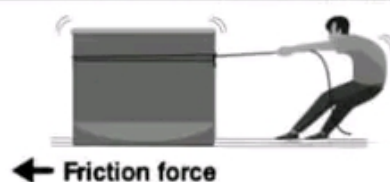


Friction



Friction is the opposing force that is set up between the surfaces of contact, when one body slides or tends to do so on the surface of another body.

- * The force of friction is parallel to the surface and opposite to the direction of intended motion.
- * Friction arises on account of strong atomic or molecular forces of attraction between the two surfaces at the point of actual contact.



Types of Friction

1.] Static Friction

The opposing force that comes into play when one body tends to move over the surface of another but the actual motion has yet not started is called static friction.

- * The force of static friction exactly balances the applied force during the stationary state of the body.
- * Static friction is a self-adjusting force and it changes itself in accordance with the applied force and is always equal to the net external force.
- * If a body is at rest and no pulling force is acting on it, then the force of friction on it is zero.

2.] Limiting Friction

If the applied force is increased, the force of static friction also increases. If the applied force exceeds a certain (maximum) value, then the body starts moving. This maximum value of static friction upto which body does not move is called limiting friction.

- * The magnitude of limiting friction between any two bodies in contact is directly proportional to the normal reaction between them.

$$F_s \propto R \quad \text{or} \quad \boxed{F_s = \mu_s R}$$

Here μ_s is called coefficient of static friction.

3.] Kinetic or dynamic Friction

If the body is in motion, then the friction opposing its motion is called Kinetic or dynamic friction.

- * Kinetic friction is also depends upon the normal reaction

$$F_k \propto R \quad \text{or} \quad \boxed{F_k = \mu_k R}$$

Here μ_k is called coefficient of Kinetic friction.

- * Kinetic friction does not depend upon the velocity of the body.

Note-

(i) The value of μ_s and μ_k for two bodies in contact is independent of the apparent contact area and depends on the nature of the material of the surfaces in contact and their roughness.

(ii) Kinetic friction is always less than limiting friction.

$$F_k < F_L$$

$\therefore$

$$\mu_k < \mu_s$$

(iii) Value of μ_s lies in between 0 and 1.

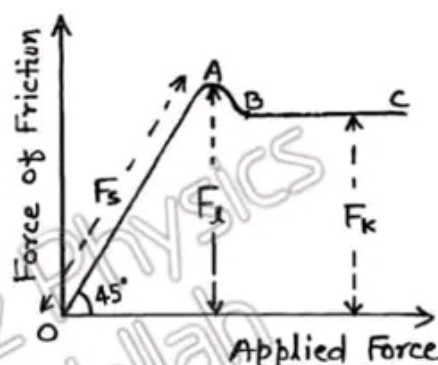
Graph between Applied force and Force of Friction-

1.] The part OA of the curve represents static friction (F_s). Its value increases with the applied force.

2.] At point A, the static friction is maximum. This represents the limiting friction (F_L).

3.] Beyond A, the force of friction is seen to decrease slightly. The portion BC of the curve shows the Kinetic friction (F_k).

4.] As the portion BC of the curve is parallel to x-axis therefore Kinetic friction does not change with the applied force, it remains constant.



Types of Kinetic Friction.

(A.) Sliding Friction-

The opposing force that comes into play when one body is actually sliding over the surface of the other body is called sliding friction.

Eg. Flat block moving over a horizontal table.



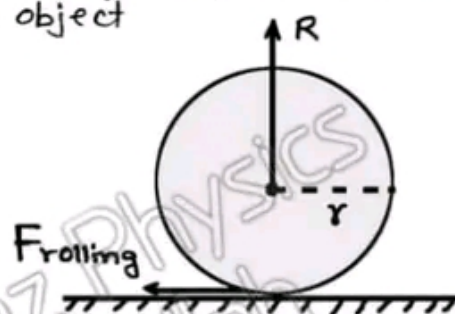
(B.) Rolling Friction

When objects such as a wheel (disc or ring), sphere or a cylinder rolls over a surface, then the force of friction that comes into play is called rolling friction.

