CHAPTER

2

Work, Power and Energy

Chapter Objectives

- Work
- Power: Rate of Doing Work
- Energy
- Mechanical Energy
- Potential Energy
- Transformation of Energy
- Principle of Conservation of Energy

In our daily life, we generally use the terms work, energy and power. Work is done by a force, when the force produces a displacement in the body on which it acts, in any direction other than the direction perpendicular to the applied force.

Work and energy both are equivalent to each other. In physics, energy is the **capacity** to do work. The power is the rate of work done, the machine or men who does more work in lesser time has more power. The aim of this chapter is to understand the concepts of these three physical quantities, i.e., **work**, **power** and **energy.**

Work

Work is said to be done, if on applying a force on an object, it is displaced from its position in direction of force.

After spending lot of time in studies, reading books, drawing diagrams, attending classes, performing experiments, you may get completely exhausted, but have not done any work in terms of science as there is no displacement.

Scientific Conception of Work

From the point of view of science, following two conditions need to be satisfied for work to be done

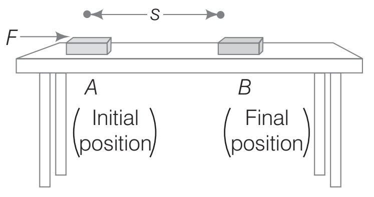
(i) a force should act on an object (ii) the object must be displaced.

If any one of the above conditions does not exist, work is not said to be done.

e.g., A girl pulls a trolley and the trolley moves through a distance. In this way, she has exerted a force on the trolley and as a result it is displaced. Hence, work is said to be done.

Work Done by a Constant Force

"Work done by a force on an object is equal to the magnitude of the force multiplied by the displacement moved in the any direction of applied force."



Work done by a force when the body moves in the direction of force

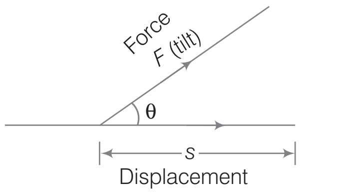
Let us assume, if a constant force F acts on an object at point A (shown in the figure), due to which the object gets displaced through a distance s in the direction of the force and reach at point B, then the work done (W) by force (F) on that object will be equal to the product of the force and displacement.

$\therefore$ Work done = force × displacement in the direction of force

or $$\boxed{W = F \times s} \quad \text{...(i)}$$

When force F on an object acts in such a direction that it makes an angle θ with the direction of displacement s, then the work done by the force is

$$\boxed{W = Fs\cos\theta}$$



Angle subtended between the direction of force and the direction of displacement

SI Unit of Work

In Eq. (i), if $F = 1$ N and $s = 1$ m, then the work done by the force will be 1 N-m.

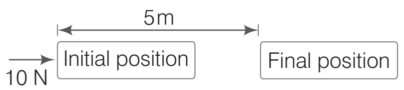
The SI unit of work is **newton-metre** (N-m) or **joule** (J).

Thus, **1 J is the amount of work done on an object when a force of 1 N displaces it by 1 m along the line of action of the force.**

$$\boxed{1 \text{ joule} = 1 \text{ newton} \times 1 \text{ metre} \Rightarrow 1\text{ J} = 1\text{N-m}}$$

Work is a scalar quantity, it has only magnitude and no direction.

Example 1. **A force of 10 N is acting on an object. The object is displaced through 5 m in the direction of force. What is the work done in this case?**



Sol. Given, force, $F = 10$N, displacement, $s = 5$m

$\therefore$ Work done, $W = F \times s = 10 \text{ N} \times 5\text{m} = 50$ N-m or 50J

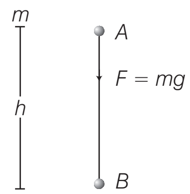
Positive, Negative and Zero Work

When the force F and displacement s are in the same directions (i.e., angle between direction of force and displacement is 0°), work done is said to be **positive**.

e.g., A boy pulls an object towards himself. Here, the direction of force and direction of displacement are same.

$$\boxed{W = +F \times s}$$

Similarly, in free fall of a body of mass m under gravity through a height h from A to B, then the force of gravity ($F = mg$) is in the direction of displacement ($s = h$), then the work done by the force of gravity is $W = Fs = mgh$.



When the force F and displacement s are in opposite directions (i.e., angle between direction of force and displacement is 180°), work done is said to be **negative**.

e.g., Frictional force acts in the direction opposite to the direction of displacement, so work done by friction will be negative.

$$\boxed{W = -F \times s}$$

When the force and displacement are in perpendicular directions (i.e., angle between direction of force and displacement is 90°), work done is said to be **zero.**

e.g., A coolie carrying load on his head. In this case, force is acting vertically downward (i.e., weight of load) and displacement is along horizontal direction, i.e., force and displacement are perpendicular to each other.

$$\boxed{W = 0}$$

Absolute Units of Work

Work done is said to be one absolute unit if an absolute unit of force displaces a body through a unit distance in the direction of the force.

(i) **Joule** It is an absolute unit of work in SI system, named after British physicist James Prescott Joule (1811-1869).

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

From work done (W) = $Fs\cos\theta$,

$$1\text{ J} = 1\text{ N} \times 1\text{ m} \times \cos 0° = 1\text{ N-m}$$

(ii) **Erg** It is an absolute unit of work in CGS system. One erg of work is said to be done if a force of one dyne displaces a body through a distance of one centimetre in its own direction.

From work done (W) = $Fs\cos\theta$

$$1\text{ erg} = 1\text{ dyne} \times 1\text{ cm} \times \cos 0° = 1\text{ dyne-cm}$$

Relation between Joule and Erg

$$1\text{ J} = 1\text{ N} \times 1\text{ m}$$
$$= 10^5\text{dyne} \times 10^2\text{ cm}$$
$$= 10^7\text{ dyne-cm}$$
$$1\text{ J} = 10^7\text{ erg}$$

Gravitational Units of Work

Work done is said to be one gravitational unit if a gravitational unit of force displaces a body through a unit distance in the direction of the force.

(i) **Kilogram-metre** (kg-m) It is the gravitational unit of work in SI system. One kilogram-metre of work is said to be done when a force of a one kilogram weight displaces a body through a distance of one metre in its own direction.

We know, work done $(W) = Fs\cos\theta$

$1\text{ kg-m} = 1\text{ kgf} \times 1\text{ m} \times \cos 0° = 9.8\text{ N} \times 1\text{m} \times 1 = 9.8\text{ J}$

i.e., 1 kg-m = 9.8 J

(ii) **Gram-centimetre** (g-cm) It is the gravitational unit of work in CGS system. One gram-centimetre of work is said to be done when a force of one gram weight displaces a body through one centimetre in its own direction.

$\therefore \quad 1\text{ g-cm} = 1\text{ g-wt} \times 1\text{cm} = 980\text{ dyne} \times 1\text{ cm}$

or $\quad 1\text{ g-cm} = 980\text{ erg}$

Larger Units of Work

There are some larger units of work, which are very important to be remembered.

They are as follows

1 kilojoule (kJ) $= 10^3$ J ; 1 Megajoule (MJ) $= 10^6$ J ;

1 Gigajoule (GJ) $= 10^9$ J

Example 1. A lawn roller has been pushed by a gardener through a distance of 30 m. What will be the work done by him if he applies a force of 30 kg-wt in the direction inclined at 60° to the ground? (Take, $g = 10\text{ m/s}^2$).

Sol. Displacement, $s = 30$ m

Force, $F = 30\text{ kg-wt} = 30 \times 10 = 300\text{ N}$

$\theta = 60°$

The work done by the gardener,

$$W = \mathbf{F} \cdot \mathbf{s} = Fs\cos\theta = 300 \times 30 \times \cos 60° = 300 \times 30 \times \frac{1}{2}$$

$$= 4500\text{ J} \qquad \left(\because \cos 60° = \frac{1}{2}\right)$$

Example 2. A person is holding a bag by applying a force of 15 N. He moves forward and covers the horizontal distance of 8 m and then he climbs up and covers the vertical distance of 10 m. What will be the work done by him?

Sol. The net work done by the person is the sum of work done to cover the horizontal distance and the work done to climb up in the vertical distance.

$F = 15\text{ N}, s_1 = 8\text{ m and } s_2 = 10\text{ m}$

As person is walking horizontally, therefore the angle between the bag and distance covered is 90°.

Thus, $\theta = 90°$

The work done, $W_1 = Fs_1\cos\theta = 15 \times 8\cos 90° = 0$ J

Now, the person climbs up and covers the distance of 10 m vertically. Therefore, the angle between the bag and the vertical plane is 0°.

Thus, $\theta = 0°$

The work done, $W_2 = Fs_2\cos\theta = 15 \times 10 \times \cos 0° = 150$ J

The net work done by him, $W = W_1 + W_2 = 0 + 150 = 150$ J

Example 3. A cyclist comes to a skidding stop in 10 m. During this process, the force on the cycle due to the road is 200 N and is directly opposed to the motion.

(i) How much work does the road do on the cycle?

(ii) How much work does the cycle do on the road?

Sol. (i) The stopping force and the displacement make an angle of 180° with each other. Thus, work done by the road or the work done by the stopping force is

$$W_r = Fs\cos\theta = 200 \times 10 \times \cos 180° = -2000\text{ J}$$

It is thus negative work that brings the cycle to a halt.

(ii) According to Newton's third law, an equal and opposite force acts on the road due to the cycle. Its magnitude is 200 N. However, the road undergoes no displacement. So, work done by the cycle on the road is zero.

CHECK POINT 01

1 State whether the work done by an applied force on a body moving on through horizontal plane with uniform velocity is positive or negative.

2 What should be the angle between force and displacement to get the work (i) maximum (ii) minimum?

3 A coolie carrying a load on his head and moving on a frictionless horizontal platform does no work. Explain the reason, why?

4 A person continues to push a rock for sometimes but fails to move it. What is the work done by it?

5 What is the work done when you apply a 10 N force on a wall? ***Ans.*** zero

6 If a 5 kg mass is raised to a height of 2 m, calculate the work done against the force of gravity. (Take, $g = 9.8\text{ ms}^{-2}$) ***Ans.*** 98 J

Power: Rate of Doing Work

The rate of doing work or the rate at which energy is transferred or used or transformed to other form is called **power.**

If work W is done in time t, then

$$\text{Power, } P = \frac{\text{Work}}{\text{Time}} \Rightarrow \boxed{P = \frac{W}{t}}$$

The SI unit of power is **watt** in honour of James Watt having the symbol W. i.e., $1\text{ W} = 1\text{ Js}^{-1}$

Other Units of Power

Apart form the units of power in SI and CGS systems, there are some of its major units which are required to be discussed.

1 kilo Watt (kW) $= 10^3$ W

1 Mega Watt (MW) $= 10^6$ W

1 Giga Watt (GW) $= 10^9$ W

1 Horse Power (HP) $= 746\text{ W} \simeq 750$ W.

Average Power

Average power is defined as the ratio of total work done by the total time taken. A power or machine may perform work at different rates at different intervals of time. In such situation, average power is considered by dividing the total energy consumed by the total time taken.

$$\therefore \quad \text{Average power} = \frac{\text{Total energy consumed}}{\text{Total time taken}}$$

Example 4. Calculate the power of an electric engine which can lift 20 tonne of coal per hour from a mine 180 m depth.

