Chapter

2 Work, Energy and Power

SYLLABUS

(i) Work, energy, power and their relation with force.

Scope of syllabus : Definition of work. $W = FS \cos\theta$; special cases of $\theta = 0°, 90°$. $W = mgh$. Definition of energy, energy as work done. Various units of work and energy and their relation with S.I. units. [erg, calorie, kWh and eV]. Definition of power, $P = W/t$; S.I. and C.G.S. units; other units, kilowatt (kW), megawatt (MW) and gigawatt (GW); and horse power (1 H.P. = 746 W) [Simple numerical problems on work, power and energy].

(ii) Different types of energy (e.g., chemical energy, mechanical energy, heat energy, electrical energy, nuclear energy, sound energy, light energy).

Scope of syllabus : Mechanical energy : potential energy $U = mgh$ (derivation included), gravitational potential energy, examples; kinetic energy $K = \frac{1}{2}mv^2$ (derivation included); forms of kinetic energy : translational, rotational and vibrational – only simple examples. [Numerical problems on K and U only in case of translational motion]; qualitative discussions of electrical, chemical, heat, nuclear, light and sound energy, conversion from one form to another; common examples.

(iii) Principle of conservation of energy.

Scope of syllabus : Statement of the principle of conservation of energy; theoretical verification that $U + K$ = constant for a freely falling body. Application of this law to simple pendulum (qualitative only); simple numerical problems.

(A) WORK, ENERGY AND POWER, THEIR MEASUREMENTS AND UNITS

2.1 WORK

In our daily parlance, the word 'work' is used for some sort of exertion (physical or mental) or for various activities such as writing, reading or eating; we say that we are doing work. But in Physics the word work is used in a specific sense. Work is said to be done only when a body moves under the influence of a force. If there is no displacement of the body even when a force acts on it, no work is said to be done or the work done is zero. Thus,

Work is said to be done only when the force applied on a body makes the body move (i.e., there is a displacement of the body).

For example, a man while pushing a car (Fig. 2.1), a cyclist while pedalling a cycle, a horse while pulling a cart, a boy going upstairs, a coolie lifting a load, all exert force which produces motion, so they do work.

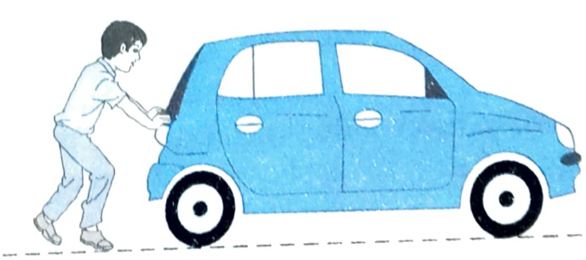

Fig. 2.1 Pushing the car, work is being done

However, if a man tries to push a wall (Fig. 2.2) or a child tries to push a heavy stone and they are unable to move them, then scientifically, no work is being done by them,

Fig. 2.2 Pushing the wall, no work is being done

Similarly, a coolie does no work while standing with a heavy load on his head (although he feels tired), since the displacement of load is zero.

2.2 MEASUREMENT OF WORK

The amount of work done on a body depends on *two* factors :

(i) the magnitude of the force applied, and

(ii) the displacement produced by the force.

If forces F_1 and F_2 (where $F_1 > F_2$) move two different bodies across the same distance, the work done by the force F_1 is said to be more than that by the force F_2. Similarly, if a force F moves bodies 1 and 2 by distances S_1 and S_2 respectively (where $S_1 > S_2$), the work done by the force F on body 1 is said to be more than on body 2. Thus, the amount of work done depends on both factors : the magnitude of the force applied, and the magnitude of the displacement produced.

> *The amount of work done by a force is equal to the product of the force and the displacement of the point of application of the force in the direction of force.*

i.e., Work = Force × displacement of the point of application of force in the direction of force

In Fig. 2.3, suppose a constant force F displaces a body from position A to position B along its own direction. Then the displacement of the body is AB (= S), and the work done is

$$\boxed{W = F \times S} \qquad .....(2.1)^*$$

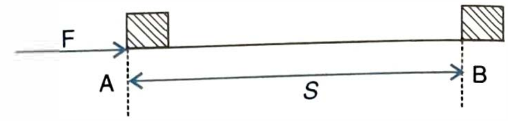

Fig. 2.3 Work done by a force

Here we assume that the force does not change during the displacement and it acts so long the body moves

In eqn. (2.1), if $S = 0$, then $W = 0$. Thus,

> *If a force acts on a body and the body does not move i.e., displacement is zero, then no work is done.*

Work is a *scalar* quantity.

Expression for work ($W = F\, S \cos\theta$)

It is not necessary that a force always causes displacement of the body in its own direction. If under some circumstances, a force displaces the body in a direction other than the direction of force, then we can determine the amount of work done by the force in either of the *two* ways : (1) by finding the component of displacement of the body in the direction of force, or (2) by finding the component of force in the direction of displacement.

(1) By finding the component of displacement along the force : In Fig. 2.4, suppose a constant force F acts on a body along AB and displaces the body on an inclined surface from A to C. The displacement of the body from the point of application of force is AC = S, which is at an angle θ to the direction of force. To find the component of displacement in the direction of force (*i.e.,*

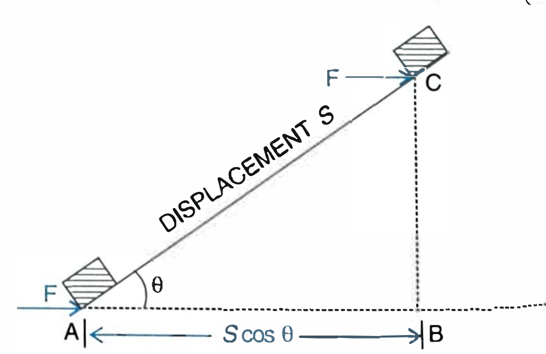

Fig. 2.4 Work done by a force when the displacement is not along the force by taking the component of displacement along the force

* In eqn. (2.1), the sign "×" means simple multiplication of two scalars F and S which are the magnitudes of force and displacement respectively. It does not mean the cross or vector product of two vectors $\vec{F}$ and $\vec{S}$.

along AB), a perpendicular CB is drawn from the point C on AB. Then the component of displacement in the direction of force is AB.

Hence, work done $W = F \times AB$

But in the right angled Δ ABC,

$$\cos\theta = \frac{\text{base}}{\text{hypotenuse}} = \frac{AB}{AC} = \frac{AB}{S}$$

or $\quad AB = S\cos\theta$

Hence, $\boxed{W = F \times S\cos\theta}$ .....(2.2)

or W = Force × component of displacement in the direction of force

(2) By finding the component of force along the displacement : In Fig. 2.5, if $\overrightarrow{PA}$ represents the magnitude and direction of force F acting on the body, then the component of force F in the direction of displacement (*i.e.*, along AC) is NA.

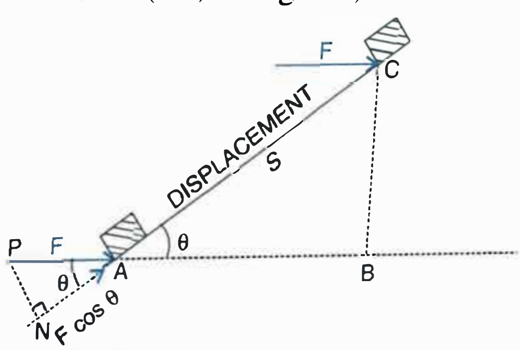

Fig. 2.5 Work done by a force when the displacement is not along the force by taking the component of force along the displacement

Therefore, work done

$$W = NA \times AC = NA \times S$$

But from right-angled Δ PNA,

$$NA = PA\cos\theta = F\cos\theta$$

Then, work done $\boxed{W = F\cos\theta \times S}$ ...(2.3)

or Work = Component of force in the direction of displacement × displacement

From eqns. (2.2) or (2.3), it is clear that the work done is equal to the product of

(i) magnitude of force F,

(ii) magnitude of displacement S, and

(iii) cosine of the angle θ between the directions of force F and displacement S (*i.e.*, $\cos\theta$).

Note : Since force F and displacement S are vector quantities and work W is a scalar quantity, so work is expressed as the dot product (or scalar product) of force and displacement vectors. The dot product of two vectors is a scalar. In vector form, work done W is written as $\quad W = \vec{F} \cdot \vec{S}$

Thus, work done depends on (i) the magnitude of force, (ii) the magnitude of displacement and (iii) the angle between the force and displacement.

Special cases

Case (i) : If the displacement is in the direction of force, *i.e.*, $\theta = 0°$, then $\cos 0° = 1$.

$$\therefore \quad W = F \times S$$

The work done is *positive.*

Examples : (1) In free fall of a body of mass m under gravity through a height h from A to B (Fig. 2.6), the force of gravity $F (= mg)$ is in the direction of displacement $S (= h)$ and the work done by the force of gravity is $W = FS = mgh$.

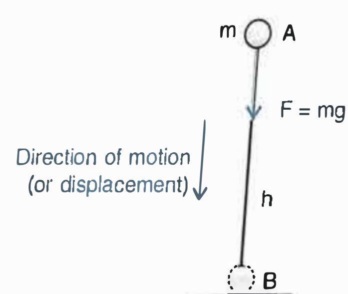

Fig. 2.6 Positive work done by the force of gravity in free fall.

(2) A coolie does work on the load when he raises it up against the force of gravity. Both the force exerted by the coolie $(= mg)$ and the displacement $(= h)$, are in upward direction. The work done by the coolie in raising the load is $W = mgh$.

(3) If a body revolves in a circular path under the influence of a force, on completing one round, the displacement becomes zero, so the work done by the force is $W = 0$ (zero).

Case (ii) : When the displacement is normal to the direction of force, *i.e.*, $\theta = 90°$, then $\cos 90° = 0$.

$$\therefore \quad W = 0$$

Hence the work done is *zero*.

Examples : (1) When a coolie walks on a horizontal ground while carrying a load on his head, no work is done against the force of gravity because the displacement of load is normal to the direction of force of gravity which is vertically downwards.

> *Note :* The coolie does work against the force of friction when he moves with the load.

(2) When a body moves in a circular path in a horizontal plane, no work is done since the centripetal force on the body at any instant is directed towards the centre of the circular path and the displacement at that instant is along the tangent to the circular path, *i.e.*, normal to the direction of force on the body (*i.e.* $\theta = 90°$) as shown in Fig. 2.7. It is for this reason that in a circular path, the kinetic energy and hence the speed of the body does not change although a force acts on the body.

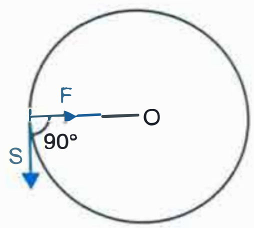

Fig. 2.7 Zero work done by the centripetal force in circular motion

Conditions for the work done by a force to be zero : From the above discussion, it is clear that the amount of work done by a force is zero in the following *two* situations :

(1) when there is no displacement (*i.e.*, $S = 0$), and

(2) when the displacement is normal to the direction of force (*i.e.*, $\theta = 90°$).

Case (iii) : If the displacement is in a direction opposite to the force, *i.e.*, $\theta = 180°$, then $\cos 180° = -1$.

$$\therefore \quad W = -F \times S$$

The work done is *negative*. This is usually the case when the force opposes the motion or it tries to stop a moving body.

Examples : (1) When a body moves on a surface, the force of friction between the body and the surface is in a direction opposite to the motion of the body (*i.e.* $\theta = 180°$). Thus, the work done by the force of friction is negative.

(2) When a ball of mass m is thrown upwards from A to B to a height h (Fig. 2.8), the displacement h (upwards) is opposite to the direction of force of gravity mg (downwards), so the work done by the force of gravity mg in displacement h is $W = -mgh$ *i.e.*, negative.

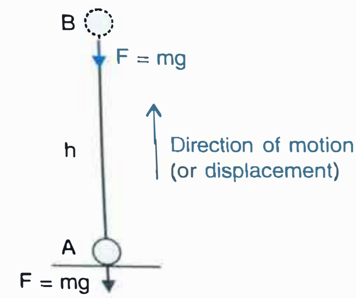

Fig. 2.8 Negative work done by the force of gravity in upward motion

> *Note :* If the force is variable (*i.e.*, force varies during displacement), the work done is determined by plotting a force-displacement graph. The force is taken on Y-axis and the displacement S (in the direction of force) is taken on X-axis. *The area enclosed by the sketch and the displacment axis (i.e., X-axis) gives the work done.* In Fig. 2.9, the force F is directly proportional to displacement and the graph for force against displacement is an inclined straight line OA. The work done by the

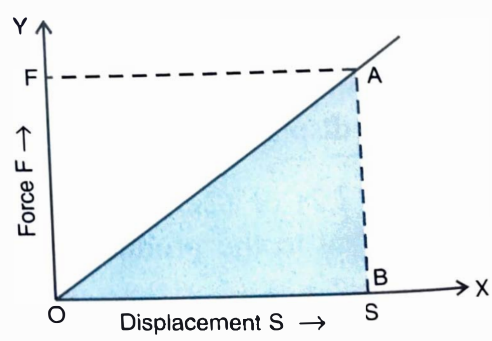

Fig. 2.9 Work done by a variable force

Case (ii) : When the displacement is normal to the direction of force, *i.e.*, $\theta = 90°$, then $\cos 90° = 0$.

$$\therefore \qquad W = 0$$

Hence the work done is *zero*.