Rolling friction is directly proportional to the normal reaction (R) and inversely proportional to the radius (r) of the rolling object

$$\therefore \boxed{F_{\text{rolling}} = \mu_r \frac{R}{r}}$$

Here μ_r is called the coefficient of rolling friction.



- * In rolling, the surfaces at contact do not rub each other.
- * The velocity of point of contact with respect to the surface remains zero all the times although the centre of the wheel moves forward.

(1) **Advantages of friction**

- (i) Walking is possible due to friction.
- (ii) Two body sticks together due to friction.
- (iii) Brake works on the basis of friction.
- (iv) Writing is not possible without friction.
- (v) The transfer of motion from one part of a machine to other part through belts is possible by friction.

(2) **Disadvantages of friction**

- (i) Friction always opposes the relative motion between any two bodies in contact. Therefore extra energy has to be spent in over coming friction. This reduces the efficiency of machine.
- (ii) Friction causes wear and tear of the parts of machinery in contact. Thus their lifetime reduces.
- (iii) Frictional force result in the production of heat, which causes damage to the machinery.

Angle of Friction

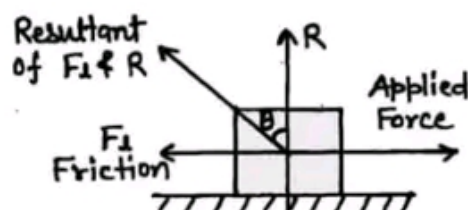
The angle which the resultant of limiting friction and normal reaction makes with the normal reaction is called 'angle of friction'.

By diagram $\tan \theta = \frac{F_1}{R}$

$$\therefore \tan \theta = \mu_s$$

$$\text{Angle of Friction } \theta = \tan^{-1}(\mu_s)$$

Hence coefficient of static friction is equal to tangent of the angle of friction.



Angle of Repose/sliding

It is defined as the maximum angle of inclination of a plane with the horizontal at which a body placed on it just begins to sliding down.

From diagram -

$$F = mg \sin \theta$$

$$R = mg \cos \theta$$

$$\text{So that } \mu_s = \frac{F}{R} = \frac{mg \sin \theta}{mg \cos \theta}$$

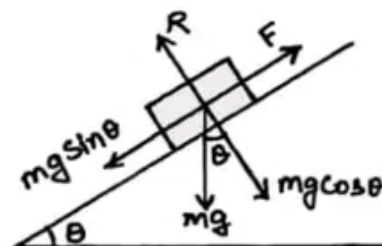
$$\text{or } \mu_s = \tan \theta$$

$$\text{Angle of Repose } \theta = \tan^{-1}(\mu_s)$$

Hence the coefficient of static friction is equal to the tangent of angle of repose.

Also

$$\text{Angle of repose} = \text{Angle of Friction}$$



WORK ENERGY POWER & COLLISION

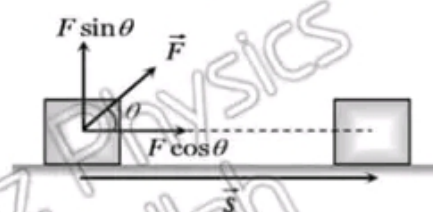
Work

Work is said to be done when a force applied on the body displaces the body through a certain distance in the direction of force.

Work is the product of the applied force and displacement of the body in the direction of force.

$$W = \vec{F} \cdot \vec{s} = FS \cos \theta$$

Here θ is the angle between force and displacement.



S.I. Unit - Joule

C.G.S. Unit - erg

Dimension - $[M^1 L^2 T^{-2}]$

1 Joule = 10^7 erg

Nature of Work done

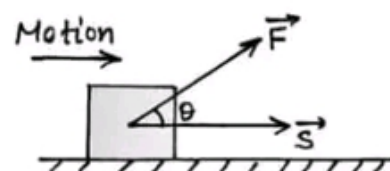
1. Positive Work -

If θ is acute ($\theta < 90^\circ$) then the work is said to be positive.

