2. Unit and Dimension

* **Fundamental or base quantities :**
The quantities which do not depend upon other quantities for their complete definition are known as fundamental or base quantities.
e.g. : length, mass, time, etc.

* **Derived quantities :**
The quantities which can be expressed in terms of the fundamental quantites are known as derived quantities e.g.
Speed (=distance/time), volume, acceleration, dorce, pressure, etc.

* **Units of physical quantities**
The chosen reference standard of measurement in multiples of which, a physical quantity is expressed is called the unit of that quantity.
Physical Quantity = Numerical Value × Unit

Systems of Units

	MKS	CGS	FPS	MKSQ	MKSA
(i)	Length (m)	Length (cm)	Length (ft)	Length (m)	Length (m)
(ii)	Mass (kg)	Mass (g)	Mass (pound)	Mass (kg)	Mass (kg)
(iii)	Time (s)	Time (s)	Time (s)	Time (s)	Time (s)
(iv)	-	-	-	Charge (Q)	Current (A)

Fundamental Quantities in S.I. System and their units

S.N.	Physical Qty.	Name of Unit	Symbol
1	Mass	kilogram	kg
2	Length	meter	m
3	Time	second	s
4	Temperature	kelvin	K
5	Luminous intensity	candela	Cd
6	Electric current	ampere	A
7	Amount of substance	mole	mol

SI Base Quantities and Units

Base Quantity	SI Units		
	Name	Symbol	Definition
Length	meter	m	The meter is the length of the path traveled by light in vacuum during a time interval of 1/(299, 792, 458) of a second (1983)
Mass	kilogram	kg	The kilogram is equal to the mass of the international prototype of the kilogram (a platinum-iridium alloy cylinder) kept at International Bureau of Weights and Measures, at Sevres, near Paris, France. (1889)
Time	second	s	The second is the duration of 9, 192, 631, 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom (1967)
Electric Current	ampere	A	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} Newton per metre of length. (1948)
Thermodynamic Temperature	kelvin	K	The kelvin, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (1967)
Amount of Substance	mole	mol	The mole is the amount of substance of a system, which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12. (1971)
Luminous Intensity	candela	Cd	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian (1979).

* **Supplementary Units**

- Radian (rad)- for measurement of plane angle
- Steradian (sr)- for measurement of solid angle

* **Dimensional Formula**
Relation which express physical quantities in terms of appropriate powers of fundamental units.

* **Use of dimensional analysis**

- To check the dimensional correctness of a given physical relation
- To derive relationship between different physical quantities
- To convert units of a physical quantity from one system to another

$$n_1u_1 = n_2u_2 \Rightarrow n_2 = n_1\left(\frac{M_1}{M_2}\right)^a\left(\frac{L_1}{L_2}\right)^b\left(\frac{T_1}{T_2}\right)^c$$

where $u = M^aL^bT^c$

* **Limitations of this method :**

- In Mechanics the formula for a physical quantity depending on more than three other pysical quantities cannot be derived. It can only be checked.
- This method can be used only if the dependency is of multiplication type. The formulae containing exponential, trigonometrical and logarithmic

$F = (m_1 + m_2)a$

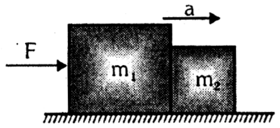


Fig.(1) : When the force F acts on mass m_1

If the force exerted by m_2 on m_1 is f_1 (force of contact) then for body m_1 : $(F - f_1) = m_1 a$

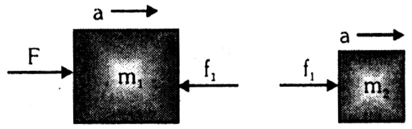


Fig. 1(a) : F.B.D. representation of action and reaction forces.

For body $m_2 = f_1 = m_2 a \Rightarrow$ action of m_1

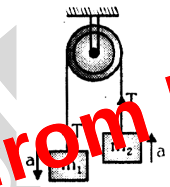
$: f_1 = \frac{m_2 F}{m_1 + m_2}$

* Pulley system

A single fixed pulley changes the direction of force only and in general, assumed to be massless and frictionless.

