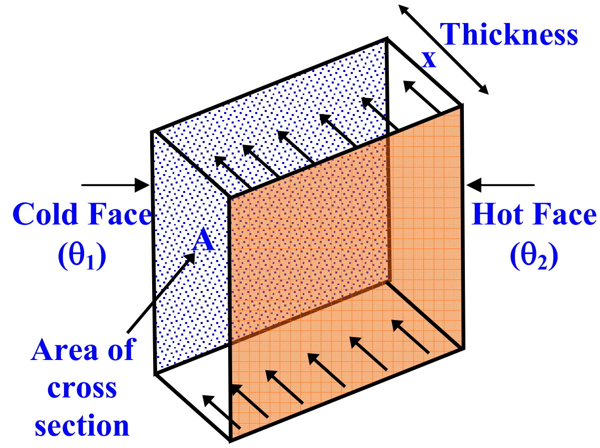


- In this process, heat transfer takes place by the bodily movement of the heated particles. **Convection** is possible only in liquids and gases.
- For example, when water is heated in a vessel, the molecules of water at the bottom receive the heat. Their density decreases with increase in temperature. Therefore they become lighter and move to the surface. The heavier molecules on the surface move to the bottom. This movement of the molecules continues till whole of the water is uniformly heated.

Radiation

- The process in which heat is transferred from a body at higher temperature to the body at a lower temperature, completely separated from each other, even in absence of medium is called radiation. It is the fastest process-taking place with the velocity of light. The heat from the Sun reaches the earth by this process.

Thermal Conductivity



- Consider a solid slab having a cross-sectional area **A** and of thickness **x** as shown in figure. Let the opposite parallel faces be at temperature θ_1 and θ_2. Now heat will start flowing from face at a higher temperature to the face at a lower temperature and the direction of flow of heat will be normal to the two parallel faces of the slab.
- The amount of heat flowing from one face to another is:
  1. Directly proportional to the face area.
     i.e $Q \propto A$
  2. Directly proportional to time for which conduction takes place,
     i.e. $Q \propto t$
  3. Directly proportional to the temperature between two faces,
     i.e. $Q \propto (\theta_1 - \theta_2)$
  4. Inversely proportional to the thickness of the slab,
     i.e. $Q \propto \frac{1}{x}$

From this it is clear that $\mathbf{Q} \propto \frac{\mathbf{A(\theta_1 - \theta_2)t}}{\mathbf{x}}$

$$\therefore \mathbf{Q} = \frac{\mathbf{KA(\theta_1 - \theta_2)t}}{\mathbf{x}}$$

Here **K** is the proportionality constant and depends on the nature of the material.

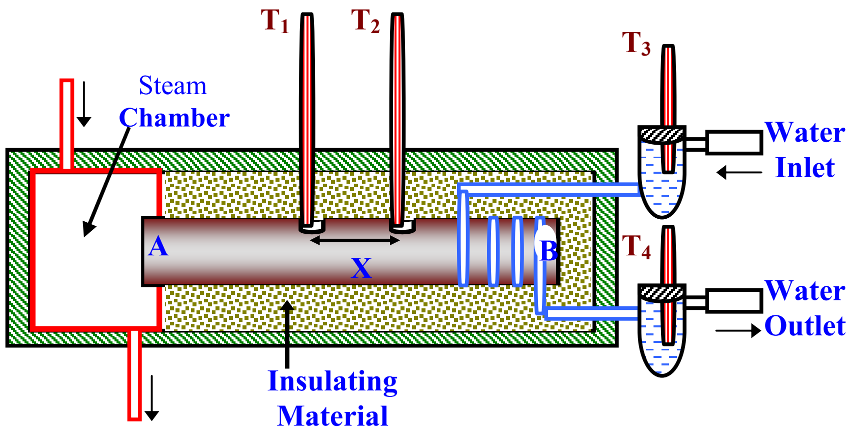
$$\mathbf{K} = \frac{\mathbf{xQ}}{\mathbf{A(\theta_1 - \theta_2)t}}$$

If A =1, $(\theta_1-\theta_2)$ = 1, t =1 & x =1, then K = Q

- Thus, **Coefficient of thermal conductivity** is equal to the quantity of heat which flows in one second through a unit cube of material when its opposite faces are maintained at a temperature difference of 1°C.

System	Units of Thermal conductivity K
M. K. S.	Kcal/m/K/s
C. G. S.	Cal/cm/°C/s
S. I.	W/m/K

Determination of thermal conductivity by Searle's method



- The material of which the coefficient of thermal conductivity is to be determined is taken in form of a thick rod **AB** of known size. One end **A** of the rod is heated by passing steam in a chamber.
- Two thermometers T_1 and T_2 are placed in the small cavities made in the rod **AB** at a known distance **x** apart.
- A copper tube is wound around end **B** of the rod and the tube carries two thermometers T_3 and T_4 for measuring the temperature of the incoming and outgoing water.
- To minimize heat-loss, some heat insulating material wounded on the rod.
- When the temperature of the thermometers T_1 and T_2 become steady, water is allowed to pass through the copper tube and collected at the other end in a beaker for some time.
- The temperature of the incoming and the outgoing water is noted and the time for which the water is allowed to pass is also recorded.

Observations

1. Mass of the water collected = **M** gm
2. Time taken for collecting water = **t** sec
3. Specific heat of water = **S**
4. Temperature reading in Thermometer $T_1 = \boldsymbol{\theta_1}$
5. Temperature reading in Thermometer $T_2 = \boldsymbol{\theta_2}$
6. Temperature reading in Thermometer $T_3 = \boldsymbol{\theta_3}$
7. Temperature reading in Thermometer $T_4 = \boldsymbol{\theta_4}$
8. Area of cross section of rod = **A** m^2 and Distance between T_1 & T_2 = **x** m

   Heat gained by water in **t** second = **MS** $\boldsymbol{(\theta_4 - \theta_3)}$

   Now heat flowing between two points at a distance **x** in **t** sec = $\dfrac{KA(\theta_1 - \theta_2)t}{x}$

- The amount of heat flowing through any section in **t** second under steady state will be same. Hence the quantity of heat, which flows between two points, will be equal to the heat gained by water.

$$\therefore \frac{KA(\theta_1 - \theta_2)t}{x} = MS(\theta_4 - \theta_3)$$

$$\therefore K = \frac{MS(\theta_4 - \theta_3)x}{A(\theta_1 - \theta_2)t} \qquad \text{W/m/°K or J/m/°K/s}$$

Change of state

- There are main three states of matter – **solid, liquid and gas**. Under a particular set of conditions, matter may exist in one of these states. When these conditions are changed the substances may change to another state.
- One of the conditions that cause the change of state of a substance is temperature of the substance. As we know well that as temperature of water is sufficiently low, water takes a solid form (ice) and as the temperature increases sufficiently it takes the form of gas.
- The change of state from solid to liquid is called **fusion or melting** process. The process of liquid changing to solid state is called **solidification.** The process of change of liquid in to a gas is called **vaporization.**

Fusion and latent heat of fusion

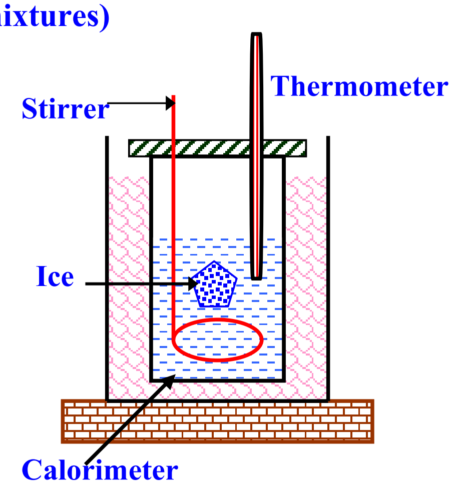
- When a solid is heated, its temperature increases. At a particular temperature the solid starts changing into a liquid (**fusion/melting**). The amount of heat, which is used for changing the solid into liquid, is known as the **latent heat** of fusion or melting.
- **Latent heat of fusion** is defined as the amount of heat required to convert unit mass of the substance from solid to liquid at its melting point without any rise in temperature.
- Let **Q** be the heat required to melt **M** mass of substance, at the same temperature. If **L** is the latent heat of fusion of a substance,

  Then we have **Q = ML**

  Therefore, **L = Q/M**

  The unit of latent heat is **cal/gm or kcal/kg or J/kg**.