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> ***Note :*** The coolie does work against the force of friction when he moves with the load.

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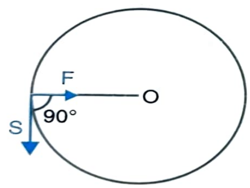

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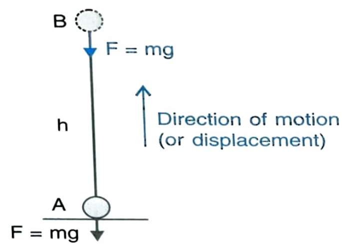

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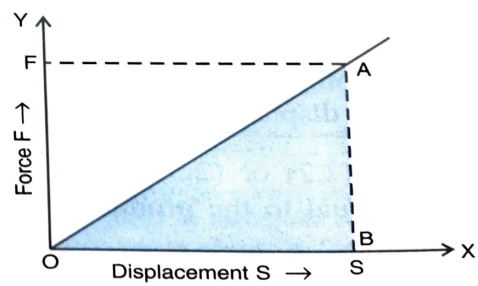
> 
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> *Fig. 2.9 Work done by a variable force*

force in displacment S is equal to the area of the triangle OAB ($= \frac{1}{2} F \times S$) which is shown shaded in Fig. 2.9.

This method is applicable in all situations. If the force is constant (*i.e.*, it does not change with displacement), the graph will be a straight line parallel to the X-axis as shown in Fig. 2.10, and the area of the rectangle OABC ($= F \times S$), enclosed between the straight line and the X-axis, will be equal to the work done.

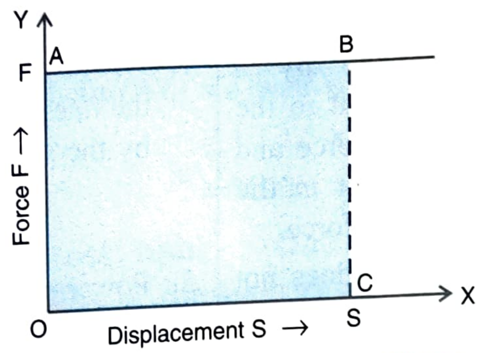

Fig. 2.10 Work done by a constant force

2.3 WORK DONE BY THE FORCE OF GRAVITY $W = mgh$

Let a body of mass m be moved down through a vertical height h either directly or through an inclined plane (*e.g.* a hill, slope or stairs). The force of gravity on the body is $F = mg$ acting vertically downwards and the vertical displacement in the direction of force is $S = h$. Therefore, the work done by the force of gravity on the body is

$$\boxed{W = FS = mgh} \quad ...(2.4)$$

Thus, work done by the force of gravity is same whether the body comes down from a certain height using stairs or slope or a lift (or elevator).*

Similarly, if a body of mass m goes up through a vertical height h either directly or through stairs or slope or lift, the work $W = -mgh$ is done by the force of gravity on the body (or the work $W = mgh$ is done by the body against the force of gravity).

* For stairs, h = number of stairs × height of each stair.

2.4 UNITS OF WORK

S.I. unit : The S.I. unit of work is **joule**. It is abbreviated as J.

Since work = force × displacement

∴ 1 joule = 1 newton × 1 metre

Thus,

1 joule of work is said to be done when a force of 1 newton displaces a body through a distance of 1 metre in its own direction.

Bigger units of work are **kilo-joule** (kJ), **mega-joule** (MJ) and **giga-joule** (GJ), where

1 kJ = 10^3 J, 1 MJ = 10^6 J and 1 GJ = 10^9 J.

C.G.S. unit : The C.G.S. unit of work is **erg**, where 1 erg = 1 dyne × 1 cm.

Thus,

1 erg of work is said to be done when a force of 1 dyne displaces a body through a distance of 1 cm in its own direction.

Relationship between joule and erg

1 joule = 1 N × 1 m

But 1 N = 10^5 dyne and 1 m = 10^2 cm

∴ 1 joule = 10^5 dyne × 10^2 cm

= 10^7 dyne × cm = 10^7 erg

Thus $\boxed{1 \text{ joule} = 10^7 \text{ erg}}$ ....(2.5)

2.5 POWER ($P = W/t$)

Definition

The rate of doing work is called power.

Power is a *scalar* quantity.

Measurement of power : The power spent by a source is measured as the amount of work done by the source in one second (or it is equal to the rate of doing work by the source).

If work W is done in time t, then

$$\text{Power } P = \frac{\text{Work done } W}{\text{Time taken } t}$$

or $$\boxed{P = \frac{W}{t}} \quad ... (2.6)$$

Thus power spent by a source depends on the following *two* factors :

(1) the amount of work done by the source, and

(2) the time taken by the source to do the said work.

If a machine (or a person) does a given amount of work in less time, more power is spent by it (or the person).

Example : If coolie A takes 1 minute to lift a load to the roof of a bus, while another coolie B takes 2 minutes to lift the same load to the roof of the same bus, the work done by both the coolies is same, but the power spent by coolie A is twice the power spent by coolie B because coolie A does work at double the rate (*i.e.*, in half the time).

> ***Note :*** If a constant force F acts on a body and it displaces the body by a distance S (in the direction of force) in time t, then work done
>
> $$W = F \times S$$
>
> and power $P = \frac{W}{t} = \frac{F \times S}{t}$
>
> But $\frac{S}{t} = v$ (average speed)
>
> ∴ Power = Force × average speed
>
> or $P = F \times v$ ... (2.7)

2.6 UNITS OF POWER

S.I. unit : The S.I. unit of power is **watt**. It is abbreviated as W.

> *If 1 joule of work is done in 1 second, the power spent is said to be 1 watt.*

i.e., $1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}} = 1 \text{ J s}^{-1}$

Bigger units of power are **kilowatt** (kW), **megawatt** (MW) and **gigawatt** (GW), where

$1 \text{ kW} = 10^3 \text{ W}$; $1 \text{ MW} = 10^6 \text{ W}$ and $1 \text{ GW} = 10^9 \text{ W}$

Smaller units of power are **milliwatt** (mW) and **microwatt** (μW), where

$1 \text{ mW} = 10^{-3} \text{ W}$ and $1 \text{ μW} = 10^{-6} \text{ W}$.

C.G.S. unit : The C.G.S. unit of power is erg per second (erg s^{-1}).

Relationship between S.I. and C.G.S. units

$$\boxed{1 \text{ W} = 1 \text{ J s}^{-1} = 10^7 \text{ erg s}^{-1}}$$

Horse power : It is another unit of power, largely used in mechanical engineering. It is related to the S.I. unit watt as below :

$$\boxed{1 \text{ H.P.} = 746 \text{ W} = 0{\cdot}746 \text{ kW}} \quad ....(2.8)$$

Difference between work and power

Work	*Power*
1. Work done by a force is equal to the product of force and displacement in the direction of force.	1. Power of a source is the rate of work done by the source.
2. Work done does not depend on time.	2. Power spent depends on the time in which work is done.
3. S.I. unit of work is joule (J).	3. S.I. unit of power is watt (W).

2.7 ENERGY (Energy as work done)

A body capable of doing work is said to possess energy. The energy possessed by a body is measured by the amount of work that the body can perform. When a body does work, its energy decreases, while if work is done on the body, its energy increases. It means that whenever work is done, there is always a transfer of energy. Thus energy and work are related to each other. We can define energy as follows :

> *The energy of a body is its capacity to do work.*

Like work, *energy is also a scalar quantity.*

> ***Note :*** There is no transfer of energy if a body is acted upon by a force normal to the direction of its displacement. *For example*, for a body moving in a circular path, centripetal force is normal to its displacement and work done is zero *i.e.*, there is no transfer of energy.

2.8 UNITS OF ENERGY

The units of energy are same as that of work.

(1) The S.I. unit of energy is **joule** (J) and the C.G.S. unit of energy is **erg**, where

$$1 \text{ J} = 10^7 \text{ erg.}$$

(2) The bigger units of energy are :

(i) **watt hour** (Wh) and

(ii) **kilowatt hour** (kWh).

(i) **Watt hour :** One watt hour (1 Wh) is the energy spent (or work done) by a source of power 1 W in 1 h, *i.e.*,

$$1 \text{ watt hour (Wh)} = 1 \text{ watt} \times 1 \text{ hour}$$
$$= 1 \text{ J s}^{-1} \times 3600 \text{ s}$$
$$= 3600 \text{ J} = 3{\cdot}6 \text{ kJ} \qquad ....(2.9)$$

(ii) **Kilowatt hour :** One kilowatt hour (1 kWh) is the energy spent (or work done) by a source of power 1 kW in 1 h. *i.e.*,

$$1 \text{ kilowatt hour (kWh)} = 1 \text{ kilowatt} \times 1 \text{ hour}$$
$$= 1000 \text{ J s}^{-1} \times 3600 \text{ s}$$
$$= 3{\cdot}6 \times 10^6 \text{ J} = 3{\cdot}6 \text{ MJ} \qquad ....(2.10)$$

Note : W (watt) and kW (kilowatt) are the units of power, while Wh (watt hour) and kWh (kilowatt hour) are the units of work or energy since power × time = work or energy.

(3) **Calorie :** Heat energy is usually measured in ***calorie***.

1 calorie is the heat energy required in raising the temperature of 1 g of water from 14·5°C to 15·5°C (or through 1°C). It is related to joule as

$$1 \text{ J} = 0{\cdot}24 \text{ calorie or } 1 \text{ calorie} = 4{\cdot}18 \text{ J} \qquad ...(2.11)$$

kilocalorie is a bigger unit of heat energy

$$1 \text{ kilocalorie} = 1000 \text{ calorie} = 4180 \text{ J}$$

(4) **Electron volt :** The energy transfer in case of atomic particles is very small, so it is measured in **electron volt** (eV).

1 eV is the energy gained by an electron when it is accelerated through a potential difference of 1 volt. *i.e.*,

$$1 \text{ eV} = \text{charge on an electron} \times 1 \text{ volt}$$
$$= 1{\cdot}6 \times 10^{-19} \text{ coulomb} \times 1 \text{ volt}$$
$$= 1{\cdot}6 \times 10^{-19} \text{ joule}$$

or $\boxed{1 \text{ eV} = 1{\cdot}6 \times 10^{-19} \text{ J}}$ ....(2.12)

Difference between energy and power

Energy	*Power*
1. Energy of a body is its capacity to do work.	1. Power of a source is the rate at which energy is supplied by it.
2. Energy spent does not depend on time.	2. Power depends on the time in which energy is spent.
3. S.I. unit of energy is joule (J).	3. S.I. unit of power is watt (W).

EXAMPLES

1. A crane pulls up a car of mass 500 kg to a vertical height of 4 m. Calculate the work done by the crane.

In order to raise the car, the crane has to do work against the force of gravity. Therefore, the force required to lift the car $F = mg$

$= 500 \times 9{\cdot}8 = 4900$ N.

Displacement S = vertical height moved = 4 m.

Work done $W = F\ S = 4900 \times 4 =$ **19600 J**

2. A force of 10 N displaces a body by a distance of 2 m at an angle 60° to its own direction. Find the amount of work done.

Given : $F = 10$ N, $S = 2$ m, $\theta = 60°$.

Work = Force × displacement in the direction of force

or $W = F \times S \cos\theta$

$\therefore\ W = 10 \times 2 \cos 60° = 10 \times 2 \times \frac{1}{2}$ $(\because \cos 60° = \frac{1}{2})$

$=$ **10 J**

3. **A boy of mass 40 kg climbs up a flight of 30 steps each 20 cm high in 2 min and a girl of mass 30 kg does the same in 1·5 min. Compare : (i) the work done, and (ii) the power developed by them ($g = 10$ m s^{-2})**

While climbing, both the boy and the girl have to do work against their force of gravity.

Force of gravity of boy

$$F_1 = m_1 g = 40 \times 10 = 400 \text{ N}$$

Force of gravity of girl

$$F_2 = m_2 g = 30 \times 10 = 300 \text{ N}$$

Total height climbed up

$$h = \text{number of steps} \times \text{height of each step}$$
$$= 30 \times 20 \text{ cm} = 600 \text{ cm} = 6 \text{ m}$$

(i) Work done by the boy

$$W_1 = F_1 \times h = 400 \times 6 = 2400 \text{ J}$$

Work done by the girl

$$W_2 = F_2 \times h = 300 \times 6 = 1800 \text{ J}$$

$\therefore$ $W_1 : W_2 = 2400 : 1800 = \mathbf{4 : 3}$

(ii) Power developed $= \dfrac{\text{Work done}}{\text{Time taken}}$

Here, $t_1 = 2$ min $= 120$ s; $t_2 = 1{\cdot}5$ min $= 90$ s

$\therefore$ Power developed by boy

$$P_1 = \frac{W_1}{t_1} = \frac{2400 \text{ J}}{120 \text{ s}} = 20 \text{ W}$$

Power developed by girl

$$P_2 = \frac{W_2}{t_2} = \frac{1800 \text{ J}}{90 \text{ s}} = 20 \text{ W}$$

$\therefore$ $P_1 : P_2 = 20 : 20 = \mathbf{1 : 1}$

Alternative : (i) Since height climbed is same,

$$\therefore \quad \frac{W_1}{W_2} = \frac{m_1 gh}{m_2 gh} = \frac{m_1}{m_2} = \frac{40}{30} = \frac{4}{3}$$

$$\text{(ii)} \quad \frac{P_1}{P_2} = \frac{W_1/t_1}{W_2/t_2} = \frac{W_1}{W_2} \times \frac{t_2}{t_1} = \frac{4}{3} \times \frac{1{\cdot}5}{2} = \frac{1}{1}$$

4. **A force of 15 N is required to pull up a body of mass 2 kg through a distance 5 m along an inclined plane making an angle of 30° with the horizontal as shown in Fig. 2.11. Calculate :**
   (i) the work done by the force in pulling the body,
   (ii) the force due to gravity on the body,
   (iii) the work done against the force due to gravity. Take : $g = 9{\cdot}8$ m s^{-2}.
   (iv) Account for the difference in answers of part (i) and part (iii).