SOME CASES OF PULLEY

Case - I



Let $m_1 > m_2$

now for mass m_1, $m_1 g - T = m_1 a$

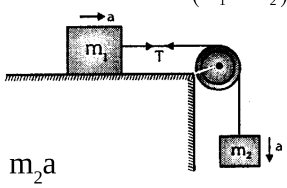
for mass m_2, $T - m_2 g = m_2 a$

Acceleration $= a = \frac{(m_1 - m_2)}{(m_1 + m_2)} g = \frac{\text{net pulling force}}{\text{total mass to be pulled}}$

Tension $= T = \frac{2m_1 m_2}{(m_1 + m_2)} g = \frac{2 \times \text{Product of masses}}{\text{Sum of two masses}} g$

Reaction at the suspension of pulley $R = 2T = \frac{4m_1 m_2 g}{(m_1 + m_2)}$

Case - II



For mass m_1 : $T = m_1 a$

For mass m_2 : $m_2 g - T = m_2 a$

Acceleration $a = \frac{m_2 g}{(m_1 + m_2)}$ and $T = \frac{m_1 m_2}{(m_1 + m_2)} g$

FRAME OF REFERENCE

* **Inertial frames of reference :** A reference frame which is either at rest or in uniform motion along the straight line. A non-accelerating frame of reference is called an inertial frame of reference. All the fundamental laws of physics have been formulated in respect of inertial frame of reference.

* **Non-inertial frame of reference :** A accelerating frame of reference is called a non-inertial frame of reference. newtons's laws of motion are not directly applicable in such frames, before application we must add pseudo force.

* **Pseudo force :** The force on a body due to acceleration of non-inertial frame is called fictitious or apparent or pseudo force and is given by $\vec{F} = -m\vec{a}_0$, where $\vec{a}_0$ is acceleration of non-inertial frame with respect to an inertial frame and m is mass of the particle or body. the direction of pseudo force must be opposite to the particle or body. the direction of pseudo force must be opposite to the direction of acceleration of the non-inertial frame.

* When we draw the free body diagram of a mass, with respect to an inertial frame of reference we apply only the real forces (forces which are actually acting on the mass). But when the free body diagram is drawn from a non-inertial frame of reference a pseudo force (in addition to all real forces) has to be applied to make the equation $\vec{F} = m\vec{a}$ to be valid in this frame also.

* **Man in a lift**

(a) If the lift moving with constnat velocity v upwards or downwards in this case there is no accelerated motion hence no pseudo force experienced by observer inside the lift.

So apparent weight $W' = Mg = \text{Actual weight}$.

(b) If the lift is accelerated upward with constant acceleration a. Then forces acting on the man w.r.t. observed inside the lift are

(i) Weight W = Mg downward

(ii) Fictitious force F_0 = Ma downward.

So apparent weight $W' = W + F_0 = Mg + Ma = M(g + a)$

(c) If the lift is accelerated downward with acceleration a < g.

Then w.r.t. observer inside the lift fictitious force F_0 = Ma acts upward while weight of man W=Mg always acts downward.

So apparent weight

$W' = W + F_0 = Mg - Ma = M(g - a)$

6. Circular Motion

* **Definition of Circualr Motion**

When a particle moves in a plane such that its distance from a fixed (of moving) point remains constant then its motion is called as circular motion with respect to that fixed point is called centre and the distance is called radius of circular path.

Radius Vector :

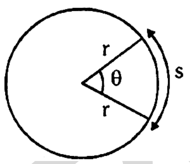
The vector joing the centre of the circle and the center of the particle performing circular motion is called radius vector. It has constnat magnitude and variable direction. It is directed outwards.

Frequency (n) :

No. of revolutions described by particle per sec. is its frequency. Its unit is revolutions per secound (r.p.s.) or revolutions per minute (r.p.m.)

