Unit 4 WORK AND ENERGY

Climbing a mountain, these cyclists do work against gravity. Does that work depend on the route chosen?

LEARNING OUTCOME

After studying this unit the students will be able to

- Describe the concept of work in terms of the product of the force *F* and displacement *d* in the direction of force.
- Distinguish between positive, negative and zero work with suitable examples.
- Describe that work can be calculated from the area under the force-displacement graph.
- Explain gravitational field as an example of field of force and define gravitational field strength as force per unit mass at a given point.
- Prove that gravitational field is a conservative field.
- Compute and show that the work done by gravity is when a mass *'m'* is moved from one given point to another does not depend on the path followed.
- Describe that the gravitational potential energy is measured from a reference level and can be positive or negative, to denote the orientation from the reference level.
- Define potential at a point as work done in bringing unit mass from infinity to that point.
- Explain the concept of escape velocity in terms of gravitational constant *G*, mass *m* and radius of the planet *r*.
- Differentiate conservative and non conservative forces giving examples of each.
- Express power as scalar product of force and velocity.
- Explain that work done against friction is dissipated as heat in the environment.

- State the implications of energy losses in practical devices and the concept of efficiency.
- Utilize work-energy theorem in a resistive medium to solve problems.
- Discuss and make a list of limitations of some conventional sources of energy.
- Discuss potentials of some non-conventional sources of energy.

The concept of energy is closely associated with that of work. When work is done by one system on another, energy is transferred between the two systems. There are many forms of energy and all energy forms can be classified as potential or kinetic energy. Potential energy is stored energy and includes chemical, gravitational, electrostatic, elastic, and nuclear energy. Kinetic energy is the energy of motion. The present conventional energy sources are inadequate to cope up with the ever increasing energy demand. New and innovate energy resources have to be explored. Wise use of available energy without sacrificing the essential comforts of life is also one energy source to which we can all contribute by developing the habit of saving unnecessary wastage of energy.

4.1 WORK

Work has a different meaning in physics than it does in everyday usage. In physics, work is done only if an object is moved through some displacement while a force is applied to it. For example, if person holding a heavy chair at arm's length, for 3 min. His tired arms may lead him to think that he has done a considerable amount of work on the chair. However, he has done no work on it whatsoever. He exerts a force to support the chair, but do not move it. Work is a scalar quantity.

Work may be done by constant force as well as by a variable force. Here we start with work done using constant force.

When we apply some force F on a body and if the body moves through some distance in the direction of force, then the product of force $\vec{F}$ and displacement ' $\vec{d}$ is called work.

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

In Figure 4.1, a person pulling a crate with a force that is at an angle θ, relative to the direction of the motion. In the diagram beside the sketch, you can see that the x-component (horizontal) of the force has a magnitude $F\cos\theta$. This component is in the direction of the motion and is the only component that is doing work.

The y-component (vertical) is perpendicular to the direction of the motion and does no work on the crate.

The body is displaced by $\vec{d}$. We have resolved $\vec{F}$ into its components $\vec{F}_x$ and $\vec{F}_y$.

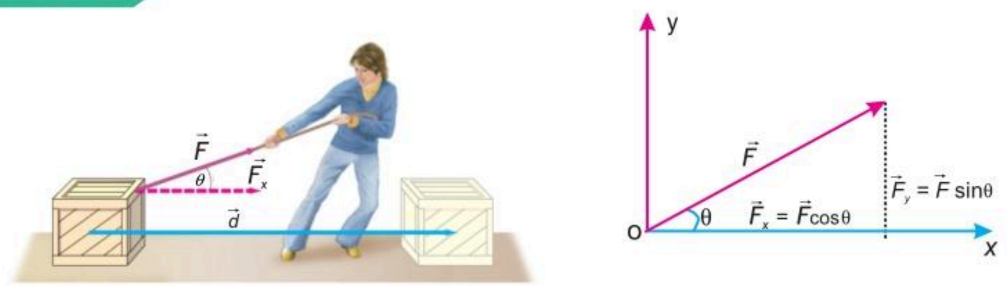
The body is displaced by force 'F_x', so work is done by 'F_x' and is given by:

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

Here $W = Fd_x = F\,(d\cos\theta) = Fd\cos\theta$.