Sol. Given, $m = 20\,\text{tonne}$

or $m = 20 \times 1000 = 20000\,\text{kg}$ $(\because 1\text{ tonne} = 1000\text{ kg})$

$h = 180\text{ m}$

$t = 1\text{h} = 3600\text{s}$

$g = 9.8\text{ m/s}^2$

We know that, power $(P) = \frac{\text{Work }(W)}{\text{Time }(t)} = \frac{mgh}{t}$

$= \frac{20000 \times 9.8 \times 180}{3600}$

$\Rightarrow \quad P = 9800\text{ W}$

Example 5. A car of mass 2000 kg is lifted up a distance of 30 m by a crane in 1 min. A second crane does the same job in 2 min. Do the cranes consume the same or different amounts of fuel? What is the power supplied by each crane? Neglect power dissipation against friction.

Sol. Here, $m = 2000\text{ kg}, s = 30\text{ m}$

$t_1 = 1\text{ min} = 60\text{s}, t_2 = 2\text{ min} = 120\text{s}$

Work done by each crane,

$W = Fs = mgs$ $(\because F = mg)$

$= 2000 \times 9.8 \times 30 = 5.88 \times 10^5\text{ J}$

As, both the cranes do same amount of work, so both consume same amount of fuel.

Power supplied by first crane,

$$P_1 = \frac{W}{t_1} = \frac{5.88 \times 10^5}{60} = 9800\text{ W}$$

Power supplied by second crane,

$$P_2 = \frac{W}{t_2} = \frac{5.88 \times 10^5}{120} = 4900\text{ W}$$

Energy

It is the ability to do work. It is always essential for performing any mechanical work. An object having a capability to do work is said to possess **energy.** The object which does the work, losses energy and the object on which work is done, gains energy.

Units of Energy

Energy has the same units as that of work. The SI unit of energy is joule (J) and in CGS system of units, unit of energy is erg.

Other Important Units of Energy

(i) **Units of Electrical Energy** Watt hour (Wh) and kilowatt hour (kWh) are the two bigger units of energy.

(a) The energy consumed by a source of power I W in 1 h, is said to be one Watt hour.

$$1\text{ watt hour (Wh)} = 1\text{W} \times 1\text{h}$$
$$= 1\text{ Js}^{-1} \times 3600\text{ s}$$
$$= 3600\text{ J} = 3.6\text{ kJ}$$

(b) The energy consumed by a source of power of 1 kW in 1h, is known as one kilowatt hour.

$$1\text{ kilowatt hour (kWh)} = 1\text{kw} \times 1\text{ h}$$
$$= 1000\text{ Js}^{-1} \times 3600\text{ s}$$
$$= 3.6\text{ MJ}$$

$\therefore$ 1 kilowatt hour (kWh) = 3.6 MJ

Note 1 kWh is also known as the commercial unit, i.e. board of trade unit.

(ii) **Units of Heat Energy** Calorie and kilocalorie are the two units in which the heat energy is measured.

(a) The quantity of energy which is required to raise the temperature of l g of water through 1°C, is known as 1 calorie.

1 calorie = 4.2 J

(b) The quantity of energy which is required to raise the temperature of 1 kilogram of water through 1°C, is known as 1 kilocalorie.

1 kilocalorie = 4.2 kJ

(iii) **Unit of Nuclear Energy** (electron volt) 1 electron volt is the energy gained by an electron.
when it is accelerated through a potential difference of 1 volt.

i.e., $1\text{ eV} = 1.6 \times 10^{-19}\text{ J}$

and $1\text{ MeV} = 1.6 \times 10^{-13}\text{ J}$

Mechanical Energy

It is the form of energy, which is possessed by a body due to its state of rest or motion, position and configuration. Mechanical energy is of two types, i.e., kinetic energy and potential energy.

Kinetic Energy

It is a form of mechanical energy which is possessed by an object due to its motion. In other words, energy due to the motion of a body is called **kinetic energy**. Kinetic energy of a body moving with a certain velocity is equal to the work done on it to make it acquire that velocity. Kinetic energy of an object increases with its speed.

Due to kinetic energy, a bullet fired from a gun can pierce a target.

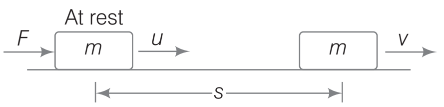
A moving hammer, drives a nail into the wood. Due to its motion, it has kinetic energy or ability to do work.

Calculation of Kinetic Energy

The kinetic energy of an object is measured by the amount of work it can do before coming to rest. Consider an object of mass m moving with a uniform velocity u. A force F is applied on it which displaces it through a distance s and it attains a velocity v.

Then, work done to increase its velocity from u to v.

$$W = Fs \quad \text{...(i)}$$



According to the equation of motion,

$$v^2 - u^2 = 2as \quad \Rightarrow \quad s = \frac{v^2 - u^2}{2a}$$

where, a is uniform acceleration.

Also, from $F = ma$

Substituting the values of F and s in Eq. (i), we have

$$W = ma \cdot \frac{v^2 - u^2}{2a}$$

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

This is known as **work-energy theorem**.

If initial velocity, $u = 0$

Then, $$W = \frac{1}{2} mv^2$$

It is clear that the work done is equal to the change in the kinetic energy of an object.

Thus, kinetic energy possessed by an object of mass m, moving with a uniform velocity v is

$$\text{KE (or } E_K) = \frac{1}{2} mv^2$$

Some important results can be derived from the formula,

$$\text{KE} = \frac{1}{2} mv^2$$

These are given below

(i) If the mass of an object is doubled, its kinetic energy also gets doubled.

(ii) If the mass of an object is halved, its kinetic energy also gets halved.

(iii) If the speed of an object is doubled, its kinetic energy becomes four times.

(iv) If the speed of an object is halved, its kinetic energy becomes one-fourth.

(v) Heavy objects moving with high speed have more kinetic energy than small objects moving with less speed.

Example 6. **Determine the kinetic energy of a body of mass 5 kg moving with a velocity 2 ms^{-1}.**

Sol. Given, mass of the body, $m = 5\text{kg}$

Velocity of the body, $v = 2\text{ms}^{-1}$.

Since, kinetic energy is given by,

$$\text{KE} = \frac{1}{2} mv^2$$

$$\therefore \quad = \frac{1}{2} \times 5 \times (2)^2 = \frac{1}{2} \times 5 \times 4 = 10 \text{ J}$$

Example 7. **A bullet of mass 8 g is fired with a velocity of 80 m/s. Calculate its kinetic energy.**

Sol. Given, mass, $m = 8\text{ g} = \frac{8}{1000}\text{ kg}$

Velocity, $v = 80\text{ m/s}$

$$\text{KE of the bullet} = \frac{1}{2} mv^2 = \frac{1}{2} \times \frac{8}{1000} \times (80)^2$$

$$= \frac{1}{2} \times \frac{8}{1000} \times 80 \times 80 = 25.6 \text{ J}$$

Example 8. **A van of mass 2000 kg is travelling at 10 ms^{-1} . Calculate its kinetic energy. If its speed increases to 20 ms^{-1}, by how much amount does its kinetic energy increases?**

Sol. Given, $m = 2000\text{ kg}$, $v_1 = 10\text{ ms}^{-1}$, $v_2 = 20\text{ ms}^{-1}$

Kinetic energy of van at 10 ms^{-1},

$$\text{KE}_1 = \frac{1}{2} mv_1^2 \quad \left(\because \text{KE} = \frac{1}{2} mv^2\right)$$

$$= \frac{1}{2} \times 2000 \text{ kg} \times (10 \text{ ms}^{-1})^2$$

$$= 100000 \text{ J} = 100 \text{ kJ}$$

Kinetic energy of van at 20 ms^{-1},

$$\text{KE}_2 = \frac{1}{2} mv_2^2 = \frac{1}{2} \times 2000 \text{ kg} \times (20 \text{ ms}^{-1})^2$$

$$= 400000 \text{ J} = 400 \text{ kJ}$$

The change in kinetic energy $= \text{KE}_2 - \text{KE}_1$

$$= 400 \text{ kJ} - 100 \text{ kJ} = 300 \text{ kJ}$$

So, the kinetic energy of van increases by 300 kJ when it speeds up from 10 ms^{-1} to 20 ms^{-1}.

Relation between Kinetic Energy (KE) and Momentum (p) of a Body

$$\text{As, KE} = \frac{1}{2}mv^2 = \frac{1}{2}(mv)^2\frac{m}{m}$$
$$= \frac{m^2v^2}{2m} = \frac{(mv)^2}{2m} = \frac{p^2}{2m}$$

Example 9. A body of mass 50 kg has a momentum of 2000 kg ms^{-1}. Calculate (i) KE of the body (ii) the velocity of the body.

Sol. (i) $\text{KE} = \frac{p^2}{2m} = \frac{(2000)^2}{2\times 50} = 40{,}000\text{ J}$

(ii) Velocity of the body,

$$v = \frac{p}{m} = \frac{2000}{50} = 40\text{ m/s}$$

Different Forms of Kinetic Energy

There are three different forms of kinetic energy

(i) **Translational Kinetic Energy** Translational motion is the motion of a body in a straight line path. So, the kinetic energy of the body due to motion in a straight line is known as translational kinetic energy. e.g., A truck moving on a road covering straight path, a freely falling body, etc.

(ii) **Rotational Kinetic Energy** Rotational motion comes in to play when a body rotates about an axis. So, the kinetic energy of body due to rotational motion known as rotational kinetic energy. e.g., Rotation of earth on its own axis, spinning top, etc.

(iii) **Vibrational Kinetic Energy** Vibrational motion comes in to existence, when a body moves to and fro about its mean position. So, the kinetic energy of the body due to its vibrational motion is called vibrational kinetic energy.

e.g. A polyatomic molecule has the vibrational motion in addition to rotational and translational energies.

CHECK POINT 02

1. How can you define the term 'power'? State its SI unit.
2. What is the necessity of using term 'Average Power' instead of power?
3. Why it is required to use kilowatt hour or board of trade as commercial unit of energy?
4. What amount of energy is kWh is consumed in 10 h by a machine of power 500 W? ***Ans.*** 5 kWh
5. Compute the speed of 2 kg ball having kinetic energy of 4 J. ***Ans.*** 2 ms^{-1}
6. Calculate the kinetic energy of a body of mass 0.1 kg and momentum 40 kg ms^{-1}. ***Ans.*** 8000 J

Potential Energy

The energy possessed by a body due to the change in its position or shape, is called potential energy or we can say that, the potential energy possessed by a body is the energy present in it by virtue of its position or configuration.

e.g., A stretched rubber band, spring, string of the bow, etc. Now, we can say that a body mass possesses energy even when it is not in motion.

Examples of potential energy are given below

(i) Water stored in dam has potential energy due to its position at the height.

(ii) A stone lying on the roof of the building has potential energy due to its height.

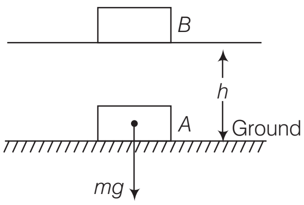
(iii) A wound spring of a watch has potential energy due to its shape.

Potential Energy of an Object at a Height

When an object is raised through a certain height above the ground, its energy increases. This is because work is done on it against gravity while it is being raised. The energy present in such an object is the **gravitational potential energy.** The gravitational potential energy of an object at a point above the ground is defined as the work done in raising it from the ground to that point against gravity.