Time period(T) :

It is time taken by particle ot complete one revolution. $T = \frac{1}{n}$



* Angle $\theta = \frac{\text{arc lenght}}{\text{radius}} = \frac{s}{r}$

* Average angular velocity $\omega = \frac{\Delta\theta}{\Delta t}$ (a scalar quantity)

* Instantaneous angular velocity

$$\omega = \frac{d\theta}{dt} \text{ (a vector quantity)}$$

* For uniform angular velocity $\omega = \frac{2\pi}{T} = 2\pi f$ or $2\pi n$

Angular displacement $\theta = \omega t$

$\omega \rightarrow$ Angular frequency n or f = frequency

* Relation between ω and v $\omega = \frac{v}{r}$

* In vector form velocity $\vec{v} = \vec{\omega} \times \vec{r}$

* Acceleration

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}(\vec{\omega} \times \vec{r}) = \frac{d\vec{\omega}}{dt} \times \vec{r} + \vec{\omega} \times \frac{d\vec{r}}{dt} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times \vec{v} = \vec{a}_t + \vec{a}_C$$

* Tangential acceleration : $a_t = \frac{dv}{dt} = \alpha r$

$$\left[\vec{a}_t = \text{component of } \vec{a} \text{ along } \vec{v} = (\vec{a}.\hat{v})\hat{v} = \left(\frac{dv}{dt}\right)\hat{v}\right]$$

* Centripetal acceleration : $a_C = \omega v = \frac{v^2}{r} = \omega^2 r$ or $\vec{a}_C = \omega^2 r(-\hat{r})$

* Magnitude of net acceleration : $a = \sqrt{a_C^2 + a_t^2} = \sqrt{\left(\frac{v^2}{r}\right)^2 + \left(\frac{dv}{dt}\right)^2}$

* Maximum speed of in circular motion.

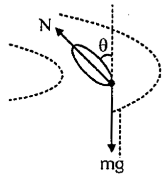
* On unbanked road : $v_{max} = \sqrt{\mu_s Rg}$

* On banked road : $v_{max} = \sqrt{\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)Rg} = \sqrt{\tan(\theta + \phi)Rg}$

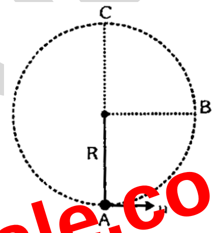
$$v_{min} = \sqrt{Rg\tan(\theta - \phi)};\ v_{min} \le v_{car} \le v_{max}$$

where ϕ = angle of friction $= \tan^{-1}\mu_s$; θ = angle of banking

* Bending of cyclist : $\tan\theta = \frac{v^2}{rg}$



* **Circular motion in vertical plane**

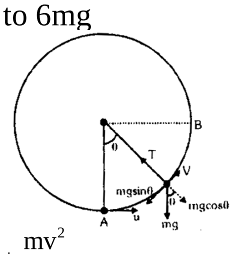


A. Condition to complete vertical circle $u \ge \sqrt{5gR}$

* If $u = \sqrt{5gR}$ then Tension at C is equal to 0 and tension at A is equal to 6mg

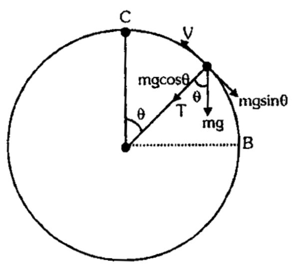
Velocity at B : $v_B = \sqrt{3gR}$

Velocity at C : $v_C = \sqrt{gR}$



From A to B: $T = mg\cos\theta + \frac{mv^2}{R}$

From B to C: $T = \frac{mv^2}{R} - mg\cos\theta$



B. Condition for pendulum motion (oscillating condition)

$u \le \sqrt{2gR}$ (in between A to B)