Thus $\boxed{W = \vec{F}.\vec{d}}$ 4.1

FIGURE 4.1



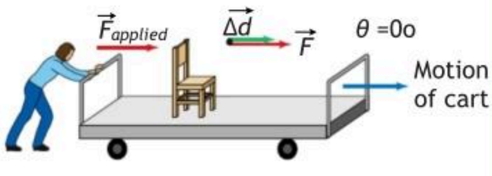
The only component of the force acting on an object that does work is the component that is parallel to the direction of the displacement.

Figure 4.2: shows four special cases that will clarify the question of whether work is being done by a force. In Figure 4.2 (a) a person is pushing a cart with a force (F) that is in the same direction as the motion of the cart.

$W = F\,.\Delta d = F\,\Delta d\cos 0 = F\,\Delta d \qquad \theta = 0$

Thus positive work is being done on the cart by increasing its kinetic energy.

FIGURE 4.2



(a) Positive work

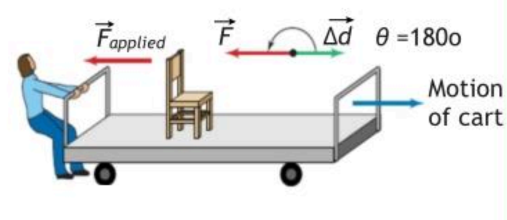
In Figure 4.2 (b) the direction of the force that the person is exerting on the cart is opposite to the direction of the motion.

$W = F . \Delta d = F \Delta d \cos 180^\circ$ $\theta = 180^\circ$

$= -F \Delta d$ $\cos \theta = -1$

Thus negative work is being done on the cart slowing it down and reducing its kinetic energy.

FIGURE 4.2



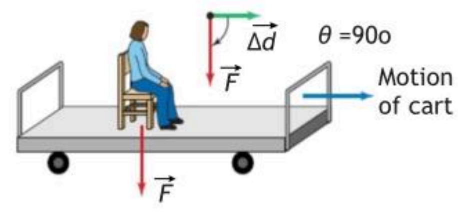
(b) Negative work

In part of Figure 4.2 (c) the person is sitting on the cart, exerting a downward force while cart has horizontal motion.

$W = F . \Delta d = F \Delta d \cos 90^\circ$ $\theta = 90^\circ$

$=0$ $\cos 90^\circ = 0$

FIGURE 4.2



(c) No Work

Even though the cart is moving, the force that the person is exerting is not doing work, because it is not directly affecting the horizontal motion of the cart.

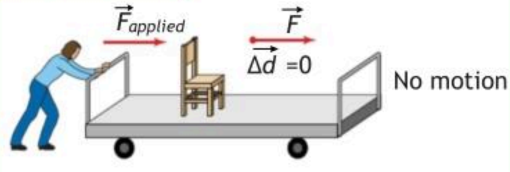
Finally, in part (d), the person is pushing on the cart, but the cart is not moving.

$W = F . \Delta d = F \Delta d \cos 0$ $d = 0$

$=0$

Thus the person is not doing work on the cart, because the displacement is zero.

FIGURE 4.2



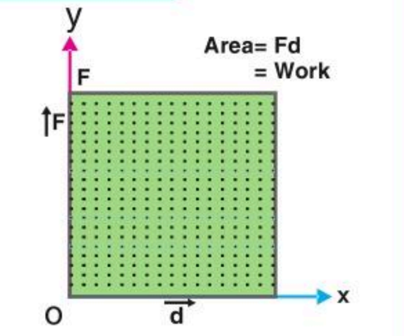
(d) No Work

4.1.1 Work done by a constant force

When a constant force acts through a distance *d*, the event can be plotted on a simple graph (Figure 4.3). The distance is normally plotted along x-axis and the force along y-axis.

If the constant force *F* and the displacement *d* are in the same direction then the work done is *Fd as shown b*y shaded area in Figure. 4.3. Hence, the area under a force- displacement curve can be taken to represent the work done by the force. "Work is said to be 1 J if a force of 1 newton displaces a body by 1 metre in the direction of force".
If force is 1 N and d= 1m, then W = 1N 1m = 1 J

FIGURE 4.3



Work done by a constant force.