Determination of latent heat of ice (method of mixtures)



- Take a dry calorimeter with a stirrer and weigh it.
- Fill it with two-thirds with water and Weigh it.
- Note the initial temperature of the water in the calorimeter.
- Put some ice in the calorimeter and stir the mixture till the temperature of the mixture stops falling.
- Note the final temperature of the mixture and finally, weigh the calorimeter along with the mixture.

Observations

1. Mass of empty the calorimeter + stirrer = m_1 gm
2. Mass of the calorimeter + stirrer + water = m_2 gm
3. Initial temperature of water and the calorimeter = t_1°C
4. Final temperature of the mixture = t°C
5. Mass of the calorimeter + stirrer + water + ice = m_3 gm
6. Temperature of ice = 0°C
7. Specific heat of water = S_2
8. Specific heat of calorimeter = S_1
9. Latent heat of ice = L

- Here,
- Total heat lost by (calorimeter +stirrer +water) = Total heat gained by ice is the heat used in melting the ice and in raising the temperature of the melted ice to the final temperature of the mixture.

Heat lost by (calorimeter +stirrer) + Heat lost by water = Heat gained by ice for melting + Heat gained by the melted ice water

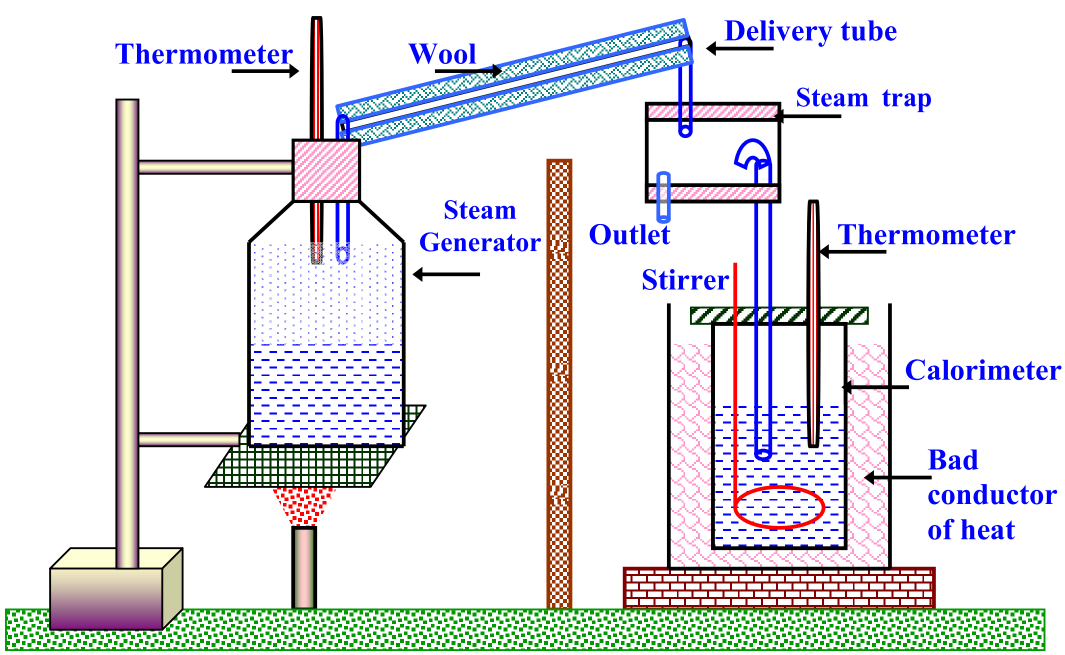
$$m_1S_1(t_1 - t) + (m_2 - m_1)S_2(t_1 - t) = (m_3 - m_2)L + (m_3 - m_2)S_2(t-0)$$

$$\therefore\ L = -\frac{[m_1S_1 + (m_2 - m_1)S_2](t_1 - t) + (m_3 - m_2)S_2 t}{(m_3 - m_2)}$$

Latent heat of vaporization

- The process of conversion of a substance from liquid to gaseous state is called vaporization. The reverse of this process is called condensation.
- When a liquid is heated its temperature starts increasing and at a particular temperature its temperature stops rising and the liquid starts boiling. During this process, the heat supplied is to the liquid is not utilized in increasing the temperature but in changing the state of the substance from liquid to gas.
- The heat used for changing the state from liquid to gas (vapor) state is called **latent heat of vaporization.**
- The latent heat of vaporization is defined as the amount of heat required to convert unit mass of the liquid into its vapor state at the same temperature. The **units** are cal/gm, kcal/kg and J/kg.

Determination of latent heat of vaporization



- Take a dry calorimeter with a stirrer and weigh it.
- Fill the calorimeter two-thirds with water and weigh the calorimeter with water.
- Heat the water in the boiler to produce steam. The steam is allowed to pass through a delivery tube to a steam trap.
- Allow the steam to enter inside the water present in the calorimeter.
- Allow the temperature of water in the calorimeter to rise by 10°C or so.
- Take out the tube and measure the final temperature of the mixture.
- Weigh the calorimeter with the stirrer and the water.

Observations

1. Mass of empty the calorimeter + stirrer = m_1 gm
2. Mass of the calorimeter + stirrer + water = m_2 gm
3. Initial temperature of the water in the calorimeter = t_1°C
4. Final temperature of the mixture = t°C
5. Mass of the calorimeter + stirrer + water + steam = m_3 gm
6. Temperature of the steam = 100°C
7. Specific heat of the calorimeter and stirrer = S_1
8. Specific heat of water = S_2
9. Latent heat of vaporization of water = L

- Here, Total heat lost by steam = Total heat gained by water and calorimeter.

Heat lost by steam in condensing to 100°C wate Heat lost by condensed steam in lowering temperature by t°C = Heat gained by calorimeter and stirrer + Heat gained by water

$$(m_3 - m_2)L + (m_3 - m_2)\, S2\, (100 - t) = m_1S_1(t - t_1) + (m_2 - m_1)S_2(t - t_1)$$

$$\therefore L = \frac{[m_1S_1 + S_2(m_2 - m_1)](t - t_1)}{m_3 - m_2} - S_2(100 - t)$$

Expansion of Gases

- Like solids and liquids gases also expand on heating. In case of gases the volume of a gas depends not only on the temperature of the gas but also on the pressure to which the gas is subjected. Thus in case of gases we have three variables - volume (**V**), pressure (**P**) and temperature (**T**). All these are mutually dependent on each other. There are three gas laws.

Boyle's law

- It states that at constant temperature the volume (V) of a given mass of a gas is inversely proportional to its pressure (P).
- In Boyle’s law if the pressure of the gas is increased, keeping the temperature constant, the volume will decrease and vice versa i.e.

$$P \propto \frac{1}{V} \qquad \therefore PV = \text{Constant}$$

In general, $\mathbf{P_1V_1 = P_2V_2 = P_3V_3 = Constant}$

- Where P_1, P_2, P_3 are the pressures of a gas and V_1, V_2, V_3 are the corresponding volumes.