7. Work, Energy and Power

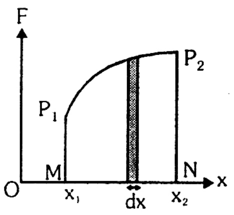
* **Work done** $W = \int dW = \int \vec{F}.d\vec{r} = \int Fdr\cos\theta$

  [where θ is the angle between f & dr]

  * For constnat force $W = \vec{F}.\vec{d} = Fd\cos\theta$
  * For nidirectional force

  $W = \int dW = \int Fdx$ = Area between F-x curve and x-axis

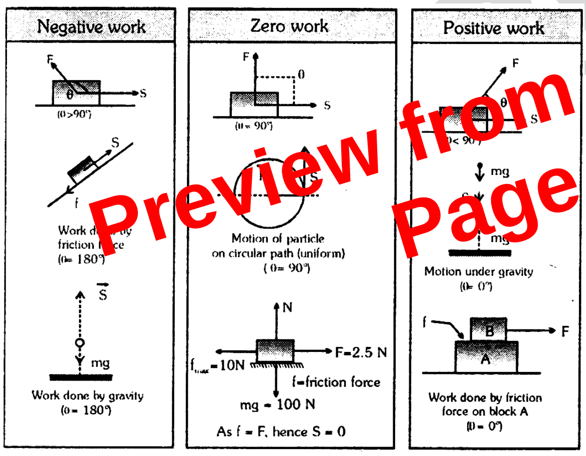
* **Calculation of work done from force-displacement graph :**



Total work done,

$$W = \sum_{x_1}^{x_2} dW = \sum_{r_1}^{r_2} Fdx = \text{Area of } P_1P_2NM = \int_{x_1}^{x_2} fdx$$

* **Nature of work done :** Although work done is a scalar quantity, yet its value may be positive, negative or even zero



* If $\vec{F}$ is a conservative force then $\vec{\nabla} \times \vec{F} = \vec{0}$ (i.e. curl of $\vec{F}$ is zero)

Conservative Forces

* Work done does not depend upon path
* Work done in a roud trip is zero.
* Central dorces, spring forces etc. are conservative forces
* When only a conservative force acts within a system, the kinetic energy and potential energy can change into each other. However, their sum, the mechanical energy of the system, doesn't change.
* Work done is completely recoverable.

Non-conservative Forces

* Work done depends upon path.
* Work done in a round trip is not zero.
* Force are velocity-dependent & retarding in nature e.g. friction, viscous force etc.
* Work done against a non-conservative force may be dissipated as heat energy
* Work done is not recoverable.

Kinetic energy

* The energy possessed by a body by virtue of its motion is called kinetic energy.

$$K = \frac{1}{2}mv^2 = \frac{1}{2}m(\vec{v}.\vec{v})$$

* Kinetic enrgy is a frame dependent quantity because velocity is a frame depends.

Potential energy

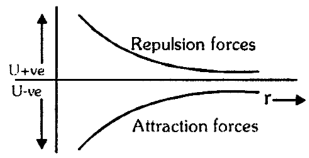
* The energy which a body has by virtue of its position or configuration in a conservative force field.
* Potential energy is a relative quantity.
* Potential energy is defined only for conservative force field.
* Relationship between conservative force field and potential energy :

$$\vec{F} = -\nabla U = -\text{grad}(U) = -\frac{\partial U}{\partial x}\hat{i} - \frac{\partial U}{\partial y}\hat{j} - \frac{\partial U}{\partial z}\hat{k}$$

* If force varies only with one dimension (along x-axis) then

$$F = -\frac{dU}{dx} \Rightarrow U = -\int_{x_1}^{x_2} Fdx$$

* Potential energy may be positive or negative



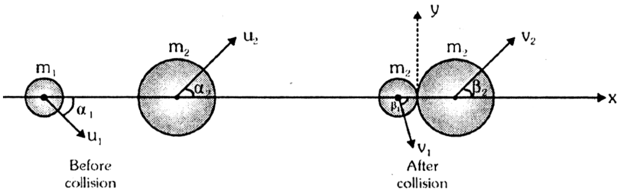
(i) Potential energy is positive, if force field is repulsive in nature

