11th Standard - Physics

Work, Energy and Power

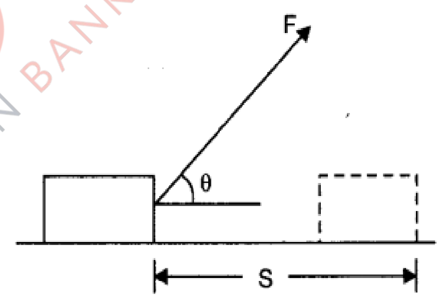
Work is said to be done when a force applied on the body displaces the body through a certain distance in the direction of applied force.

It is measured by the product of the force and the distance moved in the direction of the force, i.e., W = F-S

• If an object undergoes a displacement 'S' along a straight line while acted on a force F that makes an angle 0 with S as shown.

The work done W by the agent is the product of the component of force in the direction of displacement and the magnitude of displacement.

i.e., $W = FS\cos\theta = \vec{F}\cdot\vec{S}$



• Work done is a scalar quantity measured in newtonmetre. Its dimension is $[ML^2T^{-2}]$.

(1 newton-metre = 1 joule)

• Following are some significant points about work done, derived from the definition given above.

(*i*) Work done by a force is zero if displacement is perpendicular to the force ($\theta = 90°$).

(*ii*) Work done by the force is positive if angle between force and displacement is acute ($\theta < 90°$).

(*iii*) Work done by the force is negative if angle between force and displacement is obtuse ($\theta > 90°$).

• If the applied force varies with time/position, the work done is given by:

$$W = \int \vec{F}\cdot d\vec{s}$$

• If we plot a graph between force applied and the displacement, then work done can be obtained by finding the area under the F-s graph.

• If a spring is stretched or compressed by a small distance from its unstretched configuration, the spring will exert a force on the block given by

F = -kx, where x is compression or elongation in spring, k is a constant called spring constant whose value depends inversely on unstretched length and the nature of material of spring.

The negative sign indicates that the direction of the spring force is opposite to x, the displacement of the free-end.

Work done by spring when block is displaced by x_0 is given by

$$W = -\int_0^{x_0} kx\,dx = -\frac{1}{2}kx_0^2$$

Work done by an agent in giving an elongation or compression of x_0 is given as

• Energy

The energy of a body is its capacity to do work. Anything which is able to do work is said to possess energy. Energy is measured in the same unit as that of work, namely, Joule.

Mechanical energy is of two types: Kinetic energy and Potential energy.

• Kinetic Energy

The energy possessed by a body by virtue of its motion is known as its kinetic energy.

For an object of mass m and having a velocity v, the kinetic energy is given by:

K.E. or K = $1/2\ mv^2$

• Potential Energy

The energy possessed by a body by virtue of its position or condition is known as its potential energy.

There are two common forms of potential energy: gravitational and elastic.

—> Gravitational potential energy of a body is the energy possessed by the body by virtue of its position above the surface of the earth.

It is given by

(U)P.E. = mgh

where m —> mass of a body

g —> acceleration due to gravity on the surface of earth. h —> height through which the body is raised.

—> When an elastic body is displaced from its equilibrium position, work is needed to be done against the restoring elastic force. The work done is stored up in the body in the form of its elastic potential energy.

If an elastic spring is stretched (or compressed) by a distance Y from its equilibrium position, then its elastic potential energy is given by

$U = 1/2\ kx^2$

where, k —> force constant of given spring

• Work-Energy Theorem

According to work-energy theorem, the work done by a force on a body is equal to the change in kinetic energy of the body.

$$W = \text{Change in K.E. of a body} = \Delta(K.E.)$$

Δ(K.E.) → The difference between the final and initial kinetic energies of the body.

- Energy and momentum are related by, $E = \frac{p^2}{2m}$, where m is the mass.