4.1.2 Work done by a variable force

In many cases the force does not remain constant during the process of doing work. For example:
(i) As rocket moves away from earth, work is done against the force of gravity, which varies as the inverse square of distance from Earth' s centre so force decreases and does not remains, constant.

(ii) Force exerted by a spring increases with the amount of stretch (pulling) so force does not remain constant.

While considering the equation (work = $F_x d\cos\theta$) for the measurement of work, we suppose that the force F_x is constant throughout the displacement d.

We shall now consider the work done by a force which is not constant. The work done by a varying force can be determined graphically.

To do so, we plot the force F_x as a function of distance Δd, as in Fig. 4.4.We divide the distance Δd into small segments. For each segment, we indicate the average of F_x by a horizontal dashed line.

Then the work done for each segment is $\Delta W = F_x \, \Delta d$ which is the area of a rectangle Δd wide and F_x high as shown in Figure 4.5. The total work done to move the object a total distance $\Delta d = d_B - d_A$ is the sum of the areas of the rectangles (five in the case shown in Figure 4.5). Usually, the average value of F_x for each segment must be estimated, and a reasonable approximation of the work done can then be made.

If we subdivide the distance into many more segments, Δd can be made smaller and our estimate of the work done would be more accurate.

In Figure 4.5 the path of a body in xy-plane as it moves from point 'A' to point 'B'.

We have divided the whole distance into a number; of small displacements

$$\Delta\vec{d}_1, \Delta\vec{d}_2, \Delta\vec{d}_3, \Delta\vec{d}_4, \ldots\ldots\ldots\ldots, \Delta\vec{d}_n$$

respectively and the corresponding forces *are*

$$\vec{F}_{x1}, \vec{F}_{x2}, \vec{F}_{x3}, \vec{F}_{x5}, \ldots\ldots\ldots \vec{F}_{xn}$$

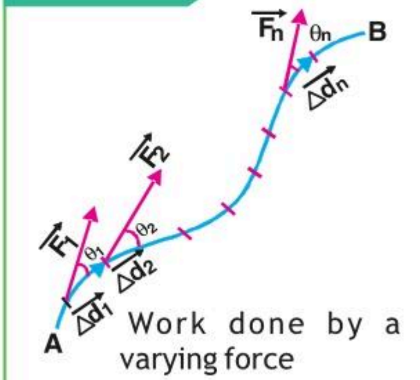
Total work done in this case will be: -

$$W = \Delta W_1 + \Delta W_2 + \Delta W_3 + \Delta W_4 + \ldots\ldots\ldots\ldots \Delta W_n$$

$$W = (F_{x1}\cos\theta_1)\,\Delta d_1 + (F_{x2}\cos\theta_2)\,\Delta d_2 + \ldots + (F_{xn}\cos\theta_n)\,\Delta d_n$$

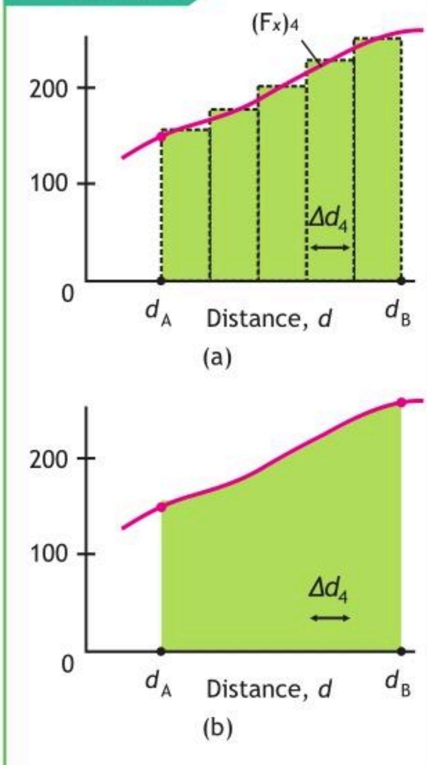
$$W = \sum_{i=i}^{i=n} \left(F_{xi}\cos q_i\right)\Delta d_i$$