(ii) Potential energy is negative, if force field is attractive in nature

* If $r\uparrow$ (separation between body and force centre), $U\uparrow$, force field is attractive or vice-versa.
* If $r\uparrow$, $U\downarrow$, force field is repulsive in nature.

$$m_1u_1\cos\alpha_1 + m_2u_2\cos\alpha_2 = m_1v_1\cos\beta_1 + m_2v_2\cos\beta_2 \ \&$$

$$m_2u_2\sin\alpha_2 - m_1u_1\sin\alpha_1 = m_2v_2\sin\beta_2 - m_1v_1\sin\beta_1$$



Since no force is acting on m_1 and m_2 along the tangent (i.e. y-axis) the individual momentum of m_1 and m_2 remains conserved.

$$m_1u_1\sin\alpha_1 = m_1v_1\sin\beta_1 \ \& \ m_2u_2\sin\alpha_2 = m_2v_2\sin\beta_2$$

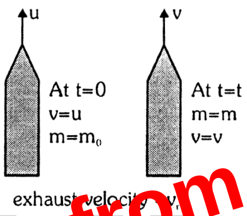
By using Newton's experimental law along he line of impact $e = \dfrac{v_2\cos\beta_2 - v_1\cos\beta_1}{u_1\cos\alpha_1 - u_2\cos\alpha_2}$

Rocket propulsion :

Thrust force on the rocket $= v_r\left(-\dfrac{dm}{dt}\right)$

Velocity of rocket at any instant

$$v = u - gt + v_r \ell n\left(\frac{m_0}{m}\right)$$



KEY POINTS

* Sum of mass moments about contre of mass is zero. i.e. $\sum m_i \vec{r}_{i/cm} = 0$

* A quick collision between two bodies is more violent then slow collision, even when initial and final velocities are equal because the rate of change of momentum determines that the impulsive force small or large.

* Heavy water is used as moderator in nuclear reactors as energy transfer is maximum if $m_1 = m_2$

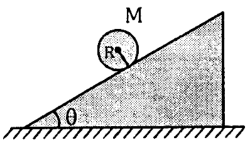
* Impulse momentum theorem is equivalent to Newton's second law of motion.

* For a system, conservation of linear momentum is equivalent o Newton's third law of motion.

- If $v_{cm} < R\omega$ then rolling with backward slipping
- Total kinetic energy in pure rolling

$$K_{total} = \frac{1}{2}Mv_{cm}^2 + \frac{1}{2}(Mk^2)\left(\frac{v_{cm}^2}{R^2}\right) = \frac{1}{2}Mv_{cm}^2\left(1+\frac{k^2}{R^2}\right)$$

* **Pure rolling motion on an inclined plane**



- Acceleration $a = \frac{g\sin\theta}{1+k^2/R^2}$
- Minimum frictional coefficient $\mu_{min} = \frac{\tan\theta}{1+R^2/k^2}$

* **Torque** $\vec{\tau} = I\vec{\alpha} = I\frac{d\vec{\omega}}{dt} = \frac{d(I\vec{\omega})}{dt} = \frac{d\vec{L}}{dt}$ or $\frac{d\vec{J}}{dt}$
* **Change in angular momentum** $\Delta\vec{L} = \vec{\tau}\Delta t$
* **Work done by a torque** $W = \int \vec{\tau} \cdot d\vec{\theta}$