Charles' law

- It states that at constant pressure the volume (V) of a given mass of a gas is directly proportional to its absolute temperature (T).
- In Charles' law if the temperature of a gas is increased keeping the pressure constant, the volume of the gas will also increase and vice versa. i.e.

$$V \propto T$$

$$\therefore \frac{V}{T} = \text{Constant}$$

$$\text{From this it follows } \frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} = \text{Constant}$$

- Let, V_0 and V_t be the volumes of a given mass of a gas at 0°C and t°C respectively at constant pressure.
- Then $\frac{V_t}{V_0} = \frac{T}{T_0} = \frac{273+t}{273} = \left(1+\frac{t}{273}\right) \Rightarrow \frac{V_t}{V_0} = \left(1+\frac{t}{273}\right)$

$$\therefore V_t = V_0\left(1+\frac{1}{273}\times t\right)$$

As γ_p = 1/273 (coefficient of cubical expansion of gas at constant pressure)

$$\therefore V_t = V_0(1 + \gamma_p t)$$

Gay- Lussac's law

- It states that at constant volume the pressure (P) of a given mass of a gas is directly proportional to its absolute temperature (T).
- In Charles' law if the temperature of a gas is increased keeping the pressure constant, the volume of the gas will also increase and vice versa. i.e.

$$P \propto T$$

$$\therefore \frac{P}{T} = \text{Constant}$$

$$\text{From this it follows } \frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{P_3}{T_3} = \text{Constant}$$

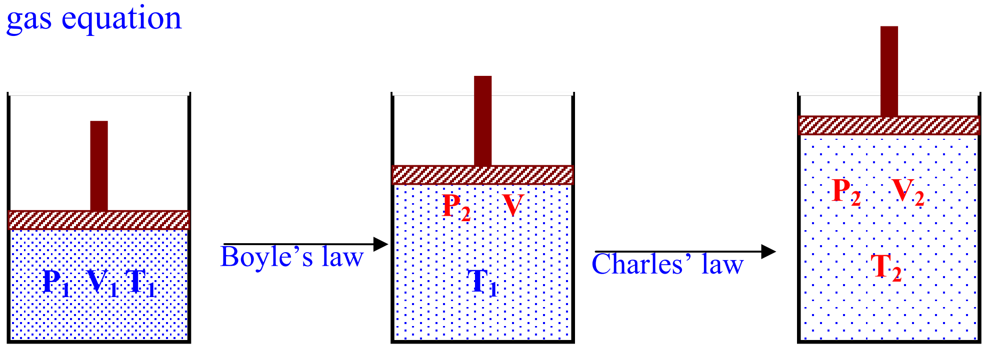
- Let, P_0 and P_t be the pressures of the gas at 0°C and t°C respectively at constant volume.
- Then $\frac{P_t}{P_0} = \frac{T}{T_0} = \frac{273+t}{273} = \left(1+\frac{t}{273}\right) \Rightarrow \frac{P_t}{P_0} = \left(1+\frac{t}{273}\right)$

$$\therefore P_t = P_0\left(1+\frac{1}{273}\times t\right)$$

As γ_v = 1/273 (coefficient of cubical expansion of gas at constant volume)

$$\therefore P_t = P_0(1 + \gamma_v t)$$

General gas equation



- Consider a gas having pressure (P_1), volume (V_1) and at absolute temperature (T_1).
- In the first phase, If we apply Boyle's law, i.e. let the temperature (T_1) of a gas be constant and pressure is changed to (P_2), so that new volume (V) of a gas will be given as $P_1V_1 = P_2V$

$$\therefore V = \frac{P_1V_1}{P_2} \quad \text{------------------} \quad (1)$$

- Now, in the second phase, let the pressure of a gas be kept constant and if the temperature be changed to T_2 from T_1, the final volume V_2 will be given by Charles' law as

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

$$\therefore V = \frac{T_1V_2}{T_2} \quad \text{-----------------} \quad (2)$$

- From equation (1) and (2), we can have

$$\frac{P_1V_1}{P_2} = \frac{T_1V_2}{T_2}$$

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

$$\therefore \frac{PV}{T} = \text{constant(say R)} \quad \text{----------} \quad (3)$$

or $PV = \mathbf{R}T$

- This is the General Gas Equation, and constant **R** is known as universal gas constant. The value of **R = 8.314 J/mol. K.**

Specific heat of a gas at constant pressure [C_P]

- Specific heat of gas at constant pressure is defined as "The amount of heat required to increase the temperature of one kilogram of a gas through 1^0 K at constant pressure. It is denoted by C_P and is measured in Joule/kg. ^{0}K

Specific heat of a gas at constant volume [C_V]

- Specific heat of gas at constant volume is defined as "The amount of heat required to increase the temperature of one kilogram of a gas through 1^0 K at constant volume. It is denoted by C_V and is measured in Joule/kg. ^{0}K

Relation between C_P and C_V

- If we heat **m** gram of gas at constant volume, only pressure and temperature of gas will increase. As there is no increase in volume there will be no external work done and whole of heat energy [C_V] supplied will be used for increasing the temperature of the gas only.
- If we heat **m** gram of gas at constant pressure, only volume and temperature of gas will increase. As there is increase in volume there will be some external work done. Therefore the heat energy [C_P] supplied will be used for
    1. Increasing the temperature of the gas, and
    2. Doing external work, to increasing the volume of the gas.
- As during heating of the gas at constant pressure extra work is done, the value of [C_P] is greater than [C_V]. i.e. $C_P > C_V$.

  Therefore

  [C_P] = [C_V] + Heat required for doing external work [H]. -------------- (1)

  Suppose,

  V_1 = Initial volume of a gas, and

  V_2 = final volume of a gas at constant pressure.

  Then the work done **W** in expanding the gas from volume V_1 to volume V_2,

  W = (pressure) x (change in volume of gas)

  $W = (p) \times (V_2 - V_1)$ -- (2)

- Now, the relation between the amount of heat produced **H** and work-done **W** is given by joule's law, as

$$H = \frac{W}{J} = \frac{P(V_2 - V_1)}{J} \quad \text{--------------------(3)}$$

  Where '**J**' is joule's constant known as mechanical equivalent of heat. The value of J = 4200 joules/ kilocalorie or J = 4.2 joule/calorie.

- Now from equation (1) and (3), we can have

$$C_P = C_V + \frac{P(V_2 - V_1)}{J}$$

$$\therefore C_P = C_V + \frac{PV_2 - PV_1}{J}$$

  According to general gas equation at constant pressure, $PV_1 = RT_1$ and $PV_2 = RT_2$.

$$\therefore C_P = C_V + \frac{R(T_2 - T_1)}{J}$$

  As specific heat of gas is "The amount of heat required to raise the temperature of unit mass of a gas through 1^0 K. Then $(T_2 - T_1) = 1^0$K.

$$\therefore C_P = C_V + \frac{R}{J}$$

$$\therefore C_P - C_V = \frac{R}{J} \quad \text{--------------------------(4)}$$

  Constant **R** is known as universal gas constant. The value of **R = 8.314 J/mol. K.**

