Chapter 4

WORK AND ENERGY

LEARNING OBJECTIVES

At the end of this chapter the students will be able to:

Understand the concept of work in terms of the product of a force and displacement in the direction of the force.

Understand and derive the formula Work = wd = mgh for work done in a gravitational field near Earth's surface.

Relate power to work done.

Define power as the product of force and velocity.

Quote examples of power from everyday life.

Explain the two types of mechanical energy.

Understand the work-energy principle.

Derive an expression for absolute potential energy.

Define escape velocity.

Give examples of conservation of energies from everyday life.

Describe some non-conventional sources of energy.

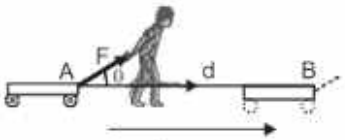
Q.1 Define the term work done. Describe the special cases when the work done is positive, negative and zero.

Ans. **WORK DONE BY A CONSTANT FORCE**

Work done on a body by a constant force is defined as;

"The product of the magnitude of the displacement and the component of the force in the direction of the displacement."

Consider, an object which is being pulled by a constant force F, at an angle θ to the direction of motion. The force moves the object from A to B through a displacement $\vec{d}$, as shown in figure.



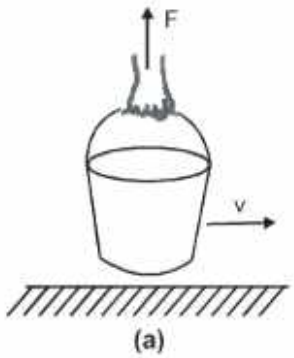
Since $W = Fd$

$W = (F \cos \theta)\, d$

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

Where $F \cos \theta$ is the component of the force in the direction of $\vec{d}$. So,

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



(a)

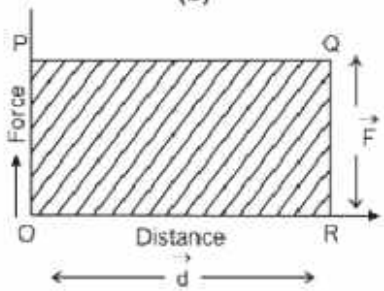
So work is also defined as; "The dot product of force $\vec{F}$ and displacement $\vec{d}$." When a constant force acts through a distance $\vec{d}$, the event can be plotted on a simple graph as show in figure. The displacement is plotted along the x-axis and the force along y-axis.



(b)

As the force is constant so the graph will be a horizontal straight line. Clearly, the shaded area in figure is also Fd.

Hence area under a force-displacement graph can be taken to represent the work done by the force. If $\vec{F}$ is not in the direction of the displacement the graph is plotted between $F \cos \theta$ and d.



From the definition of work we find the following important results

(i) Work is a scalar quantity.

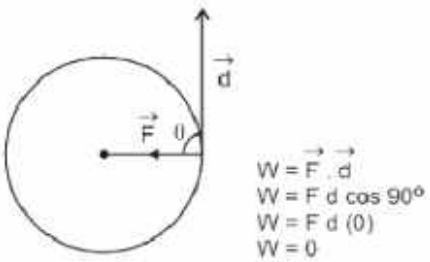
(ii) If $\theta < 90^\circ$, work is done and it is said to be positive work e.g., work is maximum when F is parallel to the direction of motion of the body i.e., $\theta = 0^\circ$.

$W = F\, d \cos 0^\circ$

$W = Fd \times 1$

$W = F\, d$

(iii) If $\theta = 90^\circ$, no work is done



Example

Work done by the centripetal force is 0 and when a person holding a pail by force F is moving forward then $\theta = 90^\circ$.

$$W = 0$$

(iv) If $\theta > 90^\circ$, the work done is said to be negative.

Example

When a body moves against the force of friction on a horizontal plane i.e., $\theta = 180^\circ$.

$$\therefore \quad W = F\,d\cos 180^\circ$$

$$W = F\,d\,(-1)$$

$$W = -F\,d$$

(v) SI unit of work is Nm known as joule (J).

$$\boxed{1J = 1N \times 1m}$$

Joule

The SI unit of work is Joule.

The amount of work done is 1 J when a force of 1N is acting on a body displaces it, through a distance of 1m.

$$\therefore \quad 1J = Nm$$

Dimensions

$$[W] = J$$
$$= Nm$$
$$= kg\,m/s^2 \times m$$
$$= kg\,m^2/s^2 \qquad (\because F = ma, \quad N = kg\,m/s^2)$$
$$= [ML^2T^{-2}]$$

Q.2 Explain how can you calculate the work done by a variable force?

Ans. WORK DONE BY A VARIABLE FORCE

Variable Force

"If magnitude or direction of force changes during the process of the doing work, is called variable force."

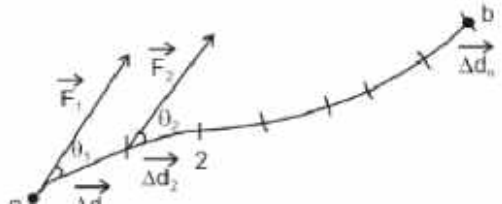
Example

(i) As a rocket moves away from the earth, work is done against the force of gravity, which varies as the inverse square of the distance from

Earth's centre $\left(F = \dfrac{G\,Mm}{r^2}\right)$

(ii) Force exerted by a spring increases with the amount of stretch ($F \propto x$).

Consider the path of a particle in the xy-plane as it



intervals.

During each small interval, the force is supposed to be approximately constant. So the work done by the first interval can then be written as;

$$\Delta W_1 = F_1 . \Delta d_1 = F_1 \cos \theta_1 \Delta d_1$$

and in the second interval;

$$\Delta W_2 = F_2 . \Delta d_2 = F_2 \cos \theta_2 \Delta d_2$$

and so on. The total work done in moving the object can be calculated by adding all these terms

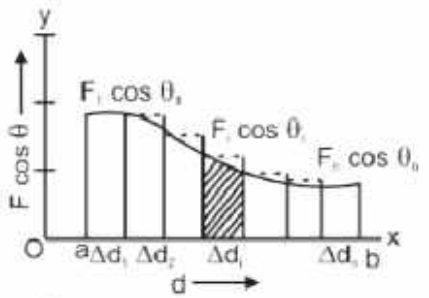
$$W_{total} = \Delta W_1 + \Delta W_2 + ... + \Delta W_n \quad ..... (i)$$

$$= F_1 \cos \theta_1 \Delta d_1 + F_2 \cos \theta_2 \Delta d_2 + ... + F_n \cos \theta_n d_n$$

$$W_{total} = \sum_{i=1}^{n} F_i \cos \theta_i \Delta d_i \quad ..... (ii)$$

We can examine this graphically by plotting F cos θ verses d as shown in Fig. The displacement d has been subdivided into n equal intervals. The value of F cos θ at the beginning of each interval is indicated in the figure by horizontal lines.

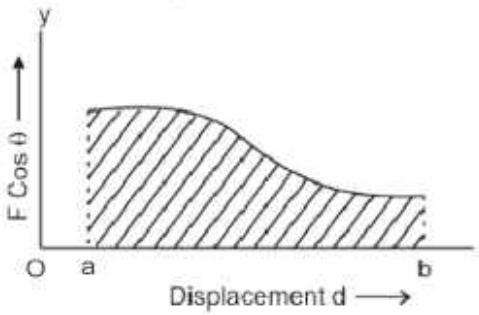
Now the ith shaded rectangle has an area $F_i \cos \theta_i \Delta d_i$ which is the work done during the ith interval. Thus, the work done by given equation (ii) equals the sum of the areas of all the rectangles. If we subdivide the distance into a large number of intervals so that each Δd becomes very small, the work done given by equation (ii) becomes more accurate. If we let each Δd to approach zero then we obtain an exact result for the work done, such as



$$W_{total} = \lim_{\Delta d \to 0} \sum_{i=1}^{n} F_i \cos \theta_i \Delta d_i$$

In this limit Δd approaches to zero, the total area of the rectangles approaches the area between the F cos θ curve and d-axis from a to b as show in figure shaded.

Thus, the work done by a variable force in moving a particle between two points is equal to the area under the F cos θ verses d curve between the two points a and b as shown in figure.

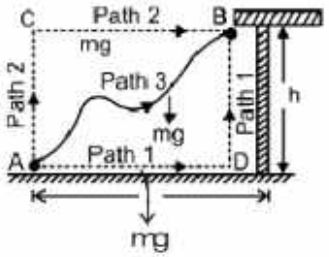


Q.3 Prove that the work done by gravitational field is independent of the path followed by the body.

Ans. WORK DONE BY GRAVITATIONAL FIELD

"The space around the Earth in which its gravitational force acts on a body, is called the gravitational field."

When an object is moved in the gravitational field, the work is done by the gravitational force. if displacement is in the direction of the gravitational force, the work is positive. If the displacement is against the gravitational force, the work is negative.



Consider an object of mass "m" being displaced with constant velocity from point A to B along various paths in the presence of a gravitational force, as shown in figure.

In this case gravitational force is equal to the weight "mg" of the object.