KEY POINTS

* A ladder is more apt to slip, when you are high up on it than when you just begin to climb because at the high up on a ladder the torque is large and on climbing up the torque is small.
* When a sphere is rolls on a horizontal table, it shows down and eventually stops because when the sphere rolls on the table, both the sphere and the surface deform near the contact. As a result the normal force does not pass through the centre and provide an angular deceleration.
* The spokes near the top of a rolling bicycle wheel are more blurred than those near the bottom of the wheel because the spokes near the top of wheel are moving laster than those near the bottom of the wheel.
* Instantaneous angualr velocity is a vector quantity because infinitesimal angular displacement is a vector.
* The relative angular velocity between any two points of a rigid body is zeo at any instant.
* All particles of a rigid body, which do not lie on an axis of rotation move on circular paths with centres at an axis of rotation.
* Instantaneous axis of rotation is stationary w.r.t. ground.
* Many greater rivers flow toward the squator. The sediment that they carry increases the time of rotation of the earth about its own axis because the angular momentum of the earth about its rotation axis is conserved.
* The hard boiled egg and raw egg can be distinguished on the basis of spinning of both.

* **Orbital velocity of satellite** $v_0 = \sqrt{\frac{GM}{r}} = \sqrt{\frac{GM}{(R+h)}}$

□ For nearby satellite $v_0 = \sqrt{\frac{GM}{R}} = \frac{v_e}{\sqrt{2}}$

Here V_e = escape velocities earth surface.

* **Time period of satellite** $T = \frac{2\pi r}{v} = \frac{2\pi r^{3/2}}{\sqrt{GM}}$

* **Energies of a satellite**

□ Potential energy $U = -\frac{GMm}{r}$

□ Kinetic energy $K = \frac{1}{2}mv^2 = \frac{GMm}{2r}$

□ Mechanical energy $E = U + K = -\frac{GMm}{2r}$

□ Binding energy $BE = -E = \frac{GMm}{2r}$

* **Kepler's laws**

□ **I^st^** Law of orbitals

Path of a planet is elliptical with the sun at a focus

□ **II^nd^** Law of areas

Areal velocity $\frac{dA}{dt} = \text{constant} = \frac{L}{2m}$

□ **III^rd^** Law of periods

$T^2 \propto a^3$ or $T^2 \propto \left(\frac{r_{max} + r_{min}}{2}\right) \propto (\text{mean radius})^3$

For circular orbits $T^2 \propto R^3$

KEY POINTS

* At the centre of earth, a body has centre of amass, but not centre of gravity.

* The center of mass and entre of gravity of a body coincide it gravitation field is uniform.

* You does not experience gravitational force in daily life due to objects of same sizer as value of G is very small.

* Moon travellers tie heavy weight at their back before landing on Moon due to smaller value of g at Moon.

* Space rockets are usually launched in equatorial line form West to East because g is minimum at equator and earth rotates from West to East about its axis.

* Angular momentum in gravitational field is conserved because gravitational force is a central force.

* Kepler's second law or constancy of areal velocity is a consequence of conservation of angular momentum.

Work done = Change in surface energy

$$= 4\pi R^3 T\left(\frac{1}{r}-\frac{1}{R}\right) = 4\pi R^2 T\left(n^{1/3}-1\right)$$

* **Excess pressure** $P_{ex} = P_{in} - P_{out}$

  - In liquid drop $P_{ex} = \frac{2T}{R}$
  - In soap bubble $P_{ex} = \frac{4T}{R}$

ANGLE OF CONTACT (θ_c)

The angle enclosed between the tangent plane at the liquid surface and the tangent plane at the liquid surface and the tangent plane at the solid surface at the point of contact inside the liquid is defined as the angle of contact.

The angle of contact depends the nature of the solid and liquid in contact.

* **Angle of contact**

  $\theta < 90^o \Rightarrow$ concave shape, Liquid rise up

* **Angle of contact**

  $\theta > 90^o \Rightarrow$ convex shape, Liquid falls

* **Angle of contact**

  $\theta = 90^o \Rightarrow$ plane shape, Liquid neither rise nor falls

* **Effect of Temperature on angle of contact**

  On increasing temperature surface tenstion decreases, thus $\cos\theta$, increases $\left[\because \cos\theta_c \propto \frac{1}{T}\right]$ and θ_c decrease. So on increasing temperature, θ_c decreases.