Numerical

1. Find the quantity of heat conducted in 10min across a silver sheet of size 40cmx30cm, thickness 6mm, if its two faces are at temperatures of 40^0C and 30^0C. K_{silver} = 0.1kcal/m ^{0}C s.
2. A nickel plate of thickness 4mm has a temperature difference of 32^0C between its faces. It transmits 200kcal per hour through an area of 5cm^2. Calculate the thermal conductivity of nickel.
3. Heat is conducted through a composite slab of two different metals having thermal conductivity 0.2 and 0.3 kcal/m^{0}Cs and equal thickness. The outer faces are at 100^0C and 0^0C. Find the temperature of the interface.
4. A bar of copper of length 75cm and a bar of steel of length 125cm are joined together end to end. Both are of circular cross section with diameter 2cm. The free ends of copper and steel are maintained at 100^0C and 0^0C respectively. What is the temperature of copper-steel junction? Thermal conductivity of copper is 9.2E-2 kcal/m ^{0}C s and that of steel is 1.1E-2 kcal/m ^{0}C s.
5. A copper rod 19cm long having cross sectional area 0.785 cm^2 is heated at one end through 100^0C while the other end is kept at 30^0C. Calculate the amount of heat which will flow in 10 min along the way. Thermal conductivity of copper is 380 W/m^{0}K.
6. 5 gm ice at 0^0C is dropped in a beaker containing 20 gm water at 40^0C. What will be the final temperature? Latent heat of ice = 80 cal/gm and specific heat of ice = 1 cal/gm^{0}C.
7. How much heat is needed to change a mass of 20 kg ice at -10^0C in to water at 30^0C? Specific heat of ice = 2100 J/Kg ^{0}K, Latent heat of ice = 336x10^3 J/Kg and specific heat of water = 4200 J/Kg ^{0}K.
8. How much steam will just melt 2000gm ice at -10^0C. Temperature of steam is 100^0C. Latent heat of steam = 540 cal/gm, Latent heat of ice = 80 cal/gm, Specific heat of ice= 0.5 cal/gm^{0}C.
9. A copper calorimeter of mass 260 gm contains 80 gm water at 15^0C. If 50 gm water at 80^0C is added in to calorimeter, what will be the temperature of mixture? Specific heat of copper = 400 J/Kg ^{0}K and that of water is 4200 J/kg ^{0}K.
10. 200 gm of liquid at 360^0K is poured in to a copper calorimeter of weight 600gm and containing 700 gm water at 305^0K. Find the temperature of mixture. Specific heat of copper is 391 J/kg ^{0}K , Specific heat of water is 4200 J/kg ^{0}K and that of liquid is 1974 J/kg^{0}K.
11. The initial pressure of a gas is 60 cm of mercury at 20^0C. It is heated to 150^0C keeping volume constant. Find its new pressure.
12. A gas at 17^0C is heated at constant pressure till its volume increases 2.5 times the initial volume. Find its final temperature.
13. Certain mass of a gas occupies 40cm^3 at 27^0C and 780mm of pressure. Find its volume at 47^0C and 680mm of pressure.
14. An air bubble at the bottom of a lake 90m deep has a volume 2.5 cm^3. What will be its volume just below the surface if atmospheric pressure is equivalent to 10m of water? Temperature at the bottom of lake is 4^0C and that on the surface is 13^0C.
15. The density of a gas at NTP is 1.50 Kg/m^3. Find the density of gas at -15^0C and at a pressure of 84 cm of Hg.
16. The ratio of (C_p/C_V) for a gas is 1.4 and R/J=1.986. Find the value of C_p and C_v.

4. Sound

Periodic motion:

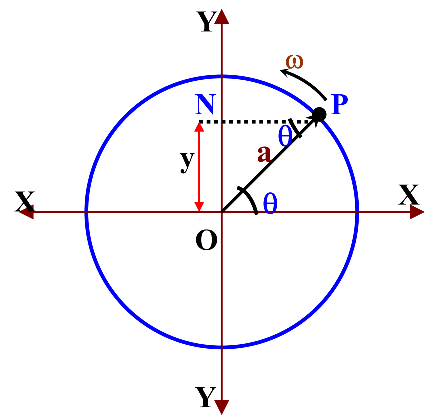
- It is defined as motion in which the body describes the same path in the same way again and again in equal intervals of time.
- For a body moving in a circular path, it has **circular periodic motion** and if the motion is repeated along a line, known as **linear periodic motion**. Periodic motion is also called harmonic motion.
- Repeated motion of particle on the same path around some mean position and within a fixed interval of time is known as **simple harmonic motion**. e.g. simple pendulum, motion of mass attached to spring, projection of circular motion etc.

Wave motion:

- Wave motion is a form of disturbance, which travels in the material medium and is due the repeated periodic motion of the medium particles about their mean positions, the motion being handed on from one particle to the next after a regular interval of time.
- For example, when a stone is thrown in water, water waves are produced i.e.. When a stone is dropped in to water, the water molecules perform simple harmonic motion in vertical direction and the waves travel in the horizontal direction.

Displacement:

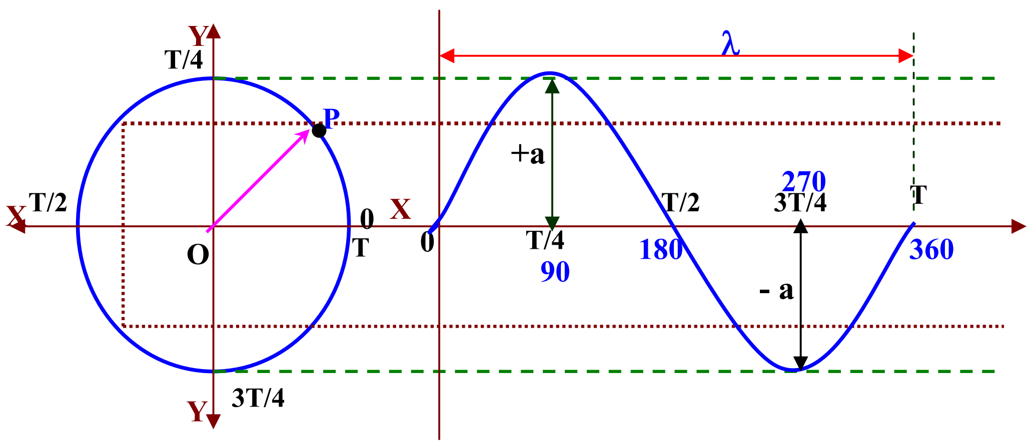
- The distance of the particle measured along the path of the motion from its mean position, at a given instant is called **displacement**
- Consider a particle **P** moving in circular path of radius '**a**' with angular velocity ω (radians/sec.). Its position at any instant is given by the angle subtended by the line joining the particle with origin **O**. i.e. $\theta = \omega t$
- Its projection on Y-axis is Simple Harmonic Motion. From figure, the displacement particle **N** is equal to **ON** or **y**.



$\sin\theta = ON / OP$, $\therefore ON = OP \sin\theta$

$\therefore$ Displacement $\mathbf{y = a \sin\theta}$, But $\theta = \omega t$

$\therefore$ Displacement $\mathbf{y = a \sin\omega t}$



Amplitude (a): The maximum displacement of the particle on either side of its mean position is called its amplitude.

Periodic Time (T): It is the time required to complete one vibration or one oscillation. Its unit is second.

Frequency (f): It is the number of vibrations performed by a particle in 1 sec.

Wavelength(λ): The distance traveled by a wave in one periodic time (T) is called wavelength.

Relation between f & λ:

Wave velocity = Distance/time

$\therefore$ **v** = wavelength / periodic time

$\therefore \mathbf{v} = \lambda / \mathbf{T}$ But, $\mathbf{f = 1/T}$

$\therefore \mathbf{v} = \mathbf{f}\,\lambda$

Types of waves: There are two types of waves.

(1) Longitudinal waves and, (2) Transverse waves

Longitudinal waves:

- These are the waves in which the vibrations of the particles of the medium are in the direction of propagation of waves.
- For example, sound waves or waves transmitted along a stretched spring by compressing its one end and then releasing it.

Transverse waves :

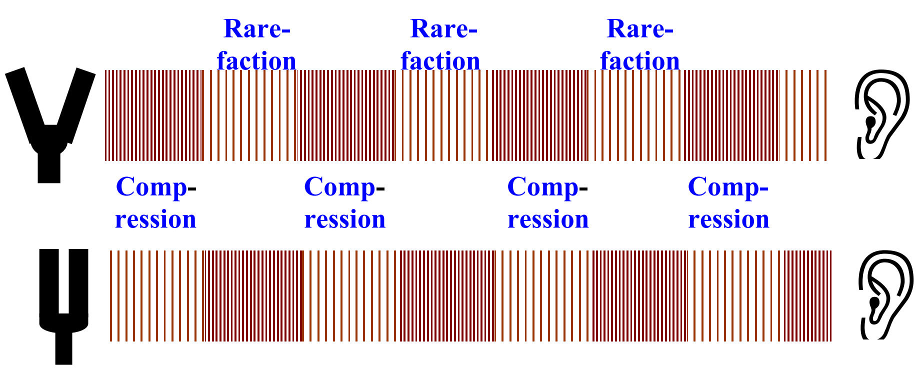
- These are the waves in which vibrations of the particles of the medium are perpendicular to the direction of propagation of waves.
- For example, ripples on the surface of water when a stone is thrown in water or waves formed when a string tied at one end is vibrated.