Work Done Along Path ADB

The work done by the gravitational field along the path ADB can be divided into two steps i.e., the 1st step from A to D, the work done along this path is zero because the weight mg is perpendicular to this path i.e.,

$$\begin{aligned} W_{AD} &= \vec{F} \cdot \vec{d} \\ &= Fd \cos 90^\circ \\ &= mgd\,(0) \\ &= 0 \end{aligned}$$

and the 2nd step is from D to B, the work done along this path is

$$\begin{aligned} W_{DB} &= \vec{F} \cdot \vec{d} \\ &= Fd \cos 180^\circ \\ &= mgh\,(-1) \\ &= -mgh \end{aligned}$$

The total work done along ADB is

$$\begin{aligned} W_{ADB} &= W_{AD} - W_{DB} \\ &= 0 + (-mgh) \\ &= -mgh \qquad \ldots\ldots (i) \end{aligned}$$

Work Done Along Path ACB

The work done by the gravitational field along the path ACB can be divided into two steps i.e., one from A to C, the work done along AC is

$$\begin{aligned} W_{AC} &= \vec{F} \cdot \vec{d} \\ &= Fd \cos 180^\circ \\ &= mgh\,(-1) \\ &= -mgh \end{aligned}$$

and the second step from C to A the work done along CA is zero because

$$W_{CA} = \vec{F} \cdot \vec{d}$$

Thus the total work done along ACB is

$$W_{ACB} = W_{AC} + W_{CB}$$
$$= -mgh + 0$$
$$W_{ACD} = -mgh \quad \ldots\ldots \text{(ii)}$$

Work Done Along the Curved Path

Imagine the curved path, to be divided into a series of horizontal and vertical steps as shown in figure. There is no work done along the horizontal steps, because mg is perpendicular to the displacement for these steps. Work is done by the force of gravity only along the vertical displacement.

$$W_1 = \vec{F} \cdot \vec{d}$$
$$= mg\,\Delta y_1 \cos 180^\circ$$
$$= -mg\,\Delta y_1$$

Similarly

$$W_2 = -mg\,\Delta y_2$$
$$\vdots \qquad \vdots \quad \vdots$$
$$W_n = -mg\,\Delta y_n$$
$$W_{AB} = W_1 + W_2 + \ldots\ldots + W_n$$
$$= -mg\,\Delta y_1 - mg\,\Delta y_2 \ldots\ldots mg\,\Delta y_n$$
$$= -mg(\Delta y_1 + \Delta y_2 + \ldots\ldots + \Delta y_n)$$

As $\Delta y_1 + \Delta y_2 + \ldots\ldots + \Delta y_n = h$

$\therefore$ $W_{AB} = -mgh \quad \ldots\ldots \text{(iii)}$

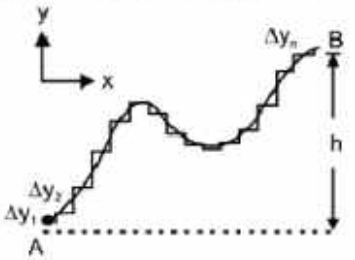
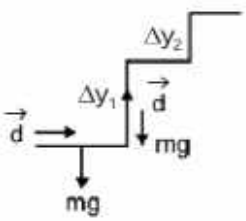


Fig. A smooth path may be replaced by a series of infinitesimal x and y displacements. Work is done only during they displacements.



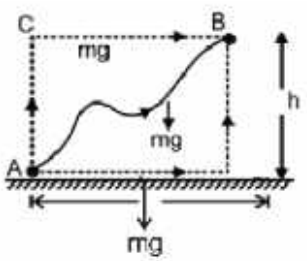
We conclude that

From eq. (i), (ii) and (iii)

"Work done in the Earth's gravitational field is independent of the path followed by the body".

Q.4 Prove that work done along the closed path in a gravitational field is zero.

Ans. Consider a closed path ABCA in a gravitational field. In order to calculate the work done along a closed path, we proceed as.



The total work done along this path is

$$W_{total} = W_{A \to B} + W_{B \to C} + W_{C \to A}$$

Since $W_{A \to B} = -mgh$

and $W_{B \to C} = \vec{F} \cdot \vec{d}$

$$= Fd \cos 90^\circ$$

and $W_{C \to A} = \vec{F} \cdot \vec{d}$

$= Fd \cos 0°$

$= mgh\,(0)$

$= mgh$

Thus $W_{total} = -mgh + 0 + mgh$

$= 0$

Thus the work done along a closed path is zero.

Conservative Field

"The field in which the work done is independent of the path followed and work done in a closed path be zero, is called a conservative field."

For Example:

Gravitational field and electrostatic field.

Note: *The frictional force is a non-conservative force, because if an object is moved over a rough surface between two points along different paths, the work done against the frictional force certainly depends on the path followed.*

Q.5 Define power and give the values of average power and instantaneous power. Also give the unit of power.

Ans. **POWER**

"The rate of doing work is known as power." **(OR)** Power is the measure of the rate at which work is being done. If work ΔW is done in the time interval Δt then average power P_{ave} during the interval Δt is defined as

$$P_{ave} = \frac{\Delta W}{\Delta t}$$

Instantaneous Power

If work is expressed as a function of time, the instantaneous power P at any instant is defined as:

$$P_{inst} = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t}$$

Average power is equal to instantaneous power if work is done at constant rate.

Power and Velocity

For Your Information

Conservative Forces

Gravitational force

Elastic spring force

Electric force

Non-Conservative Forces

Frictional force

Air resistance

Tension in a string

Normal force

Propulsion force of a rocket

Propulsion force of a motor

For Your Information

Approximate Powers

Device	Power (W)
Jumbo Jet Aircraft	1.3×10^8

Colour TV	120
Flash light (two cells)	1.5
Pocket calculator	7.5×10^{-4}

exert, a constant force $\vec{F}$ on the boat, it moves with constant velocity $\vec{V}$. The power delivered by the motor at any instant is given by;

$$P = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t}$$

Since, $\Delta W = \vec{F} \cdot \Delta \vec{d}$

$$\therefore \quad P = \lim_{\Delta t \to 0} \frac{\vec{F} \cdot \Delta \vec{d}}{\Delta t}$$

$$= \lim_{\Delta t \to 0} \vec{F} \cdot \frac{\Delta \vec{d}}{\Delta t}$$

$$= \vec{F} \cdot \lim_{\Delta t \to 0} \frac{\Delta \vec{d}}{\Delta t} \quad \left(\lim_{\Delta t \to 0} \frac{\Delta \vec{d}}{\Delta t} = \vec{V} \right)$$

$$P = \vec{F} \cdot \vec{V}$$

Hence power is also defined as: "The dot product of force and velocity."

Power is a scalar quantity.

Unit

SI unit of power is watt.

Do You Know?

It takes about 9×10^9 J to make a car and the car then uses about 1×10^{12} J of energy to complete its lifetime

Watt

"Rate of doing 1J of work in one second is called watt."

$$1 \text{ W} = 1 \text{ J/1 sec}$$

Dimensions

$$P = \text{Watt}$$

As $P = J/s$

$$[P] = \frac{Nm}{Sec} \quad (\because 1J = Nm)$$

$$= \frac{kg\, m/s^2 \times m}{s}$$

$$= kg\, m^2/s^3$$

$$= [ML^2/T^3]$$

$$= [ML^2 T^{-3}]$$

In electrical measurements, the unit of work is watt x second

Commercial unit of electrical energy is kilowatt hour (k w h).

Kilowatt Hour

One kilowatt hour is the work done in one hour by an agency whose power is one kilowatt.

$\therefore$ 1 k w h = 1000 W x 3600 sec

= 36×10^5 W sec

= 36×10^5 J ($\because$ W sec = J)

= 3.6×10^6 J

= 3.6 M J

1 h p = 746 watt

Q.6 Define energy. What do you mean by K.E and P.E with its formula?

Ans. **ENERGY**

"Energy of a body is its capacity to do work."

For example; mechanical, heat, sound energies etc.

There are two basic forms of mechanical energy

1. Kinetic energy
2. Potential energy

Kinetic Energy

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

Mathematically:

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

Potential Energy

The energy possessed by a body due to its position is called potential energy. There are two types of potential energy:

(i) Gravitational potential energy.

(ii) Elastic potential energy.

Gravitational Potential Energy

The energy possessed by a body because of its position in a force field. e.g. gravitational field. The potential energy due to gravitational field near the surface of the Earth at a height h is given by the formula.

$$P.E. = mgh$$

arbitrary position which is assigned the value of zero P.E. In the present case, this reference level is the surface of the Earth as position of zero P.E. In some cases a point at infinity from the Earth can also be chosen as zero reference level.

Elastic Potential Energy

The energy stored in a compressed spring is the potential energy possessed by the spring due to its compressed or stretched state. This form of energy is called the elastic potential energy.

Source	Energy (J)
Burning 1 ton coal	30×10^9
Burning 1 litre petrol	5×10^7
K.E. of car at 90 km h^{-1}	1×10^6
Running person at 10 km h^{-1}	3×10^2
Fission of one atom of uranium	1.8×10^{-11}
K.E. of a molecule of air	6×10^{-21}

Q.7 Derive work energy relation or principle.

Ans. **WORK-ENERGY PRINCIPLE**

This principle states that, work done on the body equals change in its K.E.

Consider a body of mass "m" moving with velocity "V_i". A force F acting through a distance d increases the velocity to V_f, then by using third equation of motion.

$$2ad = V_f^2 - V_i^2$$

$$d = \frac{1}{2a}\left(V_f^2 - V_i^2\right) \quad \ldots\ldots\ldots (1)$$

As $F = ma$ $\ldots\ldots\ldots (2)$

Multiply equation (1) with equation (2)

$$Fd = \frac{ma}{2a}\left(V_f^2 - V_i^2\right)$$

$$W = \frac{1}{2}m\left(V_f^2 - V_i^2\right) \qquad (\because Fd = W)$$

$$= \frac{1}{2}mV_f^2 - \frac{1}{2}mV_i^2$$

$$= K.E_f - K.E_i$$

$$\therefore \quad W = \text{Change in K.E.}$$

This is known as work–energy principle.

Tid-bits

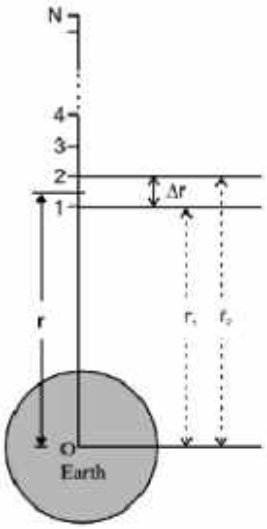


Note: *If a body is raised up from the Earth's surface, the work done changes the gravitational potential energy and if a spring is compressed, the work done on it equals the increase in its elastic potential energy.*

Q.8 Define absolute potential energy. Calculate the value of absolute potential in the gravitational field.