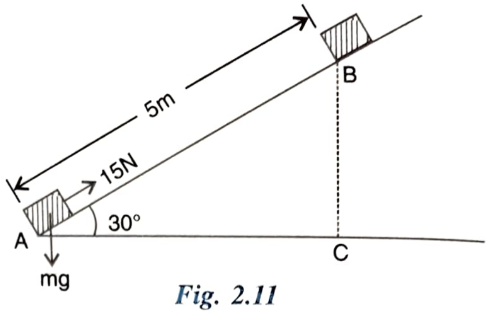

Fig. 2.11

(i) Work done by the force in pulling the body up

W = Force × displacement in the direction of force = 15 N × 5 m = **75 J**

(ii) Force due to gravity on the body

$$F = mg = 2 \times 9{\cdot}8 = \mathbf{19{\cdot}6 \text{ N}}$$

(iii) Work done against the force due to gravity W' = Force due to gravity × vertical height moved

$$= mg \times \text{BC}$$

But in right angled Δ ACB, $\sin 30° = \dfrac{\text{BC}}{\text{AB}}$

$\therefore$ BC = AB sin 30°

Hence $W' = mg \times \text{AB} \sin 30°$

$$= 19{\cdot}6 \times 5 \times \frac{1}{2} \qquad (\because \sin 30° = \tfrac{1}{2})$$

$$= \mathbf{49 \text{ J}}$$

(iv) We note that $W > W'$. The difference in work W and W' is 75 J – 49 J = 26 J. Actually 26 J is the work done against the force of friction between the body and the inclined plane.

5. **Calculate the power of an engine required to lift 10^5 kg of coal per hour from a mine 360 m deep. (Take $g = 10$ m s^{-2}).**

Given : $m = 10^5$ kg, $g = 10$ m s^{-2}, $h = 360$ m,

$t = 1$ h $= 60 \times 60$ s $= 3600$ s

The work needed in lifting a mass m to a height h against the force due to gravity is

$$W = mg \times h = mgh$$

and $\quad$ Power $P = \dfrac{\text{Work done}}{\text{Time taken}} = \dfrac{mgh}{t}$

$$\therefore \quad P = \frac{10^5 \times 10 \times 360}{3600} = 10^5 \text{ W} = \mathbf{100 \text{ kW}}$$

Note : In fact, the actual power of the engine will be much more than 100 kW because (i) some energy will get wasted in overcoming the force of friction and (ii) the efficiency of the engine will always be less than 100%.

6. An electric motor of power 100 W is used to drive the stirrer in a water bath. If 50% of the energy supplied to the motor is spent in stirring the water, calculate the work done on water in one minute.

Given, power supplied = 100 W, time t = 1 minute = 60 s

Power used in stirring the water

$$= 50\% \text{ of the power supplied}$$

$$= \frac{50}{100} \times 100 \text{ W} = 50 \text{ W}$$

Work done on water = power used × time

$$= 50 \text{ W} \times 60 \text{ s} = 3000 \text{ J}$$

7. A man exerts a force of 200 N in pulling a cart at a constant speed of 16 m s^{-1}. Calculate the power spent by the man.

Given, force = 200 N, velocity = 16 m s^{-1}

Power = force × velocity

$$= 200 \text{ N} \times 16 \text{ m s}^{-1} = 3200 \text{ W}$$

8. The work done by the heart is 1 J per beat. Calculate the power of the heart if it beats 72 times in 1 minute.

Given : Number of beats in 1 minute = 72

$\therefore$ Number of beats per second $= \frac{72}{60} = 1{\cdot}2$

Power of heart = work done per second

= work done per beat × number of beats in 1 second

$= 1 \text{ J} \times 1{\cdot}2 \text{ s}^{-1}$

$= \mathbf{1{\cdot}2 \text{ J s}^{-1}}$ (or **1·2 W**)

9. Express 5 kWh into joule.

1 kilowatt hour (kWh) = 1000 W × (60 × 60 s)

$= 3{\cdot}6 \times 10^6$ J

$\therefore$ 5 kWh $= 5 \times 3{\cdot}6 \times 10^6$ J

$= \mathbf{1{\cdot}8 \times 10^7 \text{ J}}$

10. The energy of an electron is 4·0 × 10^{-19} J. Express it in eV.

Since 1 eV $= 1{\cdot}6 \times 10^{-19}$ J

$$\therefore \quad 4{\cdot}0 \times 10^{-19} \text{ J} = \frac{4{\cdot}0 \times 10^{-19}}{1{\cdot}6 \times 10^{-19}} \text{ eV} = 2{\cdot}5 \text{ eV}$$

EXERCISE–2(A)

1. Define work. When is work said to be done by a force ?
2. How is the work done by a force measured when (i) force is in the direction of displacement, (ii) force is at an angle to the direction of displacement ?
3. A force F acts on a body and displaces it by a distance S in a direction at an angle θ with the direction of force. (a) Write the expression for the work done by the force. (b) What should be the angle between the force and displacement so that the work done is (i) zero, (ii) maximum ?
   Ans. (a) $F\,S \cos\theta$, (b) (i) 90° (ii) 0°
4. A body is acted upon by a force. State *two* conditions when the work done is zero.
5. State the condition when the work done by a force is (a) positive, (b) negative. Explain with the help of examples.
6. A body is moved in a direction opposite to the direction of force acting on it. State whether the work is done by the force or work is done against the force.
   Ans. Work is done against the force.
7. When a body moves in a circular path, how much work is done by the body ? Give reason.
   (*Hint* : The body is acted upon by the centripetal force)
   Ans. Zero
   Reason : Force is normal to displacement.
8. A satellite revolves around the earth in a circular orbit. What is the work done by the satellite ? Give reason.
   Ans. Zero
   Reason : Force of gravity on the satellite is normal to its displacement.
9. State whether work is done or not, by writing yes or no, in the following cases :
   (a) A man pushes a wall.
   (b) A coolie stands with a box on his head for 15 min.
   (c) A boy climbs up 20 stairs.
   Ans. (a) No (b) No (c) Yes
10. A coolie X carrying a load on his head climbs up a slope and another coolie Y carrying the identical load on his head moves the same distance on a frictionless horizontal platform. Who does more work ? Explain the reason.
   Ans. Coolie X does work against the force of gravity while coolie Y does no work because his displacement is normal to the force of gravity.

11. The work done by a fielder when he takes a catch in a cricket match is negative. Explain.

Ans. The fielder applies force opposite to the direction of displacement of the ball.

12. Give an example when work done by the force of gravity acting on a body is zero even though the body gets displaced from its initial position.

Ans. A coolie while moving on a horizontal ground with a load does no work against the force of gravity.

13. What are the S.I. and C.G.S units of work ? How are they related ? Establish the relationship.

14. State and define the S.I. unit of work.

15. Express joule in terms of erg.

16. A body of mass m falls down through a height h. Obtain an expression for the work done by the force of gravity.

17. A boy of mass m climbs up the stairs of vertical height h.

(a) What is the work done by the boy against the force of gravity ?

(b) What would have been the work done if he uses a lift in climbing the same vertical height ?

Ans. (a) mgh, (b) mgh

18. Define the term energy and state its S.I. unit.

19. What physical quantity does the electron volt (eV) measure ? How is it related to the S.I. unit of that quantity ? **Ans.** Energy, $1 \text{ eV} = 1{\cdot}6 \times 10^{-19}$ J

20. Complete the following sentences :

(a) 1 J = ... calorie.

(b) 1 kWh = ... J.

Ans. (a) 0·24 (b) $3{\cdot}6 \times 10^6$

21. Name the physical quantity which is measured in calorie. How is it related to the S.I. unit of that quantity ?

Ans. Heat energy, 1 calorie = 4·18 joule

22. Define kilowatt hour. How is it related to joule ?

23. Define the term power. State its S.I. unit.

24. State *two* factors on which power spent by a source depends. Explain your answer with examples.

25. Differentiate between work and power.

26. Differentiate between energy and power.

27. State and define the S.I. unit of power.

28. (a) Name the physical quantity measured in terms of horse power.

(b) How is horse power related to the S.I. unit of power ?

29. Differentiate between watt and watt hour.

30. Name the quantity which is measured in

(a) kWh (b) kW (c) Wh (d) eV.

Ans. (a) Energy, (b) Power, (c) Energy, (d) Energy

31. Is it possible that no transfer of energy takes place even when a force is applied to a body ?

Ans. Yes, when force is normal to displacement.

MULTIPLE CHOICE TYPE

1. One horse power is equal to :

(a) 1000 W (b) 500 W

(c) 764 W (d) 746 W. **Ans.** (d) 746 W

2. kWh is the unit of :

(a) power (b) force

(c) energy (d) none of these

Ans. (c) energy

NUMERICALS

1. A body, when acted upon by a force of 10 kgf, gets displaced by 0·5 m. Calculate the work done by the force, when the displacement is (i) in the direction of force, (ii) at an angle of 60° with the force, and (iii) normal to the force. ($g = 10 \text{ N kg}^{-1}$)

Ans. (i) 50 J (ii) 25 J (iii) zero

2. A boy of mass 40 kg climbs up the stairs and reaches the roof at a height 8 m in 5 s. Calculate :

(i) the force of gravity acting on the boy,

(ii) the work done by him against the force of gravity,

(iii) the power spent by the boy.

(Take $g = 10 \text{ m s}^{-2}$)

Ans. (i) 400 N (ii) 3200 J (iii) 640 W

3. A man spends 6·4 kJ energy in displacing a body by 64 m in the direction in which he applies force, in 2·5 s. Calculate : (i) the force applied, and (ii) the power spent (in H.P.) by the man.

Ans. (i) 100 N, (ii) 3·43 H.P.

4. A weight lifter lifted a load of 200 kgf to a height of 2·5 m in 5 s. Calculate : (i) the work done, and (ii) the power developed by him. Take $g = 10 \text{ N kg}^{-1}$. **Ans.** (i) 5000 J, (ii) 1000 W

5. A machine raises a load of 750 N through a height of 16 m in 5 s. Calculate :

(i) the energy spent by the machine,

(ii) the power of the machine if it is 100% efficient.

Ans. (i) 12000 J (ii) 2400 W

6. An electric heater of power 3 kW is used for 10 h. How much energy does it consume ? Express your answer in (i) kWh, (ii) joule.

Ans. (i) 30 kWh, (ii) $1{\cdot}08 \times 10^8$ J.

7. A water pump raises 50 litre of water through a height of 25 m in 5 s. Calculate the power of the pump required.

(Take g = 10 N kg^{-1} and density of water = 1000 kg m^{-3}). **Ans.** 2500 W

8. A pump is used to lift 500 kg of water from a depth of 80 m in 10 s. Calculate :

(a) the work done by the pump,

(b) the power at which the pump works, and

(c) the power rating of the pump if its efficiency is 40%. (Take g = 10 m s^{-2})

[Hint : Efficiency $= \dfrac{\text{useful power}}{\text{power input}}$]

Ans. (a) 4×10^5 J (b) 40 kW (c) 100 kW

9. An ox can apply a maximum force of 1000 N. It is taking part in a cart race and is able to pull the cart at a constant speed of 30 m s^{-1} while making its best effort. Calculate the power developed by the ox.

Ans. 30 kW

10. The power of a motor is 40 kW. At what speed can the motor raise a load of 20,000 N ? **Ans.** 2 m s^{-1}

11. Rajan exerts a force of 150 N in pulling a cart at a constant speed of 10 m s^{-1}. Calculate the power exerted. **Ans.** 1500 W

12. A boy weighing 350 N climbs up 30 steps, each 20 cm high in 1 minute. Calculate :

(i) the work done, and (ii) the power spent.

Ans. (i) 2100 J, (ii) 35 W

13. It takes 20 s for a person A of mass 50 kg to climb up the stairs, while another person B of same mass does the same in 15 s. Compare the (i) work done, and (ii) power developed by the persons A and B.

Ans. (i) 1 : 1 (ii) 3 : 4

14. A boy weighing 40 kgf climbs up a stair of 30 steps each 20 cm high in 4 minutes and a girl weighing 30 kgf does the same in 3 minutes. Compare : **(2016)**

(i) the work done by them, and

(ii) the power developed by them.

Ans. (i) 4 : 3, (ii) 1 : 1

15. A man raises a box of mass 50 kg to a height of 2 m in 20 s, while another man raises the same box to the same height in 50 s.

(a) Compare : (i) the work done, and (ii) the power developed by them.

(b) Calculate : (i) the work done, and (ii) the power developed by each man. Take g = 10 N kg^{-1}.