The positive work means that the external force favours the motion of the body.

Eg. When a body falls freely under the action of gravity ($\theta = 0^\circ$) then the work done by the gravity is positive.

* When $\theta = 0^\circ$ then the force does maximum positive work.



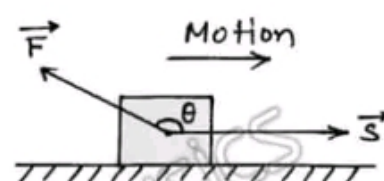
2.] Negative Work -

If the angle θ is obtuse ($\theta > 90^\circ$) then the work is said to be negative.

It signifies that the direction of force is such that it opposes the motion of the body.

Eg. Work done by the frictional force is negative when it opposes the motion.

- * When $\theta = 180^\circ$ the force does maximum negative work.

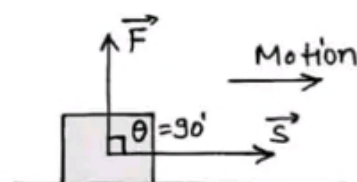


3.] Zero Work -

If $\theta = 90^\circ$ then the work done will be zero. If there is no displacement ($S = 0$) or no force acting on the body ($F = 0$) then also work done is zero.

Eg. In circular motion the work done by centripetal force is zero.

When a coolie travels on a horizontal platform with load then work done against gravity by the coolie is zero.



Examples-



Positive Work



Negative Work



Zero Work

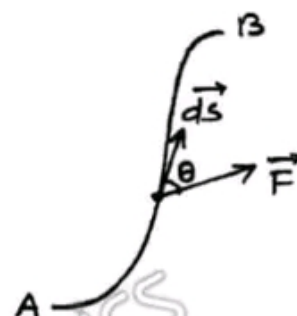
Work done by a variable Force

When magnitude and direction of force varies with position then work done by force for infinitesimal displacement (ds) is given by

$$dw = \vec{F} \cdot d\vec{s}$$

Total work done for displacement from A to B is

$$W_{AB} = \int_A^B \vec{F} \cdot d\vec{s} = \int_A^B F ds \cos\theta$$



In terms of rectangular components

$$\vec{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k} \quad \text{and} \quad d\vec{s} = dx \hat{i} + dy \hat{j} + dz \hat{k}$$

then work done is

$$W_{AB} = \int_A^B (F_x \hat{i} + F_y \hat{j} + F_z \hat{k}) \cdot (dx \hat{i} + dy \hat{j} + dz \hat{k})$$

or

$$W_{AB} = \int_{x_A}^{x_B} F_x dx + \int_{y_A}^{y_B} F_y dy + \int_{z_A}^{z_B} F_z dz$$

Note-

- (i) Work is defined for an interval or displacement there is no term like instantaneous work.
- (ii) For a particular displacement work is independent of time
- (iii) Effect of Work is change in Kinetic energy and potential energy.

Work done Calculation by Force - Displacement graph

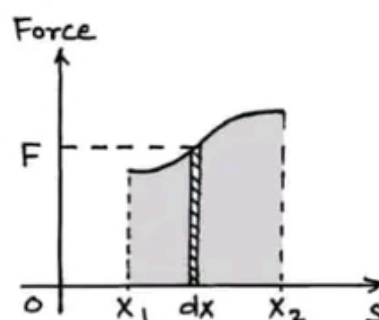
Work done for small displacement

$$dW = F dx = \text{Area of strip}$$

Total work done within the interval position x_1 to x_2 is

$$W = \int_{x_1}^{x_2} F dx$$

$$W = \int_{x_1}^{x_2} (\text{Area of strip of width } dx)$$



$$W = \text{Area under the curve between } x_1 \text{ and } x_2$$

i.e. Area under the force-displacement curve with proper algebraic sign represents work done by the force.