Ans. **ABSOLUTE POTENTIAL ENERGY**

Work done by the gravitational force is true only near the surface of the earth where the gravitational force is nearly constant. But if the body is displaced through a large distance from point 1 to N as shown in figure. Then the gravitational force will not remain same, since it varies inversely to the square of the distance $\left(F_g = \frac{G M m}{r^2}\right)\left(\because \quad F_g \propto \frac{1}{r^2}\right)$.



Thus we divide the distance between point 1 and N into small steps each of length Δr so that the force remains constant for each small step. Hence, the total work done can be calculated by adding the work done during all these steps.

If r_1 and r_2 are distances of points 1 and 2 respectively from the centre O of the Earth as shown in Fig.

The distance, between the centre of 1st step and the centre of Earth will be

$$r = \frac{r_1 + r_2}{2} \ldots\ldots (1) \text{ (average distance)}$$

As $\Delta r = r_2 - r_1$

$$r_2 = r_1 + \Delta r$$

Putting this value of r_2 in equation (1)

$$\therefore \quad r = \frac{r_1 + r_1 + \Delta r}{2}$$

$$r = \frac{2r_1 + \Delta r}{2}$$

$$r = \frac{2r_1}{2} + \frac{\Delta r}{2}$$

$$\therefore \quad r = r_1 + \frac{\Delta r}{2}$$

Squaring both sides

$$r^2 = r_1^2 + \left(\frac{\Delta r}{2}\right)^2 + 2r_1 \frac{\Delta r}{2}$$

$$r^2 = r_1^2 + \frac{(\Delta r)^2}{4} + r_1 \Delta r$$

Since Δr is very small so $\frac{\Delta r^2}{4}$ is neglected.

$$\therefore \quad r^2 = r_1^2 + r_1 \Delta r$$

Putting value of Δr

$$\therefore \quad r^2 = r_1^2 + r_1 (r_2 - r_1)$$

$$\therefore \quad r^2 = r_1^2 + r_1 r_2 - r_1^2$$

$$r^2 = r_1 r_2$$

The gravitational force F at the centre of this step is

$$F = \frac{G\,Mm}{r^2}$$

Putting value of r^2

$$\therefore \quad F = \frac{G\,Mm}{r_1 r_2}$$

As this force is assumed to be constant during the interval Δr, so the work done is

$$W_{1 \to 2} = \vec{F} \cdot \Delta \vec{r}$$

$$= F \Delta r \cos 180^\circ$$

$$= F \Delta r (-1)$$

$$= -F \Delta r$$

Putting the value of F and Δr

$$\therefore \quad W_{1 \to 2} = -\frac{G\,Mm}{r_1 r_2}(r_2 - r_1)$$

$$= -G\,Mm\left(\frac{r_2}{r_1 r_2} - \frac{r_1}{r_1 r_2}\right)$$

$$= -G\,Mm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Similarly,

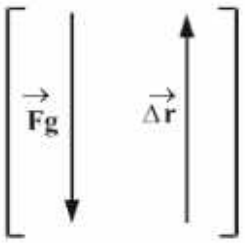
$$W_{2 \to 3} = -G\,Mm\left(\frac{1}{r_2} - \frac{1}{r_3}\right)$$

$$\vdots \qquad \vdots \qquad \vdots$$

Do You Know?



There is more energy reaching Earth in 10 days of sunlight than in all the fossil fuels on the Earth.



Tid-bits

Hence, $W_{total} = W_{1\to2} + W_{2\to3} + \ldots\ldots + W_{N-1\to N}$

$$\therefore \quad W_{total} = -G\,Mm\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-G\,Mm\left(\frac{1}{r_2}-\frac{1}{r_3}\right)\ldots\ldots-G\,Mm\left(\frac{1}{r_{N-1}}-\frac{1}{r_N}\right)$$

$$W_{total} = -G\,Mm\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)+\left(\frac{1}{r_2}-\frac{1}{r_3}\right)+\ldots\ldots+\left(\frac{1}{r_{N-1}}-\frac{1}{r_N}\right)\right]$$

$$= -G\,Mm\left[\frac{1}{r_1}-\frac{1}{r_2}+\frac{1}{r_2}-\frac{1}{r_3}+\ldots\ldots+\frac{1}{r_{N-1}}-\frac{1}{r_N}\right]$$

$$= -G\,Mm\left(\frac{1}{r_1}-\frac{1}{r_N}\right)$$

If the point N is situated at an infinity distance from the centre of the earth then

$$r_N = \infty$$

$$\frac{1}{r_N} = \frac{1}{\infty} = 0$$

$$\therefore \quad W_{total} = -G\,Mm\left(\frac{1}{r_1}-0\right)$$

$$W_{total} = -\frac{G\,Mm}{r_1}$$

Therefore, gravitational potential energy of a body at a distance 'r' from the center of Earth is;

$$U = -\frac{G\,Mm}{r}$$

This is also known as the absolute value of potential energy.

(i) When r increases, the gravitational force does negative work and U increases i.e., becomes less negative.

(ii) When r decreases, the body falls towards the Earth, the work, is positive and potential energy decreases i.e., becomes more negative.

(iii) The absolute P.E. on the surface of Earth is found by putting r = R (Radius of Earth).

$$\therefore \quad U = -\frac{G\,Mm}{R}$$

Negative sign shows that Earth's gravitational field for mass 'm' is attractive.

Q.9 Define escape velocity. Also derive the relation for the escape velocity.

Ans. ESCAPE VELOCITY

"The minimum initial velocity of an object with which it goes out of the Earth's gravitational field, is known as escape velocity."

The escape velocity corresponds to initial K.E. gained by the body which carries it to an infinite

We know that work done in lifting a body from Earth's surface to an infinite distance is equal to increase (change) in its potential energy. i.e.,

$$\therefore \quad \text{Increase in P.E.} = 0 - \left(-\frac{G\,Mm}{R} \right)$$

$$= G\frac{Mm}{R}$$

The body will escape out of the gravitational field if the initial K.E. of the body is equal to absolute P.E.

$$\frac{1}{2} m V_{esc}^2 = \frac{G\,Mm}{R}$$

$$V_{esc}^2 = \frac{2\,G\,M}{R}$$

Taking square root

$$V_{esc} = \sqrt{\frac{2\,G\,M}{R}} \quad \ldots\ldots\ldots (1)$$

As mass of earth is

$$M = \frac{g\,R^2}{G}$$

$$\therefore \quad G\,M = g\,R^2$$

Putting this value in equation (1)

$$\therefore \quad V_{esc} = \sqrt{\frac{2\,g\,R^2}{R}}$$

$$V_{esc} = \sqrt{2\,g\,R}$$

As $R = 6.4 \times 10^6$ m

$g = 9.8$ m / s^2

$$\therefore \quad V_{esc} = \sqrt{2 \times 9.8 \times 6.4 \times 10^6}$$

$$V_{esc} = 11.2 \times 10^3 \text{ m / s}$$

or $V_{esc} = 11.2$ km / s

The value of V_{esc} comes at to be approximately 11 km s^{-1}.

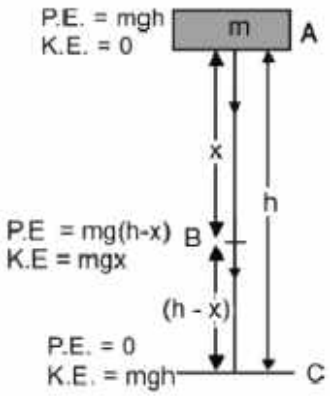
Note: *Escape velocity does not depend on mass of the object.*

For Your Information	
Some Escape Speeds (kms^{-1})	
Heavenly body	**Escape speed**
Moon	2.4
Mercury	4.3
Mars	5.0
Venus	10.4
Earth	11.2
Uranus	22.4
Naptuna	25.4
Satum	37.0
Jupiter	61

Q.10 Explain the phenomena inter conversion of potential energy and kinetic energy.

Ans. **INTER CONVERSION OF POTENTIAL ENERGY AND KINETIC ENERGY**

Consider a body of mass 'm' at rest, at a height 'h' above the surface of the Earth as shown in figure. At the position A, the body has P.E. = mg h with respect to the earth and K.E. = 0. We release the body and as it falls, we can examine how K.E. and P.E. associated with it interchange.



$$\text{P.E.} = mg(h - x)$$

$$\text{K.E.} = \frac{1}{2} m V_B^2$$

V_B can be calculated by

Using $V_f^2 = V_i^2 + 2gS$ ..... (1)

Here $V_f = V_B$

$V_i = 0$

$S = x$

Putting these values in equation (1)

$$\therefore \quad V_B^2 = 0 + 2gx$$

$$= 2gx$$

$\therefore$ K.E. at point B is

$$\therefore \quad \text{K.E.} = \frac{1}{2} m V_B^2$$

$$\text{K.E.} = \frac{1}{2} m (2gx)$$

$$= mgx$$

Total energy at B = P.E. + K.E.

$$= mg(h - x) + mgx$$

$$= mgh - mgx + mgx$$

$$= mgh$$

At position 'C', just before the body strikes the Earth, P.E. = 0 and K.E. $= \frac{1}{2} m V_C^2$ where V_C can be found out by the following expression.

$$V_C^2 = V_i^2 + 2gh = 2gh$$

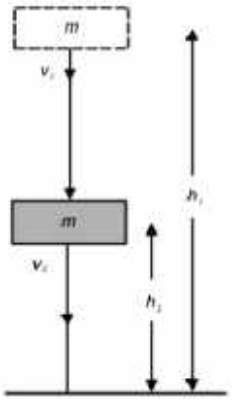
As $V_i = 0$

i.e., $$\text{K.E.} = \frac{1}{2} m V_C^2$$

$$= \frac{1}{2} m \times 2gh$$

$$= mgh$$

Thus at point C, K.E. is equal to the original value of the P.E. of the body. Actually when a body falls, its velocity increases i.e., the body is being accelerated under the action of gravity. The increase in velocity results in the increase in its K.E. On the other hand, as the body falls, its height decreases and hence, its potential energy also decreases. Thus, from figure



$$\text{Loss in P.E.} = \text{Gain in K.E.}$$

$$mg(h_1 - h_2) = \frac{1}{2} m \left(V_2^2 - V_1^2 \right)$$

Where V_1 and V_2 are velocities of the body at the height h_1 and h_2 respectively. This result is truly only when frictional force is not considered.