FIGURE 4.4



Work done by a varying force

FIGURE 4.5



Graphical illustration of Work done by a varying force

In the limit as Δd approaches zero, the total area of the many narrow rectangles approaches the area under the curve, Figure 4.5. That is, *the work done by a variable force in moving an object between two points is equal to the area under the F_x vs Δd curve between those two points.*

$$W_T = \lim_{\Delta t \to 0} \sum_{i=i}^{i=n} (F_{xi} \cos\theta_i)\Delta d_i$$

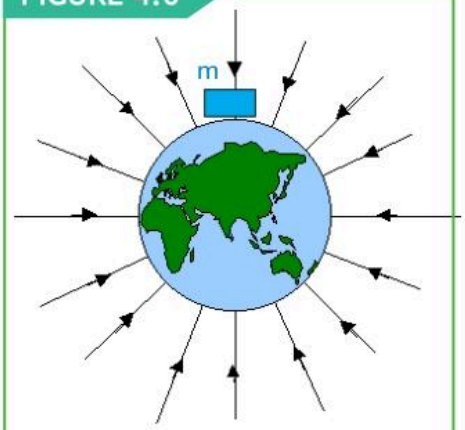
Quiz?

The Moon revolves around the Earth in a nearly circular orbit, kept there by the gravitational force exerted by the Earth. Does gravity do (*a*) positive work, (*b*) negative work, or (*c*) no work on the Moon?

4.2 WORK DONE IN GRAVITATIONAL FIELD

We know that a body placed in space surrounding the earth experiences a force which is equal to its weight and is directed towards the centre of the earth as shown in the Figure 4.6.

FIGURE 4.6



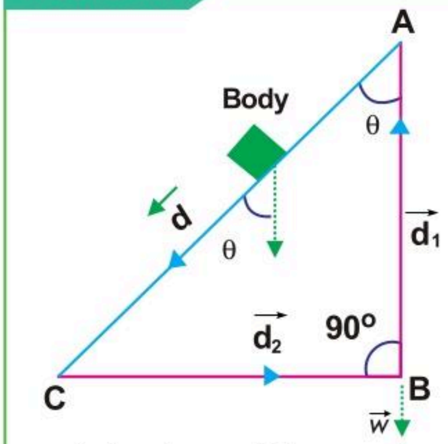
Gravitation field around earth

This space around the earth with in which it exerts a force of attraction on other bodies is known as gravitational field. The gravitational force per unit mass on a body is known as gravitational field strength. Its SI unit is N kg $^{-1}$. If we carry a body in a closed path in such field, that the total work done will be zero. Such a field is known as conservative. In gravitational field

The work done is independent of path followed by a body in a closed path.

Let us consider a closed path 'ABCA' in gravitational field, as shown in Figure 4.7. A body of mass m and weight w is carried along the closed path from C to B and then from B to A. The angle between w and d_2 is 90° and the angle between BA and w is 180°. The angle between BA and

FIGURE 4.7



work done in two different paths

CA is θ. Now we have to calculate the total work done as:

(i) Work done between C and B will be:

$\Delta W_{c\rightarrow B} = w\,.d_2 = wd_2 \cos 90^o$

$\Delta W_{c\rightarrow B} = 0$

(ii) Work done between B and A will be:

$\Delta W_{B\rightarrow A} = wd_1 \cos 180^o = w\, d_1\, (-1)$

or $\Delta W_{B\rightarrow A} = -\, w\, d_1$

(iii) Work done between C and A will be:-

$\Delta W_{C\rightarrow A} = w\, d\cos\theta = w\, (d\cos\theta)$ ......(i)

From right angle triangles (Figure 4.7)

$d_1 = d\cos\theta$

Then Eq:(i) becomes

$\Delta W_{C\rightarrow A} = w\,(d\cos\theta) = w\, d_1$

$\Delta W_{C\rightarrow A} = w\, d_1$

Total work done in closed path 'ABCA' will be:

$W_T = \Delta W_{c\rightarrow B} + \Delta W_{B\rightarrow A} + \Delta W_{C\rightarrow A}$

Putting the values, then

$W_T = 0 + (-wd_1) + wd_1 = 0$

Thus $W_T = 0$

Since total work done in a closed path 'ABCA' in gravitational field is zero, so gravitational field is a conservative field.

Now consider another Figure 4.8. Let the body be displaced in gravitational field by two different paths.