Conservative & Non-Conservative Forces

1. Conservative Forces -

A force is said to be conservative, if work done by the force on a particle moving between two points, does not depend on the path taken by the particle.

Eg. Gravitational force, Electrostatic force etc.

2. Non-Conservative Forces -

A force is said to be non conservative, if work done by the force in moving a body from one position to another, depends on the path.

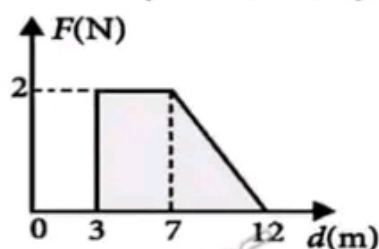
Eg. Friction force, viscous force etc.

1. A particle moves from a point $(-2\hat{i}+5\hat{j})$ to $(4\hat{j}+3\hat{k})$ when a force of $(4\hat{i}+3\hat{j})$ N is applied. How much work has been done by the force?
(a) 8 J (b) 11 J (c) 5 J (d) 2 J
(NEET-II 2016)
2. A uniform force of $(3\hat{i}+\hat{j})$ newton acts on a particle of mass 2 kg. Hence the particle is displaced from position $(2\hat{i}+\hat{k})$ metre to position $(4\hat{i}+3\hat{j}-\hat{k})$ metre. The work done by the force on the particle is
(a) 13 J (b) 15 J
(c) 9 J (d) 6 J
(NEET 2013)
3. A body moves a distance of 10 m along a straight line under the action of a 5 N force. If the work done is 25 J, then angle between the force and direction of motion of the body is
(a) 60° (b) 75° (c) 30° (d) 45° (1997)
4. A body, constrained to move in y -direction, is subjected to a force given by $\vec{F}=(-2\hat{i}+15\hat{j}+6\hat{k})$ N. The work done by this force in moving the body through a distance of $10\hat{j}$ m along y -axis, is
(a) 150 J (b) 20 J
(c) 190 J (d) 160 J (1994)
5. When a body moves with a constant speed along a circle
(a) no work is done on it
(b) no acceleration is produced in it
(c) its velocity remains constant
(d) no force acts on it. (1994)

6. A force $F = 20 + 10y$ acts on a particle in y -direction where F is in newton and y in meter. Work done by this force to move the particle from $y = 0$ to $y = 1$ m is
(a) 20 J (b) 30 J (c) 5 J (d) 25 J

(NEET 2019
(1994, 1992))

7. Force F on a particle moving in a straight line varies with distance d as shown in figure. The work done on the particle during its displacement of 12 m is



- (a) 18 J (b) 21 J
(c) 26 J (d) 13 J

(2011, 2005)

8. A body of mass 3 kg is under a constant force which causes a displacement s in metres in it, given by the relation $s = \frac{1}{3}t^2$, where t is in seconds. Work done by the force in 2 seconds is

- (a) $\frac{19}{5}$ J (b) $\frac{5}{19}$ J (c) $\frac{3}{8}$ J (d) $\frac{8}{3}$ J (2006)

9. A force acts on a 3 g particle in such a way that the position of the particle as a function of time is given by $x = 3t - 4t^2 + t^3$, where x is in metres and t is in seconds. The work done during the first 4 second is

- (a) 490 mJ (b) 450 mJ
(c) 240 mJ (d) 530 mJ (1998)

Answer Key

1	2	3	4	5
c	c	a	a	a
6	7	8	9	
d	d	d	d	

Fluid Mechanics

Fluid-

fluid is the name given to a substance which begins to flow when external force is applied on it. The fluids do not have their own shape but take the shape of the containing vessel.

The branch of physics which deals with the study of fluids at rest is called hydrostatics.

The branch of physics which deals with the study of fluids in motion is called hydrodynamics.

Pressure of liquid-

The normal force exerted by liquid at rest on a given surface in contact with it is called thrust.