If we assume that a frictional force 'f' is present during the downward motion, then a part of P.E. is used in doing work against friction equal to f h. The remaining P.E. = mg h – f h is converted into K.E.

$$\text{Hence,} \quad mg\,h - f\,h = \frac{1}{2} m V^2$$

$$\text{or} \quad mg\,h = \frac{1}{2} m V^2 + f\,h$$

Thus, Loss in P.E. = Gain in K.E. + Work done against friction.

CONSERVATION OF ENERGY

The kinetic and potential energies are both different forms of the same basic quantity, i.e., mechanical energy. Total mechanical energy of a body is the sum of the kinetic energy and potential energy. In our previous discussion of a falling body, potential energy may change into kinetic energy and vice versa, but the total energy remains constant. Mathematically,

Total energy = P.E. + K.E. = Constant

This is a special case of the law of conservation of energy which states that:

"Energy cannot be destroyed. It can be transformed from one kind into another, but the total amount of energy remains constant".

This is one of the basic laws of physics. We daily observe many energy transformations from one form to another. Some forms, such as electrical and chemical energy, are more easily transferred than others, such as heat. Ultimately all energy transfers result in heating of the environment and energy is wasted. For example, the P.E. of the falling object changes to K.E., but on striking the ground, the K.E. changes into heat and sound. If it

For Your Information

Source of energy	Original source
Solar	Sun
Bio mass	Sun
Fossil fuels	Sun
Wind	Sun
Waves	Sun
Hydro electric	Sun
Tides	Moon
Geothermal	Earth

Energy Sources

Renewable	Non-renewable
Hydroelectric	Coal
Wind	Natural gas
Tides	Oil
Geothermal*	Uranium
Biomass	Oil shale
Sunlight	Tar sands
Ethanol/Methanol**	

* Individual fields may run off

Q.11 Describe briefly the non-conventional energy sources.

Ans. **NON-CONVENTIONAL ENERGY SOURCES**

These are the energy sources not very common these days. However, it is expected, that these sources will contribute substantially to the world energy demand of the future. Some of these are introduced briefly here.

Energy From Tides

One very novel example of obtaining energy from gravitational field is the energy obtained from tides. Gravitational force of the moon gives rise to tides in the sea. The tides raise the water in the sea roughly twice a day. If the water at the high tide is trapped in a basin by constructing a dam, then it is possible to use this as a source of energy. The dam is filled at high tide and water is released in a controlled way at low tide to drive the turbines. At the next high tide the dam is filled again and the in rushing water also drives turbines and generates electricity as shown systematically in the figure.

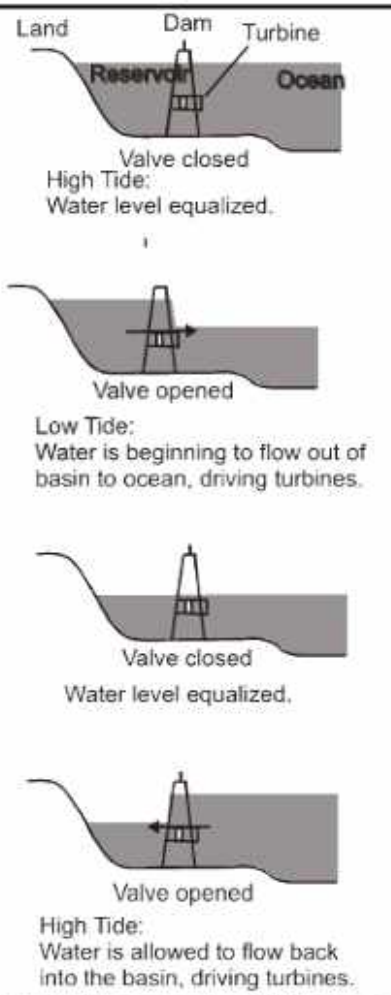
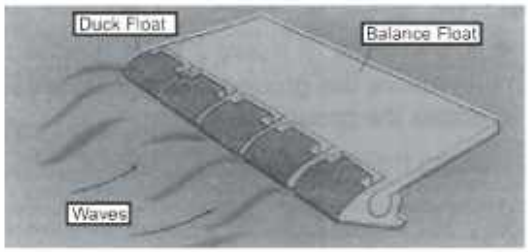


Fig. Tidal power plant. Turbine are located inside the dam.

Energy From Waves

The tidal movement and the winds blowing across the surface of the ocean produce strong water waves. Their energy can be utilized to generate electricity. A method of harnessing wave energy is to use large floats which move up and down with the waves. One such device invented by Professor Salter is known Salter's duck (figure). It consists of two parts (i) Duck float (ii) Balance float.



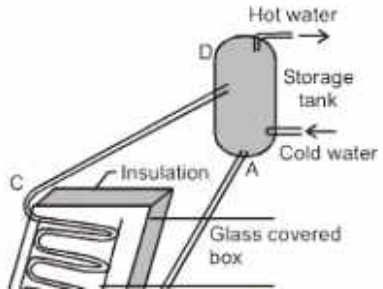
The wave energy makes duck float move relative to the balance float. The relative motion of the duck float is then used to run electricity generators.

Do You Know?

The pull of the Moon does not only pull the sea up and down. This tidal effect can also distort the continents pulling land up and down by as much as 25 cm.

Solar Energy

The Earth receives huge amount of energy directly from the Sun each day. Solar energy at normal incidence outside the Earth's atmosphere is about 1.4 kWm^{-2} which is referred as solar constant. While passing through the atmosphere, the total energy is reduced due to reflection, scattering and absorption by dust particles, water vapours and other gases. On a clear day at noon, the intensity of the solar energy reaching the Earth's surface is about $1kWm^{-2}$. This energy can be used directly to heat water using large solar reflectors and thermal absorbers or be converted to electricity. In one method



Much higher temperature can be achieved by concentrating solar radiation on to a small surface area by using huge reflectors (mirrors) or lenses to produced steam for running a turbine.

The other method is the direct conversion of sunlight into electricity through the use of semi conductor devices called solar cells also known as photo voltaic cells. Solar cells are thin wafers made from silicon. Electrons in the silicon gain energy from sunlight to create a voltage. The voltage produced by a single voltaic cell is very low. In order to get sufficient high voltage for practical use, a large number of such cells are connected in series forming a solar cell panel.



(b)

For cloudy days or nights, electric energy can be stored during the Sun light in Nickle cadmium batteries by connecting them to solar panels. These batteries can then provide power to electrical appliances at nights or on cloudy days.

Solar cells, although, are expensive but last a long time and have low running cost. Solar cells are used to power satellites having large solar panels which are kept facing the Sun figure (b). Other examples of the use of solar cells are remote ground based weather stations and rain forecast communication systems. Solar calculators are also in use now a days.

Q.12 Explain the energy from biomass.

Ans. **ENERGY FROM BIOMASS**

Biomass is a potential source of renewable energy. This includes all the organic materials such as crop residue, natural vegetation, trees, animal dung and sewage. Biomass energy or bio conversion refers to the use of this material as fuel or its conversion into fuels.

There are many methods used for the conversion of biomass into fuels. But the most common are:

(1) Direct combustion.

(2) Fermentation.

Direct combustion method is usually applied to get energy from waste products commonly known as solid waste. It will be discussed in the next section.

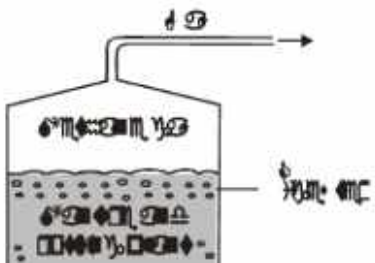
Biofuel such as ethanol (alcohol) is a replacement of gasoline. It is obtained by fermentation of biomass using enzymes and by decomposition through bacterial action in the absence of air (oxygen).

The rotting of biomass in a closed tank called a digester produces Biogas which can be piped out to use for cooking and heating (figure).

For Your Information

The rapid growth of human population has put a strain on our natural resources. A sustainable society minimizes waste and maximizes the benefit from each resource. Minimizing the use of energy is an other method of conservation we can save energy by,

(i) turning off lights and electrical appliances when not in use
(ii) using fluorescent bulbs instead of incandescent bulbs
(iii) using sunlight in offices, commercial centers and houses during daylight hours
(iv) taking short hot shawers.



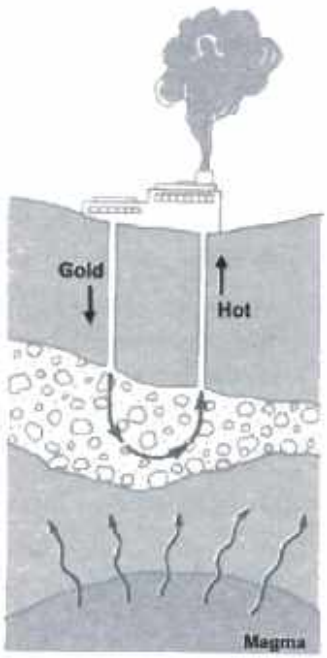
Energy from Waste Products

Waste products like wood waste, crop residue, and particularly municipal solid waste can be used to get energy by direct conversion. It is probably the most commonly used conversion process in which waste material is burnt in a confined container. Heat produced in this way is directly utilized in the boiler to produce steam that can run turbine generator.