Ans. (a) (i) 1 : 1 (ii) 5 : 2,
(b) (i) 1000 J, 1000 J (ii) 50 W, 20 W

16. A boy takes 3 minutes to lift a 20 litre water bucket from a 20 m deep well, while his father does it in 2 minutes. (a) Compare : (i) the work, and (ii) power developed by them. (b) How much work each does ? Take density of water = 10^3 kg m^{-3} and g = 9·8 N kg^{-1}.

Ans. (a) (i) work 1 : 1, (ii) power 2 : 3,
(b) work done by each = 3·92 kJ

(B) DIFFERENT FORMS OF ENERGY

2.9 MECHANICAL ENERGY AND ITS DIFFERENT FORMS

The energy possessed by a body due to its state of rest or of motion, is called mechanical energy. It is in two forms :

(1) potential energy, and

(2) kinetic energy.

The total mechanical energy of a body is the sum of its potential energy and kinetic energy.

2.10 POTENTIAL ENERGY (U)

The energy possessed by a body at rest due to its position or size and shape is called potential energy.

It is usually denoted by the symbol U.

Examples : A body placed at a height above the ground, a wound up watch spring, a compressed spring, a bent bow, a stretched rubber string, *etc.* have potential energy.

Forms of potential energy

In mechanics, potential energy is mainly of two kinds : (1) gravitational potential energy due to its changed position, and (2) elastic potential energy due to its changed size and shape.

(1) **Gravitational potential energy :** Each body experiences a force of attraction due to Earth which is called the force due to gravity or weight of the body. The potential energy possessed by a body due to the force of attraction of Earth on it, is called its gravitational potential energy.

The gravitational potential energy of a body is zero when it is at infinity because the force of attraction of Earth on the body is then zero. The gravitational potential energy of a body at a point is equal to the amount of work done by the force of attraction of Earth in bringing that body from infinity to that point. Since work is done by the force of gravity itself, so at a finite distance from Earth. the gravitational potential energy of the body is negative.

As the distance of the body from the surface of Earth increases, the force of attraction of Earth decreases and its gravitational potential energy increases (*i.e.* the negative value of gravitational potential energy decreases and finally it becomes zero at infinite separation).

(2) **Elastic potential energy :** When an external force is applied on a non-rigid body, it gets deformed due to change in its size and shape. On removal of the force, it regains its orginal form due to the property of elasticity. Some work is done by the external force in deforming the body. This work is stored in the body in the form of its elastic potential energy. Thus the potential energy possessed by a body in the *deformed state due to change in its size and shape* is called elastic potential energy. It is the amount of work done in deforming the body (or in changing the size and shape of the body).

2.11 GRAVITATIONAL POTENTIAL ENERGY AT A HEIGHT ($U = mgh$)

The gravitational potential energy of a body at a height above the ground is measured by the amount of work done in lifting it up from the ground to that height against the force of gravity (assuming that its gravitational potential energy on the ground is zero). It is usually denoted by the symbol U.

Let a body of mass m be lifted from the ground (or the earth's surface) to a vertical height h. The least upward force required to lift the body (without acceleration) must be equal to the force of gravity (*i.e.*, $F = mg$) on the body acting vertically downwards. The work done W on the body in lifting it to a height h is

$$W = \text{Force of gravity } (mg) \times \text{displacement } (h)$$
$$= mgh$$

This work is done in lifting the body up and it gets stored in the body in the form of its gravitational potential energy when it is at height h. Thus,

$$\text{Gravitational potential energy } U = mgh \quad ...(2.13)$$

Note : Precisely mgh is the gain in potential energy of the body when it is raised to a height h above the ground. But here we have assumed that when the body is on the earth's surface (or ground), its gravitational potential energy is zero, so we consider the gravitational potential energy of the body at height h equal to mgh.

Thus when a body is thrown vertically upwards, the height of the body from the ground increases, hence its potential energy increases. Similarly, when a body is released from a height, it falls down, so the height of the body from the ground decreases, hence its potential energy decreases and it becomes zero at the earth's surface.

When a body of mass m is taken up from a height h_1 to a height h_2 above the ground ($h_2 > h_1$), the gain in potential energy

= final potential energy − initial potential energy = $mgh_2 - mgh_1 = mg\,(h_2 - h_1)$.

But if a body of mass m falls down from a height h_1 to a height h_2 above the ground ($h_2 < h_1$), the loss in potential energy = initial potential energy − final potential energy = $mg\,(h_1 - h_2)$.

2.12 KINETIC ENERGY (K)

The energy possessed by a body due to its state of motion is called its kinetic energy.

It is usually denoted by the symbol K.

Examples : A fast moving stone has the capacity of breaking a window pane on striking it because it has kinetic energy. Similarly, a car in motion, moving hands of a clock, a bullet fired from a gun, a rolling ball, an apple falling from a height, etc. have kinetic energy.

Expression for kinetic energy ($K = \frac{1}{2}mv^2$)

The kinetic energy possessed by a moving body is equal to the amount of work which the moving body can do before coming to rest. It can be calculated by finding the amount of work needed to be done by an opposing force to stop the body.

Suppose a body of mass m is moving with a velocity v. It is brought to rest by applying a constant opposing force F. Let a be the uniform retardation produced by the opposing force and the body travels a distance S before coming to rest. Then,

retarding force F = mass × retardation = $m\,a$ ..(i)

Kinetic energy of the body = work done by the retarding force F in displacement S before stopping it.

or Kinetic energy K = retarding force F × displacement S

or $K = F \times S$ ..... (ii)

Now to calculate the displacement S, we have

initial velocity (u) = v,

final velocity (v) = 0

Since a is the retardation, so accelaration = $-a$

From the relation $v^2 = u^2 + 2aS$

On substituting, $0 = v^2 - 2aS$

∴ Displacement $S = \dfrac{v^2}{2a}$ .... (iii)

Substituting the values of F and S from eqns. (i) and (iii) in eqn. (ii), we get

Kinetic energy $K = F \times S$

$$= ma \times \frac{v^2}{2a} = \frac{1}{2}mv^2$$

or

$$K = \frac{1}{2}m\,v^2$$

Kinetic energy = $\frac{1}{2}$ *mass* × *(velocity)*^{2} ..(2.14)

Thus, kinetic energy of a body depends on square of its velocity of motion. On doubling the velocity of motion of a body, its kinetic energy becomes four times. In other words, a faster moving body has more kinetic energy than a slowly moving body of same mass.

Relationship between kinetic energy and momentum

Let a body of mass m be moving with a velocity v. Then its

kinetic energy $K = \frac{1}{2}m\,v^2$ ...(i)

momentum $p = m\,v$ ...(ii)

Substituting the value of $v = p/m$ from eqn. (ii) in eqn. (i), we get

$$K = \frac{1}{2}m\,(p/m)^2 = p^2/2m$$

or $p^2 = 2\,mK$

Thus, kinetic energy K and momentum p are related as :

$$p = \sqrt{2mK} \text{ or } K = p^2/2m \qquad ..(2.15)$$

Case (i) : If a light body A of mass m and a heavy body B of mass M, both have same momentum p, then the kinetic energy of the light body A will be more than that of the heavy body B.

$$\frac{K_A}{K_B} = \frac{p^2/2m}{p^2/2M} = \frac{M}{m}$$

Since M > m, so $K_A > K_B$.

Case (ii) : If a light body A of mass m and a heavy body B of mass M have the same kinetic energy K, then the heavy body B will have more momentum than the light body A.

$$\frac{p_B}{p_A} = \frac{\sqrt{2MK}}{\sqrt{2mK}} = \sqrt{\frac{M}{m}}$$

Since, $M > m$, so $p_B > p_A$.

Work-energy theorem

When a force is applied in the direction of motion of a body, it accelerates the motion and thus increases the kinetic energy of the body. This increase in kinetic energy is equal to the work done by the force on the body. This is called the work-energy theorem. Thus,

> *According to the work energy theorem, the increase in kinetic energy of a moving body is equal to the work done by a force acting in the direction of the moving body.*

Proof : Let a body of mass m be moving with an initial velocity u. When a constant force F is applied on the body along its direction of motion, it produces an acceleration a and the velocity of the body changes from u to v in moving a distance S. Then

Force F = mass × acceleration = $m\,a$ ...... (i)

Work done by the force = Force × displacement

or $W = F \times S$ ...... (ii)

From relation $v^2 = u^2 + 2aS$

Displacement $S = \dfrac{v^2 - u^2}{2a}$ ...... (iii)

Substituting the values of F and S from eqns (i) and (iii) in eqn (ii), we get

$$W = m\,a \times \left(\frac{v^2 - u^2}{2a}\right)$$

$$= \frac{1}{2} m\,(v^2 - u^2)$$

or $\boxed{W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2}$ ...(2.16)

But initial kinetic energy $K_i = \frac{1}{2}mu^2$

and final kinetic energy $K_f = \frac{1}{2}mv^2$

Then from eqn. (2.16),

$$W = K_f - K_i$$

Thus, work done on the body

= Increase in kinetic energy ...(2.17)

Forms of kinetic energy

A body can have *three* types of motion namely translational motion, rotational motion and vibrational motion, so kinetic energy is also of *three* forms : (1) translational kinetic energy, (2) rotational kinetic energy, and (3) vibrational kinetic energy.

(1) Translational kinetic energy : The motion of a body in a straight line path is called *translational motion* and the kinetic energy of the body due to motion in a straight line is called ***translational kinetic energy.***

Examples : A car moving on a straight path, a freely falling body and a molecule of monoatomic gas have translational kinetic energy.

(2) Rotational kinetic energy : If a body rotates about an axis, the motion is called *rotational motion* and the kinetic energy of the body due to rotational motion is called ***rotational kinetic energy*** or simply ***rotational energy***.

Examples : A spinning top, a rotating wheel and a rotating fan have rotational kinetic energy. Earth rotating on its own axis has a huge amount of rotational kinetic energy. The atoms of a moving diatomic (or polyatomic*) molecule rotate about a fixed axis in addition to their translational motion, so they possess both rotational and translational kinetic energies.

(3) Vibrational kinetic energy : If a body moves to and fro about its mean position, the motion is called *vibrational motion*. The kinetic energy of the body due to its vibrational motion is called ***vibrational kinetic energy*** or simply ***vibrational energy.***

Examples : A wire clamped at both the ends when struck in the middle, vibrates. The energy possessed by the wire is vibrational kinetic energy. A steel strip, clamped at one end, vibrates

* A molecule with two or more than two atoms such as H_2, O_2, N_2, HCl, H_2O, NH_3 etc., is called a polyatomic molecule.

when the other free end is slightly displaced and then released. The steel strip is then said to possess vibrational kinetic energy. In a solid, atoms vibrate about their mean positions, so they possess vibrational kinetic energy. In a polyatomic molecule atoms can vibrate about their mean positions, so a polyatomic molecule has the vibrational energy in addition to the rotational and translational energies.

> *Note* : Depending upon its state of motion, a moving body may possess either one or more than one form of kinetic energy simultaneously. For example, a rolling ball and the wheel of a moving vehicle have kinetic energies both in translational and rotational forms simultaneously.

Distinction between potential energy and kinetic energy

Potential energy	Kinetic energy
1. It is the energy possessed by a body due to its changed position or changed size and shape.	1. It is the energy possessed by a body due to its state of motion.
2. It is equal to the work done in bringing the body to its changed state.	2. It is equal to the work that a moving body can do before coming to rest.
3. It can change *only* in the form of kinetic energy.	3. It can change into any other form.
4. It does not depend on the speed of the body.	4. It depends on the speed of the body.

2.13 CONVERSION OF POTENTIAL ENERGY INTO KINETIC ENERGY

Potential energy changes into kinetic energy whenever it is put to use.

Examples : **(1)** A hammer at a height has gravitational potential energy which is equal to the work done in moving the hammer to that height against the force due to gravity on it. When the hammer is made to fall on a nail fixed upright on a wooden piece, the nail begins to penetrate. The reason is that as the hammer starts falling, its potential energy begins to change into its kinetic energy. The falling hammer now has both potential and kinetic energy. When it strikes the nail, hammer does work on the nail. The kinetic energy of the hammer changes into the kinetic energy of the nail due to which the nail moves into the wooden piece.

(2) A wound up watch spring has elastic potential energy which is equal to the work done in bringing it to the wound-up state. As the spring unwinds itself, the potential energy stored in it changes into kinetic energy which does work in moving the hands of the watch and thus changes into the kinetic energy of the hands.

(3) When the string of a bow is pulled, some work is done which is stored in the deformed state of the bow in the form of its elastic potential energy. On releasing the string to shoot an arrow, the potential energy of the bow changes into the kinetic energy of the arrow which makes it move.

(4) A compressed spring has elastic potential energy due to its compressed state. When it is released, the potential energy of the spring changes into kinetic energy which does work on the ball placed on it and changes into the kinetic energy of the ball due to which it flies away (Fig. 2.12).