The normal force (or thrust) exerted by liquid at rest per unit area of the surface in contact with it, is called pressure of liquid or hydrostatic pressure.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

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

SI Unit - N/m^2 or Pascal

Dimensions - $[M^1 L^{-1} T^{-2}]$

Atmospheric Pressure-

Force exerted by air column on unit cross-section area of sea level is called atmospheric pressure.

$$1 \text{ atm} = 1.01 \times 10^5 \text{ Pa} = 1.01 \text{ bar}$$

* 'Barometer' is used to measure atmospheric pressure.

Gauge Pressure -

The pressure difference between hydrostatic pressure (P) and atmospheric pressure P_0 is called gauge pressure

$$P - P_0 = \rho gh$$

* Gauge pressure is always measured with the help of 'manometer'.

Density (ρ) -

mass per unit volume of a substance is defined as density.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \Rightarrow \rho = \frac{M}{V}$$

SI Unit - Kg/m^3

Dimensions - $[M^1 L^{-3} T^0]$

Specific Weight or Weight density (ω)-

It is defined as the ratio of the weight of the fluid to its volume or the weight acting per unit volume of the fluid.

$$\omega = \frac{\text{Weight}}{\text{Volume}} = \frac{mg}{V} = \rho g$$

SI Unit - N/m^2

Dimensions - $[M^1 L^{-2} T^{-2}]$

* Specific weight of pure water at 4°C is 9.8 KN/m^2

Relative density-

It is defined as the ratio of the density of the given fluid to the density of pure water at 4°C.

$$\text{Relative density} = \frac{\text{density of given fluid}}{\text{density of pure water at } 4^{\circ}\text{C}}$$

* Relative density is a unitless scalar quantity.

Note-

1.] If m_1 mass of liquid of density ρ_1 and m_2 mass of liquid of density ρ_2 are mixed, then

$$\text{Density of Mixture } \rho_{\text{mix}} = \frac{M_{\text{mix}}}{V_{\text{mix}}}$$

or

$$\rho_{\text{mix}} = \frac{m_1 + m_2}{\frac{m_1}{\rho_1} + \frac{m_2}{\rho_2}}$$

2.] If V_1 volume of liquid of density ρ_1 and V_2 volume of liquid of density ρ_2 are mixed then

$$\rho_{\text{mix}} = \frac{M_{\text{mix}}}{V_{\text{mix}}} = \frac{\rho_1 V_1 + \rho_2 V_2}{V_1 + V_2}$$

Pascal's Law-

If the gravity effect is ignored then the pressure at every point of liquid at rest is same.

or

The change in pressure at a particular point of the enclosed liquid in equilibrium or rest is transmitted equally to all other points of the liquid and also to the walls of the container.

Applications - hydraulic jacks, lifts, breaks etc.

Working of hydraulic Lift -

It is used to lift the heavy loads by applying a small force.

$$\text{Pressure applied} = \frac{F_1}{A_1}$$

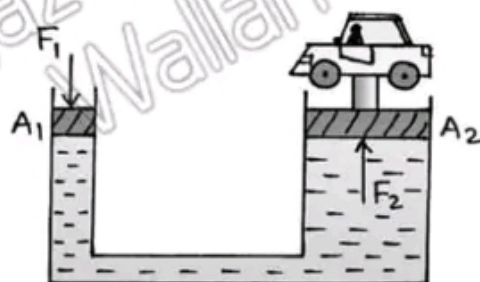
$$\text{Pressure transmitted} = \frac{F_2}{A_2}$$

By Pascal's Law the pressure is transmitted equally, so that

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

$$\therefore \text{Upward force on } A_2 \text{ is } F_2 = \frac{F_1}{A_1} \times A_2$$

As $A_2 > A_1$, therefore $F_2 > F_1$.



Buoyancy and Buoyant Force -

If a body is partially or wholly immersed in a fluid, then it experiences an upward force due to the fluid surrounding it. This phenomenon is called buoyancy and the force exerted by the fluid is called buoyant force.