The energy (E) equivalent to mass m is given by the relation

$$E = mc^2 \quad \text{where,} \quad c = 3 \times 10^8\ ms^{-1}, \text{ velocity of light in v}$$

- When a body moves with a velocity v, comparable to the velocity of light 'C' its ma

$$m = \frac{m_0}{\sqrt{1-\left(\frac{v^2}{c^2}\right)}}, \text{ where } m_0 \text{ its rest mass.}$$

- **Power**

It is the rate of doing work, *i.e.,* the work done per unit time.

$$p = \frac{dW}{dt} = \vec{F}.\vec{v} = Fv\cos\alpha$$

where α is the angle between the force F and the velocity v.

- Power is a scalar quantity. Its *SI* unit is watt, 1 watt = 1 Js^{-1}. The dimensional for is $[M^1L^2T^{-3}]$.
- Other commonly used units of power are:

1 kilowatt = 1 KW = 10^3 W

1 megawatt = 1 MW = 10^3 KW = 10^6 W

1 horse power (hp) = 746 watt = 0.746 KW.

• Collision

Collision is defined as an isolated event in which two or more colliding bodies exert relatively strong forces on each other for a relatively short time.

Collision between particles have been divided broadly into two types.

(i) Elastic collisions (ii) Inelastic collisions

• Elastic Collision

A collision between two particles or bodies is said to be elastic if both the linear momentum and the kinetic energy of the system remain conserved.

Example: Collisions between atomic particles, atoms, marble balls and billiard balls.

• **Inelastic Collision**

A collision is said to be inelastic if the linear momentum of the system remains conserved but its kinetic energy is not conserved.

Example: When we drop a ball of wet putty on to the floor then the collision between ball and floor is an inelastic collision.

• Collision is said to be one dimensional, if the colliding particles, move along the same straight line path both before as well as after the collision.

• In one dimensional elastic collision, the relative velocity of approach before collision is equal to. the relative velocity of separation after collision.

• If two particles of mass m_1 and m_2 moving with velocities $\vec{u}_1$ and $\vec{u}_2$ respective on such that $\vec{v}_1$ and $\vec{v}_2$ be their respective velocities after collision, then,

$$\vec{v}_1 = \frac{(m_1 - m_2)\vec{u}_1 + 2m_2\vec{u}_2}{(m_1 + m_2)} \quad \text{and} \quad \vec{v}_2 = \frac{2m_1\vec{u}_1 + (m_2 - m_1)\vec{u}_2}{(m_1 + m_2)}$$

• **Coefficient of Restitution or Coefficient of Resilience**

Coefficient of restitution is defined as the ratio of relative velocity of separation after collision to the relative velocity of approach before collision.

It is represented by 'e'.

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

- **Elastic and Inelastic Collisions in Two Dimensions**

Let us consider two bodies *A* and *B* moving with their initial velocities $\vec{u}_1$ and $\vec{u}_2$
a two dimensional plane. If they collide with each other and still moving with ce
$\vec{v}_1$ and $\vec{v}_2$ respectively after the collision, then the collision is known as two dim
oblique) collision Fig. (*i*).

When the collision is elastic the total kinetic energy of the two bodies before the co
to the total energy of the bodies after the collision. It means, the kinetic energy is co
of elastic collision.

The kinetic energy is not conserved in case of inelastic collision.

When the body *A* is moving with a velocity of $\vec{u}_1$ and the body *B* is at rest i.e. $\vec{u}$
(*ii*) after the collision, let θ be the angle known as scattering angle made by the bod
direction Fig. (*iii*) and the body *B* moves with an angle of ϕ with its initial direct
is known as 'angle of recoil'.