Q.13 Explain geothermal energy.

Ans. **GEOTHERMAL ENERGY**

This is the heat energy extracted from inside the Earth in the form of hot water or steam. Heat within the Earth is generated by the following processes.



1. Radioactive Decay

The energy, heating the rocks, is constantly being released by the decay of radioactive elements.

2. Residual Heat of the Earth

At some places hot igneous rocks, usually within 10 km of the Earth's surface, are in a molten and partly molten state. They conduct heat energy from the Earth's interior which is still very hot. The temperature of these rocks is about 200°C or more.

3. Compression of Material

The compression of material deep inside the Earth also causes generation of heat energy.

In some place water beneath the ground is in contact with hot rocks and is raised to high temperature and pressure. It comes to the surface as hot springs, geysers, or steam vents. The steam can be directed to turn turbines of electric generators.



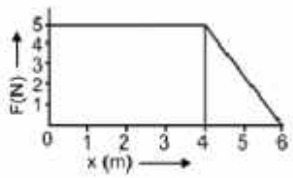
Where water is not present and hot rocks are not very deep, the water is pumped down through them which returns as steam (figure). The steam then can be used to drive turbines or for direct heating.

An interesting phenomenon of geothermal energy is a geyser. It is a hot spring that discharges steam and hot water, intermittently releasing an explosive column into the air (figure). Most geysers erupt at irregular intervals. They usually occur in volcanic regions. Extraction of geothermal heat energy often occurs closer to geyser sights. This extraction seriously disturbs geyser system by reducing heat flow and aquifer pressure. Aquifer is a layer of rock holding water that allows water to percolate through it with pressure.

SOLVED EXAMPLES

EXAMPLE 4.1

A force F acting on an object varies with distance x as shown in the figure. Calculate the work done by the force as the object moves from x = 0 to x = 6 m.



Data

Force = F

Distance = x

To Find

Work done = W = ?

SOLUTION

[Total area under the graph] = (Area of rectangle) + (Area of triangle)

$$= (4 \times 5) + \frac{1}{2}(6-4)(5)$$

$$= 20 + \frac{1}{2}(2)(5)$$

$$= 20 + 5 = 25 \text{ J}$$

Since area under F–d graph is equal to work done

Hence, W = 25 J

Result

Work done by the force = W = 25 J

EXAMPLE 4.2

A 70 kg man runs up a long flight of stairs in 4.05 s. The vertical height to the stairs is 4.5m calculate his power out put in watts.

Data

Mass of man = m = 70 kg

= t = 4 sec

Height of stairs = h = 4.5 m

To Find

Power output = P = ?

SOLUTION

Since $W = P.E. = mgh$

$$\therefore \quad P = \frac{mgh}{t}$$

$$= \frac{70 \times 9.8 \times 4.5}{4}$$

$$= 7.7 \times 10^2 \text{ watt}$$

Result

Power output $= P = 7.7 \times 10^2$ watt

EXAMPLE 4.3

A brick of mass 2.0 kg is dropped from a rest position 5.0 m above the ground. What is its velocity at a height of 3.0 m above the ground?

Data

Mass of brick $= m = 2$ kg

rest position $= h_1 = 5$ m

At a height $= h_2 = 3$ m

To Find

Velocity $= V = ?$

SOLUTION

Using Loss of P.E. = Gain in K.E.

$$mg(h_1 - h_2) = \frac{1}{2} m (V_2^2 - V_1^2)$$

$\therefore \quad V_1 = 0$ and $V_2 = V$

$$\therefore \quad mg(h_1 - h_2) = \frac{1}{2} m (V^2 - 0^2)$$

$$g(h_1 - h_2) = \frac{1}{2} V^2$$

$$V^2 = 2g(h_1 - h_2)$$

Taking square root

$$V = \sqrt{2g(h_1 - h_2)}$$

Putting values

$$V = \sqrt{2 \times 9.8 (5 - 3)}$$

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

$$= \sqrt{39.2}$$

$$V = 6.26 \text{ m/s}$$



WORK AND ENERGY

Each question has four possible answers, encircled the correct answer:

1. Work is the product of:

(a) Force and distance **(b)** Force and displacement

(c) Force and velocity **(d)** Force and energy

2. Work is the product of:

(a) Two vectors **(b)** Two scalars

(c) Vector and scalar **(d)** None of these

3. The product of force and displacement represents:

(a) Torque **(b)** Momentum

(c) Work **(d)** Energy

4. Work done will be maximum when angle between $\vec{F}$ and $\vec{d}$ is:

(a) 180° **(b)** 90°

(c) 60° **(d)** 0°

5. The work done will be negative when force and displacement are:

(a) In opposite direction **(b)** Same direction

(c) Perpendicular **(d)** None of these

6. The work done will be zero when angle between $\vec{F}$ and $\vec{d}$ is:

(a) 180° **(b)** 90°

(c) 60° **(d)** 0°

7. The area under force displacement curve gives:

(a) Energy **(b)** Work

(c) Momentum **(d)** Torque

8. The dimensions of work are:

(a) $[MLT^{-2}]$ **(b)** $[ML^2T]$

(c) $[ML^2T^{-2}]$ **(d)** [MLT]

9. The SI units of work is:

(a) Newton **(b)** $N \times m^2$

(c) Joule **(d)** Kelvin

10. The unit of work is similar to that of:

(a) Energy **(b)** Power

(c) Force **(d)** Weight

11. The space where gravitational force acts is called:

(a) Electric field **(b)** Gravitational field

(c) Gravity **(d)** Conservative field

12. The work done is independent of:

(a) Path followed by the body **(b)** Force

(c) Direction **(d)** None of these

13. The total work done in a closed path in gravitational field is:

(a) Maximum **(b)** Zero

(c) Constant **(d)** None of these

14. Work is defined as ———— of force and displacement:

(a) Vector product **(b)** Scalar product

(c) Both (a) and (b) **(d)** None of these

15. A field in which work done is independent of the path followed is called:

(a) Electric field **(b)** Gravitational field

(c) Magnetic field **(d)** Conservative field

16. When a body is moved through a certain displacement $\vec{d}$ by a force $\vec{F}$ then work done is:

(a) $\vec{F} \cdot \vec{d}$ **(b)** $\vec{F} \times \vec{d}$

(c) $\vec{F} \div \vec{d}$ **(d)** None of these

17. If a force $\vec{F}$ makes an angle θ with the displacement $\vec{d}$ along the direction of motion, the work done is:

(a) $Fd \tan \theta$ **(b)** $Fd \cos \theta$

(c) $Fd \sin \theta$ **(d)** Fd

18. Work is a:

(a) Scalar quantity **(b)** Vector quantity

(c) Both (a) and (b) **(d)** None of these

19. Which of the following force can do no work on the body when it acts:

(a) Elastic force **(b)** Centripetal force

(c) Frictional force **(d)** Gravitational force

20. If a body of weight w is lifted through a height h then work done will be:

(a) wh **(b)** Zero

(c) wh sin θ **(d)** – wh

21. If a body of mass 5 kg raised vertically through a height of 1 m then work done will be:

(a) 49.0 J **(b)** 4.9 J

(c) 490 J **(d)** None of these

22. A force acting at right angle to the displacement perform:

(a) Negative work **(b)** No work

(c) Positive work **(d)** Maximum work

23. The component of the force in the direction of the displacement $\vec{d}$ is:

(a) Fd cos θ **(b)** Fd sin θ

(c) F cos θ **(d)** Zero

24. The rate of doing work is called:

(a) Work **(b)** Force

(c) Momentum **(d)** Power

25. Power is the scalar product of:

(a) Force and velocity **(b)** Force and distance

(c) Force and momentum **(d)** Force and energy

26. ♀ The S.I unit of power is:

(a) Joule **(b)** Joule-sec

(c) Watt **(d)** Newton-m

27. One horse power is equal to:

(a) 746 watt **(b)** 745 watt

(c) 750 watt **(d)** 775 watt

28. In British engineering system, the unit of power is:

(a) Joule **(b)** Watt

(c) Horse power **(d)** Kilowatt horse

29. One Giga watt (Gw) is equal to:

(a) 10^3 watt **(b)** 10^9 watt

(c) 10^{12} watt **(d)** 10^{18} watt

30. ♀ 1 kwh is equal to:

(a) 3.6×10^5 J **(b)** 36×10^5 J

(c) 36×10^6 J **(d)** 3.5×10^6 J

31. Dimensions of power are:

(a) $[MLT^{-3}]$ **(b)** $[M^2LT^{-2}]$

(c) $[ML^{-2}T]$ **(d)** $[ML^2T^{-3}]$

32. Commercial unit of electrical energy is:

(a) Erg-sec **(b)** J/s

(c) kwh **(d)** J-s

33. Work is always on a body when:

(a) It moves through a certain distance **(b)** It experiences a force while in motion