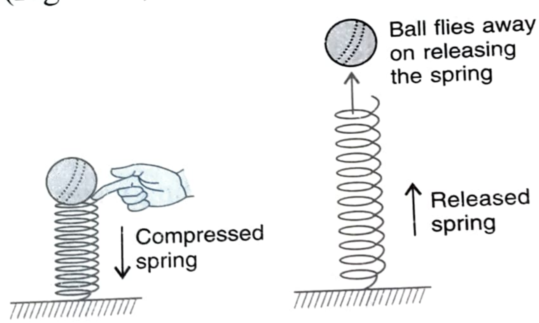

Fig. 2.12 Ball flies away on releasing the spring

2.14 DIFFERENT FORMS OF ENERGY

Nature has provided us energy in various forms namely, *(1) solar energy, (2) heat (or radiant) energy, (3) light energy, (4) chemical (or fuel) energy, (5) hydro energy, (6) electrical energy, (7) nuclear energy, (8) geo-thermal energy, (9) wind energy, (10) sound energy, (11) magnetic energy, and (12) mechanical energy*, etc. These forms of energy are discussed briefly ahead.

(1) **Solar energy** : *The energy radiated out by the Sun is called solar energy.* Solar energy cannot be used directly to perform work, because it is too diffused and it is not always available uniformly. However, a number of devices such as (i) solar panels, (ii) solar furnaces, and (iii) solar cells, *etc.* have been invented to make use of solar energy.

(i) A *solar panel* consists of a black-painted metal surface which absorbs the sun's energy and heats water in its contact.

(ii) A *solar furnace* has a large aperture parabolic mirror which focuses the sun rays on a small area so that a high temperature is achieved. Thus, by storing water at the focus of the mirror, water can be boiled to produce steam. Steam can then be used to drive the turbine of an electric generator so as to produce electrical energy.

(iii) *Solar cells* are devices used to convert solar energy directly into electrical energy. These cells are made from thin slices of a semiconducting material. However, the efficiency of a solar cell to convert solar energy into electrical energy is very low.

(2) **Heat energy** : *The energy released on burning coal, oil, wood or gas is called heat energy.* The steam obtained on heating water possesses heat energy and it has the capacity to do work. In a steam engine, heat energy of steam is used to obtain work (*i.e.*, mechanical energy). The Sun is also a source of heat energy. Earth receives heat energy directly from the Sun.

(3) **Light energy** : *It is a form of energy in the presence of which other objects are seen.* The natural source of light energy is Sun. Moon reflects the sunlight at night. Many sources such as fire, burning candle, heated filament of a bulb etc. also give light energy along with heat energy.

(4) **Chemical (or fuel) energy** : *The energy possessed by the fossil fuels such as coal, petroleum and natural gas is called chemical energy (or fuel energy).* These fuels contain chemical energy stored in them. When fuels are burnt, chemical energy changes into heat and light energy.

The food that we eat also has chemical energy in it. Plants convert solar energy into the chemical energy of food during the process of photosynthesis. A battery has chemical energy stored in it and it provides electrical energy when in use, by a chemical reaction which takes place inside it.

(5) **Hydro energy** : *The energy possessed by fast moving water is called hydro energy.* This energy is used to generate electricity in hydroelectric power stations. For this, water is stored in dams built across the rivers high up in the hills and the water from the dams is allowed to flow down through channels. The kinetic energy of the fast flowing water drives the turbines of the generators to produce electrical energy.

(6) **Electrical energy** : *When two dry bodies are rubbed together, they get charged due to the movement of free electrons from one body to the other body, so they possess electrical energy.* In an electric cell, as a result of a chemical reaction, the movement of ions from one electrode to the other electrode within the cell becomes a source of electrical energy.

(7) **Nuclear energy** : *The energy released due to loss in mass during the processes of nuclear fission and fusion, is called nuclear (or atomic) energy.* In both these processes the loss in mass gets converted into energy in accordance with Einstein's mass-energy relation $E = mc^2$. This energy is used in nuclear reactors for constructive purposes to produce electrical energy and is used in nuclear bomb for destructive purposes to produce heat and other forms of energy so as to destroy the enemy in war.

(8) **Geo thermal energy :** *The energy released in nuclear disintegrations in the interior of Earth gets stored deep inside the Earth and is called geo thermal energy.* This energy heats up the underground water to produce natural steam. Sometimes, this natural steam may burst out from the surface of the Earth as hot springs. The electric power companies may drill wells into the Earth to trap the natural steam which may be used to run the turbines of generators to produce electricity.

(9) **Wind energy :** *The energy possessed by the fast moving air is called wind energy.* This energy is used in driving a wind mill. In rural areas for past many years, wind mills were used to pump out the underground water and to grind grains. Now a days, giant wind mills are being used to drive the turbine of electric generators for producing electricity.

10. **Sound energy :** *A vibrating body possesses sound energy.* It is sensed by our ears. When the disturbance produced by a vibrating body in the atmospheric air layers reaches our ears and produces vibrations in the ear-membrane, sound is heard.

11. **Magnetic energy :** *The energy possessed by a magnet due to which it can attract iron filings, is called magnetic energy.* An electromagnet has magnetic energy.

12. **Mechanical energy :** *The energy possessed by a body due to its state of rest or of motion, is called mechanical energy. It is the sum of potential energy and kinetic energy.* A body at a height, a moving body, a stretched bow, etc. have mechanical energy.

2.15 CONVERSION OF ONE FORM OF ENERGY INTO THE OTHER FORM

In our daily life, we require energy in various forms. Since one form of energy can be converted into other forms, we can obtain energy in the required form from the form of energy available to us. Fig. 2.13 shows some examples of conversion of energy from one form to another form.

Now let us consider some more examples of conversion of one form of energy into another form.

(1) **Mechanical energy to electrical energy:** The water stored in the reservoir of a dam has potential energy. When water flows down, its potential energy decreases and kinetic energy increases. If the falling water is made to rotate a turbine near the bottom of the dam, the kinetic energy of water is transferred to the turbine in the form of rotational kinetic energy due to which it rotates. The turbine rotates the armature of the generator connected to it and thus kinetic energy gets transformed into electrical energy in the generator.

Thus, an electric generator (or a dynamo) converts mechanical energy into electrical energy.

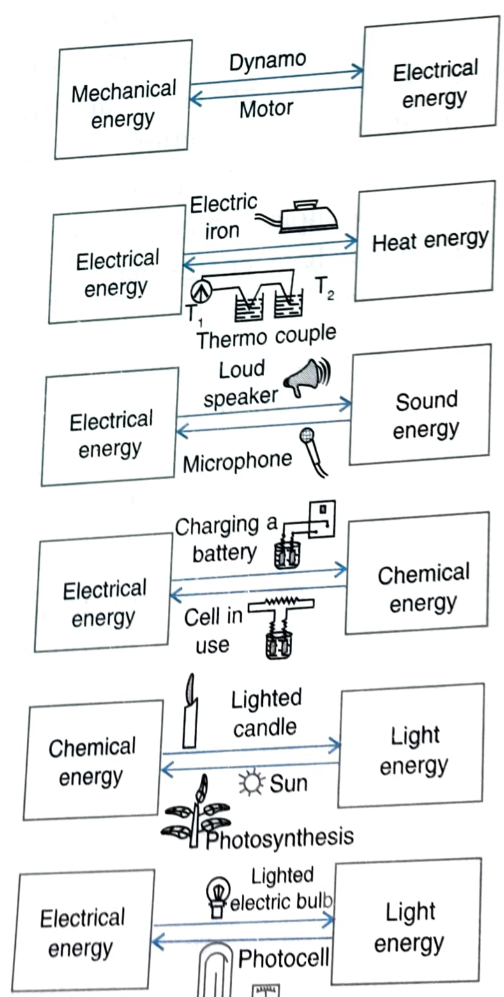

Fig. 2.13 Examples of energy conversion

(2) **Electrical energy to mechanical energy :** In an electric motor, when an electric current is passed in a coil, freely suspended (or pivoted) in a magnetic field, a torque acts on the coil due to which it rotates. The shaft attached to the coil also rotates with it. Thus, the electrical energy in an electric motor changes into mechanical energy.

The electric motor is used in many home appliances such as electric fan, washing machine, mixer, grinder, etc. It is also used to run industrial machines.

(3) **Electrical energy to heat energy :** In electric appliances such as heater, oven, geyser, toaster, etc. electrical energy changes into heat energy when a current passes through their resistance wire (or filament).

(4) **Heat energy to electrical energy :** In a thermocouple, when two junctions of two different metals are kept at different temperatures (one junction is kept hot, while the other cold), a current flows in the thermocouple. Thus, a thermocouple changes the heat energy supplied at the hot junction into electrical energy.

(5) **Electrical energy to sound energy :** A loudspeaker when in use, receives electrical energy in form of electrical signals from the microphone and changes it into sound energy.

In an electric bell when an electric current is passed, the electrical energy changes into sound energy.

(6) **Sound energy to electrical energy :** A microphone converts the sound energy into electrical energy in form of varying electric signals.

(7) **Electrical energy to chemical energy :** While charging a battery, electrical energy changes into the chemical energy of the cell.

(8) **Chemical energy to electrical energy :** When current is drawn from an electric cell, the chemical energy stored in it changes into electrical energy.

(9) **Chemical energy to light energy :** When a candle burns, it gives light. Similarly in a kerosene lamp when the oil soaked in its wick burns, the chemical energy changes into light energy.

(10) **Light energy to chemical energy :** The light energy from the Sun is absorbed by the green plants and they change it in the form of chemical energy (food) during the process of photosynthesis.

(11) **Electrical energy to light energy :** When an electric bulb glows on passing an electric current through it, the electrical energy changes into heat and light energies.

(12) **Light energy to electrical energy :** In a photoelectric cell, light energy gets converted into electrical energy.

In a solar cell, light (or solar) energy changes into electrical energy.

(13) **Heat energy to mechanical energy :** In a steam engine, the heat energy of steam changes into the kinetic energy of piston.

(14) **Chemical energy to heat energy :** When fuel such as wood, coal, bio-gas, *etc.* burns, the chemical energy changes into heat energy. In a steam engine, the chemical energy of coal on burning changes into the heat energy of steam. In explosion of crackers, the chemical energy changes into heat, light and sound energies. In lighting a candle or match stick, the chemical energy changes into heat and light energies. In respiration, the chemical energy is converted into heat energy.

(15) **Chemical energy to mechanical energy :** In automobiles, while in motion, the

chemical energy of petrol (or diesel) changes into mechanical energy (or kinetic energy).

(16) **Electrical energy to magnetic energy :** While making an electromagnet, an electric current is passed in a coil wound around a soft iron bar which gets magnetised. Thus, electrical energy changes into magnetic energy.

(17) **Nuclear energy to electrical energy :** In a nuclear reactor, the energy released in the process of nuclear fission is nuclear energy which is converted into electrical energy.

(18) **Mechanical energy to heat energy :** When water falls from a height, the potential energy stored in water at that height changes into the kinetic energy of water during the fall. On striking the ground (or bottom), a part of the kinetic energy of water changes into heat energy due to which the temperature of water rises.

The moving parts of a machine get heated due to friction, thus a part of mechanical energy changes into heat energy.

Note : (1) Whenever mechanical energy changes to other forms, it is always in the form of kinetic energy and not in the form of potential energy i.e., the stored potential energy first changes to kinetic energy and then kinetic energy changes to other forms.

(2) Degraded energy : While transforming energy from one form to another desired form, the entire energy does not change into the desired form. A part of this energy changes either to some other undesirable form (usually heat due to friction) or a part is lost to the surroundings due to radiation and becomes useless. This conversion of energy to the undesirable (or non-useful) form is called dissipation of energy. Since this part of energy is not available to us for any productive purpose, so we call this part of energy as degraded form of energy.

Examples : (1) When a bulb is lighted using electrical energy, a major part of it is lost in the form of heat energy, only a small part converts into useful light energy.

(2) When a vehicle is run by using the chemical energy of its fuel, a major part is wasted in the form of heat and sound energies, only a part of the chemical energy changes into useful mechanical energy.

EXAMPLES

1. **A body of mass 5 kg is taken from a height 5 m to 10 m. Find the increase in its potential energy ($g = 10$ m s^{-2}).**

Given : $m = 5$ kg, $h_1 = 5$ m, $h_2 = 10$ m, $g = 10$ m s^{-2}

Increase in potential energy $= mg\,(h_2 - h_1)$

$= 5 \times 10 \times (10 - 5) = $ **250 J**

2. **A body of mass 1 kg falls from a height of 5 m. How much energy does it possess at any instant? (Take $g = 9{\cdot}8$ m s^{-2})**

Given : $m = 1$ kg, $h = 5$ m, $g = 9{\cdot}8$ m s^{-2}

The energy possessed by the body at any instant

= Initial potential energy of the body

$= mgh = 1 \times 9{\cdot}8 \times 5 = $ **49 J**

3. **500 litre of water is raised from the first floor of a house at height 4 m to its third floor at height 12 m. State whether the potential energy of water will decrease or increase.**

Find the decrease/increase in potential energy of water. Take : $g = 10$ N kg^{-1}, density of water $= 1$ kg $litre^{-1}$

Given, mass of water m = volume × density $= 500$ litre $\times 1$ kg $litre^{-1} = 500$ kg,

$h_1 = 4$ m, $h_2 = 12$ m, g $= 10$ N kg^{-1}.

Since height of water above the ground increases ($h_2 > h_1$), so the potential energy of water increases.

Increase in potential energy $= mg\,(h_2 - h_1)$

$= 500 \times 10 \times (12 - 4)$

$= \mathbf{4 \times 10^4\ J}$

4. A block of mass 30 kg is pulled up a slope as shown in Fig. 2.14 with a constant speed by applying a force of 200 N parallel to the slope from the initial position A to the final position B.