Expression for (Gravitational) Potential Energy

Consider a body of mass m, lying at a point A on the earth's surface. Here, its potential energy is zero and its weight mg acts vertically downwards. To lift the object to another position B at a height h, we have to apply a minimum force which is equal to mg in the upward direction. So, work is done on the body against the force of gravity.



Therefore, work done = force × displacement

$$W = F \times s$$

But, $F = mg$ (weight of the body)

$$s = h,$$

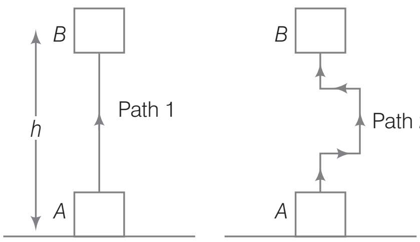
Therefore, $W = mg \times h = mgh$

i.e., $\text{PE} = mgh$

This work done is equal to the gain in energy of the body. This is called the potential energy of the body.

The potential energy of an object at a height depends on the ground level or the zero level you choose. An object in a given position can have a certain potential energy with respect to one level and a different value of potential energy with respect to another level.

The work done by gravity depends on the difference in vertical heights of the initial and final positions of the objects and not on the path along which the object is moved. It is clear from the figure given below.



In both the above situations, the work done on the object is *mgh*.

The another type of potential energy is elastic potential energy which is described below.

Elastic Potential Energy

As elasticity is the property by virtue of which a body regains original configuration on the removal of external force. So, elastic potential energy is the energy possessed by the body in the deformed state due to change in its configuration. For example, energy possessed by a compressed or elongated spring is elastic potential energy.

Example 10. **On falling from a height of 12 m, a ball hits the ground. Find out of the velocity with which the ball hits the ground.**

Sol. Given, $h = 20\text{m}$, $v = ?$

When the ball hits the ground its kinetic energy is converted into potential energy.

When it hits the ground KE = PE

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

$$\therefore \quad v = \sqrt{2gh} = \sqrt{2\times 9.8\times 20}$$

$$= \sqrt{392} = 19.798\,\text{m/s}$$

Example 11. **Suppose two bodies *A* and *B* having equal masses are kept at heights of *h* and 3 *h*, respectively. Find the ratio of their potential energies.**

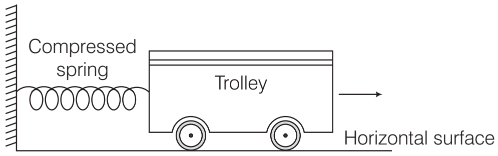
Sol. Let the mass of each body be m.

$$\text{PE of body}A = mgh$$

$$\text{PE of body } B = mg \times 3h$$

$$\therefore \text{ Ratio of their potential energies} = \frac{mgh}{mg \times 3h} = \frac{1}{3} = 1:3$$

Example 12. **A spring is kept compressed by a small trolley of mass 1 kg lying on a smooth horizontal surface as shown in the figure given below:**



When the trolley is released, it is found to move at a speed of 4 ms^{-1}. What potential energy did the spring possess when compressed ?

Sol. The potential energy of the spring when compressed

= Kinetic energy of the trolley

$$= \frac{1}{2}\times 1\times (4\text{ ms}^{-1})^2 = \frac{1}{2}\times 4\times 4 = 8\text{ J}$$

Various Forms of Energy

There are six various forms of energy

(i) **Heat Energy** A body possesses heat energy due to the disorderly motion of its molecules. Heat energy is also related to the internal energy of the body. In winter, we generate heat by rubbing our hands against each other.

(ii) **Chemical Energy** A stable chemical compound has lesser energy than its constituent atoms, the difference being in the arrangement and motion of electron in the compound. This difference is called chemical energy. If the total energy of the reactant is more than the product of the reaction, then heat is released and the reaction is said to be an exothermic reaction. If the reverse is true, then heat is absorbed and the reaction is called endothermic.

(iii) **Electrical Energy** Work is said to be done when electric charge moves from one point to another in an electric field or motion of a current carrying conductor inside a magnetic field. This energy is associated with an electric charge. The flow of electric charge causes bulbs to glow, motor to run and electric heater to produce heat.

(iv) **Nuclear Energy** When U^{235} nucleus breaks up into lighter nuclei on being bombarded by a slow neutron, a tremendous amount of energy is released. Thus, the energy so released is called nuclear energy and this phenomenon is known as nuclear fission. Nuclear reactors and nuclear bombs are the sources of nuclear energy.

(v) **Light Energy** It is a form of energy due to which we can see the objects around us. We can experience our surroundings, e.g., If we burn a candle, we will notice that this source of heat energy will provide a light energy. The light coming from sun is a natural source of light.

(vi) **Sound Energy** It is a form of mechanical energy which causes the sensation of hearing in us, e.g., A vibrating body possesses the sound energy, which is sensed by our ears.

Principle of Conservation of Energy

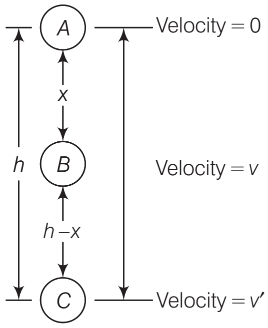
It states that, the energy can neither be created nor be destroyed but can only be converted from one form to another.

It is one of the fundamental laws and is applied in all the processes taking place in the universe.

Whenever energy in one form disappears, then equivalent amount of energy appears in some other form. Thus, the total energy remains constant.

Conservation of Mechanical Energy in a Freely Falling Body

Consider a body of mass m lying at position A at a height h above the ground. As the body falls, its kinetic energy increases at the expense of potential energy as shown in figure.



Conservation of energy in a freely falling body

At point A, The body is at rest,

KE of the body, $K_A = 0$

PE of the body, $U_A = mgh$

Total mechanical energy,

$$E_A = K_A + U_A = 0 + mgh$$

$\Rightarrow$ **Mechanical energy at position** A, $E_A = mgh$

At point B Suppose the body falls freely through height x and reaches the point B with velocity v. Then,

$$v^2 - 0^2 = 2as \qquad (\text{using } v^2 - u^2 = 2as)$$

$$\Rightarrow \quad v^2 = 2gx$$

$$\therefore \quad K_B = \frac{1}{2}m(v')^2 = \frac{1}{2} \times m \times 2gx = mgx$$

PE, $$U_B = mg(h - x)$$

$$\Rightarrow \quad E_B = K_B + U_B = mgx + mg(h - x) = mgh$$

Mechanical energy at position B, $E_B = mgh$

At point C Suppose the body finally reached at point C on the ground with velocity v'. Then, considering motion from A to C.

$$v'^2 - 0^2 = 2gh \text{ or } v'^2 = 2gh$$

$$K_C = \frac{1}{2}m(v')^2 = \frac{1}{2} \times m \times 2gh = mgh$$

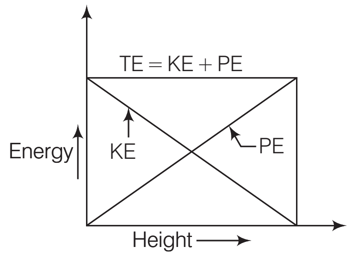
$$U_C = mg \times 0 = 0$$

$$\therefore \quad E_C = U_C + K_C = 0 + mgh = mgh$$

Mechanical energy at position C, $E_C = mgh$

Clearly, as the body falls as PE decreases and KE increases by an equal amount. Thus, its total mechanical energy remains constant at all points.

Hence, total mechanical energy is conserved during free fall of the body as shown in figure.

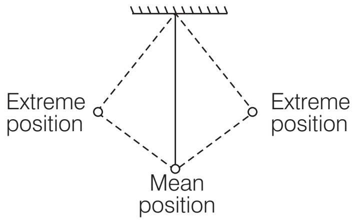


Plot of PE and KE during free fall of a body

Conservation of Mechanical Energy in Simple Pendulum

In an isolated system, the mechanical energy E of the system cannot change which means for isolated system mechanical energy of the system is conserved.

The oscillatory motion of a simple pendulum is another example of conversion of PE into KE and *vice-versa* and hence conservation of mechanical energy.



Simple Pendulum

At the mean position, bob of the simple pendulum has maximum KE. The PE at this position is zero.

At the two extreme positions, the bob of the simple pendulum has maximum PE. The KE at these two point is zero.

Example 13. The bob of a pendulum is released from a horizontal position. If the length of the pendulum is 1.5 m, what is the speed with which the bob arrives at the lowermost point?

Sol. On releasing the bob of pendulum from horizontal position, it falls vertically downward by a distance equal to length of pendulum, i.e., $h = l = 1.5$ m.

According to conservation of mechanical energy,

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

$$\Rightarrow \quad v = \sqrt{2 \times gh}$$

$$= \sqrt{2 \times 9.8 \times 1.5}$$

$$= 5.42 \text{ ms}^{-1}$$

Example 14.

(i) A body of mass 1 kg is allowed to fall freely under gravity, what is the momentum of the body after 5 s?

(ii) What is the height of the freely falling body?

Sol. (i) Here, mass $(m) = 1$ kg, $u = 0$, $t = 5$ s, $p = ?$

$$v = u + at$$

$$= 0 + 10 \times 5 = 50 \text{ m/s}$$

Linear momentum $(\mathbf{p}) = m \cdot (\mathbf{v}) = 1 \times 50 = 50$ kg-m/s

(ii) Kinetic energy of a body

$$= \frac{1}{2}mv^2 = \frac{1}{2} \times 1 \times (50)^2$$

$$= 1250 \text{ J}$$

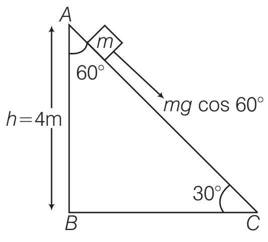
So, for a freely falling of the body from height h,

we get, $mgh = \frac{1}{2}mv^2$

$\Rightarrow \; 1 \times 10 \times h = 1250, \; h = 125$ m

Example 15. If a body slides on an inclined plane making an angle of 60°. Find its kinetic energy at the bottom as given in the figure and also find work done (by gravity) on the body.

(Take, initial velocity, $u = 0$, $g = 10 \text{ ms}^{-2}$)



Sol. As from the figure,

potential energy at the top $= mgh$

So, according to conservation of energy, kinetic energy at the bottom will be equal to the potential energy at the top.

So, KE at bottom $= mgh = 4mg$

Now, work done

$$(W) = \text{force } (F) \times \text{displacement } (s)$$

$$= mg \times (AB)$$

$$= mg \times (AC \cos 60°)$$

$$= mg \times (AB) = mg \times (4) = 4mg$$

Transformation of Energy

Energy can be converted into its one form to another. This phenomenon is called transformation of energy when an object is dropped from a height, its potential energy continuously converts into kinetic energy. When an object is thrown upwards, its kinetic energy continuously converts into potential energy.

e.g.,

(i) Green plants prepare their own food (stored in the form of chemical energy) using solar energy through the process of photosynthesis.

(ii) When we throw a ball, the muscular energy which is stored in our body, gets converted into kinetic energy of the ball.

(iii) The wound spring in the toy car possesses potential energy. As the spring is released, its potential energy changes into kinetic energy due to which, toy car moves.

(iv) In a stretched bow, potential energy is stored. As it is released, the potential energy of the stretched bow gets converted into the kinetic energy of arrow which moves in the forward direction with large velocity.