(c) A force is exerted on it **(d)** None of these

34. The power needed to lift a mass of 5 kg to a height of 1 m in 2 sec is:

(a) 24.5 watt **(b)** 2.45 watt

(c) 0.245 watt **(d)** 245 watt

35. The average and instantaneous powers become equal if work is done at:

(a) Constant rate **(b)** Variable rate

(c) Any rate **(d)** None of these

36. The power is one kilo-watt if work is done at the rate of:

(a) 500 J/s **(b)** 1000 J/s

(c) 1000 J/min **(d)** 1500 J/s

37. The relation between horse power and watt is:

(a) 1 hp = 546 watts **(b)** 1 hp = 846 watts

(c) 1 hp = 1000 watts **(d)** 1 hp = 746 watts

38. If an agent consumes a power of 1 kilo-watt in one hour, the work done is:

(a) One watt **(b)** One kilo-watt

(c) One kilo-watt hour **(d)** None of these

39. The capacity to do work is called:

(a) Work **(b)** Energy

(c) Power **(d)** Velocity

40. The energy possessed by the body due to its motion is:

(a) Kinetic energy **(b)** Potential energy

(c) Chemical energy **(d)** None of these

41. The energy possessed by the body due to its position is:

(a) Kinetic energy **(b)** Potential energy

(c) Chemical energy **(d)** None of these

42. The expression for kinetic energy is:

(a) $K.E = \frac{1}{2}mv^2$ **(b)** $K.E = \frac{1}{2}m^2v$

(c) $K.E = mv^2$ **(d)** $K.E = \frac{1}{2}mv$

43. The expression for potential energy is:

(a) $P.E = mgh^2$ **(b)** $P.E = \frac{1}{2}mgh$

(c) $P.E = mgh$ **(d)** $P.E = m^2gh$

44. The unit of potential energy is same as that:

(a) Work **(b)** Force

(c) Momentum **(d)** Power

45. Work done is equal to:

(a) Change in K.E **(b)** Change in momentum

(c) Change in force **(d)** None of these

46. The SI unit of energy is:

(a) Watt **(b)** Newton

(c) Joule **(d)** J-s

47. Energy stored in the spring of a watch is:

(a) Kinetic energy **(b)** Elastic potential energy

(c) Chemical energy **(d)** Magnetic energy

48. What is the kinetic energy of 50 kg mass moving with a speed of 5 m/s is:

(a) 625 J **(b)** 526 J

(c) 652 J **(d)** 256 J

49. When the speed of the moving body is doubled then its:

(a) Kinetic energy is doubled **(b)** Potential energy is doubled

(c) Both (a) and (b) **(d)** None of these

50. A body of mass 5 kg moving with a velocity of 2 m/s then its K.E is:

(a) 20 J **(b)** 5 J

(c) 10 J **(d)** 15 J

51. The potential energy of an object on the surface of earth is:

(a) $\frac{1}{2}mv^2$ **(b)** mgh

(c) 2mg **(d)** Zero

52. The work done on a body from earth surface to infinity appears as:

(a) Elastic potential energy **(b)** Absolute P.E

(c) Zero P.E **(d)** Maximum P.E

53. The absolute P.E on the surface of earth is:

(a) Zero **(b)** $\frac{GMm}{R}$

(c) Maximum **(d)** mgh

54. Kinetic and potential energies are:

(a) Two forms of energies **(b)** Two forms of torque

(c) Not related with each other **(d)** None of these

55. The velocity of a body with which it goes out of the earth's gravitational field is called:

(a) Average velocity **(b)** Escape velocity

(c) Instantaneous velocity **(d)** Maximum velocity

56. The expression for escape velocity is:

(a) $\sqrt{gR}$ **(b)** $2g\sqrt{R}$

(c) $2\sqrt{gR}$ **(d)** $\sqrt{2gR}$

57. The value of escape velocity is:

(a) 1.1 km/s **(b)** 11 km/s

(c) 11 km/h **(d)** 1.1 km/h

58. When a body falls, its velocity increases due to action of:

(a) Gravity **(b)** Force of friction

(c) Momentum **(d)** Rotation

59. The loss of potential energy is equal to gain of kinetic energy, is true only if there is no:

(a) Net force **(b)** Friction

(c) Weight **(d)** Gravity

60. According to conservation of energy, the total amount of energy remains:

(a) Change **(b)** Constant

(c) Increases **(d)** Decreases

61. The absolute potential energy is measured from the:

(a) Centre of earth **(b)** Surface of earth

(c) Near to earth **(d)** Infinity

62. Formula of work-energy principle is of the form:

(a) $\text{Work} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_1^2$ **(b)** $\text{Work} = \frac{1}{2}mv_f^2 + \frac{1}{2}mv_i^2$

(c) $\text{Work} = \frac{1}{2}mv_f^2 \div \frac{1}{2}mv_i^2$ **(d)** None of these

63. Gravitational potential energy by convention is:

(a) Positive **(b)** Negative

(c) Both (a) and (b) **(d)** None of these

64. The formula for escape velocity of a planet $v_{es} = \sqrt{2gR}$ gives only approximate value since:

(a) Value of g is not constant **(b)** Mass of planet may also affect the escape velocity

(c) Radius of the planet **(d)** All of these

65. The value of g at the earths centre is:

(a) Minimum **(b)** Maximum

(c) Zero **(d)** None of these

66. Energy possessed by a body due to its special configuration is called:

(a) Electrostatic energy **(b)** Gravitational P.E

(c) Elastic P.E **(d)** None of these

67. P.E of any form increases only when we get:

(a) Against the force **(b)** In the direction of force

(c) Perpendicular to the force **(d)** None of these

68. Gravitational interaction between the earth and the moon serves as source of:

(a) Tidal energy **(b)** Mechanical energy

(c) Thermal energy **(d)** Gravitational energy

69. The energy of waves can be used to generate:

(a) Magnetic effect **(b)** Electricity

(c) Solar energy **(d)** Geothermal energy

70. The solar cells are also known as:

(a) Dry cell **(b)** Chemical cell

(c) Photovoltaic cell **(d)** Wet cell

71. What is the work done in kilo joules in lifting a man of 10 kg through a vertical height of 10 m:

(a) 9.8 kJ **(b)** 980 kJ

(c) 0.98 kJ **(d)** 98 kJ

72. Solar cells are made up from the material called:

(a) Steel **(b)** Carbon

(c) Iron **(d)** Silicon

73. A solar cell is a device which converts solar energy into:

(a) Mechanical energy **(b)** Heat energy

(c) Chemical energy **(d)** Electrical energy

74. The relation which takes place in nuclear reactor is a:

(a) Fission reaction **(b)** Chemical reaction

(c) Fusion reaction **(d)** None of these

75. The tidal energy is due to the gravitational pull of:

(a) Sun **(b)** Planet

(c) Mars **(d)** Moon

76. Absolute potential energy of the body at the earths surface is equal to:

(a) $U_m = \frac{GMe}{Re}$ **(b)** $U_m = \frac{GMem}{Re}$

(c) $U_m = \frac{GmMe}{Re}$ **(d)** None of these

77. The source of geothermal energy is:

(a) The fusion in sun **(b)** The radioactive decay in the earths interior

(c) The rotation of earth around sun **(d)** None of these

78. 25000 watts power is equal to:

(a) 2.6 kilowatt **(b)** 25 h-p

(c) 50 h-p **(d)** 35.5 hp

79. Which one is the biggest unit of energy:

(a) Erg **(b)** Joule

(c) Kilowatt hour **(d)** Watt hour

80. The power of a machine is one kilowatt when work is done by it at the rate:

(a) 1000 J/min **(b)** 500 J/s

(c) 500 J/min **(d)** 1000 J/s

81. If a body of mass 5 kg is raised vertically through a distance of 1 m then the work done is:

(a) 49.0 J **(b)** 4.9 J

(c) 0.49 J **(d)** 490 J

82. Geyser derives its energy from the:

(a) Jupitter **(b)** Sun

(c) Snow **(d)** Earth

83. Geysers usually occurs in:

(a) Hot regions **(b)** Cold regions

(c) Volcanic regions **(d)** None of these

84. The energy stored in a dam is:

(a) Kinetic energy **(b)** Potential energy

(c) Chemical energy **(d)** Electrical energy

85. Ethanol is the replacement of:

(a) Kerosene oil **(b)** Gas oil

(c) Gasoline oil **(d)** Refinery oil

86. The process of getting energy by direct combustion method from the waste products is commonly known as:

(a) Liquid waste **(b)** Solid waste

(c) Gaseous waste **(d)** All of these

87. Biomass is a potential source of:

(a) Non-renewable energy source **(b)** Renewable energy source

(c) Both (a) and (b) **(d)** None of these

88. Earth receives huge amount of energy directly from:

(a) Moon **(b)** Wind

(c) Water **(d)** Sun

89. Tidal energy and wind energy is used to generate:

(a) Electric field **(b)** Magnetic field

(c) Friction **(d)** Electricity

90. The methods used to convert biomass into fuels are:

(a) Direct combustion **(b)** Fermentation

(c) Both (a) and (b) **(d)** None of these

91. Which of the following is non-renewable source of energy:

(a) Wind **(b)** Biomass

(c) Coal **(d)** None of these

92. Which of the following is renewable source of energy:

(a) Sunlight **(b)** Natural gas

(c) Oil **(d)** None of these

93. One dyne is equal to:

(a) 10^{3} N **(b)** 10^{5} N

(c) 10^{-5} N **(d)** 10^{-3} N

94. A body of mass 5 kg, initially at rest, is moved by a force of 2 N on smooth horizontal surface. The work done by the force in 10 s is:

(a) 20 J **(b)** 30 J

(c) 40 J **(d)** 60 J

95. The kinetic energy of a body of mass m is E. Its momentum is:

(a) $\sqrt{2mE}$ **(b)** 2mE

(c) $\sqrt{\frac{mE}{2}}$ **(d)** $\frac{2E}{m}$

96. The time taken by an engine of power 10 kw to lift a mass of 200 kg to a height of 40 m is:

(a) 2 sec. **(b)** 4 sec.

(c) 8 sec. **(d)** 16 sec.

97. The decrease in the potential energy of a ball of mass 20 kg which falls from a height of 50 cm is:

(a) 968 J **(b)** 98 J

(c) 1980 J **(d)** None

98. A body of mass 2 kg is thrown up vertically with a K.E of 490 J. If $g = 9.8\ ms^{-2}$ the height at which the kinetic energy becomes half its original value.