* **Effect of impurities on angle of contact**

  (a) Solute impurities increase surface tenstion, so $\cos\theta_c$ decreases and angle of contact θ_c increases.

  (b) partially solute impurities decrease surface tenstion, so angle of contact θ_c decreses.

* **Effect of Water Proofing Agent**

  Angle of contact increases due to water profing agent. It gets converted acute to obtuse angle.

* **Capillary rise** $h = \frac{2T\cos\theta}{r\rho g}$

  * Zurin's law $h \propto \frac{1}{r}$

  * Jeager's method $T = \frac{rg}{2}(H\rho - hd)$

  * The height 'h' is measured from the bottom of the meniscus. However there exist some liquid above this line also. Iff correction of this is applied then the formuls will be

  $$T = \frac{r\rho g\left[h + \frac{1}{3}r\right]}{2\cos\theta}$$

* When two soap bubbles are in contact then radius of curvature of the common surface $r = \frac{r_1 r_2}{r_1 - r_2}\ (r_1 > r_2)$

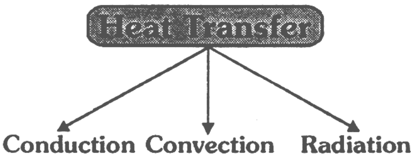
* When two soap bubbles are combining to form a new bubble then radius of new bubble $r = \sqrt{r_1^2 + r_2^2}$

* Force required to separate two plates $F = \frac{2AT}{d}$

to latent heat of vaporization.

* Heat is energy in transit which is transferred from hot body to cold body.
* One calorie is the amount of heat required to raise the temperature of one gram of water through 1°C (more precisely from 14.5 °C to 15.5°C).
* Clausins & clapeyron equation (effect of pressure on boiling point of liquids & melting point of solids related with latent heat)

$$\frac{dP}{dT}=\frac{L}{T\left(V_2-V_1\right)}$$

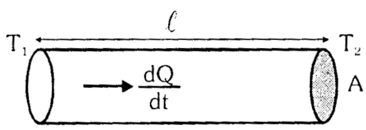


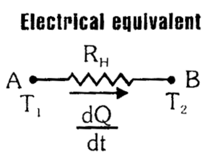
In condiction, heat is transferred from one point ot another without the actual motion of heated particles.

In the process of convection, the heated particles of matter actually move. In radiation, intervening medium is not affected and heat is transferred without any material medium.

Conduction	Convection	Radiation
Heat transfer due to Temperature difference	Heat transfer due to density difference	Heat transfer with out any medium
Due to free electron or vibration motion of molecules	Actual motion of particles	Electromagnetic radiation
heat transfer in solid body (in mercury also)	Heat transfer in fluids (Liquid + gas)	All
Slow process	Slow process	Fast process (3×10^8 m/sec)

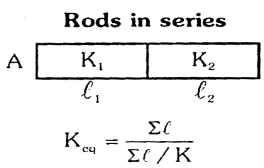
THERMAL CONDUCTION

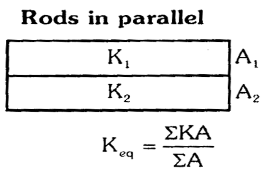




Rate of heat flow $\frac{dQ}{dt}=-KA\frac{dT}{dx}$ or $\frac{Q}{t}=\frac{KA\left(T_1-T_2\right)}{\ell}$

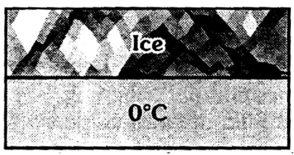
Thermal resistance $R_H=\frac{\ell}{KA}$





Growth of Ice on Ponds

Thus taken by ice to grow a thickness from x_1 to x_2 : $t=\frac{\rho L}{2K\theta}\left(x_2^2-x_1^2\right)$



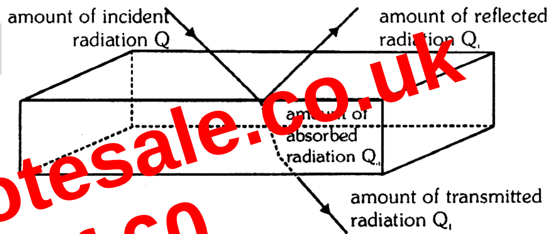
[K = thermal conductivity of ice, ρ =density of ice]

RADIATION

* **Spectral, emissive, absorptive and transmittive power of a given body surface :**

Due to incident radiations on the surface of a body following phenomena occur by which the radiation is divided into three parts.