Some Energy Transformations

S.No.	Instrument	Transformation
(i)	Electric motor	Electrical energy into mechanical energy.
(ii)	Electric generator	Mechanical energy into electrical energy.
(iii)	Steam engine	Heat energy into kinetic energy.
(iv)	Electric bulb	Electrical energy into light energy.
(v)	Dry cell	Chemical energy into electrical energy.
(vi)	Solar cell	Light energy into electrical energy.
(vii)	Atomic bomb	Atomic energy into heat and light energy.

CHECK POINT 03

1 Does work done by the gravity depends on the path covered by object?

2 If an engine supplies 100 J of energy to a weight of 200 g, how high it can be lifted? ***Ans.*** 51.02 m

3 How total energy of the universe is remains conserved?

4 How does the total mechanical energy remain constant in a simple pendulum during the oscillations?

5 In dry cell which type of energy transformation takes place?

SUMMARY

- Work is said to be done by a force, when a body is displaced through some distance in the direction of the force.
- Work done by a force is the dot product of force and displacement.

  $$W = F \cdot s = F\,s\cos\theta$$

  where θ is the angle between the direction of force (F) and displacement (s).
- Work done is zero if direction of 'F' is perpendicular to direction of 's'.
- Work done is positive if F and s are in the same direction and negative if they are in opposite directions.
- The capacity to do work is called energy.
- The units of work and energy are same. The SI unit of work and energy is joule (J).
- The rate at which work is done is called power.

  $$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

  The SI unit of power is watt (W).
- Mechanical energy is the sum of kinetic energy and potential energy.
- The energy possessed by a body by virtue of its motion is called kinetic energy.
- The kinetic energy of a body of mass m moving with a velocity v is given by

  $$= \frac{1}{2} mv^2$$
- The energy possessed by a body due to the change in its position or shape is called its potential energy.
- Potential energy possessed by an object of mass m at a height h is given by $= mgh$. This is called gravitational potential energy.
- Energy can be transformed from one form to another, but the total energy of an isolated system remains constant. Energy can be neither created nor destroyed. This is called principle of conservation of energy.

EXAM PRACTICE

a 2 Marks Questions

1. Define work. State its SI unit.

Sol. Work is said to be done when the force applied on a body displaces it in the direction of force applied on the body. The SI unit of work is joule (J). ***[1+1]***

2. Define Joule. SI unit of work and establish a relationship between the SI and CGS units of work. ***[2008]***

Sol. When a force of one newton displaces a body through one metre in its own direction, the work done is said to be 1 Joule.

$$1\text{ J} = 1\text{ N} \times 1\text{ m} = 10^5 \text{dyne} \times 100\text{ cm}$$
$$= 10^7 \text{ dyne cm} = 10^7 \text{ erg}$$
$$\therefore \quad 1\text{ J} = 10^7 \text{ erg} \quad \textit{[1]}$$

This is a required relation between the SI unit and CGS unit of work. ***[1]***

3. A man having a box on his head, climbs up a slope and another man having an identical box walks the same distance on a levelled road. Who does more work against the force of gravity and why? ***[2014]***

Sol. A man having a box on his head climbs up a slope does more work, because the work done by the man walking on a levelled road is zero as the angle between displacement and force is 90°, as ***[1]***

$$w = mgs\cos 90° = mgs \times 0 = 0 \quad \textit{[1]}$$

4. A man holding bucket of water on his head stands stationary. Is he doing any work? Give reason.

Sol. No, he is not doing any work. It is because, there is zero displacement occur.

$$\therefore \quad W = F \times s = F \times 0 = 0 \quad \textit{[1+1]}$$

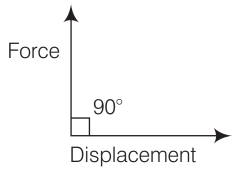
5. "If a satellite revolves around the earth in a circular orbit, the amount of work done by the satellite is zero". Justify the statement.

Sol. If a satellite revolves around the earth in a circular orbit, the amount of work done by the satellite is zero. It is due to the fact that the force of gravity is directed towards the centre of circular path of the satellite, i.e., the earth and the displacement at all instant is along the tangent to the circular path or normal to the direction of force on the satellite. ***[1]***

$$\because \quad W = F \times s\cos 90°$$
$$\Rightarrow \quad W = F \times s \times 0 = 0 \quad \textit{[1]}$$

6. Is it possible that an object is in the state of accelerated motion due to external force acting on it, but no work is being done by the force? Explain it with an example.

Sol. Yes, when force acts in a direction perpendicular to the direction of displacement.



e.g., Earth revolves around the Sun under gravitational force of Sun on Earth, but no work is done by the Sun, though Earth has centripetal acceleration. ***[2]***

7. (i) State and define the SI unit of power.

(ii) How is the unit horse power related to the SI unit of power? ***[2018]***

Sol. (i) The rate of doing work is called the power and the SI unit of power is watt(W). ***[1]***

(ii) 1HP = 746 W. ***[1]***

8. An object of mass m is moving with a constant velocity v. How much work should be done on the object in order to bring the object to rest?

Sol. Change in kinetic energy (KE) = Work done

Given, mass = m, initial velocity, $u = v$

Final velocity, $v = 0$

So, $$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$\Rightarrow \quad W = \frac{1}{2}m(0)^2 - \frac{1}{2}mv^2 \Rightarrow W = -\frac{1}{2}mv^2 \quad \textit{[1]}$$

Hence, the work that should be done in order to bring the object to rest is $\frac{1}{2}mv^2$. ***[1]***

9. If a speed of a particle is doubled, what will be the ratio of its kinetic energy to its momentum?

Sol. $\therefore$ Kinetic energy, $KE' = \frac{1}{2}m(v')^2 \qquad (\because v' = 2v)$

$$= \frac{1}{2}m(2v)^2 = 4\text{ KE} \quad \textit{[1]}$$

and momentum, $p' = mv' \qquad (\because v' = 2v)$

$$= m(2v) = 2p$$

$$\therefore \quad \frac{KE'}{p'} = \frac{4KE}{2p} = 2 \times \left(\frac{KE}{p}\right)$$

Hence, ratio gets doubled. ***[1]***

10. Two bodies of masses m_1 and m_2 have equal kinetic energies. What will be the ratio of their linear moment?

Sol. Given, $K_1 = K_2$

$$\Rightarrow \quad \frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_2 v_2^2 \Rightarrow \frac{v_1}{v_2} = \sqrt{\frac{m_2}{m_1}}$$

$$\Rightarrow \quad \frac{m_1 v_1}{m_2 v_2} = \frac{m_1}{m_2}\sqrt{\frac{m_2}{m_1}} \Rightarrow \frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}}$$ **[2]**

11. (i) Why is the motion of a body moving with a constant speed around a circular path said to be accelerated?

(ii) Name the unit of physical quantity obtained by the formula $\frac{2K}{v^2}$, where K is kinetic energy and v is linear velocity. **[2018]**

Sol. (i) In a circular motion with constant speed, linear velocity changes in terms of direction therefore it is said to be accelerated motion. **[1]**

(ii) We know that,

$$\text{kinetic energy } (K) = \frac{1}{2} mv^2 \quad \ldots\text{(i)}$$

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

From Eq. (i), we get,

$$= \frac{2}{v^2} \times \left(\frac{1}{2} mv^2\right) = m \text{ (mass)}$$

Hence, the physical quantity is mass. **[1]**

12. (i) Is it possible a body possesses energy without having momentum?

(ii) Is it possible a body possesses momentum without having energy?

Sol. (i) Yes it is possible, it is because a body at rest can possesses the potential energy or energy stored due to position or shape as elastic potential energy even when there is zero momentum. **[1]**

(ii) No, it is not possible, if a body possesses some momentum, then it must be in motion, it must have some kinetic energy. **[1]**

13. Define potential energy. Write an expression for potential energy. Write the SI unit of potential energy.

Sol. The energy possessed by a body due to its configuration is known as potential energy.

The potential energy of a body is given by

$$\text{PE} = mg$$

The SI unit of potential energy is joule (J). **[2]**

14. Derive an expression for the gravitational potential energy.

Sol. Let us consider that, m = mass of the object, h = height at which object is placed and F = force required to lift the object against the force of gravity.

$$F = mg$$

Now, work done on lifting the object to height h is **[1]**

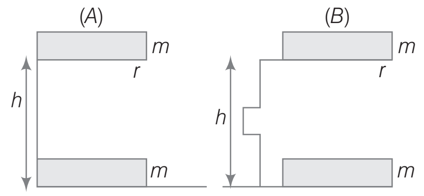
$$W = \text{Force} \times \text{Displacement}$$
$$= mg \times h = mgh$$

This work done on the body is stored in it in the form of gravitational potential energy, i.e., U.

$$\therefore \quad U = mgh$$ **[1]**

15. (i) What is meant by potential energy of a body?

(ii) A body of mass m is raised to a vertical height h through two different paths A and B.



What will be the potential energy of the body in the two cases? Give reason for your answer.

Sol. (i) Energy possessed due to the position of a body is called potential energy. **[1]**

(ii) The work done against gravity in both the cases is *mgh*. It is independent of the path along which the body is moved and it depends only on the initial and final positions of the body. **[1]**

16. A ball is placed on a compressed spring. When the spring is released, the ball is observed to fly away.

(i) What form of energy does the compressed spring possess?

(ii) Why does the ball fly away? **[2012]**

Sol. (i) The compressed spring possesses elastic potential energy. **[1]**

(ii) The ball flies away, because potential energy is converted into kinetic energy and it is also transferred to the ball. **[1]**

17. What is meant by transformation of energy? Explain with the help of two suitable examples.

Sol. Refer to theory (Page 25).

18. State the energy changes in the following cases while in use

(i) An electric iron.

(ii) A ceiling fan. **[2018]**

Sol. (i) An electric iron converts electrical energy into heat energy. *[1]*

(ii) A ceiling fan converts electrical energy into mechanical energy. *[1]*

19. Write the statement of law of conservation of mechanical energy.

Sol. Refer to theory (Page 24). *[2]*

20. Mention any two examples in which the mechanical energy of the system remains constant?

Sol. (i) Mechanical energy of the vibrating body of simple pendulum remains constant. *[1]*

(ii) Mechanical energy of a freely falling body remains constant. *[1]*

21. At the bottom of the waterfall, water is warmer than at the top. Give reason.

Sol. When water falls on the ground, its mechanical energy (KE + PE) is converted into heat energy, due to which the temperature of water at the bottom of the waterfall increases. *[2]*

22. The moment, an arrow is shoot from its bow, it has some kinetic energy. From where does it get the kinetic energy?

Sol. On the account of a change in the shape of stretched bow, it possesses potential energy. In order to shoot an arrow, the bow is released. So, the potential energy of the bow changes into kinetic energy. *[2]*

b 3 Marks Questions

23. (i) Derive a relationship between SI and CGS unit of work.