(a) 10 m **(b)** 12.5 m

(c) 25 m **(d)** 50 m

99. The K.E of a body of mass 2 kg and momentum 2 Ns is:

(a) 1 J **(b)** 2 J

(c) 3 J **(d)** 4 J

100. The momentum of particle is numerically equal to its K.E. What is the velocity of the particle?

(a) $9\ ms^{-1}$ **(b)** $3\ ms^{-1}$

(c) $2\ ms^{-1}$ **(d)** $1\ ms^{-1}$

101. Which of the following is not a conservative force?

(a) Electric force **(b)** Elastic spring force

(c) Frictional force **(d)** Gravitational force

102. One erg is equal to:

(a) 10^5 J **(b)** 10^7 J

(c) 10^{-5} J **(d)** 10^{-7} J

103. If moon's radius is 1600 km and 'g' on its surface is $1.6\ ms^{-2}$ then the escape velocity on the moon is:

(a) $1600\ ms^{-1}$ **(b)** $50.6\ ms^{-1}$

(c) $50.8\ ms^{-1}$ **(d)** $2263\ ms^{-1}$

104. A body of mass 3 kg lies on the surface of the table 2 m high. It is moved on the surface by 4 m. The change of P.E. will be:

(a) Zero **(b)** 9.8 J

(c) 19.6 J **(d)** 329 J

105. The escape velocity of a body depends upon:

(a) The mass of the body **(b)** The mass of the planet

(c) Density of the planet **(d)** Volume of the planet

106. If a power of 1 kw is maintained for 1 second then work done is equal to:

(a) 10^3 J **(b)** 10^5 J

(c) 3.6×10^6 J **(d)** 3.6×10^5 J

107. Energy required to accelerate a car from 10 ms^{-1} to 20 ms^{-1} compared with that required to accelerate from 0 to 10 ms^{-1} is:

(a) Twice **(b)** Three times

(c) Four times **(d)** Same

108. Ratio of dimensions of power and K.E is:

(a) 1 : 1 **(b)** T : 1

(c) 1 : T **(d)** M : T

109. How large a force is required to accelerate a body of weight 5 N with 4 ms^{-2} is:

(a) 10 N **(b)** 5 N

(c) 2 N **(d)** 1 N

110. Which of the following is not a biomass?

(a) Crop residuce **(b)** Animal dung

(c) Coal **(d)** Sewage

111. A child on a swing is 1 m above the ground at the lowest point and 6 m above the ground at the highest point. The horizontal speed of the child at the lowest point of the swing is approximately.

(a) 8 ms^{-1} **(b)** 10 ms^{-1}

(c) 12 ms^{-1} **(d)** 14 ms^{-1}

ANSWERS

1.	(b)	**2.**	(a)	**3.**	(c)	**4.**	(d)
5.	(a)	**6.**	(b)	**7.**	(b)	**8.**	(c)
9.	(c)	**10.**	(a)	**11.**	(b)	**12.**	(a)
13.	(b)	**14.**	(b)	**15.**	(d)	**16.**	(a)
17.	(b)	**18.**	(a)	**19.**	(b)	**20.**	(d)
21.	(a)	**22.**	(b)	**23.**	(c)	**24.**	(d)
25.	(a)	**26.**	(c)	**27.**	(a)	**28.**	(c)
29.	(b)	**30.**	(a)	**31.**	(d)	**32.**	(c)
33.	(c)	**34.**	(a)	**35.**	(a)	**36.**	(b)
37.	(d)	**38.**	(c)	**39.**	(b)	**40.**	(a)
41.	(b)	**42.**	(a)	**43.**	(c)	**44.**	(a)
45.	(a)	**46.**	(c)	**47.**	(b)	**48.**	(a)
49.	(a)	**50.**	(c)	**51.**	(d)	**52.**	(b)
53.	(b)	**54.**	(a)	**55.**	(b)	**56.**	(d)
57.	(b)	**58.**	(a)	**59.**	(b)	**60.**	(b)
61.	(a)	**62.**	(a)	**63.**	(b)	**64.**	(d)
65.	(c)	**66.**	(c)	**67.**	(a)	**68.**	(a)
69.	(b)	**70.**	(c)	**71.**	(c)	**72.**	(d)
73.	(d)	**74.**	(a)	**75.**	(d)	**76.**	(b)
77.	(b)	**78.**	(d)	**79.**	(c)	**80.**	(d)
81.	(a)	**82.**	(d)	**83.**	(c)	**84.**	(b)
85.	(c)	**86.**	(b)	**87.**	(b)	**88.**	(d)
89.	(d)	**90.**	(c)	**91.**	(c)	**92.**	(a)
93.	(b)	**94.**	(c)	**95.**	(a)	**96.**	(c)
97.	(b)	**98.**	(c)	**99.**	(a)	**100.**	(c)
101.	(c)	**102.**	(d)	**103.**	(d)	**104.**	(a)
105.	(b)	**106.**	(c)	**107.**	(d)	**108.**	(c)
109.	(c)	**110.**	(c)	**111.**	(b)		

SHORT QUESTIONS

4.1 A person holds a bag of groceries while standing still, taking to a friend. A car is stationery with its engine running. From the stand point of work, how are these two situations similar?

Ans. In both the situations there is no work done because both the bodies have zero displacement i.e.,

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

$$= Fd \cos\theta \qquad \text{But} \qquad d = 0$$

$$W = F(0) \cos\theta$$

$$W = 0$$

Hence no work is done in both the cases.

4.2 Calculate the work done in kilo joules in lifting a mass of 10 kg (at a steady velocity) through a vertical height of 10m.

Ans. ***Data***

Mass = m = 10 kg

Vertical height = h = 10 m

To Find

Work done in KJ = ?

Solution

By formula:

$$\text{Work done} = W = mgh$$

$$= 10 \times 10 \times 9.8$$

$$= 980 \text{ J} = \frac{980}{1000} \text{ KJ}$$

Work done = 0.98 KJ

4.3 A force F acts through a distance L. The force is then increased to 3 F, and then acts through a further distance of 2L. Draw the work diagram to scale.

Ans. Work diagram is a force distance graph as shown in figure. A force F acts through a distance L then work done is FL. If the force is increased to 3F through a distance 2L then

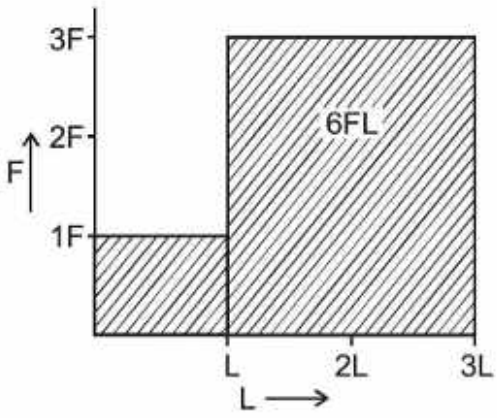
Work done = 3F . 2L

= 6FL

Hence the total:

Work done = FL + 6FL

= 7FL



4.4 In which case is more work done? When a 50 kg bag of books is lifted through 30 cm, or when a 50 kg create is pushed through 2m across the floor with a force of 50 N?

Ans. In 1st case when m = 50 kg

h = 50 cm = 0.5 m

Work done in this case is:

Work done = W_1 = mgh

= $50 \times 0.5 \times 9.8$

W_1 = 245 J

In 2nd case:

m = 50 kg

d = 2 m

F = 50 N

Work done in this case is:

W_2 = F . d

= 50×2

W_2 = 100 J

It is clear that more work is done in 1st case.

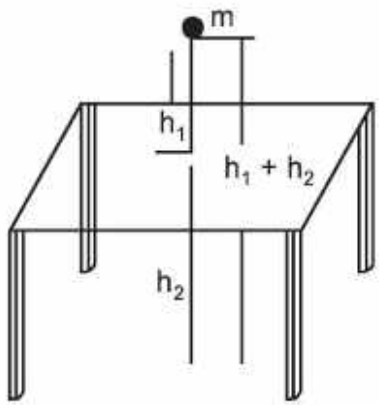
4.5 An object has 1 J of potential energy. Explain what does it mean?

Ans. As 1 J = 1 N × 1 m

When one Newton force is applied on a body in lifting it through a height of one metre. Then work done is stored in a body as P.E which is 1 Joule i.e., the body has the ability of doing 1 Joule of work.

4.6 A ball of mass m is held at a height h_1 above a table. The table top is at a height h_2 above the floor. One student says that the ball has potential energy mgh_1 but another says that it is $mg(h_1 + h_2)$. Who is correct?

Ans. The ball is at a height h_1 with respect to the table and the table is at height h_2 with respect to the ground, so the ball is at a height of $h_1 + h_2$ from the ground. Therefore the potential energy stored in the ball with respect to the top is mgh_1 and with respect to ground is $mg(h_1 + h_2)$. Hence both the students are correct because one student is telling with respect to the top and other is telling with respect to the ground.



4.7 When a rocket re-enters the atmosphere, its nose cone becomes very hot. Where does this heat energy come from?

Ans. When the rocket re-enters into the atmosphere then a part of its kinetic energy is used to do work against friction with air and dust particles present in atmosphere which will be appear in the form of heat therefore due to this reason nose cone of rocket become very hot.

4.8 What sort of energy is in the following:

(a) Compressed spring

(b) Water in a high dam

(c) A moving car

Ans. (a) A compressed spring has elastic potential energy.

(b) A water in a high dam has gravitational potential energy.

(c) A moving car has kinetic energy.

4.9 A girl drops a cup from a certain height, which breaks into pieces. What energy changes are involved?

Ans. At a certain height, a cup has gravitational potential energy. When it is dropped its gravitational potential energy decreases and kinetic energy increases. Just before striking the floor, kinetic energy is maximum. On striking, kinetic energy is changed into sound energy, heat energy and energy to break the cup if air friction is ignored. If air friction is present then some part of K.E is also used to overcome this friction.

4.10 A boy uses a catapult to throw a stone which accidentally smashes a green house window. List the possible energy changes.

Ans. Elastic potential energy stored in catapult, which is transferred to the stone as its kinetic energy. When the stone strikes the green house window, its kinetic energy changes into sound, heat and energy to break the glass window.

PROBLEMS WITH SOLUTIONS

PROBLEM 4.1

A man pushes a lawn mower with a 40 N force directed at an angle of 20° downward from the horizontal. Find the work done by the man as he cuts a strip of grass 20m long.