Sound waves: The following are necessary for the transmission of sound:

Source - the vibrating object, which produces sound

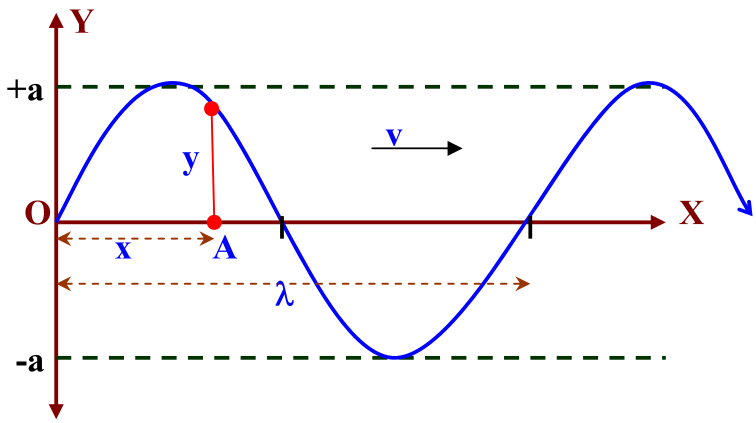
Medium - to transmit the sound

Receiver - the ear or a microphone to receive the sound.



- During the vibrations of a body, air is pushed and contracts. i.e. air get compressed and the pressure gets slightly increased. Due to this increase in pressure, these layers expand towards right and push the neighboring layers where pressure is low.
- The region where pressure is low is called rarefaction and the region where pressure is high is called compression. As the body keeps on vibrating rapidly, the compressions and rarefactions reaches ear alternately and produce sound.

Equation of a plane progressive wave:



- Figure shows a plane progressive simple harmonic wave originating at the origin **O** from its mean position at any time **t,** and propagating in the +ve **x**-direction with velocity **v**.
- As the wave proceeds, each successive particle of the medium is set into simple harmonic motion. The displacement of the particle at '**O**' at any time '**t**' is given by

$$y = a\sin\omega t = a\sin\left(\frac{2\pi}{T}\right)t \quad \text{---------------------------(1)}$$

Where, ($\omega = 2\pi/T$) and T is periodic time.

- Consider a particle of the medium at a point **A**. it is at a distance **x** from **O**. The wave starting from **O** would reach this point in ('t'= **x/v)** seconds. i.e. this particle will start vibrating **(x/v**) sec. later than the particle at **O**. Therefore displacement of a particle **A** after a time **t** can be obtained by substituting (t-x/v) in place of **t** in equation (1).

$$\therefore y = a\sin\omega\left(t - \frac{x}{v}\right)$$

$$\therefore y = a\sin\frac{2\pi}{T}\left(t - \frac{x}{v}\right) \qquad (2)$$

$$\therefore y = a\sin\frac{2\pi}{Tv}(vt - x) \qquad (3)$$

$$\therefore y = a\sin\frac{2\pi}{\lambda}(vt - x) \qquad (4)$$

$$\therefore y = a\sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right) \qquad (5)$$

- Equations (2) to (5) represent the different forms of the equation of a plane progressive wave.
- **For example** if the eq^n of the wave is y = 8sinπ (0.02x - 4.00t) and y and x are in cm and t is in seconds, find the amplitude, frequency and velocity of the wave.
- Now compare y = 8sinπ (0.02x - 4.00t) with the following equation of the plane progressive wave. $y = a\sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$

  We find that a =8 and n = 1/T = 2.00 sec^{-1} and λ = 1/0.01 =100 cm
  Velocity (v) =nλ = 2 * 100 =200 cm/sec

Newton's formula for Velocity of sound:

- Newton assumed that the propagation of sound waves in air is an isothermal phenomenon i.e. a process in which heat is transferred and temperature remains constant.
- He argued that the small amount of heat, which is produced at compression, is rapidly taken away to the places of rarefactions where a slight cooling is produced and the temperature of medium remains constant. Thus for a given mass of gas at pressure P and volume V, we have PV = constant
- Newton derived the formula for velocity of sound based on Boyle's Law, which given by

$$v = \sqrt{\frac{P}{\rho}}$$ Where P is the pressure and ρ is the density of gas.

This is Newton's formula.

For air at 0°C, $P = 76 \times 13.6 \times 980$ dynes/cm^2

$\rho = 0.00129$ gm/c.c

$\therefore v = 28021$ cm/sec c

This value is much lower than the experimental value of 33200 cm/sec or 332 m/sec.

Laplace's formula for velocity of sound

- Laplace pointed out that the propagation of sound in air is not an isothermal process but it is an adiabatic process. i.e. a process in which there is no exchange of heat.

Laplace argued that due to the reason

1. Compressions and rare-fractions take place very rapidly.
2. There are large distances between compressions and rare-fractions and
3. Air is a poor conductor; there is no appreciable heat flow from compressions to rarefactions.

∴ The condition do not remain isothermal, i.e Temperature increases in the region of compressions.

- According to Laplace, the velocity of sound is given by

$$v = \sqrt{\frac{\gamma P}{\rho}} = 331.6 \text{ m/sec} \qquad \text{For air } \gamma = 1.41$$

Effect of pressure, temperature and humidity on the speed of sound

Effect of pressure:

- When pressure of a given mass of a gas changes, there is a corresponding change of volume and density. According to Boyle's Law, **$P \propto 1/V$** at constant temperature.

i.e **PV = constant**

But we know that Volume(V) = mass (m)/ density (ρ)

∴ **P(m/ρ) = constant**

∴ **P/ρ = constant,** as **m** is constant for a given gas.

$$v = \sqrt{\frac{\gamma P}{\rho}} = \text{Constant.}$$

∴ Velocity of sound does not change with pressure.

Effect of temperature:

- When the temperature of the gas changes its density also changes without affecting the pressure. Thus speed of sound also changes.
- Let ρ_0 and ρ_t be the densities of a gas at **0º** C and **tº** C respectively

$$v_0 = \sqrt{\frac{\gamma P}{\rho_0}} \quad \text{and} \quad v_t = \sqrt{\frac{\gamma P}{\rho_t}}$$

Therefore $\frac{v_t}{v_0} = \sqrt{\frac{\rho_0}{\rho_t}}$

Now according to Charles's law $\rho_0 = \rho_t(1+\alpha t)$

$$\therefore \frac{v_t}{v_0} = \sqrt{\frac{\rho_t(1+\alpha t)}{\rho_t}} = \sqrt{1+\alpha t} = \sqrt{\left(1+\frac{t}{273}\right)} = \sqrt{\frac{273+t}{273}} = \sqrt{\frac{T_t}{T_0}}$$

$\therefore \frac{v_t}{v_0} = \sqrt{\frac{T_t}{T_0}}$ Where T_t and T_0 are absolute temperatures.

- Thus the speed of sound is directly proportional to the square root of the absolute temperature.

Effect of humidity:

- For the same temperature and pressure, the density of water vapour is less than that of air. Therefore the pressure of the moisture in the same volume of air lowers the density of the mixture.

  ∴ The speed of the sound in moist air is greater than in dry air.

Ultrasonic waves and their applications

- Human ear can hear the sound waves having frequency between 20 Hz and 20,000 Hz. The sound waves having frequencies above the audible range (20 Hz to 20,000 Hz) are known as ultrasonic waves.
- The sound waves having frequencies less than the audible range are called infrasonic waves.

Applications:

1. It can be used to detect flaws inside the metal.
2. Detection of submarines, iceberg and other objects in the ocean.
3. For finding the depth of the sea.
4. Ultrasonic waves can be used for drilling, Soldering and cutting process in metals, washing clothes, and removing dust and soot from the chimney.
5. Used for signaling in particular direction.
6. The animals like rats, frogs, fishes etc. can be killed or injured by high intensity ultrasonic waves
7. Abnormal growth in the brain, certain tumors that cannot be detected by x-rays can be detected with ultrasonic waves.