(ii) A force acts on a body and displaces it by a distance S in a direction at an angle θ with the direction of force. What should be the value of θ to get the maximum positive work? *[2018]*

Sol. (i) The SI unit of work is joule

$$1\text{J} = 1\text{N} \times 1\text{m} = 10^5 \text{ dyne} \times 100 \text{ cm}$$
$$= 10^7 \text{ dyne cm}$$
$$= 10^7 \text{ erg}$$ *[1½]*

(ii) For maximum work done, the angle should be 0°.

i.e. $W_{max} = \text{F} \cdot \text{s}$

$$= |\text{F}||\text{s}| \cos 0° = Fs \qquad (\because \cos 0° = 1)$$ *[1½]*

24. Read the following statements and state whether the work done in the following cases is positive or negative.

(i) Work done by friction on a body sliding down an inclined plane. *[1]*

(ii) Work done by a man in lifting a bucket out of the well by means of rope tied to the bucket. *[1]*

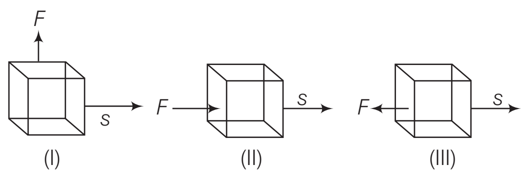
(iii) Work done by a resistive force of air on a vibrating pendulum in bringing it to a rest. *[1]*

Sol. (i) In this case, the frictional force acts opposite to the direction of motion of body, so the work done by the friction on a body sliding down an inclined plane will be negative. *[1]*

(ii) In this case, the bucket moves in the direction of the applied force by the man, so the work done will be positive. *[1]*

(iii) The resistive force of air always acts opposite to the direction of motion of the oscillating pendulum due to which the work done will be negative. *[1]*

25. In each of the following, a force F is acting on an object of mass m. The direction of displacement is from West to East shown by the longer arrow. Observe the figure carefully and state whether the work done by the force is negative, positive or zero.



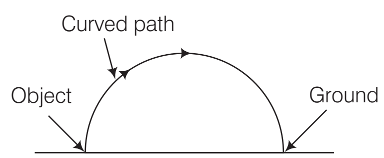
Sol. (i) In Fig. (I), angle between F and s is 90°, so work done is zero. *[1]*

(ii) In Fig. (II), angle between F and s is 0°, so work done is positive. *[1]*

(iii) In Fig. (III), angle between F and s is 180°, so work done is negative. *[1]*

26. An object thrown at a certain angle to the ground moves in a curved path and falls back to the ground. The initial and the final points of the object lie on the same horizontal line. What is the work done by the force of gravity on the object?

Sol. *The path can be traced as shown below*



Thus, the work done by the force of gravity,

$$W = mgh$$

where, h = difference in height of initial and final positions of the object.

According to question, the initial and final positions of the object lie in same horizontal line, so $h = 0$.

$\therefore$ Work done, $W = mg \times 0 = 0$ **[3]**

27. A boy weighing 40 kgf in 4 minute and a girl weighing climbs up a stair of 30 steps each 20 cm high 30 kgf does the same in 3 minutes. Compare

(i) the work done by them

(ii) the power developed by them.

Sol. (i) Both of them climbs up the same number of stairs, so work done by them will be equal. **[1]**

(ii) Power developed by the girl is more, because

$$\text{power of boy} = \frac{40 \times 10 \times 30 \times 20}{4 \times 100 \times 60} = \frac{600}{60}\ \text{W} = 10\ \text{W}$$

$$\text{power of Girl} = \frac{30 \times 10 \times 30 \times 20}{3 \times 60 \times 100} = 10\ \text{W}$$

Power developed is same but girl takes lesser time. **[2]**

28. Differentiate between the potential energy (U) and the kinetic energy (K).

Sol.

Potential Energy	Kinetic Energy
The energy possessed by a body by virtue of its state of position is known as potential energy.	It is the energy possessed by a body by the virtue of state of motion.
Potential energy of a body is equal to the work done on the body to lift it to a height h.	Kinetic energy of a body is equal to the amount of work done by the body before it comes to rest.
A body mass possess this energy, when it is not in motion.	Kinetic energy of the body increases by increasing the motion of the body.

[1 × 3]

29. A car is moving on a levelled road and gets its velocity doubled. In this process,

(i) how would the potential energy of the car change?

(ii) how would the kinetic energy of the car change?

(iii) how will its momentum change? Give reasons for your answer.

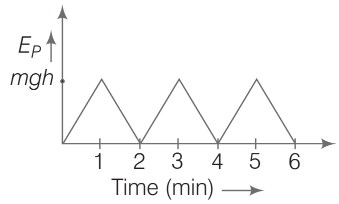
Sol. (i) The potential energy of the car remains same, since PE (= mgh) is independent of velocity.

(ii) The kinetic energy of the car becomes four times, since KE$\left(= \frac{1}{2} mv^2\right)$ is proportional to square of velocity.

(iii) The momentum of the car will also get doubled, since momentum ($p = mv$) is proportional to velocity. **[1+1+1]**

30. A girl sits and stands repeatedly for 6 min. Draw a graph to show the variation of potential energy of her body with time.

Sol. *The path can be traced as shown below*



[1]

From the graph shown above, we can take the sitting position of the girl as the position of zero potential energy. Let m be the mass of the girl and h be the position of centre of gravity while standing above the sitting position.

The PE while standing is + mgh and while sitting is zero. We can assume that there is no acceleration or deceleration while standing and sitting, this is repeated after every minute. **[2]**

31. Write transformation of energy in

(i) solar cell

(ii) electric iron

(iii) induction cooker

Sol. (i) Light energy to electrical energy. **[1]**

(ii) Electrical energy to heat energy. **[1]**

(iii) Electrical energy to heat energy. **[1]**

32. A battery lights a bulb. Describe the energy changes involved in the process.

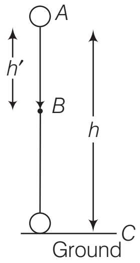
Sol. A battery contains chemical and supplies electrical energy. So, a battery converts chemical energy into electrical energy. In an electrical bulb, the electrical energy is first converted into heat energy. This heat energy causes the filament of bulb to become white-hot and produce light energy. **[2]**

Thus, the energy changes are

Chemical energy $\Rightarrow$ Electrical energy $\Rightarrow$ Heat energy $\Rightarrow$ Light energy **[1]**

33. The potential energy of a freely falling object decreases progressively.

Does this violate law of conservation of energy? If no/yes, then why?



Sol. It is true that the potential energy of freely falling object decreases progressively. But as the object falls down, its speed increases, i.e., the kinetic energy of the object increases progressively (kinetic energy will increase with the increase in speed). ***[2]***

Now, we can say that the law of conservation of energy is not violated, because the decrease in potential energy results in the increase of kinetic energy. ***[1]***

34. If a body falls from a height bounces from ground and again goes upwards with loss of a part of its energy.

(i) How will its potential energy change?

(ii) What are various energy conversions taking place?

(iii) What will be its ultimate energy?

Sol. (i) When it strikes ground, its PE is zero and after bouncing, its potential energy increases gradually. ***[1]***

(ii) At the time it strikes the ground, it has maximum KE and after it bounces, its KE starts changing into potential energy. ***[1]***

(iii) The ultimate or total energy remains constant at any point of time during the motion. ***[1]***

C *4 Marks Questions*

35. Given below are a few situations, study them and state in which of the given cases work is said to be done. Give reason for your answer.

(i) A person pushing hard a huge rock but the rock does not move.

(ii) A bullock pulling a cart up to 1 km on road.

(iii) A girl pulling a trolley for about 2 m distance.

(iv) A person standing with a heavy bag on his head.

Sol. (i) As the displacement is zero in first case. So, work done = zero. ***[1]***

(ii) The work done in pulling a cart by the bullock will be positive. As F and s are in same direction. ***[1]***

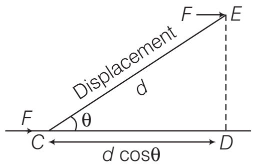
(iii) Work done in case of pulling a trolley by the girl will be positive. As force and displacement are in same direction. ***[1]***

(iv) As there is no displacement, so work done by a person standing with a heavy bag on his head is zero. ***[1]***

36. Explain, how do the work is related to direction of force and displacement.

Sol. When the displacement of the body is not in the direction of the force, so in order to calculate the amount of work done, we should find the component of the displacement in the direction of force. e.g., Let us assume that the force F is acting along CD and it displaces the point of application of force from C to E such that the displacement $CE (= d)$ is at an angle θ to the direction of force. ***[1]***

The component of the displacement in the direction of force is CD.



$\therefore$ Work done, $W = F \times CD$ ...(i)

In right angled ΔCDE, ***[2]***

$$\cos\theta = \frac{CD}{CE} = \frac{CD}{d} \Rightarrow CD = d \cos\theta$$

Substituting this value in Eq. (i), we get

$$W = F \times d \cos\theta$$

which is a required relationship between work, force and the displacement. ***[1]***

37. If a body of mass m is moving with velocity v, then derive an expression for its kinetic energy.

Sol. Consider a body of mass m is moving with velocity v. It is brought to rest by an opposing force F. Let it travels a distance s before coming to rest and a be the uniform retardation produced by the force. ***[1]***

Kinetic energy of the body = Work done by the retarding force in stopping it.

Kinetic energy = force × displacement ...(i)

Retarding force, $F = ma$ ...(ii)

Initial velocity, $u = v$, final velocity, $v = 0$ ***[1]***

From the relation, $v^2 = u^2 + 2as$

$$0 = v^2 - 2as$$

$\therefore$ Displacement, $s = \dfrac{v^2}{2a}$ ...(iii) ***[1]***

Put the values of F and s from Eqs. (ii) and (iii) in Eq. (i), we get

Kinetic energy, $K = F \times s = ma \times \dfrac{v^2}{2a} = \dfrac{1}{2} mv^2$

Kinetic energy $= \dfrac{1}{2} \times \text{mass} \times (\text{velocity})^2$ ***[1]***

38. Two protons are brought towards each other. Will the potential energy energy of the system decrease or increase? What happens if a proton and an electron are brought nearer?

Sol. The potential energy will increase, because in bringing two protons closer, work has to be done against the force of repulsion. This work done gets stored up in the form of potential energy. However, the potential energy will decrease when a proton and an electron are brought nearer to each other.

The work done gets stored up in the from of potential energy. However, the potential energy will decrease when a proton and an electron are brought nearer to each other. The work will be done by the force of attraction between them. ***[2 + 2]***

39. State the energy changes in each of the following cases given below

(i) Explosion of crackers

(ii) Burning of match stick

(iii) Respiration

(iv) Charging of a battery

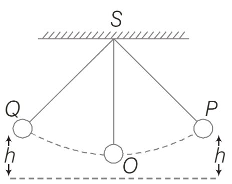
Sol. (i) Chemical energy into heat, light and sound energy.

(ii) Chemical energy into light and heat energy.

(iii) Chemical energy into heat energy.

(iv) Electrical energy into chemical energy. ***[1 × 4]***

40. Illustrate the law of conservation of energy by discussing the energy changes which occur when we draw a pendulum bob to one side and allow it to oscillate. Why does the bob eventually come to rest? What happens to its energy eventually? Is it a violation of the law of conservation of energy?



Sol. Let a simple pendulum be suspended from a rigid support S and OS be the equilibrium position of the pendulum. Let the pendulum be displaced to a position P, where it is at rest. At position P, the pendulum has potential energy (mgh). When the pendulum is released from position P, it begins to move towards position O.

The speed of the pendulum increases and its height decreases that means the potential energy is converting into kinetic energy. ***[1]***

At position O, whole of the potential energy of the pendulum is converted into its kinetic energy.

Then, the pendulum swings to other side due to inertia of motion.

As the pendulum begins to move towards position Q, the speed of pendulum decreases and height increases that means kinetic energy is converting into potential energy. At point Q, whole of the kinetic energy is converted into potential energy. ***[1]***

Thus, we find that the potential energy is converted into kinetic energy and *vice-versa* during the motion of the pendulum. But the total energy remains constant.