Data

Force exerted = F = 40 N

Angle = θ = 20°

Length of strip of grass = d = 20 m

To Find

Work done = W = ?

SOLUTION

By formula

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

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

$$W = (40)(20) \cos 20°$$

$$= 751.7 \text{ J}$$

$$= 7.5 \times 10^2 \text{ J}$$

Result

Work done = W = 7.5×10^2 J

PROBLEM 4.2

A rain drop ($m = 3.35 \times 10^{-5}$kg) falls vertically at a constant speed under the influence of the forces of gravity and friction. In falling through 100 m, how much work is done by.

(a) Gravity and (b) Friction

Data

Mass of raindrop = m = 3.35×10^{-5} kg

Height = h = 100 m

To Find

(a) Work done by gravity = W = ?

(b) Work done by friction = W = ?

SOLUTION

(a) As we know that work done by gravity is

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

$$= Fd \cos 0°$$

$$= Fd\,(1)$$

$$W = mgh$$

Putting values

$$W = 3.35 \times 10^{-5} \times 9.8 \times 100$$

$$W = 0.0328\ J$$

(b) Now work done by friction is

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

$$= Fd \cos 180°$$

$$= Fd\,(-`1)$$

$$= -mgh$$

Putting values

$$W = -3.35 \times 10^{-5} \times 9.8 \times 100$$

$$= -0.0328\ J$$

Result

(a) Work done by gravity = W = 0.0328 J

(b) Work done by friction = W = –0.0328 J

PROBLEM 4.3

Ten bricks, each 6.0 cm thick and mass 1.5 kg, lie flat on a table. How much work is required to stack them one on the top of another?

Data

Number of bricks = 10

Mass of each brick = m = 1.5 kg

Height of each brick = h = 6 cm

= 0.06 m

To Find

Work done by placing one on the top = W = ?

SOLUTION

Now the total work done placing one brick on the top of another is

$$\begin{aligned} W &= mgh + 1\,mgh + 2\,mgh + 3\,mgh + 4\,mgh + 5\,mgh + 6\,mgh \\ &\quad + 7\,mgh + 8\,mgh + 9\,mgh \\ &= (1+2+3+4+5+6+7+8+9)mgh \\ &= 45\,mgh \\ &= 45 \times 1.5 \times 9.8 \times 0.06 \\ &= 39.69\ J \\ W &= 40\ J \end{aligned}$$

Result

Work done by placing one on the top of another = W = 40 J

PROBLEM 4.4

A car mass 800 kg traveling at 54 kmh^{-1} is brought to rest in 60 meters. Find the average retarding force on the car. What has happened to original kinetic energy?

Data

Mass of car = m = 800 kg

Initial velocity of car = v_i = 54 km/hr

$$= \frac{54 \times 1000}{3600}$$

$$= 15\ m/s$$

Distance = d = 60 m

Final velocity of car = v_f = 0

To Find

Average force = F = ?

SOLUTION

By formula

$$F \times d = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$F \times 60 = \frac{1}{2}m(0^2 - 15^2)$$

$$60F = \frac{1}{2} \times 800(-15^2)$$

$$= 400 \times -225$$

$$60F = 400 \times -225$$

$$60F = -90000$$

$$F = \frac{-90000}{60}$$

$$F = -1500 \text{ N (negative shows force is retarding)}$$

Result

Average force = F = 1500 N

Note: Original K.E. energy has been used in doing work against the friction between tyre and road.

PROBLEM 4.5

A 1000 kg automobile at the top of an incline 10 metre high and 100m long is released and rolls down the hill. What is its speed at the incline if the average retarding force due to friction is 480 N?

Data

Mass of automobile = m = 1000 kg

Height of inclined plane = h = 10 m

Length of plane = S = 100 m

Retarding force = f = 480 N

To Find

Speed of automobile = v = ?

SOLUTION

As Loss of P.E = Gain in K.E + Work done against friction

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

$$\frac{1}{2}mv = mgh - fS$$

$$\frac{1}{2} \times 1000\, v^2 = 1000 \times 9.8 \times 10 - 480 \times 100$$

$$500\, v^2 = 98000 - 48000$$

$$v^2 = 50{,}000$$

$$v^2 = \frac{50{,}000}{500}$$

$$v^2 = 100$$

$$v = 10 \text{ ms}^{-1}$$

Result

Speed of automobile = v = 10 m/s

PROBLEM 4.6

100 m^3 of water is pumped from a reservoir into a tank, 10 m higher than the reservoir, in 20 minutes. If density of water 1000 kg m^{-3}, find.

(a) The increase in P.E.

(b) The power delivered by the pump.

Data

Volume of water = V = 100 m^3

Height of tank = h = 10 m

Time taken = t = 20 min.

= 20×60

= 1200 sec.

To Find

(a) Increase in P.E. = ?

(b) Power delivered by pump = P = ?

SOLUTION

(a) For increase in P.E.

$$\boxed{P.E = mgh}$$

But Mass = Volume × Density

$= 100 \times 1000$

$m = 10^5$ kg

So $P.E = 10^5 \times 9.8 \times 10$

$P.E = 9.8 \times 10^6$ J

(b) For power delivered by pump

$$\text{Power} = \frac{P.E}{\text{Time}}$$

$$= \frac{9.8 \times 10^6}{1200}$$

$$P = 8.16 \times 10^{-3+6}$$

$= 8.16 \times 10^3$ watt

= 8.2 k watt

Result

(a) Increase in P.E = 9.8×10^6 J

(b) Power delivered = P = 8.2 k watt

PROBLEM 4.7

A force (thrust) of 400 N is required to overcome road friction and air resistance in propelling an automobile at 80 kmh^{-1}. What power (kW) must the engine develop?

Data

Force required = F = 400 N

Velocity of automobile = v = 80 km/h

$$= \frac{80 \times 1000}{3600}$$

= 22.22 m/s

To Find

Power = P = ?

SOLUTION

As we know that

$$P = \vec{F} \cdot \vec{v}$$

$$= Fv \cos\theta \qquad \text{But} \qquad \theta = 0°$$

$$P = Fv \cos 0°$$

$$P = Fv$$

$$= (400)(82.22)$$

$$= 8888 \text{ watt}$$

$$= 8.88 \text{ k watt}$$

$$= 8.9 \text{ k watt}$$

Result

Power = P = 8.9 k watt

PROBLEM 4.8

How large a force is required to accelerate an electron ($m = 9.1 \times 10^{-31}$kg) from rest to a speed of 2.0×10^7 ms^{-1} through a distance of 5.0 cm?

Data

Mass of electron = m = 9.1×10^{-31} kg

Initial velocity = v_i = 0

Final velocity = v_f = 2×10^7 m/s

Distance = d = 5 cm = 0.05 m

To Find

Force required = F = ?

SOLUTION

According to work energy principle

$$Fd = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$Fd = \frac{1}{2}mv_f^2 \qquad \text{Since} \quad v_i = 0$$

$$F \times 0.05 = \frac{1}{2} \times 9.1 \times 10^{-31} (2 \times 10^7)^2$$

$$0.05\,F = 18.2 \times 10^{-31-14}$$

$$0.05\,F = 18.2 \times 10^{-17}$$

$$F = \frac{18.2 \times 10^{-17}}{0.05}$$

$$F = 364 \times 10^{-17}$$

$$F = 3.64 \times 10^{-15}\ N$$

Result

Force required $= F = 3.64 \times 10^{-15}\ N$

PROBLEM 4.9

A diver weighing 750 N dives from a board 10 m above the surface of a pool of water. Use the conservation of mechanical energy to find his speed at a point 5.0 m above the water surface, neglecting air friction.

Data

Weight of diver $= W = 750\ N$

Height of board $= h_1 = 10\ m$

Height of point from water $= h_2 = 5\ m$

To Find

Speed of diver $= v = ?$

SOLUTION

As we know that

$$\text{Gain in K.E} = \text{Loss of P.E}$$

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

$$\sqrt{v^2} = \sqrt{2gh}$$

$$v = \sqrt{2g(h_1 - h_2)}$$

$$v = \sqrt{2 \times 9.8 \times 5} \qquad \text{Since} \quad h = h_1 - h_2$$

$$v = 9.89 \text{ m/s}$$

$$v = 9.9 \text{ m/s}$$

Result

Speed of diver = v = 9.9 m/s

PROBLEM 4.10

A child starts from ret at the top of a slide of height 4.0m, (a) what is his speed at the bottom if the slide is frictionless? (b) if he reaches the bottom, with a speed of 6 ms^{-1}, what percentage of his total energy at the top of the slide is lost as a result of friction?

Data

Height of slide = h = 4 m

To Find

(a) Speed at bottom = v = ?

(b) % of total energy lost = ?

If v′ = 6 m/s

SOLUTION

(a) As we know that

Gain in K.E = Loss of P.E

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

$$v^2 = 2gh$$

$$v = \sqrt{2gh}$$

$$= \sqrt{2 \times 9.8 \times 4}$$

$$= \sqrt{78.4}$$

$$= 8.8 \text{ m/s}$$

K.E when the child is moving with 8.8 m/s

$$K.E = \frac{1}{2}mv^2$$

$$= \frac{1}{2}m\,(8.8)^2$$

$$K.E = 38.72 \text{ mJ}$$

(b) K.E when the child is moving with 6 m/s

$$K.E' = \frac{1}{2} mv'^2$$

$$= \frac{1}{2} m (6)^2$$

$$K.E' = 18 \text{ mJ}$$

$$\text{Loss of energy} = K.E - K.E'$$

$$= 38.72 \text{ m} - 18 \text{ m}$$

$$= 20.72 \text{ mJ}$$

$$\% \text{ loss of energy} = \frac{20.72 \text{ m}}{38.72 \text{ m}} \times 100$$

$$= 53.5\%$$

$$= 54\%$$

Result

(a) Speed of child at bottom = v = 8.8 m/s

(b) % loss of energy = 54%