(i) Direct path from 'A' to 'C':

In this case:-

$W_T = w\, d\cos\theta$, from figure, $d\cos\theta = d_1$

So $W_T = w\,(d\cos\theta) = wd_1$

$W_T = wd_1$ ....(i)

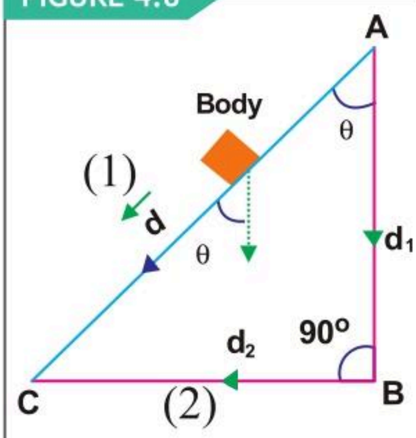
(ii) For In direct path ABC:

FOR YOUR INFORMATION

1. Conservative forces are:-
- Electric force
- Elastic spring force
- Gravitation force

2. Non conservative forces are:-
- Frictional forces
- Air resistance
- Tension in a string
- Normal force
- Propulsion force of a motor
- Propulsion force of a rocket

FIGURE 4.8



work done in two different paths

From ‘A’ to ‘B’, work done will be:

$$\Delta W_{A\rightarrow B} = wd_1 \cos 0^o = wd_1$$

And from B to C, $\Delta W_{B\rightarrow C} = wd_2 \cos 90^o = 0$

So total work done using indirect path will be:

$$W_T = \Delta W_{A\rightarrow B} + \Delta W_{B\rightarrow C} = wd_1 + 0 = wd_1$$

So $$W_T = wd_1 \qquad \text{(ii)}$$

Comparing (i) and (ii), we conclude that work done on the body in between any two points in gravitational field is independent of the path followed by the body. Thus gravitational field is a conservative field. Electrostatic field is also a conservative field. Another example is magnetic field.

FOR YOUR INFORMATION

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.

4.3 POWER

Machines may be classified by the speed with which they transferred energy or do work. No time factor is involved in the definition of work. The same amount of work may be done by an agency in a small interval of time, say one second, while it may be done by another agency in much larger time, say one hour. From our daily experience, we can say that the former agency have more power than the later one.

Thus Power is defined as the rate of transfer of energy. In other words, we can also define power. *The amount of work done by a body in one second is called power.*

If ‘W’ is the work done by a body in time ‘t’, then

$$P = \frac{W}{t}$$

Putting $W = \vec{F}.\vec{d}$

Then $$\boxed{P = \frac{\vec{F}.\vec{d}}{t} = \vec{F}.\vec{v}} \qquad 4.2$$

Thus we can say the dot product of force and velocity is called power.

(i) *"The total work 'ΔW' done by a body in total time 'Δt' is called average power".*

$$P_{av} = \left(\frac{\text{total work done}}{\text{total time}}\right)$$

(ii) The rate of doing work in any instant of time is called instantaneous power".

$$P_{inst} = \lim_{\Delta t \to 0} \left(\frac{\Delta W}{\Delta t}\right) \qquad 4.3$$

Anyone may find the power he or she is able to develop when running upstairs by measuring the total vertical height of a stairway and using a stop-watch to find the time taken.

The unit of power is called watt. Power is said to be one watt if one Joule of work is done by a body in 1second.

1 watt = Js^{-1}

Watt is a very small unit. Usually we use kilowatts

1 kW = 1000 watts.

Watt is commonly used in the power of bulbs and electric fans. The power of generating stations and that of grid stations is expressed in mega watts (1MW = 10^6 watts). We usually use the unit kilowatt hour (1kwh), which is the commercial unit of work (electrical energy).

Sometimes, for example, in the electrical energy measurements, the unit of work is expressed as watt second. However, a commercial unit of electrical energy is kilowatt-hour. One kilowatt-hour is the work done in one hour by an agent whose power is one kilowatt.

1kwh = 1000 watts × 3600 s $=3.6\times10^6$ J= 3.6 M J.

The power of TV set is 120 watts and that of pocket calculator is 7.5×10^{-4} watts.

FOR YOUR INFORMATION

In British Engineering system, the unit of power is called horse power (hp) and numerically, 1hp = 746 watts.