When the pendulum oscillates in air, the air friction opposes its motion.

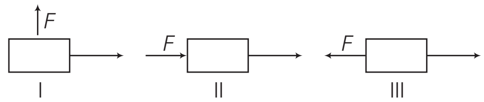
So, some part of kinetic energy of pendulum is used to overcome this friction. ***[1]***

With the passage of time, energy of the pendulum goes on decreasing and finally becomes zero.

The energy of the pendulum is transferred to the atmosphere. So, energy is being transferred, i.e., is converted from one form to another. So, no violation of law of conservation of energy takes place. ***[1]***

Numerical Based Questions

41. In each of the following a force, F is acting on an object of mass m. The direction of displacement is from West to East shown by the longer arrow. Observe the diagrams carefully and state whether the work done by the force is negative, positive or zero.



Sol. ***Case* I** The force and displacement are perpendicular to each other, so $\theta = 90°$.

Work done, $W = Fs\cos\theta$

$= Fs\cos 90°$

$= Fs \times 0 = 0 \qquad (\because \cos 90° = 0)$

i.e., the work done is zero. ***[1]***

***Case* II** The force and displacement are in the same directions, so $\theta = 0°$

$\therefore$ Work done, $W = Fs\cos\theta = Fs\cos 0°$

$= Fs \times 1 = Fs \qquad (\because \cos 0° = 1)$

i.e., the work done is positive. ***[1]***

***Case* III** The force and displacement are in opposite directions, so $\theta = 180°$.

$\therefore$ Work done, $W = Fs\cos\theta = Fs\cos 180°$

$= Fs \times -1 = -Fs$

$(\because \cos 180° = -1)$

i.e., the work done is negative. ***[1]***

42. If a force of 10 kg is applied on a body and the body gets displaced by 0.5 m. Determine the work done by the force when the displacement

(i) is in the direction of force.

(ii) at an angle of 60° with the force.

(iii) normal to the force (Take, $g = 10\ \text{Nkg}^{-1}$).

Sol. Given, force $F = 10$ kg, $F = 100$ N.

Displacement, $s = 0.5$ m.

(i) When displacement is in the direction of force, $\theta = 0°$

$$W = Fs\cos 0° \qquad (\because \cos 0° = 1)$$

$$\Rightarrow \quad W = 100 \times 0.5 = 50\ \text{J}$$ **[1]**

(ii) When displacement is at an angle of 60°,

$$\Rightarrow \quad W = Fs\cos 60°$$

$$\Rightarrow \quad W = 100 \times 0.5 \times \frac{1}{2} \qquad \left(\because \cos 60° = \frac{1}{2}\right)$$

$$\Rightarrow \quad W = 25\ \text{J}$$ **[1]**

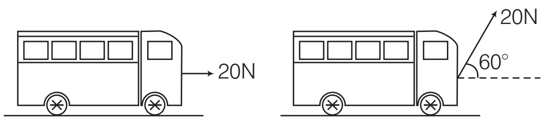
(iii) When displacement is normal to the direction of force,

$$W = Fs\cos 90°$$

$$\Rightarrow \quad W = 100 \times 0.5 \times 0 \qquad (\because \cos 90° = 0)$$

$$\Rightarrow \quad W = 0$$ **[1]**

43. When a 20N force acts in two different ways to displace a trolley in the same displacement. Find the ratio of the work done as determined in both the cases.



Sol. In case (i), work done, $W_1 = 20 \times d\cos 0° = 20d$ **[1/2]**

In case (ii), work done, $W_2 = 20 \times d\cos 60° = 20d \times \frac{1}{2}$

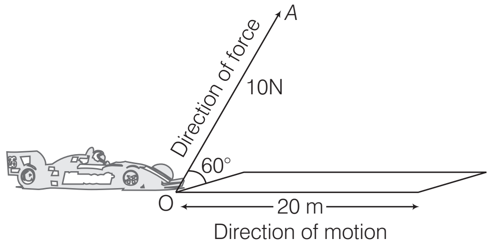
$$= 10d$$ **[1/2]**

$\therefore$ The required ratio, $\dfrac{W_1}{W_2} = \dfrac{20d}{10d}$

$$\Rightarrow \quad \frac{W_1}{W_2} = 2$$ **[1]**

44. A child pulls a toy car through a distance of 20 m on smooth and horizontal floor. The string held in child's hand makes an angle of 60° with horizontal surface. If the force applied by the child be 10 N, calculate the work done by the child in pulling the car.

Sol. We know that, work done when a body moves at an angle to the direction of force is



[1]

$$W = Fs\cos\theta$$ **[1]**

Here, force, $F = 10$ N

Angle, $\theta = 60°$

and distance, $s = 20$ m

So, on putting values in above formula, we get

Work done, $W = 10 \times 20 \times \cos 60°$

As, the value of $\cos 60° = 0.5$

So, $W = 10 \times 20 \times 0.5 = 100$ J **[1]**

45. Determine the power of the motor in terms of HP of an elevator, which can carry 10 persons of average mass 60 kg through a vertical height of 20 m in 30s.

Sol. Given, mass = 60 kg, time = 30 s, $h = 20$ m

Mass to be lifted $= 10 \times 60 = 600$ kg

$$\text{Power, } P = \frac{mgh}{t}$$ **[1]**

$$= \frac{600 \times 10 \times 20}{30}$$

$$= \frac{120000}{30}$$

$$\Rightarrow \quad P = 4000\ \text{W}$$ **[1]**

$$\text{In HP} = \frac{P}{750} = \frac{4000}{750} = 5.33\ \text{HP}$$

$(\because 1\ \text{HP} \approx 750\ \text{W})$ **[1]**

46. A girl of mass 40 kg runs up stairs and reaches the 8 m high first floor in 5s. Determine

(i) the force of gravity acting on the body.

(ii) the work done by her against the gravity.

(iii) the power spent by the girl.

Sol. Given, $m = 40$ kg, $h = 8$ m,

$t = 5$ s, $g = 10\ \text{ms}^{-1}$

(i) Let the force of gravity on the girl be F.

$$\therefore \quad F = mg = 40 \times 10 = 400\ \text{N}$$ **[1]**

(ii) Work done by the girl against the gravity,

$$W = mgh = 4 \times 10 \times 8 = 3200 \text{ J}$$ **[1]**

(iii) Power spent, $P = \frac{W}{t} = \frac{3200}{5}$

$= 640 \text{ Js}^{-1}$

$= 640 \text{ W}$ **[1]**

47. Determine the horse power of an engine, which lifts 4000 m^3 of water from a depth of 50 m in 40 min.

Sol. Mass of water $= V \times D = 4000 \times 10^3$

$= 4 \times 10^6$ kg

($\because$ density of water $= 10^3$ kg/m^3) **[1]**

Work done in lifting water $= mgh$

$= 4 \times 10^6 \times 10 \times 50$

$= 2 \times 10^9$ J **[1]**

Power of engine $= \frac{W}{t} = \frac{2 \times 10^9}{2400} = \frac{10^9}{1200}$ W

$\therefore$ Power in horse power $= \frac{1 \times 10^9}{1200 \times 750}$

$= 1111.1$ HP **[1]**

48. The human heart does 1.5 J of work in every beat. How many times per minute does it beat, if its power is 2 W?

Sol. Given, power, $P = 2$ W, time, $t = 1 \text{ min} = 60$ s

Total work, $W = Pt$ $\left(\because P = \frac{W}{t}\right)$

$= 2 \times 60 \text{ s} = 120$ J **[1]**

$\because$ 1.5 J work is done in 1 beat.

$\therefore$ 120 J work will be done in $\frac{1 \times 120}{1.5} = 80$ beats

Therefore, number of beats per min $= 80$ **[1]**

49. For an experiment to measure his power, a student records the time taken by him in running up a flight of steps on a staircase.
Use the following data to calculate the power of the student.
(Take, number of steps $= 28$, height of each step $= 20$ cm, time taken $= 5.4$ s, mass of student $= 55$ kg and acceleration due to gravity $= 9.8 \text{ ms}^{-2}$)

Sol. Given, $n = 28$, $h = 20 \text{ cm} = 0.2$ m, $t = 5.4$ s

$m = 55$ kg, $g = 9.8 \text{ m s}^{-2}$

We know that the power of student is given by

$$P = n \times \frac{W}{t} = n \times \frac{mgh}{t} \qquad (\because W = mgh)$$

$$= \frac{28 \times 55 \times 9.8 \times 0.2}{5.4}$$

$= 559$ W **[2]**

50. If a man raises a box of 50 kg mass to a height of 2 m, while the other man raises the same box to a same height in 5 min. Compare

(i) the work done.

(ii) the power developed by them.

Sol. (i) For the first man, $m = 50$ kg

Height, $h = 2$ m

Time, $t_1 = 2 \text{ min} = 2 \times 60 \text{ s} = 120$ s

For the second mass, $m = 50$ kg

Height, $h = 2$ m

Time, $t = 5 \text{ min} = 5 \times 60 = 300$ s

Let work done by the first man be W.

Since, $W = mgh$

Therefore, the work done by the second man is the same.

$\therefore$ $W_1 : W_2 = 1 : 1$ **[2]**

(ii) Let power developed by the first man $= P_1$.

$\because$ $W = mgh = 50 \times 10 \times 2 = 1000$ J

$P_1 = \frac{W}{t_1} = \frac{1000}{120} \text{ W} = \frac{25}{3}$ W **[1]**

Now, assume that the power developed by the second man $= P_2$.

Therefore, power,

$P_2 = \frac{W}{t} = \frac{1000}{300} \text{ W} = \frac{10}{3}$ W

$\therefore$ $\frac{P_1}{P_2} = \frac{25}{3} : \frac{10}{3}$

$\therefore$ $\frac{P_1}{P_2} = \frac{5}{2}$

$\Rightarrow$ $P_1 : P_2 = 5 : 2$ ($\because$ $t_2 = 5$ min) **[1]**

51. A boy X can run with a speed of 8 ms^{-1} against the frictional force of 10 N and another Y can move with a speed of 3 ms^{-1} against the frictional force of 20 N. Find the ratio of powers of X and Y.

Sol. Given, distance travelled by the boy X in 1 s $= 8$ m

Distance travelled by the boy Y in 1 s $= 3$ m

As we know, work done by the boy X to run against the frictional force of 10 N = 10 N × 8 m = 80 J

So, power of 80 J of work done by $X = \frac{W}{t} = \frac{80 \text{ J}}{1 \text{s}}$

$= 80$ W **[1]**

Similarly, work done by the boy Y to run against the frictional force of 20 N = 20 N × 3 m = 60J

$$\text{Power of } Y = \frac{60 \text{ J}}{1 \text{ s}} = 60 \text{ W}$$

So, ratio of two values of powers is given by

$$\frac{\text{Power of } X}{\text{Power of } Y} = \frac{80}{60} = \frac{4}{3} = 4:3$$ **[1]**

52. Calculate the total energy consumed in the month of November in a household in which four devices of power 500 W each are used daily for 10 h.

Sol. Given, power, $P = 500$ W, time, $t = (4 \times 10 \times 30)$ h

Energy consumed in the month of November

$= 500 \text{ W} \times 4 \times 10 \text{ h} \times 30$

$= 600000 \text{ Wh} = 600 \text{ kWh}$

$= 600$ units **[2]**

53. In a house 3 bulbs of 25 W each are used for 5 h a day. Calculate the units of electricity consumed in a month of 31 days. Also, find the total expenditure, if 1 unit of electricity costs ₹ 2.50.