(a) Calculate :

(i) the work done by the force in moving the block from A to B, and

(ii) the potential energy gained by the block. Take : $g = 10\ m\ s^{-2}$

(b) Account for the difference in answers to parts (i) and (ii).

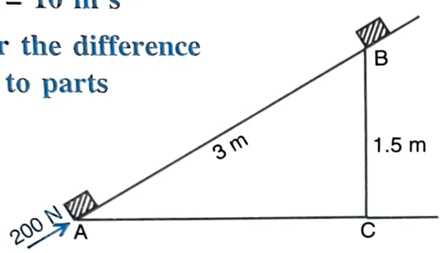

Fig. 2.14

(a) Given : $m = 30$ kg, $F = 200$ N, AB = 3 m and CB = 1·5 m.

(i) Work done by the force in moving the block from A to B

= Force × displacement in the direction of force.

or $W = F \times AB$

$= 200\ N \times 3\ m =$ **600 J**

(ii) The potential energy gained by the block $U = mgh$

where $h = CB = 1{\cdot}5$ m

$\therefore$ $U = 30 \times 10 \times 1{\cdot}5 =$ **450 J**

(b) Out of the work done 600 J, only 450 J is the useful work which raises the potential energy of the block and the remaining work = 600 J – 450 J = 150 J is spent against the force of friction between the block and the slope which gets converted into heat energy.

5. In a dam, water falls at a rate of 1000 kg s^{-1} from a height of 100 m.

(a) Calculate the initial potential energy of the water.

(b) Assuming that 60% of the energy of the falling water is converted to electrical energy, calculate the power generated. (Take $g = 9{\cdot}8\ m\ s^{-2}$).

Given : In one second 1000 kg of water falls.

i.e., $m = 1000$ kg, $t = 1$ s, $g = 9{\cdot}8\ m\ s^{-2}$, $h = 100$ m.

(a) Initial potential energy of water $= mgh$

$= 1000 \times 9{\cdot}8 \times 100 = \mathbf{9{\cdot}8 \times 10^5\ J}$

(b) Energy available from the falling water

= its initial potential energy $= mgh$

Energy converted to electrical energy

= 60% of the energy gained from the falling water

$= \frac{60}{100} \times mgh = 0{\cdot}6\, mgh$

$$\text{Power generated} = \frac{\text{Electrical energy}}{\text{Time}} = \frac{0{\cdot}6\,mgh}{t}$$

$$= \frac{0{\cdot}6 \times 1000 \times 9{\cdot}8 \times 100}{1}\ J\ s^{-1}$$

$$= \mathbf{5{\cdot}88 \times 10^5\ W}$$

6. A truck driver loads some oil drums into a truck by lifting them directly. Each drum has a mass of 80 kg and the platform of the truck is at a height of 0·8 m above the ground.

(a) What force is needed to lift a drum into the truck ?

(b) How much energy is used up in lifting a drum?

(c) After the truck is loaded, the driver drives off. List the major energy changes that take place in moving the truck.

(d) The driver stops the truck at the factory gate. What happens to the kinetic energy of the truck ?

Take $g = 10\ m\ s^{-2}$.

Given : $m = 80$ kg, $h = 0{\cdot}8$ m, $g = 10\ m\ s^{-2}$

(a) Force needed to lift a drum

= Force of gravity on drum

$= mg = 80 \times 10 =$ **800 N**

(b) Energy used up in lifting a drum

= gravitational potential energy mgh

$= 80 \times 10 \times 0{\cdot}8 =$ **640 J**

(c) In moving the truck, the chemical energy of the fuel (diesel) changes into mechanical (kinetic) energy.

(d) On stopping the truck, the kinetic energy of the truck changes into the heat and sound energies.

7. Calculate the kinetic energy of a body of mass 2 kg moving with a speed of 10 m s^{-1}.

Given : $m = 2$ kg, $v = 10\ m\ s^{-1}$

$$\text{Kinetic energy} = \frac{1}{2}mv^2 = \frac{1}{2} \times 2 \times (10)^2$$

$$= \mathbf{100\ J}$$

8. How fast should a man weighing 600 N run so that his kinetic energy is 750 J ? ($g = 10\ m\ s^{-2}$)

Given : $W = 600$ N, $g = 10\ m\ s^{-2}$,

kinetic energy = 750 J, v = ?

Since $W = mg$ $\therefore$ $600 = m \times 10$ or $m = 60$ kg

Kinetic energy $= \frac{1}{2}mv^2$

$$750 = \frac{1}{2} \times 60 \times v^2$$

$$\therefore \quad v^2 = \frac{2 \times 750}{60} = 25$$

or $\quad v = \sqrt{25} = $ **5 m s^{-1}**

9. How is the kinetic energy of a moving cart affected if (a) its mass is doubled, (b) its velocity is reduced to $\frac{1}{3}$rd of the initial velocity ?

(a) $K_1 = \frac{1}{2}mv^2$, $K_2 = \frac{1}{2} \times 2m \times v^2$

$\therefore \quad K_2 = 2K_1$

> **Alternative :** If mass m is doubled (keeping the speed same), the kinetic energy gets **doubled** (since kinetic energy is directly proportional to the mass).

i.e. Increase in kinetic energy $= K_2 - K_1 = 2K_1 - K_1$

$= K_1$ (initial kinetic energy)

(b) $K_1 = \frac{1}{2}mv^2$, $K_2 = \frac{1}{2}m \times (\frac{1}{3}v)^2 = \frac{1}{9} \times \frac{1}{2}mv^2$

$\therefore K_2 = \frac{1}{9}K_1$

> **Alternative :** If velocity v is reduced to $\frac{1}{3}$rd (keeping the mass same), the kinetic energy reduces to $\frac{1}{9}$th its initial value (since kinetic energy is directly proportional to the square of velocity).

i.e. Decrease in kinetic energy $= K_1 - K_2 = K_1 - \frac{1}{9}K_1$

$= \frac{8}{9}K_1$ (*i.e.* $\frac{8}{9}$th the initial kinetic energy)

10. A truck weighing 5×10^3 kgf and a cart weighing 500 kgf are moving with the same speed. Compare their kinetic energies.

Given, mass of truck $m_1 = 5 \times 10^3$ kg, mass of cart $m_2 = 500$ kg.

Since speeds are same, kinetic energy is directly proportional to the mass ($K \propto m$).

$$\therefore \quad \frac{K_1}{K_2} = \frac{m_1}{m_2} = \frac{5 \times 10^3}{500} = \frac{10}{1}$$

or $\quad K_1 : K_2 = $ **10 : 1**

11. For the same kinetic energy of a body, what should be the change in its velocity if its mass is increased four times ?

Let initial mass $m_1 = m$, velocity $= v_1$

Final mass $m_2 = 4m$, velocity $= v_2$

For the same kinetic energy,

$$\frac{1}{2}m_1v_1^2 = \frac{1}{2}m_2v_2^2$$

or $\quad \frac{1}{2}mv^2 = \frac{1}{2} \times 4m \times v_2^2$

or $\quad v_2^2 = \frac{1}{4}v^2 \quad$ or $\quad v_2 = \frac{1}{2}v$

Thus, velocity should be **halved.**

12. A bullet of mass 5 g travels with a speed of 500 m s^{-1}. If it penetrates a fixed target which offers a constant resistive force of 1000 N to the motion of the bullet , find : (a) the initial kinetic energy of the bullet, (b) the distance through which the bullet has penetrated before coming to rest, and (c) the speed with which the bullet emerges out of the target if target is of thickness 0·5 m.

Given : $m = 5$ g $= 5 \times 10^{-3}$ kg, $v = 500$ m s^{-1}, $F = 1000$ N

(a) Kinetic energy of the bullet $= \frac{1}{2}mv^2$

$= \frac{1}{2} \times (5 \times 10^{-3}) \times (500)^2 = $ **625 J**

(b) Let the bullet penetrate through a distance S m in the target.

Work done by the bullet against the material of the target $\quad$ = Resistive force × distance

$= 1000 \times S$ J

This work is obtained from the initial kinetic energy of the bullet.

$\therefore \quad 1000\,S = 625$

or $\quad S = 625/1000 = 0{\cdot}625$ m

Thus, the distance penetrated by the bullet = **0·625 m.**

(c) Energy spent against the resistive force offered by the target in penetrating through it

= Resistive force × thickness of target

= 1000 N × 0·5 m = 500 J

$\therefore$ Kinetic energy left with the bullet on emerging out of the target = 625 J – 500 J = 125 J

If the speed of bullet is now v', then kinetic energy

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

$\therefore \quad \frac{1}{2}mv'^2 = 125$ J or $\frac{1}{2} \times (5 \times 10^{-3})v'^2 = 125$

or $\quad v' = \sqrt{\frac{2 \times 125}{5 \times 10^{-3}}} = $ **223·6 m s^{-1}.**

13. Calculate the kinetic energy of a body of mass 0·1 kg and momentum 20 kg m s^{-1}.

Given : $p = 20$ kg m s^{-1}, $m = 0{\cdot}1$ kg

Kinetic energy $K = \frac{1}{2}mv^2$ and

momentum $\quad p = mv$ or $v = \frac{p}{m}$

Eliminating v,

$$K = \frac{1}{2} m \times \left(\frac{p}{m}\right)^2 = \frac{p^2}{2m}$$

$$\therefore \quad K = \frac{(20)^2}{2 \times 0.1} = 2000 \text{ J} = 2 \times 10^3 \text{ J}$$

14. A ball of mass 10 g falls from a height of 5 m. It rebounds from the ground to a height of 4 m. Find :

(a) the initial potential energy of the ball,

(b) the kinetic energy of the ball just before striking the ground,

(c) the kinetic energy of the ball after striking the ground, and

(d) the loss in kinetic energy on striking the ground.

Take $g = 9{\cdot}8$ m s^{-2}.

Given: $m = 10 \text{ g} = \frac{10}{1000} \text{ kg} = 0{\cdot}01$ kg,

$h = 5$ m, $g = 9{\cdot}8$ m s^{-2}, $h' = 4$ m.

(a) Initial potential energy of the ball $= mgh$

$= 0{\cdot}01 \times 9{\cdot}8 \times 5 =$ **$0{\cdot}49$ J**

(b) Kinetic energy of the ball just before striking the ground = Initial potential energy of the ball

$=$ **$0{\cdot}49$ J.**

(c) Kinetic energy of the ball after striking the ground = Potential energy of ball at the highest point after rebound.

$= mgh' = 0{\cdot}01 \times 9{\cdot}8 \times 4 =$ **$0{\cdot}392$ J**

(d) Loss in kinetic energy on striking the ground

= Initial kinetic energy – Final kinetic energy

$= 0{\cdot}49 \text{ J} - 0{\cdot}392 \text{ J} =$ **$0{\cdot}098$ J**

Note : This energy appears in the form of heat energy and sound energy when the ball strikes the ground.

14. A spring is kept compressed by a toy cart of mass 150 g. On releasing the cart, it moves with a speed of $0{\cdot}2$ m s^{-1}. Calculate the potential energy (elastic) of the spring.

Given : $m = 150 \text{ g} = 150 \times 10^{-3}$ kg, $v = 0{\cdot}2$ m s^{-1}

On releasing the cart, the spring tries to come back to its uncompressed state by pushing the cart away. Thus the potential energy stored in the spring changes into the kinetic energy of the cart.

Potential energy of spring U

= Kinetic energy gained by the cart

or $\quad U = \frac{1}{2} mv^2 = \frac{1}{2} \times (150 \times 10^{-3}) \times (0{\cdot}2)^2$

$=$ **3×10^{-3} J**

EXERCISE–2(B)

1. What are the *two* forms of mechanical energy ?
2. Name the form of energy which a wound up watch spring possesses. **Ans.** Elastic potential energy.
3. Name the type of energy (kinetic energy K or potential energy U) possessed in the following cases :
   (a) A moving cricket ball
   (b) A compressed spring
   (c) A moving bus
   (d) A stretched wire
   (e) An arrow shot out of a bow
   (f) A piece of stone placed on the roof.
   Ans. (a) K (b) U (c) K (d) U (e) K (f) U
4. Define the term potential energy of a body. Name its *two* forms and give *one* example of each.
5. Name the form of energy which a body may possess even when it is not in motion. Give an example to support your answer.
6. What is meant by gravitational potential energy ? Derive an expression for it for a body placed at a height above the ground.
7. Write an expression for the potential energy of a body of mass m placed at a height h above the earth's surface. State the assumptions made, if any.
8. What do you understand by the kinetic energy of a body ?
9. (a) A body of mass m is moving with a velocity v. Write the expression for its kinetic energy.
   (b) Show that the quantity $2K/v^2$ has the unit of mass, where K is the kinetic energy of the body.
10. State the work-energy theorem.
11. A body of mass m is moving with a uniform velocity u. A force is applied on the body due to which its velocity increases from u to v. How much work is being done by the force ? **Ans.** $\frac{1}{2} m (v^2 - u^2)$
12. A light mass and a heavy mass have equal momentum. Which will have more kinetic energy ? [**Hint :** kinetic energy $K = p^2/2m$ where p is the momentum] **Ans.** Lighter mass

13. Two bodies A and B of masses m and M (M >> m) have same kinetic energy. Which body will have more momentum ? **Ans.** Body B

14. Name the *three* forms of kinetic energy and give *one* example of each.

15. State *two* differences between potential energy and kinetic energy.

16. Complete the following sentences :
   (a) The kinetic energy of a body is the energy by virtue of its ....
   (b) The potential energy of a body is the energy by virtue of its ....
   Ans. (a) motion (b) position

17. When an arrow is shot from a bow, it has kinetic energy in it. Explain briefly from where does it get its kinetic energy.