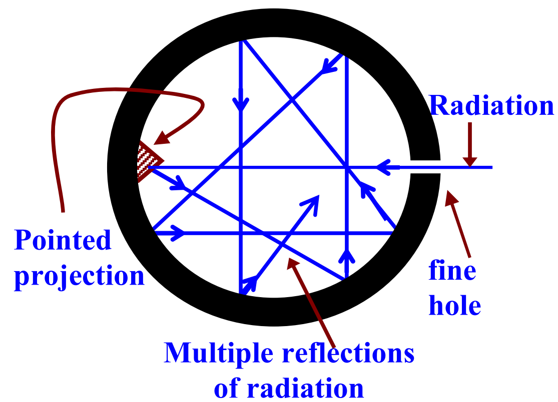
Numerical

1. A tuning fork produces waves of wavelength 0.50 m in a medium A. Calculate the length of the waves produced in a medium B, given Velocity of the waves in medium A=350 m/s , Velocity of the waves in medium B=490 m/s.
2. A body vibrating with a certain frequency sends waves 15cm long through a medium A and 20cm long through a medium B. The velocity of waves in A is 1200 cm/s. Find the velocity in B.
3. A thunder clap was heard 5.5s later then the accompanying light flash was seen. How far away did the flash occur? Velocity of sound =350m/s.
4. The velocity of sound in air at 14^0C is 340m/s. What will it be when the pressure of the gas is doubled and its temperature raised to 157.5^0 C?
5. The velocity of sound in air at 16^0C is 340m/s. Find the wavelengths in air of a note of frequency 680 at 160^0C and 51^0C.
6. The Velocity of sound at normal temperature and pressure is 332 m/s. Find the velocity of sound at 819^0C.
7. The velocity of a particle describing S.H.M. is 8 cm/s at a distance of 4 cm from the mean position and 4 cm/s at a distance of 6 cm from the mean position. Calculate the amplitude of vibration.
8. A simple progressive wave is represented by equation y = 0.5 Sin(314t-12.65x), where x and y are expressed in meters. Find Amplitude, Wavelength, Speed of wave and Frequency.
9. A simple harmonic progressive wave is given by $y = 0.6\,Sin\frac{\pi}{4}\left\{\left(80t - \frac{x}{5}\right)\right\}$. If the quantities are expressed in S.I units, find amplitude, wavelength, frequency, and velocity of the wave.

5. MODERN PHYSICS

Black Body and Black Body Radiation: -

- Black body is one, which absorbs radiations of all wavelengths incident upon it. When radiations are allowed to fall on such a body they are neither reflected nor transmitted.
- When a black body is heated, it emits radiations, which are independent of the nature of the black body and only depend upon the temperature of the black body. These radiations are known as **black body radiations**.
- Consider a hollow sphere with a fine hole and a pointed projection in front of the hole and coated with lampblack on its inner surface as shown in figure. When the radiations enter in such a body through hole, they suffer multiple reflections and are completely absorbed. Such a body acts as a **black body absorber.**



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Planck's Hypothesis and Concept of Quantum radiation: -

- In 1901, Max Planck while studying black body radiations had come to the conclusion that the absorption or emission of thermal energy is not a continuous process but take place in discrete amounts.
- According to Max Planck quantum theory of light, energy is not radiated or absorbed continuously but in the form of discrete bundles or packets of energy. These packets of energy are known as **photons**. These photons move with the velocity of light and they are not affected by electric or magnetic field.
- The quantum energy of a single photon (radiated or absorbed) is given by relation $E=h\nu$.

Where, **h** = Planck's constant = 6.626×10^{-34} **joule * sec** = 4.136×10^{-15} **eV * Sec**

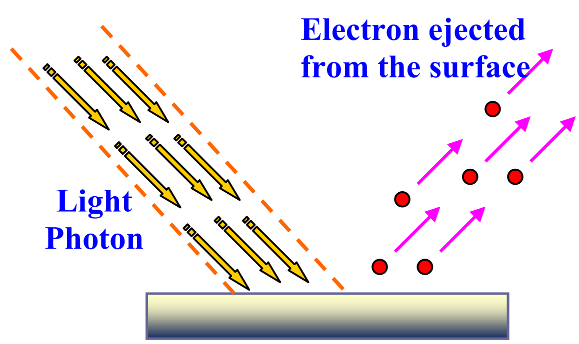
ν = Frequency of radiation

- Thus the energy radiated or absorbed is always in the integral multiple of **hν**.
- The velocity of light is given by $c = \nu \lambda$, where λ is wavelength of light.

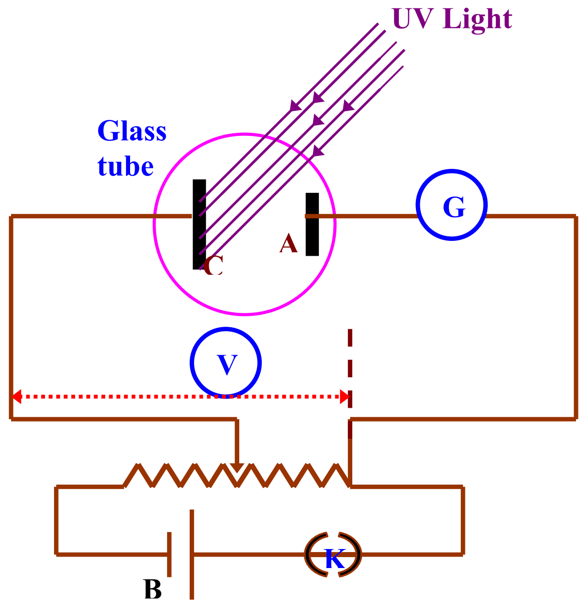
$$\therefore \nu = c/\lambda \qquad \therefore E = h\nu \qquad \therefore E = \frac{hc}{\lambda}$$

Photoelectric Effect: -

- The emission of electrons from a metal plate when illuminated by light or any other radiation of suitable frequency or wavelength is called photoelectric effect.
- Most commonly observed phenomena with light can be explained by waves. But the photoelectric effect suggested a particle nature for light.



- Figure shows a simple experimental arrangement. Two metal plates working as anode and cathode are arranged in an evacuated glass bulb. Anode is maintained at positive potential with respect to the cathode.
- When light rays of proper frequency are allowed to fall on the cathode, electrons are emitted from the surface. These electrons are attracted towards the positive anode.
- These electrons are called the **photoelectrons** and the current, which is set up due to this, is called the **photoelectric current**.



Definitions: -

Work function: - It is the minimum amount of energy required to make the electron free from the metal surface.

Threshold frequency(ν_0):- It is the minimum frequency of the incident radiation which can cause the photoelectric emission.

Threshold wavelength(λ_0):- It is the maximum wavelength of the incident radiation above which photoelectric emission is not possible.

Electron Volt (eV):-The electron volt is the unit of energy. 1 electron volt (eV) = 1.6×10^{-19} joule. It is the energy acquired by an electron when it moves through a potential difference of 1 volt.

Einstein's equation: -

- According to Planck's quantum theory, light consists of photons. Energy of each photon is equal to **hν.** When this photon is incident on the metal surface, the atom absorbs it.
- A part of this energy is used in making the electron free from the atom and the remaining amount of energy is given to the electron in the form of kinetic energy.
- Let **hν** = Energy possessed by the photon, $\frac{1}{2}mv^2$ = Kinetic Energy possessed by the photoelectron, W_0 = Minimum energy required to detach the electron = work function
- Then according to the law of conservation of energy

$$h\nu = W_0 + \frac{1}{2}mv^2$$

- This is called **Planck-Einstein's equation** or **Einstein's photoelectric equation**.
- When energy of the photon is such that it can only liberate the electron from metal, then the kinetic energy of the photoelectron will be zero. If ν_0 is the frequency corresponding to this energy, then

$$h\nu_0 = W_0 ,$$ Where ν_0 is called the threshold frequency.

$$h\nu = h\nu_0 + \frac{1}{2}mv^2$$

$$\frac{1}{2}mv^2 = h(\nu - \nu_0) = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) \quad \text{as } \nu = c/\lambda \quad \text{---------(1)}$$

This is known Einstein's photoelectric equation.