Sol. Given, power of each bulb = 25 W, time = 5 h

Cost of 1 unit of electricity = ₹ 2.50

Electric energy consumed by 3 bulbs in a day

$= \text{power} \times \text{time} = 3 \times 25 \times 5 = 375$ Wh **[1/2]**

∴ Electricity consumed in 31 days

$= 375 \times 31 = 11625$ Wh

$= 11.625$ kWh = 11.625 units

∴ Cost of electricity consumed $= 11.625 \times 2.50$

= ₹ 29.06 **[1½]**

54. When a body of mass m moves with a uniform velocity, a force is applied on the body due to which its velocity changes. State how much work is being done by the force?

Sol. Let us suppose that force acts on the body through a distances, which changes its velocity from u to v.

Let the force acts for a time t.

∴ Work done by the force $= F \times s$

$= ma \times s$ $(\because F = ma)$

$= m\left(\frac{v-u}{t}\right) \times s$ **[1]**

Since, $\frac{s}{t}$ = average velocity $= \frac{u+v}{2}$

Therefore, work done by the force

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

$W = \frac{1}{2} m(v^2 - u^2)$ **[1]**

= change in kinetic energy.

It is also called work-energy theorem.

55. A force is applied on a body of mass 20 kg moving with a velocity of 40 ms^{-1}. The body attains a velocity of 50 ms^{-1} in 2s . Determine the work done by the body. **[2013]**

Sol. Given, $m = 20$ kg, $u = 40$ ms^{-1}, $v = 50$ ms^{-1}, $t = 2$ s

According to work-energy theorem,

work done $= \frac{1}{2} mv^2 - \frac{1}{2} mu^2$ **[1]**

$= \frac{1}{2} \times 20 \times (50)^2 - \frac{1}{2} \times 20 \times (40)^2$

$= \frac{1}{2} \times 20 \times 2500 - \frac{1}{2} \times 20 \times 1600 = 25000 - 16000$

$\Rightarrow \quad W = 9 \times 10^3$ J **[1]**

56. Calculate the work required to be done to stop a car of 1500 kg moving at a velocity to 60 kmh^{-1}.

Sol. Change in kinetic energy is equal to the work done W.

Given, initial velocity, $u = 60$ kmh^{-1}

$= 60 \times \frac{5}{18} = \frac{50}{3}$ ms^{-1}

$(\because 1 \text{ kmh}^{-1} = 5/18 \text{ ms}^{-1})$

Final velocity, $v = 0$

So, magnitude of change in kinetic energy $= W$ **[1]**

$= \frac{1}{2} mv^2 - \frac{1}{2} mu^2$

$\Rightarrow \quad W = \frac{1}{2} m(v^2 - u^2)$

$= \frac{1}{2} \times 1500 \times \left(\frac{-50 \times 50}{9}\right)$

$= -\frac{1}{2} \times \frac{1500 \times 50 \times 50}{9}$

$W = -\frac{625000}{3}$

$= -208333.3$ J **[1]**

Hence, the work required to be done to stop a car is 208333.3 J.

57. 6.4 kJ of energy causes a displacement of 64 m in a body in the direction of force in 2.5 s. Calculate
(i) the force applied.
(ii) power in Horse Power (HP). (Take, 1 HP = 746 W) **[2009]**

Sol. As change in kinetic energy is equal to the total work done by work energy theorem, so by applying work energy, then you can get net force.
Given, energy, $E = 6.4\text{ kJ} = 6400\text{ J}$, time, $t = 2.5\text{ s}$
Displacement, $s = 64\text{ m}$, force, $F = ?$,
Power in HP = ?
(i) Energy = Work done = Fs

$$\therefore \quad E = Fs$$
$$\therefore \quad F = \frac{E}{s}$$
$$\Rightarrow \quad F = \frac{6400}{64} = 100\text{ N}$$ **[1]**

(ii) Power, $P = \frac{E}{t} = \frac{6400}{2.5} = 2560\text{ W}$
$$= \frac{2560}{746} = 3.43\text{ HP} \quad (\because 1\text{HP} = 746\text{ W})$$ **[1]**

58. A child drops a stone of 1 kg from the top of a tower. Find its kinetic energy, 5 s after it starts falling. (Take, $g = 10\text{ m s}^{-2}$)

Sol. Given, mass of stone, $m = 1$ kg
Initial velocity, $u = 0$, time, $t = 5$ s
Acceleration due to gravity, $g = 10\text{ m s}^{-2}$
As from equation of motion,
$$v = u + gt \qquad \text{(for downward motion)}$$
$$\Rightarrow \quad v = 0 + 10 \times 5 \quad \Rightarrow \quad v = 50\text{ ms}^{-1}$$ **[1]**
$\therefore$ Kinetic energy of the stone is given by
$$\frac{1}{2}mv^2 = \frac{1}{2} \times 1 \times (50)^2 = 1250\text{ J}$$ **[1]**

59. A mass of 20 kg is dropped from a height of 0.5 m. Find its
(i) velocity and
(ii) KE as it just reaches the ground.

Sol. Given, height, $h = 0.5$ m, mass, $m = 20$ kg
(i) $\therefore v^2 = 2gh = 2 \times 10 \times 0.5 = 10 \qquad (\because g = 10\text{ ms}^{-2})$
$$v = \sqrt{10} = 3.16\text{ ms}^{-1}$$ **[1]**
(ii) We know that, $\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2} \times 20 \times 10 = 100\text{ J}$ **[1]**

60. How fast should a man weighing 60 kg run so that, his kinetic energy is becomes 750 J ?

Sol. Given, mass, $m = 60$ kg, KE = 750 J **[1]**
$$\because \quad \text{KE} = \frac{1}{2}mv^2$$
$$\therefore \quad v = \sqrt{\frac{2\text{KE}}{m}} = \sqrt{\frac{2 \times 750}{60}} = \sqrt{25} = 5\text{ ms}^{-1}$$ **[1]**

61. A moving body weighing 400 N possesses 500 J of KE. Calculate the velocity with which the body is moving (Take, $g = 10\text{ m/s}^2$). **[2012]**

Sol. Calculate mass of the body from the given weight and then calculate velocity from KE.
Given, weight, $w = 400\text{ N} = mg \Rightarrow m = \frac{w}{g}$
Kinetic energy, KE = 500 J
Velocity, $v = ?$ and $g = 10\text{ m/s}^2$ **[1]**
$$\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}\frac{w}{g}v^2 \qquad \left(\because m = \frac{w}{g}\right)$$
$$500 = \frac{1}{2} \times \frac{400}{10} \times v^2$$
$$\Rightarrow \quad v = \sqrt{\frac{500 \times 20}{400}} = 5\text{ m/s}$$ **[1]**

62. Determine the decrease in the kinetic energy of a moving body, if its velocity reduces to 1/3 rd of the initial velocity.

Sol. Let us assume that original kinetic energy,
$$K = \frac{1}{2}mv^2$$
When velocity reduces to 1/3rd of the initial velocity.
$$v' = \frac{1}{3}v$$
$$\therefore \quad \text{New kinetic energy, } K' = \frac{1}{2}m\left(\frac{1}{3}v\right)^2$$
$$= \frac{1}{9}\left(\frac{1}{2}mv^2\right) = \frac{K}{9}$$ **[1]**
$$\therefore \quad \text{Decrease in KE} = K - K' = K - \frac{K}{9} = \frac{8K}{9}$$ **[1]**

63. If two bodies have masses in the ratio 1 : 8, have their speed in the ratio 4 : 5, find the ratio of their KE.

Sol. Given, $m_1/m_2 = 1:8$, and $v_1/v_2 = 4:5$
$$\Rightarrow \quad \frac{\text{KE}_1}{\text{KE}_2} = \frac{1/2\ m_1v_1^2}{1/2\ m_2v_2^2} = \frac{m_1}{m_2}\left(\frac{v_1}{v_2}\right)^2 = \frac{1}{8} \times \left(\frac{4}{5}\right)^2$$
$$= \frac{1}{8} \times \frac{16}{25} = \frac{2}{25} = 2:25$$
$$\therefore \quad \text{KE}_1 : \text{KE}_2$$ **[2]**

64. A rocket is moving up with a velocity v. If the velocity of this rocket is suddenly tripled, what will be the ratio of two kinetic energies?

Sol. Given, $v_1 = v$ and $v_2 = 3v$

$\therefore$ Kinetic energy of rocket, $K = \frac{1}{2}mv^2$

The ratio of two kinetic energies, $\frac{K_1}{K_2} = \frac{\frac{1}{2}mv_1^2}{\frac{1}{2}mv_2^2}$

$$\frac{K_1}{K_2} = \frac{v_1^2}{v_2^2} \qquad (\text{put } v_2 = 3v \text{ and } v_1 = v)$$

$\therefore$ We get $= \frac{v^2}{(3v)^2} = \frac{v^2}{9v^2} = \frac{1}{9} \Rightarrow \frac{K_1}{K_2} = \frac{1}{9}$

Thus, the ratio of two kinetic energies $K_1 : K_2 = 1:9$. ***[2]***

65. The kinetic energy of an object of mass m moving with a velocity of 5 ms^{-1} is 25 J. What will be its kinetic energy when its velocity is increased three times?

Sol. Kinetic energy, $\text{KE} = \frac{1}{2}mv^2$

where, m = mass of object and

and v = velocity of the object.

Here, mass (m) is same in both the cases

$$\therefore \qquad \frac{K_1}{K_2} = \left(\frac{v_1}{v_2}\right)^2$$

Initial kinetic energy, $K_1 = 25 \text{ J}$

Initial velocity, $v_1 = 5 \text{ ms}^{-1}$ ***[1½]***

New kinetic energy, $K_2 = ?$

Final velocity, $v_2 = 3v_1 = 3 \times 5 = 15 \text{ ms}^{-1}$

$$\therefore \qquad \frac{25}{K_2} = \left(\frac{5}{15}\right)^2$$

$$\Rightarrow \qquad \frac{25}{K_2} = \frac{1}{9}$$

$$\Rightarrow \qquad K_2 = 225 \text{ J}$$ ***[1½]***

66. A body of mass 50 kg has a momentum of 3000 kg-ms^{-1}. Determine

(i) the kinetic energy of the body.

(ii) the velocity of the body. ***[2010]***

Sol. (i) Kinetic energy, $E_K = \frac{p^2}{2m} = \frac{(3000)^2}{2 \times 50} = 90000 \text{ J}$ ***[1]***

(ii) Velocity of the body, $v = \frac{p}{m} = \frac{3000}{50} = 60 \text{ ms}^{-1}$ ***[1]***

67. A body of mass 0.2 kg falls from a height of 10 m to a height of 6 m above the ground. Find the loss in potential energy taking place in the body (Take, $g = 10 \text{ ms}^{-2}$).