According to the law of conservation of momentum

$$m_1u_1 + 0 = m_1v_1 \cos\theta + m_2v_2 \cos\phi$$

(*i*)

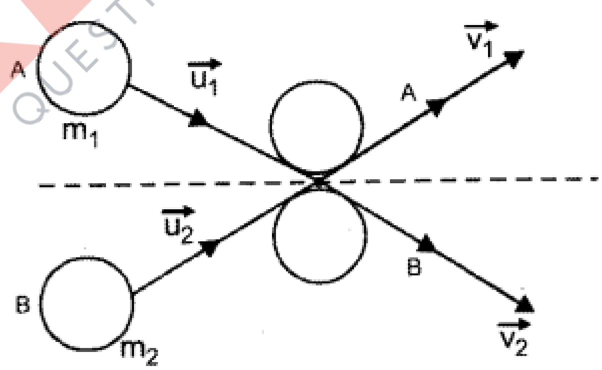


fig (*i*)

and $$0 = m_1 v_1 \sin\theta - m_2 v_2 \sin\phi$$

As the collision is perfectly elastic,

Total K.E. before the collision = Total K.E. after the collision.

$$\frac{1}{2}m_1 u_1^2 + 0 = \frac{1}{2}m_1 V_1^2 + \frac{1}{2}m_2 V_2^2$$

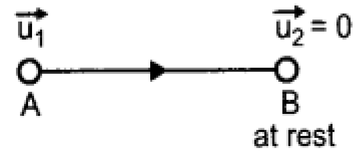


Fig. (ii)

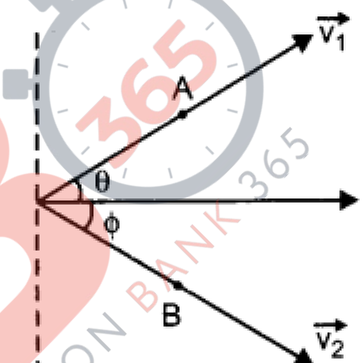


Fig. (iii)

Special Case : If $m_1 = m_2$ then the above equation (*i*), (*ii*) and (*iii*) are reduced to

$$u_1 = v_1 \cos\theta + v_2 \cos\phi$$

$$0 = v_1 \sin\theta - v_2 \sin\phi$$

and

$$u_1^2 = V_1^2 + V_2^2$$

From eq. (*iv*) and (*vi*) we get,

$$(V_1 \cos\theta + V_2 \cos\phi)^2 = V_1^2 + V_2^2$$

$$\Rightarrow \quad V_1^2 \cos^2\theta + V_2^2 \cos^2\phi + 2V_1V_2 \cos\theta \cos\phi = V_1^2 + V_2^2$$

$$\Rightarrow \quad 2V_1V_2 \cos\theta \cos\phi = V_1^2 - V_1^2 \cos^2\theta + V_2^2 - V_2^2 \cos^2\phi$$

$$\Rightarrow \quad 2V_1V_2 \cos\theta \cos\phi = V_1^2(1-\cos^2\theta) + V_2^2(1-\cos^2\phi)$$

$$\Rightarrow \quad 2V_1V_2 \cos\theta \cos\phi = V_1^2 \sin^2\theta + V_2^2 \sin^2\phi$$

$$\Rightarrow \quad 2V_1V_2 \cos\theta \cos\phi = V_1^2 \sin^2\theta + V_1^2 \sin^2\theta$$

$$\Rightarrow \quad 2V_1V_2 \cos\theta \cos\phi = 2V_1^2 \sin^2\theta$$

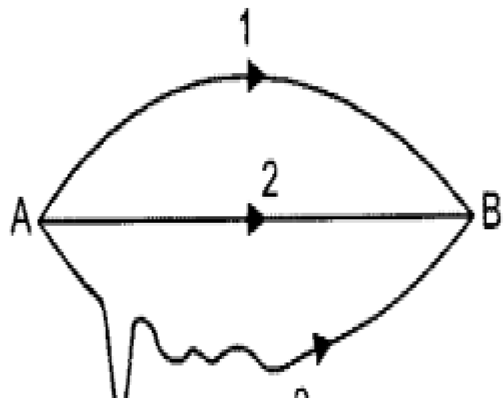
$$\Rightarrow \quad V_2 \cos\theta \cos\phi = V_1 \sin^2\theta$$

$$\therefore \quad \cos\theta = \left(\frac{V_1}{V_2}\right)\left(\frac{\sin^2\theta}{\cos\phi}\right)$$

• Non-conservative Forces

A force is said to be non-conservative if the work done in moving from one point to another depends upon the the path followed.