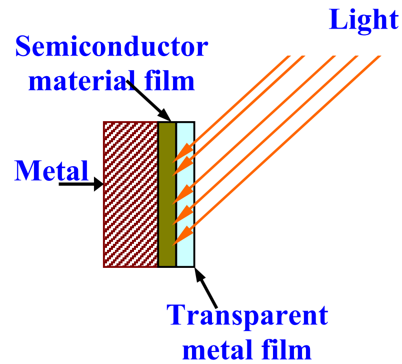
Laws of photoelectric emission: -

1. There is no time lag between the incidence of radiation and emission of photoelectrons.
2. The number of photoelectrons ejected is proportional to the intensity of the incident light.
3. The kinetic energy of emitted photoelectrons is directly proportional to the frequency of incident radiation.

Photoelectric Cells: -

Photoelectric cell is a device, which converts light energy into electrical energy. There are **three different types** of photoelectric cells:

1. Photoconductive cells: -These are based on the principle that the electrical resistance of semi-conductor materials decreases when exposed to radiation.



Applications: -

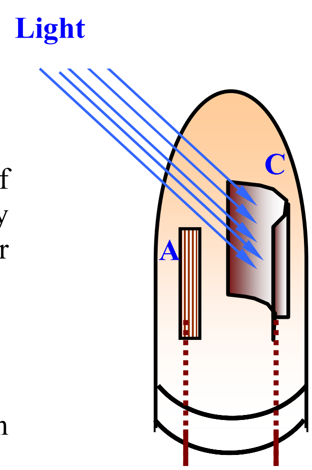
1. To measure intensity of illumination, i.e. to work as a light meters.
2. To make ON-OFF switch.
3. In street lighting control.
4. In counting applications.

2. Photo-voltaic Cells:-

These are based on the principle that when a pair of electrodes is immersed in an electrolyte and light is allowed to incident on one of them, a potential difference is developed. The potential difference so developed is directly proportional to the frequency and intensity of incident light.

Applications: -

1. Used in photographic exposure meters to measure the duration of light falling on photographic plate.
2. Used for operation of relays.



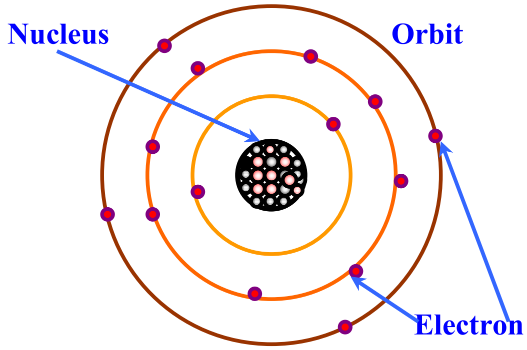
3. Photo emissive cells:- These are based on the principle of emission of electrons from a metal plate when illuminated by light or any other radiation of suitable frequency or wavelength.

Applications: -

1. Used as switch in electrical circuits.
2. Used in television because of their accurate response.
3. Gases filled photocells are used in cinematography and in the recording and reproduction of sound.

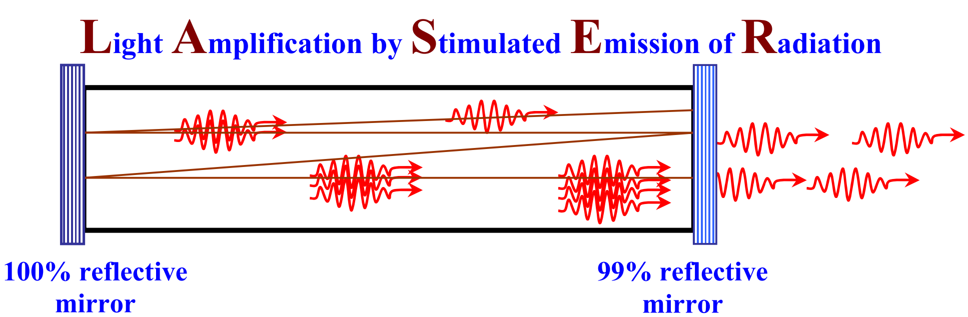
LASER

The Basics of an Atom



- As we know atoms are constantly in motion. They continuously vibrate, move and rotate. Atoms can be in different states of excitation or energy level.
- If we apply a lot of energy to an atom, it can leave the ground-state energy level and go to an excited level. The level of excitation depends on the amount of energy that is applied to the atom via heat, light, or electricity.
- This simple atom consists of a **nucleus** (containing the protons and neutrons) and an **electron cloud.** If we apply some heat to an atom, some of the electrons in the lower-energy orbital will transition to higher-energy orbital farther away from the nucleus.
- Once an electron moves to a higher-energy orbit, it eventually wants to return to the ground state. When it does, it releases its energy as a **photon** -- a particle of light.

The Laser/Atom Connection



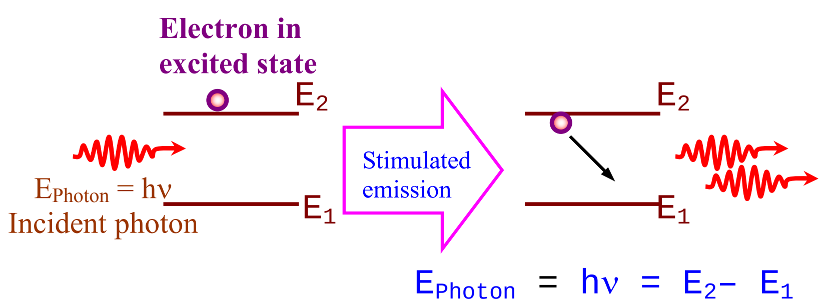
- A **laser** is a device in which the energized atoms release photons in a controlled way. The word "Laser" means **Light Amplification by Stimulated Emission of Radiation**,
- In a laser, the lasing medium is “pumped” to get the atoms into an excited state. Once the lasing medium is pumped, it contains a collection of atoms with some electrons sitting in excited levels. The excited electrons have energies greater than the ground state electrons.
- An electron in higher-energy orbit, return to the ground state and it releases its energy. This **emitted energy** comes in the form of **photons** (light energy). Laser light is very different from normal light.

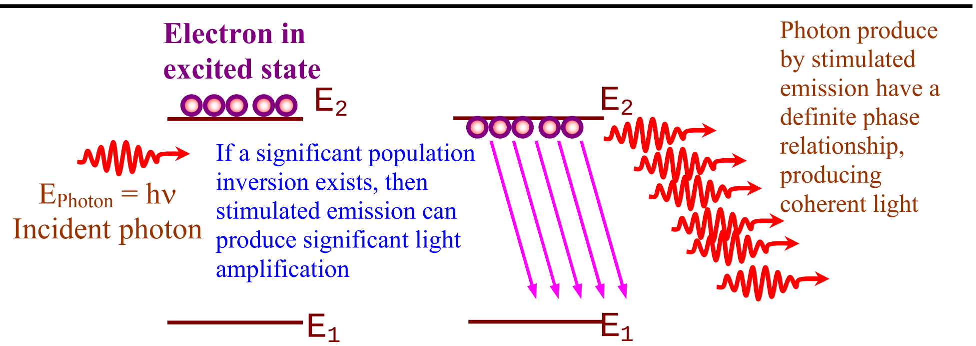
Laser light has the following properties or characteristic:

- The laser is **Monochromatic:** Laser light contains one specific wavelength of light (one specific color).
- The light released is **coherent:** It is "organized" - each photon moves in step with the others.
- The light is very **directional** or **collimated:** laser beams are very narrow and do not spread very much i.e. very tight beam and is very strong and concentrated.
- Emission of light with above three characteristic or properties is called **stimulated emission**. In stimulated emission, photon emission is organized.
- In the case of ordinary flashlight, the photon released by each atom has random direction and random phase. This is called **spontaneous** emission.