(a) Reflection (b) Absorption (c) Transmission



From energy conservation

$$Q=Q_r+Q_a+Q_t \Rightarrow \frac{Q_r}{Q}+\frac{Q_a}{Q}+\frac{Q_t}{Q}=1 \Rightarrow r+a+t=1$$

* Reflective Coefficient : $r=\frac{Q_r}{Q}$
* Absorptive Coefficient : $a=\frac{Q_a}{Q}$
* Transmittive Coefficient : $t=\frac{Q_t}{Q}$

$r = 1$ and $a = 0, t = 0 \Rightarrow$ Perfect reflector

$a = 1$ and $r = 0, t = 0 \Rightarrow$ Ideal absorber (ideal black body)

$t = 1$ and $a = 0, r = 0 \Rightarrow$ Perfect transmitter (daithermanons)

Reflection power $(r)=\left[\frac{Q_r}{Q}\times100\right]\%$

Absorption power $(a)=\left[\frac{Q_a}{Q}\times100\right]\%$

Intensity of sound in decibels

Sound level, $SL = 10\log\left(\frac{I}{I_0}\right)$

Where I_0 = threshold of human ear = $10^{-12} W/m^2$

Characteristics of sound

* Loudness $\rightarrow$ Sensation received by the ear due to intensity of sound.
* Pitch $\rightarrow$ Sensation received by the ear due to frequency of sound .
* Quality (or Timbre) $\rightarrow$ Sensation received by the ear due to waveform of sound.

Doppler's effect in sound :

A stationary source emits wave fronts that propagate with constant velocity with constnat separation between them and a stationary observer encounters them at regular constatn intervals at which they were emitted by the source.

A moving observer will encounter more or lesser number of wavefronts depending on whether he is approaching or receding the source.

A source in motion will emit different wave front at different places and therefore alter wavelength i.e. separation between the wavefronts.

The apparent change in frequency or pitch due to relative motion of source and observer along the line of sight is called Doppler Effect.

$$\text{Observed frequency } n' = \frac{\text{speed of sound wave w.r.t. observer}}{\text{observed wavelength}}$$

$$n' = \frac{v + v_0}{\left(\frac{v - v_0}{n}\right)} = \left(\frac{v + v_0}{v - v_s}\right) n$$

If v_0, v_s <<<v then $n' \approx \left(1 + \frac{v + v_s}{v}\right) n$

* Mach Number $= \frac{\text{speed of source}}{\text{speed of sound}}$

* Doppler's effect in light :

Case I :

$$\left.\begin{aligned} &\text{Frequency} \quad v' = \left(\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}}\right) v \approx \left(1 + \frac{v}{c}\right) v \\ &\text{Wavelength} \quad \lambda' = \left(\sqrt{\frac{1-\frac{v}{c}}{1+\frac{v}{c}}}\right) \lambda \approx \left(1 - \frac{v}{c}\right) \lambda \end{aligned}\right\} \text{Violet Shift}$$

Case II :

$$\left.\begin{aligned} &\text{Frequency} \quad v' = \left(\sqrt{\frac{1-\frac{v}{c}}{1+\frac{v}{c}}}\right) v \approx \left(1 - \frac{v}{c}\right) v \\ &\text{Wavelength} \quad \lambda' = \left(\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}}\right) \lambda \approx \left(1 + \frac{v}{c}\right) \lambda \end{aligned}\right\} \text{Red Shift}$$