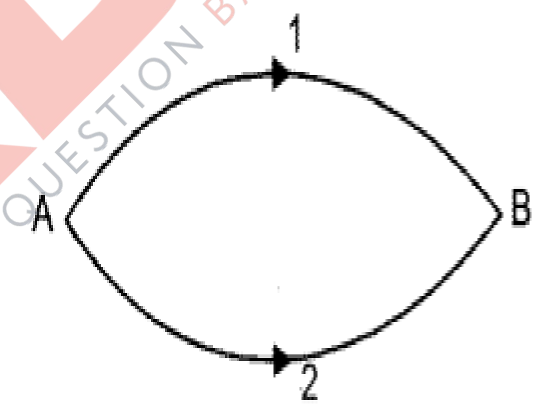
Let W, be the work done in moving from A to B following the path 1. W2 through the path 2 and W3 through the path 3. Fig. (i).



(i)

$\therefore$ For non-conservative forces $\quad W_1 \neq W_2 \neq W_3$

Also in figure (*ii*) the net work done by or against the non-conservative forc i.e. $W_1 \neq W_2$.



(ii)

Mathematically $\quad \oint F \times dS \neq 0$

Examples of non-conservative forces are :

(i) Force of friction (ii) Viscus force

TABLE 6.1 Average power consumption in some common activities

	Activity	Power (watt)
1.	Heart beat	1.2
2.	Sleeping	75
3.	Slow walking	200
4.	Cycling	500

TABLE 6.2 Some typical kinetic energy values

S.No.	Object	mass (kg)	Speed (ms^{-1})	K.E. (J)
1.	Stone dropped from 10 *m*.	0.5	14	≈ 50
2.	Rain drop at terminal speed	3.5×10^{-5}	9	$\approx 1.4 \times 10^{-3}$
3.	Air molecule	10^{-26}	500	$\approx 10^{-21}$
4.	Running athlete	70	10	3.5×10^{3}
5.	Bullet	5×10^{-2}	200	10^{3}
6.	Car	2000	20	4×10^{5}

TABLE 6.3 Energy associated with some important phenomena

S.No.	Phenomenon	Energy (J)
1.	Energy required to break one bond in DNA	$\approx 10^{-20}$
2.	Energy of an electron in an atom	$\approx 10^{-18}$
3.	Energy of a proton in a nucleus	$\approx 10^{-13}$
4.	Energy associated with discharge of a single neutron	$\approx 10^{-10}$
5.	Energy spent in turning a page	$\approx 10^{-3}$
6.	Work done by human heart beat	≈ 0.5
7.	Daily food intake of a human adult	$\approx 10^{7}$
8.	Energy released in burning 1 litre of gasoline	$\approx 3 \times 10^{7}$
9.	K.E. of a jet aircraft	$\approx 10^{9}$
10.	Energy released in burning 1000 kg of coal	$\approx 3 \times 10^{10}$
11.	Energy release of 15 megaton fusion bomb	$\approx 10^{17}$
12.	Annual solar energy incident on earth	$\approx 5 \times 10^{24}$
13.	Rotational energy of earth	$\approx 10^{29}$
14.	Energy released in a supernova explosion	$\approx 10^{44}$
15.	Rotational energy of Milky way	$\approx 10^{52}$
16.	Big Bang	$\approx 10^{68}$

TABLE 6.4 Some Important Physical Quantities, Symbols, Dimensions and Uni

Physical Quanity	Symbols	Dimensions	Units
Work	W	$[ML^2T^{-2}]$	Joule
Kinetic energy	K	$[ML^2T^{-2}]$	Joule
Potential energy	$V(x)$	$[ML^2T^{-2}]$	Joule
Mechanical energy	E	$[ML^2T^{-2}]$	Joule
Spring constant	k	$[MT^{-2}]$	Nm^{-1}
Power	P	$[ML^2T^{-3}]$	Watt