18. A ball is placed on a compressed spring. What form of energy does the spring possess ? On releasing the spring, the ball flies away. Give a reason.

19. A pebble is thrown up. It goes to a height and then comes back on the ground. State the different changes in form of energy during its motion.

20. In what way does the temperature of water at the bottom of a waterfall differ from the temperature at the top ? Explain the reason.

21. Name the form of energy in which potential energy can change. **Ans.** Kinetic energy

22. Name the form of mechanical energy, which is put to use. **Ans.** Kinetic energy

23. Name *six* different forms of energy.

24. Energy can exist in several forms and may change from one form to another. For each of the following, state the energy changes that occur in :
   (a) the unwinding of a watch spring,
   (b) a loaded truck when started and set in motion,
   (c) a car going uphill,
   (d) photosynthesis in green leaves,
   (e) charging of a battery,
   (f) respiration,
   (g) burning of a match stick,
   (h) explosion of crackers.

25. State the energy changes in the following cases while in use :
   (a) loudspeaker (b) a steam engine
   (c) microphone (d) washing machine
   (e) a glowing electric bulb (f) burning coal
   (g) a solar cell (h) bio-gas burner
   (i) an electric cell in a circuit
   (j) a petrol engine of a running car
   (k) an electric iron (l) a ceiling fan
   (m) an electromagnet.

26. Name the process used for producing electricity from nuclear energy.

27. Is it practically possible to convert a form of energy completely into another useful form ? Explain your answer.

28. What is degraded energy ?

29. What do you mean by degradation of energy ? Explain it by taking *one* example from your daily life.

30. Complete the following sentence :
   The conversion of part of energy into an undesirable form is called ....
   Ans. Degradation of energy

MULTIPLE CHOICE TYPE

1. A body at a height possesses :
   (a) kinetic energy (b) potential energy
   (c) solar energy (b) heat energy.
   Ans. (b) potential energy

2. In an electric cell while in use, the change in energy is from :
   (a) electrical to mechanical
   (b) electrical to chemical
   (c) chemical to mechanical
   (d) chemical to electrical.
   Ans. (d) chemical to electrical

NUMERICALS

1. Two bodies of equal masses are placed at heights h and $2h$. Find the ratio of their gravitational potential energies. **Ans.** 1 : 2

2. Find the gravitational potential energy of 1 kg mass kept at a height of 5 m above the ground. Calculate its kinetic energy when it falls and hits the ground. Take $g = 10$ m s^{-2}. **Ans.** 50 J, 50 J

3. A box of weight 150 kgf has gravitational potential energy stored in it equal to 14700 J. Find the height of the box above the ground.
   (Take $g = 9{\cdot}8$ N kg^{-1}). **Ans.** 10 m

4. A body of mass 5 kg falls from a height of 10 m to 4 m. Calculate : (i) the loss in potential energy of the body, and (ii) the total energy possessed by the body at any instant ? (Take $g = 10$ m s^{-2}).
   Ans. (i) 300 J, (ii) 500 J

5. Calculate the height through which a body of mass 0·5 kg is lifted if the energy spent in doing so is 1·0 J. Take $g = 10$ m s^{-2}. **Ans.** 0·2 m

6. A boy weighing 25 kgf climbs up from the first floor at a height of 3 m above the ground to the third floor at a height of 9 m above the ground. What will be the increase in his gravitational potential energy ?

(Take $g = 10$ N kg^{-1}). **Ans.** 1500 J

7. A vessel containing 50 kg of water is placed at a height of 15 m above the ground. Assuming the gravitational potential energy at ground to be zero, what will be the gravitational potential energy of water in the vessel ? ($g = 10$ m s^{-2}) **Ans.** 7500 J

8. A man of mass 50 kg climbs up a ladder of height 10 m. Calculate : (i) the work done by the man, and (ii) the increase in his potential energy.

($g = 9·8$ m s^{-2}). **Ans.** (i) 4900 J, (ii) 4900 J

9. A block A, weighing 100 N, is pulled up a slope of length 5 m by means of a constant force F (= 100 N) as illustrated in Fig. 2.15.

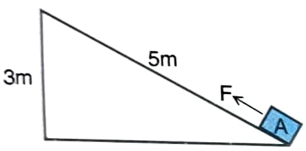

Fig. 2.15

(a) What is the work done by the force F in moving the block A, 5 m along the slope ?

(b) What is the increase in potential energy of the block A ?

(c) Account for the difference in the work done by the force and the increase in potential energy of the block.

Ans. (a) 500 J (b) 300 J (c) The difference *i.e.*, 200 J energy is used in doing work against the force of friction between the block and the slope which will appear as heat energy.

10. Find the kinetic energy of a body of mass 1 kg moving with a uniform velocity of 10 m s^{-1}.

Ans. 50 J.

11. If the speed of a car is halved, how does its kinetic energy change ? **Ans.** It becomes one-fourth

12. Two bodies of equal masses are moving with uniform velocities v and $2v$. Find the ratio of their kinetic energies. **Ans.** 1 : 4

13. Two bodies have masses in the ratio 5 : 1 and kinetic energies in the ratio 125 : 9. Calculate the ratio of their velocities. **Ans.** 5 : 3

14. A car is running at a speed of 15 km h^{-1} while another similar car is moving at a speed of 45 km h^{-1}. Find the ratio of their kinetic energies. **Ans.** 1 : 9

15. A ball of mass 0·5 kg slows down from a speed of 5 m s^{-1} to that of 3 m s^{-1}. Calculate the change in the kinetic energy of the ball. **Ans.** 4 J (decrease)

16. A cannon ball of mass 500 g is fired with a speed of 15 m s^{-1}. Find : (i) its kinetic energy, and (ii) its momentum. **Ans.** (i) 56·25 J, (ii) 7·5 kg m s^{-1}

17. A body of mass 10 kg is moving with a velocity of 20 m s^{-1}. If the mass of the body is doubled and its velocity is halved, find : (i) the initial kinetic energy, and (ii) the final kinetic energy.

Ans. (i) 2000 J (ii) 1000 J

18. A truck weighing 1000 kgf changes its speed from 36 km h^{-1} to 72 km h^{-1} in 2 minutes. Calculate : (i) the work done by the engine, and (ii) its power. ($g = 10$ m s^{-2}).

Ans. (i) $1·5 \times 10^5$ J, (ii) $1·25 \times 10^3$ W

19. A body of mass 60 kg has momentum of 3000 kg m s^{-1}. Calculate : (i) the kinetic energy, and (ii) the speed of the body.

Ans. (i) $7·5 \times 10^4$ J, (ii) 50 m s^{-1}.

20. How much work is needed to be done on a ball of mass 50 g to give it a momentum of 5 kg m s^{-1} ?

Ans. 250 J

21. How much energy is gained by a box of mass 20 kg when a man

(a) carrying the box waits for 5 minutes for a bus?

(b) runs carrying the box with a speed of 3 m s^{-1} to catch the bus ?

(c) raises the box by 0·5 m in order to place it inside the bus ? ($g = 10$ m s^{-2})

Ans. (a) Zero (b) 90 J (c) 100 J

22. A bullet of mass 50 g is moving with a velocity of 500 m s^{-1}. It penetrates 10 cm into a still target and comes to rest. Calculate : (a) the kinetic energy possessed by the bullet, and (b) the average retarding force offered by the target.

Ans. (a) 6250 J (b) 62500 N

23. A spring is kept compressed by a small trolley of mass 0·5 kg lying on a smooth horizontal surface as shown in the adjacent Fig. 2.16. When the trolley is released, it is found to move at a speed $v = 2$ m s^{-1}. What potential energy did the spring possess when compressed ?

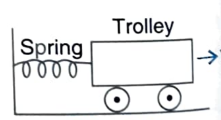

Fig. 2.16

Ans. 1·0 J

(C) CONSERVATION OF ENERGY

2.16 PRINCIPLE OF CONSERVATION OF ENERGY

The principle of conservation of energy is one of the fundamental principles of nature.

> *According to the principle of conservation of energy, energy can neither be created nor can it be destroyed. It only changes from one form to another.*

In the universe, energy occurs in various forms. The sum of all forms of energy in the universe remains constant. When there is a transformation of energy from one form to another, the total energy always remains the same *i.e.*, it remains conserved.

If there is only an interchange between potential energy and kinetic energy, the total mechanical energy (i.e., the sum of kinetic energy K and potential energy U) remains constant i.e., K + U = constant in the absence of all kinds of frictional forces.

2.17 THEORETICAL VERIFICATION OF K + U = CONSTANT FOR A FREELY FALLING BODY

Let a body of mass m be falling freely under gravity from a height h above the ground (*i.e.*, from position A in Fig. 2.17). As the body falls down, its potential energy changes into kinetic energy. At each point of motion, the sum of potential energy and kinetic energy remains unchanged. To verify it, let us calculate the sum of kinetic energy K and potential energy U at various positions, say at A (at height h above the ground), at B (when it has fallen through a distance x), and at C (on the ground).

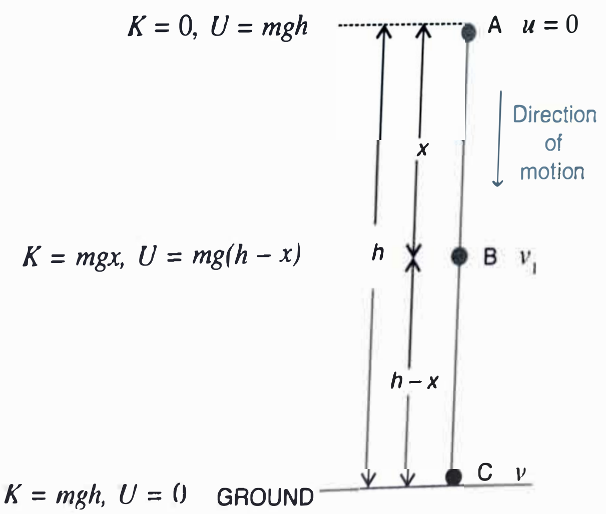

Fig. 2.17 Free fall of a body

At position A (at height h above the ground) :

Initial velocity of body $= 0$ (since body is at rest at A)

$\therefore$ Kinetic energy $K = 0$

Potential energy $U = mgh$

Hence, total energy $= K + U = 0 + mgh = mgh$ ....(i)

At position B (when it has fallen through a distance x) :

Let v_1 be the velocity acquired by the body at B after falling through a distance x. Then $u = 0$, $S = x$, $a = g$

From equation $v^2 = u^2 + 2aS$

$$v_1^2 = 0 + 2gx = 2gx$$

$\therefore$ Kinetic energy $K = \frac{1}{2}mv_1^2$

$$= \frac{1}{2}m \times (2gx) = mgx$$

Now at B, height of body above the ground $= h - x$

$\therefore$ Potential energy $U = mg\,(h - x)$

Hence, total energy $= K + U$

$$= mgx + mg(h - x) = mgh \quad .....(ii)$$

At position C (on the ground) :

Let the velocity acquired by the body on reaching the ground be v. Then $u = 0$, $S = h$, $a = g$

From equation $v^2 = u^2 + 2aS$

$$v^2 = 0 + 2gh$$

or $v^2 = 2gh$

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

$$= \frac{1}{2}m \times (2gh) = mgh$$

and potential energy $U = 0$ (at the ground when $h = 0$)

Hence total energy $= K + U = mgh + 0 = mgh$ ..(iii)

Thus, from eqns. (i), (ii) and (iii), we note that the total mechanical energy (*i.e.*, the sum of kinetic energy and potential energy) always remains constant at each point of motion and is equal to the initial potential energy at height h. As the body falls, its potential energy decreases and kinetic energy increases by the same amount. The potential energy changes into kinetic energy. Just at the instant when it strikes the ground, whole of the potential energy has changed into kinetic energy, therefore the kinetic energy of the body on reaching the ground is equal to the initial potential energy at height h.

Similarly, when a body is thrown vertically upwards under gravity, its initial kinetic energy supplied at the instant of throwing up, keeps on decreasing and the potential energy keeps on increasing *by the same amount*. When the body reaches the highest point, whole of its initial kinetic energy has changed into potential energy and therefore, the body momentarily comes to rest. At this instant, the body is still under the influence of the force of gravity, so the body starts falling down and its potential energy begins to change into kinetic energy.

Note *: The initial kinetic energy provided to the body at the ground, so as to reach a certain height h, must be equal to the potential energy of the body at that height h (i.e., equal to mgh).* Thus, the initial velocity u to be imparted to the body so as to reach a height h is given as :

$$\frac{1}{2}mu^2 = mgh \text{ or } u = \sqrt{2gh} \qquad \text{....(2.18)}$$

Fig. 2.18 represents the variation in kinetic energy and potential energy with the height above the ground.

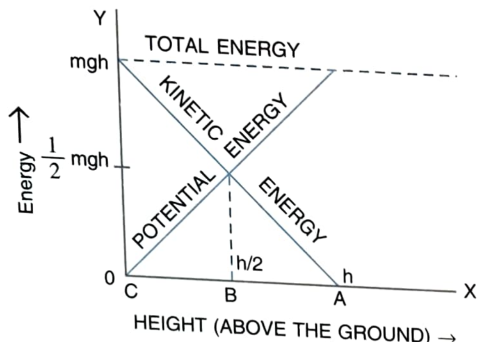

Fig. 2.18 Conservation of mechanical energy in motion under gravity

The table below represents kinetic energy K, potential energy U and total energy E of a body of mass m at various heights above the ground during vertically downward and upward motions under gravity.