Stimulated Emission

- The photon that any atom releases has a very specific wavelength (color) that is dependent on the energy difference between the excited state and the ground state. When this photon encounter another atom that has an electron in the same excited state, **stimulated emission** can occur. In this case, emitted photon (from the second atom) vibrates with the same frequency and direction as the incoming photon.





- The population inversion is the number of atoms in the excited state versus the number of atoms in ground state. In other words, when population of electrons increases in upper levels, this condition is called a "**population inversion**". It sets the stage for stimulated emission of multiple photons.
- The other key to a laser is a pair of **mirrors**, one at each end of the lasing medium. Photons, with a very specific wavelength and phase, reflect off the mirrors to travel back and forth through the lasing medium. In this process, they stimulate other electrons and can cause the emission of more photons of the same wavelength and phase. The mirror at one end of the laser is "half-silvered," meaning that some light will be reflected and some light will be transmitted. The light that it transmitted is the laser light.

Types of Lasers

There are many different types of lasers. Lasers are commonly designated by the type of lasing material employed. The laser medium can be a solid, gas, liquid or semiconductor.

1. Solid-state lasers.
2. Gas lasers.
3. Excimer lasers.
4. Dye lasers.
5. Semiconductor lasers.

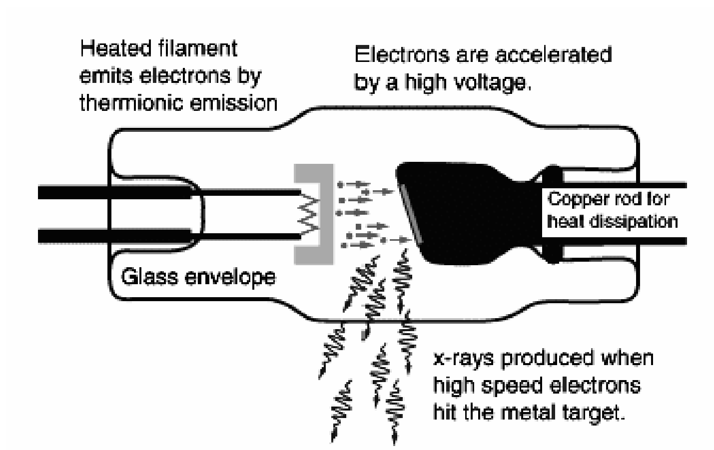
Laser Applications

1. **Medical Uses of Lasers:** Higher power lasers are used after cataract surgery. A focused laser can act as an extremely sharp scalpel for delicate surgery.
2. **Welding and Cutting:** The automobile industry makes extensive use of carbon dioxide laser for computer controlled welding on auto assembly lines. An interesting application of lasers to the welding of stainless steel handles on copper cooking pots.
3. **Surveying and Ranging:** Helium-neon and semiconductor lasers have become standard parts of the field surveyor's equipment. A fast laser pulse is sent to a corner reflector at the point to be measured and the time of reflection is measured to get the distance.
4. **Lasers in the Garment Industry:** Computer controlled laser garment cutters can be programmed to cut out garments and that might involve just a few cuts. The programmed cutter can cut dozens to hundreds of thicknesses of cloth, and can cut out every piece of the garment in a single run.
5. **Lasers in Communication:** The lasers are monochromatic and this allows the pulse shape to be maintained better over long distances.
6. **Heat Treatment:** Lasers offer some new possibilities for selective heat treatments of metal parts for hardening or annealing.
7. **Barcode Scanners:** Supermarket scanners typically use helium-neon lasers to scan the universal barcodes to identify products.

X-rays

- The German physicist W. Röntgen discovered X rays in 1895. Rontgen discovered that when a beam of fast moving electrons strikes a solid target, an invisible high penetrating radiation is produced. He called them **X-rays**.
- If the bombarding electrons have sufficient energy, they can knock an electron out of an inner shell of the target metal atoms. Then electrons from higher energy states drop down to lower energy states, emitting x-ray photons

Production of X-rays



- The X-rays are produced when fast moving electrons strike a target of suitable material.
- X-rays are produced by means of a Coolidge tube. It consists of a highly evacuated hard glass tube containing a cathode and an anode as shown in figure. The cathode consists of a filament **F** and is heated by a low-tension battery. The electrons are thus emitted from the cathode by the process of **thermionic emission**.
- The target **T** consists of a copper block in which a piece of Molybdenum or tungsten is fitted. The target is inclined at an angle of 45° with the path of electrons beam. A high AC potential of about 20,000 volts is applied between the filament **F** and the target **T**, so that the emitted electrons are accelerated and as when they strike the target they give their kinetic energy and thereby produce **X-rays**.
- It must be noted that only a small percentage of the electrons energy is converted into X-rays and the rest is dissipated as heat. This heats up the target and thus to protect the target, it is constantly cooled by cooling arrangement.
- The intensity of X-rays depends on the number of electrons striking the target. The quality or penetrating power of X-rays depends on the potential difference between the cathode and the target.
- Highly penetrating X-rays are called **hard X-rays** while low penetrating X-rays are called **soft X-rays**.

Properties of X-rays

1. X-rays are electromagnetic waves of very short wavelength and high frequency.
2. X-rays are travel with the velocity of light and are invisible to eyes.
3. Under suitable conditions X-rays are exhibit the property of light like reflection, refraction etc

4. X-rays can penetrate through substances, which are opaque to ordinary light like wood, flesh, thin paper and thin sheets of metals.
5. X-rays can ionize a gas through which they pass.
6. When X-rays fall on heavy metals, they produce secondary X-rays.

Uses and Applications of X-rays

1. X-rays are used in testing the homogeneity of welded joints, insulating materials etc.
2. X-rays are used to detect cracks in structures like airplanes.
3. X-rays are used to analyze the structure of alloys and composite bodies.
4. X-rays are used to study the structure of atoms, crystalline solids, organic compounds, and alloys.
5. X-rays are used in determining the atomic number
6. X-rays are used in identification of various chemical elements.
7. X-rays are used for detecting fractures in bones, diseased organs and foreign matter in the human body.
8. X-rays are used to destroy abnormal tissues and tumors deep inside the body. They are also used in the treatment of cancer.

Numerical

1. A photon has energy of 10eV. Calculate its wavelength.
2. The threshold frequency of a material is $2x10^{14}$ Hz. What is its work function in eV? Given h = $6.62x10^{-34}$J-s.
3. When light of wavelength 6800 A^0 is incident on metal the electrons are emitted with zero velocity. Calculate threshold frequency and work function of metal.
4. In an experiment, tungsten cathode, which has a threshold of 2300 A^0 is irradiated by ultraviolet light of wavelength 1800A^0. Calculate maximum energy of emitted photoelectrons and work function of tungsten.
5. A silver surface is illuminated by monochromatic ultraviolet radiation of wavelength 1810 A^0. Calculate the maximum energy of emitted electron. Threshold wavelength for silver is 2640 A^0.
6. Work function of metal is 2.2. eV. Calculate the maximum kinetic energy with which photoelectrons are emitted (in eV units) on irradiating this metal with light of 4800 A^0. c = 3×10^8 m/s and h = 6.625×10^{-34} J-sec.
7. Work function of metal is 2.2. eV. Calculate the wavelength of light for which with which photoelectrons are emitted. c = 3×10^8 m/s and h = 6.625×10^{-34} J-sec.
8. Threshold wavelength for tungsten is 2.73×10^{-5} cm. Light of wavelength 1.8×10^{-5} cm is incident on it. Find the 1) threshold frequency, 2) work function, and 3) maximum energy with which photoelectrons are emitted in joules and in eV units.
9. A 100-watt bulb converts 3% of electrical energy consumed by it into light energy. If the wavelength emitted by the bulb is 6625 A^0, calculate number of photons emitted per second.