Sol. Given, mass $m = 0.2$ kg,

height, $h_2 = 10$ m, height, $h_1 = 6$ m

Loss in PE = ? and $g = 10 \text{ m/s}^2$

Loss in PE = $mg(h_2 - h_1)$

$= 0.2 \times 10(10 - 6) = 8 \text{ J}$ ***[2]***

68. The power of a motor pump is 5 kW. How much water per minute the pump can raise to a height of 20 m? (Take, $g = 10 \text{ ms}^{-2}$)

Sol. Given, power, $P = 5$ kW

Time, $t = 60$ s, height, $h = 20$ m

Energy supplied to the pump = Power $\times$ Time

$= 5 \text{ kW} \times 1 \text{ min} = 5000 \text{ W} \times 60 \text{s} = 3 \times 10^5 \text{ J}$

$\therefore$ Energy, $E = mgh$

$$\Rightarrow \qquad m = \frac{E}{gh} = \frac{3 \times 10^5}{10 \times 20} = 1.5 \times 10^3 \text{ kg}$$

So, volume of water lifted per minute $= \frac{\text{mass}}{\text{density}}$

$= \frac{1.5 \times 10^3}{10^3}$ ($\because$ density of water, $\rho = 1000 \text{ kgm}^{-3}$)

$= 1.5 \text{ m}^3$ ***[2]***

69. A shotput player throws a shotput of mass 3 kg. If it crosses the top of wall 2 m high at a speed of 4 ms^{-1}. Compute the total mechanical energy gained by the shotput when it crosses the wall. (Take, $g = 9.8 \text{ ms}^{-2}$)

Sol. Given, $m = 3$ kg, $h = 2$ m, $v = 4 \text{ ms}^{-1}$, $g = 9.8 \text{ ms}^{-2}$

Total mechanical energy = KE + PE $= \frac{1}{2}mv^2 + mgh$

$= \frac{1}{2} \times 3 \times 16 + 3 \times 9.8 \times 2$

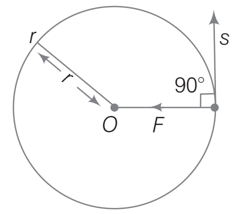
$= 24 + 58.8 = 82.8 \text{ J}$ ***[2]***

70. What is the amount of work done in the following cases? Justify your answer by giving the appropriate reason.

(i) By an electron revolving in a circular orbit of radius r around a nucleus.

(ii) By the force of gravity, when a stone of mass m is dropped from the top of a multi-storeyed building of height h.

Sol. (i) Work done is zero as shown in the figure. When electron revolves around the nucleus, a centripetal force F acts along the radius towards the centre O. The displacement (s) acts tangentially, therefore the angle between the force and the displacement is 90°. Therefore,



$$W = Fs\cos 90° = 0 \quad (\because \cos 90° = 0)$$ **[1]**

(ii) We know that, $W = mgh$

As the stone is dropped, its PE starts to convert into KE.

Let its speed be v, then from $v^2 = 2gh$

(when stone reaches the ground)

$$\Rightarrow \quad \text{KE} = \frac{1}{2}mv^2 = \frac{1}{2} \times m \times 2gh = mgh$$

$$\Rightarrow \quad W = mgh$$ **[1]**

71. At a height of 20 m above the ground, an object of mass 4 kg is released from rest. It is travelling at a speed of 20 ms^{-1} when it hits the ground. The object does not rebound and the gravitational field strength is 10 Nkg^{-1}.

How much energy is converted into heat and sound on impact?

Sol. Given, height above the ground, $h = 20$ m

Mass of the ball, $m = 4$ kg

Speed of the ball while striking the ground,

$$v = 20\ ms^{-1}$$

Acceleration due to gravity, $g = 10\ Nkg^{-1}$

According to law of conservation of energy, all the energy of the ball will be converted into sound and heat energy because the ball does not rebound. **[1]**

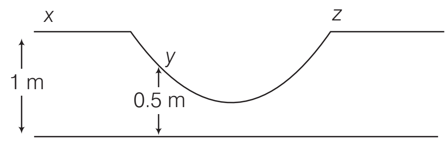
$$\therefore \text{ Energy of the ball} = \frac{1}{2}mv^2$$

$$= \frac{1}{2} \times 4 \times (20)^2$$

$$= 800\ \text{J}$$

Hence, 800 J of energy will be converted into heat and sound. **[2]**

72. A particle is placed at the point A of a frictionless track xyz as shown in figure. It is pushed slightly towards right. Find its speed when it reaches the point y. (Take, $g = 10\ m/s^2$)



Sol. Let us take the gravitational potential energy to be aero at the horizontal surface shown in the figure. The potential energies of the particle at x and y are

$$U_x = Mg\,(1\,\text{m}) \quad \text{and} \quad U_y = Mg\,(0.5\,\text{m})$$ **[1]**

The kinetic energy at the point X is zero. As the track is frictionless,no energy is lost. The normal force on the particle does no work. Applying the principle of conservation of energy,

$$U_x + K_x = U_y + K_y$$

or, $$Mg(1\,\text{m}) = Mg(0.5\,\text{m}) + \frac{1}{2}Mv_y^2$$

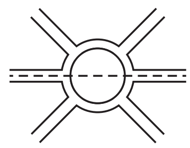
or, $$\frac{1}{2}v_y^2 = g(1\,\text{m} - 0.5\,\text{m})$$

$$= (10\,\text{m/s}^2) \times 0.5\,\text{m}$$

$$= 5\,\text{m}^2/\text{s}^2$$

$$v_y = \sqrt{10}\,\text{m/s}.$$ **[2]**

73. A boy is moving on a straight road against a frictional force of 5 N. After travelling a distance of 1.5 km, he forgot the correct path at a round about of radius 100 m as shown in figure.



However, he moves on the circular path for one and half cycle and then he moves forward up to 2 km. Calculate the work done by him.

Sol. Given, force applied by boy against friction = 5 N

Displacement on the circular path

= one cycle + half cycle = 0 + half cycle

= 0 + diameter of circular path

($\because$ displacement depends on initial and final point)

$= 0 + 2r = 0 + 2 \times 100$ (given, $r = 100$ m)

$= 0 + 200 = 200$ m **[1/2]**

$\therefore$ Total displacement = 1.5 km + 200 m + 2 km

$= 1.5 \times 1000 + 200 + 2 \times 1000$ m ($\because$ 1km = 1000 m)

= 3700 m **[1/2]**

Work done by boy = $Fs\cos\theta$

$$= 5 \times 3700 \times \cos 0° = 18500\ \text{J} \quad \begin{pmatrix} \because \quad \theta° = 0° \\ \therefore \cos 0° = 1 \end{pmatrix}$$ **[1]**

CHAPTER EXERCISE

2 Marks Questions

1. If a body of mass m falls through a height h. Establish an expression for the work done by the gravity.
2. Explain any two examples, when the work done is
   (i) positive and (ii) negative.
3. A body is acted upon by a force. State two conditions under which the work done could be zero.
4. State the two factors on which the power consumed or produced by a body depends. Explain the answer along with the example.
5. Differentiate between watt and watt hour.
6. If an electric heater of power P watt is used for time t hour, so how much energy does it consume? Give your for power consumed in expression (i) kWh and (ii) Joule.
7. What do you understand by electron volt and establish its relation with joule?
8. How does rain water possess kinetic energy?
9. State which would have greater effect on kinetic energy of an object doubling the mass or doubling the velocity?

3 Marks Questions

10. Define 1 erg of work and establish a relationship between erg and joule.
11. Assume that a boy of mass m climbs up a staircase of vertical height h. What is the work done by the boy against the force of gravity? What would have been the work done, if he uses a lift in climbing the same vertical height?
12. Mention the name of three forms of kinetic energy and give one example of each form.
13. Mention the type of energy (i.e., kinetic energy K or potential energy U) possessed in the following cases.
    (i) A moving bus
    (ii) A moving cricket ball
14. What do you mean by gravitational potential energy? Derive an expression for it.
15. Mention the form of energy that is possessed by a body in the following cases
    (i) A shooting arrow
    (ii) A called up spring and an air gun.
    (iii) A fish moving in water.

4 Marks Questions

16. Answer the given questions.
    (i) Determine the kinetic energy of a body of mass 1m moving with uniform velocity of 10 ms^{-1}.
    (ii) If the speed of the car is halved, how does the kinetic energy change?
        (a) Determine the workdone by the force F in moving the block X, 5 m along the slope?
        (b) By how much amount is the potential energy of block X increased?
        (c) Point out the difference in work done by the force and the increase in the potential energy of the block.
17. Named the energy transformation takes in following instruments.
    (i) Steam engine
    (ii) Atomic bomb
    (iii) Dry cell
    (iv) Electric generator

Numerical Based Questions

18. A boy pulls a toy car with force 50 N through a string which makes an angle of 30° with the horizontal, so as to move the toy by the distance of 1m in the horizontal direction. If the string were inclined at an angle of 45° with the horizontal.
    How much work would he apply along the string in order to moves it through the same distance of 1m?
    (Given, $\cos 30° = 0.8668$, $\cos 45° = 0.7071$)
    Ans. 43.34 J, 35.35 J
19. Find the power of an engine required to lift 10^5 kg of coal per hour from a mine 360 m deep. ***Ans.*** 10^5 W

20. Determine the velocity of a body of mass 100 g having a kinetic energy of 20 J. ***Ans.*** 20 m/s

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

(i) carrying the box waits for 5 min for a bus ?

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

(iii) raise the box by 0.5 m in order to place it inside the bus ? ***Ans.*** (i) 0, (ii) 90J, (iii) 100J

22. A force is applied on a body of mass 20 kg moving with a velocity of 40 ms^{-1}. The body attains a velocity of 50 ms^{-1} in 2 s. Calculate the work done by the body. ***Ans.*** 9000 J

23. How much work is required to be done on a ball of mass 50 g to give it a momentum of 600g cms^{-1}? ***Ans.*** 3600 erg

24. When a boy of mass 40 kg runs up height of 50 steps each 10 cm high in 5 s. Determine ***Ans.*** (i) 2000 J, (ii) 400 W

(i) the work done by the boy.

(ii) the power developed.

25. A rocket of 3×10^6 kg mass takes off from a launching pad and acquires a vertical velocity of 1 Km s^{-1} at an altitude of 25 Km. Calculate (i) PE (ii) KE. (Take, $g = 10$ ms^{-2}). ***Ans.*** (i) 7.5×10^{11} J, (ii)1.5×10^{12} J

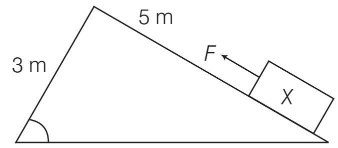
26. A metal ball of mass 2 kg is allowed to fall freely from rest from a height of 5 m above the ground.

(i) Determine the potential energy possessed by the ball when initially at rest.

(ii) What is the kinetic energy of the ball just before hitting the ground ?

(iii) What happens to the mechanical energy after the ball hits the ground and comes to rest? ***Ans.*** (i) 100 J, (ii) 100 J, (iii) 1000 J

27. There is a block X, whose weight is 100 N, is pulled up a slope of length 5 m by a constant force F (=150 N) as given in the figure.



(i) Determine the workdone by the force F in moving the block X, 5 m along the slope?

(ii) By how much amount is the potential energy of block X increased?

(iii) Point out the difference in work done by the force and the increase in the potential energy of the block. ***Ans.*** (i) 500 J, (ii) 300 J, (iii) The difference, i.e., 200 J energy is used in doing work against frictional force

28. A stone of mass 500 g is thrown vertically upwards with a velocity of 15 ms^{-1}. Calculate

(i) the PE at the greatest height

(ii) KE on reaching the ground

(iii) the total energy at its half way point. ***Ans.*** (i) 56. 25 J, (ii) 56. 25 J, (iii) 56.25 J