Table showing kinetic energy and potential energy of a body in vertical motion.

Motion	**Height above the ground**	**Kinetic energy K**	**Potential energy U**	**Total energy $E = K + U$**
Downward motion (*i.e.*, free fall)	h (*i.e.*, highest point A)	0	mgh	mgh
	$\frac{1}{2}h$ (*i.e.*, middle point B)	$\frac{1}{2}mgh$	$\frac{1}{2}mgh$	mgh
	0 (*i.e.*, ground C)	mgh	0	mgh
Upward motion	0 (*i.e.*, ground C)	mgh	0	mgh
	$\frac{1}{2}h$ (*i.e.*, middle point B)	$\frac{1}{2}mgh$	$\frac{1}{2}mgh$	mgh
	h (*i.e.*, highest point A)	0	mgh	mgh

In upward motion, it is clear that at the ground (*i.e.*, at point C) $h = 0$, potential energy = 0, kinetic energy = mgh. At the middle point B, $x = \frac{1}{2}h$, potential energy = $\frac{1}{2}mgh$, kinetic energy = $\frac{1}{2}mgh$. At the highest point A (*i.e.*, at height h), potential energy = mgh and kinetic energy = 0 (zero).

Note : In the above calculations, we have ignored the force of friction between the body and air. In fact during the fall, some of the kinetic energy will change into heat energy due to friction and it will get dissipated in air. At the ground C, kinetic energy will be less than *mgh*. The conservation of mechanical energy is therefore strictly valid only in the absence of external forces such as friction due to air etc., although the total sum of energy of all kinds is always the same or conserved.

2.17 APPLICATION OF PRINCIPLE OF CONSERVATION OF ENERGY TO A SIMPLE PENDULUM

Fig. 2.19 shows a simple pendulum suspended from a rigid support O. Its resting position is at A. When it is displaced to one side and then released, it swings from one side to the other, reaching equal distance and equal height on either side. Neglecting the force of friction between the bob and the surrounding air, the motion of pendulum is explained below by applying the principle of conservation of energy.

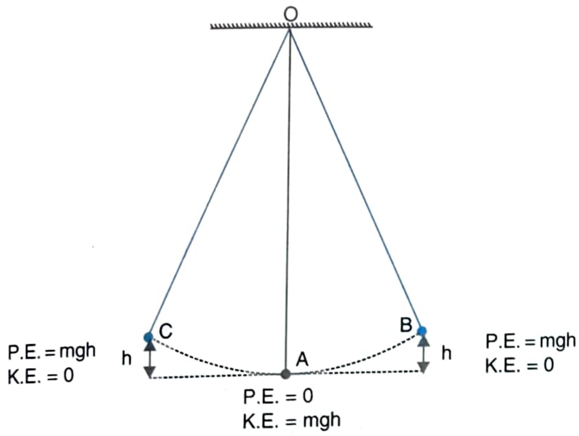

Fig. 2.19 Motion of a simple pendulum

Explanation : Let A be the resting (or mean) position of the bob when it has zero potential energy*. When the bob of the pendulum is displaced to B from its resting position A, the bob gets raised by a vertical height h, so its potential energy increases by mgh if m is the mass of the bob. Now on releasing the bob at B, it moves back from B to A. Its vertical height decreases from h to zero, so its potential energy decreases from mgh to zero and it gets converted into kinetic energy *i.e.*, $\frac{1}{2}mv^2 = mgh$. Therefore, at the point A, the bob acquires a velocity $v = \sqrt{2gh}$, so it moves towards C. At the point C, when the bob gets raised by a vertical height h above the point A, again it acquires potential energy mgh and its kinetic energy becomes zero. So the bob momentarily comes to rest at the point C. But due to the force of gravity, the bob moves back from C to A.

As the bob swings back from C to A, its potential energy decreases and kinetic energy increases. At A (mean position), it has its total mechanical energy in the form of kinetic energy and potential energy is zero, so the bob swings again from A to B to repeat the process.

Thus, during the swing, at the extreme positions B and C, the bob has only potential energy, while at the mean position A, it has only kinetic energy. At an intermediate position (between A and B or between A and C), the bob has both kinetic energy and potential energy, and the sum of both (*i.e.*, the total mechanical energy) remains constant throughout the swing. This is strictly true only in vacuum where there is no force of friction due to air.

* In fact, at the mean position, the bob has the minimum potential energy. Since we are interested only in the change in potential energy as the bob swings, so we may assume it to be zero at the mean position.

EXAMPLES

1. A ball of mass 50 g is thrown vertically upwards with an initial velocity of 20 m s^{-1}. Calculate :
(i) the initial kinetic energy imparted to the ball,
(ii) the maximum height reached if air friction is neglected, and
(iii) the maximum height reached if 40% of the initial energy is lost against the air friction.

Take g = 10 m s^{-2}.

Given : $m = 50 \text{ g} = \frac{50}{1000} \text{ kg} = 0{\cdot}05 \text{ kg}$,

$u = 20 \text{ m s}^{-1}$, $g = 10 \text{ m s}^{-2}$.

(i) Initial kinetic energy imparted to the ball

$$= \frac{1}{2}mu^2 = \frac{1}{2} \times 0{\cdot}05 \times (20)^2 = \mathbf{10\ J}$$

(ii) If air friction is negligible, then

Potential energy at the maximum height

= initial kinetic energy

or $mgh = \frac{1}{2}mv^2$

$\therefore$ $h = \frac{v^2}{2g} = \frac{(20)^2}{2\times10} = \mathbf{20\ m}$

(iii) If 40% of the initial energy is lost against the air friction, then

Potential energy at the maximum height

= 60% of the initial kinetic energy

$= \frac{60}{100} \times$ initial kinetic energy

or $mgh = \frac{60}{100} \times \frac{1}{2}mv^2$

$\therefore$ $h = \frac{0.6\,v^2}{2g} = \frac{0.6\times(20)^2}{2\times10} = \mathbf{12\ m}$

2. A ball of mass 20 g falls from a height of 10 m and after striking the ground, it rebounds from the ground to a height of 8 m.

(a) Calculate :

(i) the kinetic energy of the ball just before striking the ground, and

(ii) the loss in kinetic energy of the ball on striking the ground.

(b) What happens to the loss in kinetic energy in part (ii)?

Take g = 10 m s^{-2}. Neglect air friction.

(a) Given, m = 20 g = 0·02 kg, h = 10 m, g = 10 m s^{-2}, h' = 8 m. Air friction is negligible.

(i) The kinetic energy of ball just before striking the ground = initial potential energy of ball

$= mgh = 0{\cdot}02 \times 10 \times 10 = \mathbf{2\ J}$

(ii) The kinetic energy of the ball just after striking the ground

= potential energy of the ball at the highest point after rebound

$= mgh' = 0{\cdot}02 \times 10 \times 8 = \mathbf{1{\cdot}6\ J}$

$\therefore$ Loss in kinetic energy on striking the ground

= kinetic energy of the ball just before striking the ground – kinetic energy of the ball just after striking the ground

= 2 J – 1·6 J = **0·4 J**

(b) The loss in kinetic energy in part (ii) appears in the form of heat and sound energies when the ball strikes the ground.

3. A simple pendulum, while oscillating, rises to a maximum vertical height of 5 cm from its rest position when it reaches to its extreme position on one side. If mass of the bob of the simple pendulum is 500 g and g = 10 m s^{-2}, find :

(i) the total energy of simple pendulum at any instant while oscillating, and

(ii) the velocity of bob at its mean position. State the assumption made in your calculation.

Given, h = 5 cm = 0·05 m, m = 500 g = 0·5 kg, g = 10 m s^{-2}.

Assumption : There is no loss of energy due to air friction.

(i) Total energy of simple pendulum

= potential energy at its extreme position

$= mgh = 0{\cdot}5 \times 10 \times 0{\cdot}05 = \mathbf{0{\cdot}25\ J}$

(ii) Kinetic energy at the mean position

= potential energy at the extreme position

i.e., $\frac{1}{2}mv^2 = mgh$

or $v = \sqrt{2gh} = \sqrt{2\times10\times0{\cdot}05} = \sqrt{1}$

$= \mathbf{1\ m\ s^{-1}}$

EXERCISE–2(C)

1. State the principle of conservation of energy.
2. What do you understand by the conservation of mechanical energy ? State the condition under which mechanical energy is conserved.
3. Name *two* examples in which the mechanical energy of a system remains constant.
4. A body is thrown vertically upwards. Its velocity keeps on decreasing. What happens to its kinetic energy as its velocity becomes zero ?

   Ans. Kinetic energy changes to potential energy.
5. A body falls freely under gravity from rest. Name the kind of energy it will possess

   (a) at the point from where it falls,

   (b) while falling,

   (c) on reaching the ground.

   Ans. (a) Potential energy, (b) Potential energy and kinetic energy (c) Kinetic energy
6. Show that the sum of kinetic energy and potential energy (*i.e.*, total mechanical energy) is always conserved in the case of a freely falling body under

gravity (with air resistance neglected) from a height h by finding it when (i) the body is at the top, (ii) the body has fallen a distance x, (iii) the body has reached the ground.

7. A pendulum is oscillating on either side of its rest position. Explain the energy changes that take place in the oscillating pendulum. How does mechanical energy remain constant in it ? Draw the necessary diagram.

8. A pendulum with bob of mass m is oscillating on either side from its resting position A between the extremes B and C at a vertical height h above A. What is the kinetic energy K and potential energy U when the pendulum is at positions (i) A, (ii) B, and (iii) C ?
Ans. (i) $K = mgh$, $U = 0$ (ii) $K = 0$, $U = mgh$ (iii) $K = 0$, $U = mgh$

9. Name the type of energy possessed by the bob of a simple pendulum when it is at (a) the extreme position, (b) the mean position, and (c) between the mean and extreme positions.
Ans. (a) potential energy, (b) kinetic energy (c) both kinetic and potential energy

MULTIPLE CHOICE TYPE

1. A ball of mass m is thrown vertically up with an initial velocity so as to reach a height h. The correct statement is :
(a) Potential energy of the ball at the ground is mgh.
(b) Kinetic energy of the ball at the ground is zero.
(c) Kinetic energy of the ball at the highest point is mgh.
(d) Potential energy of the ball at the highest point is mgh.
Ans. (d) Potential energy of the ball at the highest point is mgh.

2. A pendulum is oscillating on either side of its rest position . The correct statement is :
(a) It has only the kinetic energy at its each position.
(b) It has the maximum kinetic energy at its extreme position.
(c) It has the maximum potential energy at its mean position.
(d) The sum of its kinetic and potential energies remains constant throughout the motion.
Ans. (d) The sum of its kinetic and potential energies remains constant throughout the motion.

NUMERICALS

1. A ball of mass 0·20 kg is thrown vertically upwards with an initial velocity of 20 m s^{-1}. Calculate the maximum potential energy it gains as it goes up.
Ans. 40 J

2. A stone of mass 500 g is thrown vertically upwards with a velocity of 15 m s^{-1}. Calculate : (a) the potential energy at the greatest height, (b) the kinetic energy on reaching the ground, and (c) the total energy at its half way point.
Ans. (a) 56·25 J (b) 56·25 J (c) 56·25 J

3. A metal ball of mass 2 kg is allowed to fall freely from rest from a height of 5 m above the ground.
(a) Taking $g = 10$ m s^{-2}, calculate :
(i) the potential energy possessed by the ball when it is initially at rest.
(ii) the kinetic energy of the ball just before it hits the ground ?
(b) What happens to the mechanical energy after the ball hits the ground and comes to rest ?
Ans. (a) (i) 100 J (ii) 100 J (b) Mechanical energy converts into heat and sound energy.

4. The diagram given below shows a ski jump. A skier weighing 60 kgf stands at A at the top of ski jump. He moves from A and takes off for his jump at B.

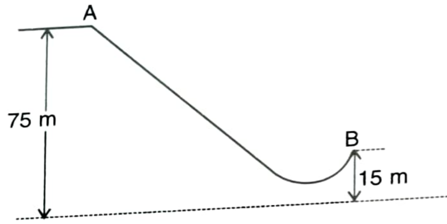

Fig. 2.20

(a) Calculate the change in the gravitational potential energy of the skier between A and B.
(b) If 75% of the energy in part (a) becomes kinetic energy at B, calculate the speed at which the skier arrives at B.
(Take $g = 10$ m s^{-2})
Ans. (a) $3·6 \times 10^4$ J (b) 30 m s^{-1}

5. A hydroelectric power station takes its water from a lake whose water level is at a height of 50 m above the turbine. Assuming an overall efficiency of 40%, calculate the mass of water which must flow through the turbine each second to produce power output of 1 MW. (Take $g = 10$ m s^{-2}).
Ans. 5000 kg

6. The bob of a simple pendulum is imparted a velocity of 5 m s^{-1} when it is at its mean position. To what maximum vertical height will it rise on reaching at its extreme position if 60% of its energy is lost in overcoming the friction of air ?
(Take $g = 10$ m s^{-2}). **Ans.** 0·5 m