Example 4.1 — A CAR NEED POWER

Calculate the power required of a 1400-kg car under the following circumstances: (a) the car climbs a 10° hill (a fairly steep hill) at a steady and (b) the car accelerates along a level road from 90 kmh^{-1} to 110 kmh^{-1} in 6.0 s to pass another car. Assume the average retarding force on the car is throughout.

GIVEN

Mass m=1400kg, angle of climb =10°, initial speed v_i =90 kmh^{-1}, final speed v_f =110 kmh^{-1}, time t=6.0s

REQUIRED

power P= ?

SOLUTION

(a) To move at a steady speed up the hill, the car must, by Newton's second law, exert a force F equal to the sum of the retarding force, 700 N, and the component of gravity parallel to the hill, $mg \sin 10°$, Thus

$\vec{F}$ = 700 N + mg sin 10°

= 700 N + (1400 kg)(9.80 ms^{-2})(0.174) = 3100 N.

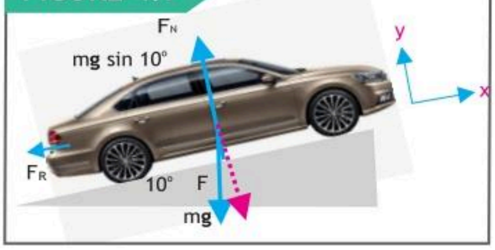
Since v = 80 kmh^{-1} = 22 ms^{-1} and is parallel to $\vec{F}$ then the power is

$P = Fv$ = (3100 N)(22 ms^{-1}) = 6.8×10^4 W = 68 kW = 91 hp.

91 hp. — Answer

(b) The car accelerates from 25 ms^{-1} to 30.6 ms^{-1} (90 kmh^{-1} to 110 kmh^{-1}) on the flat. The car must exert a force that overcomes the 700-N retarding force plus that required to give it the acceleration a_x = (30.6 ms^{-1} - 25.0 ms^{-1})/ 6.0 s = 0.93 ms^{-2}

FIGURE 4.9



We apply Newton's second law with x being the horizontal direction of motion (no component of gravity): $ma_x = \sum \vec{F}_x = \vec{F} - \vec{F}_R$.

We solve for the force required, F

$\vec{F} = ma_x + \vec{F}_R$

= (1400 kg)(0.93 ms^{-2}) + 700 N = 1300 N + 700 N = 2000 N.

Since the required power increases with speed and the motor must be able to provide a maximum power output in this case of

P = (2000 N)(30.6 ms) = 6.1×10^4 W = 61 kW = 82 hp.

Example 4.2 **POWER**

Find the work required to lift a mass of 5 tones to a height of 30 m. If this is done in 2 minutes, what power is being used?

GIVEN

Mass m=5000 kg, height h= 30 m ,
time t= 2 mint=2x60s=120 s

REQUIRED

power P= ?, work w=?

SOLUTION

$$W = Fd = mgh = (5000\text{kg})(9.81\text{ms}^{-2})(30\text{m}) = 1471500\text{J}$$

$$P = \frac{W}{t} = \frac{1471500\text{J}}{120\text{s}}$$

$$P = 12262.5 \text{ Watt}$$

=12262.5 Watt **Answer**

ASSIGNMENT 4.1

What is the power of an airplane of mass 3 000 kg if when on the runway it is capable of reaching a speed of 80 ms^{-1} from rest in 4.0 s? (4.8MW)

TID BIT

The food we eat in one day has about the same energy as 0.33 liters of petrol. Experiments shows that the average power of a man walking upstairs at an ordinary speed is only about 0.33 k W.

4.4 ENERGY

When we say that a certain body has energy, we mean that it has the ability of exerting force on another body and of doing work on it. On the other hand whenever we do work on a body, we store in it an amount of energy equal to work done. Thus energy is defined as

The capacity of a body to do work. Or
Energy is the agent which causes some change in the state of system.

(i) Kinetic Energy: We observe daily that, as moving object has the ability to push away another object at rest. Thus it is the capacity to do work because of its motion. Thus k.E is defined as:-

Energy in the body due to its motion. If m is mass of body and $\vec{v}$ is the velocity of body, then: -

$$K.E = \frac{1}{2}mv^2 \qquad (4.4)$$

(ii) Potential Energy: In daily life we see that, if we lift a brick from ground to the top of a roof, work is done against the force of gravity. This appears as P.E of brick. Thus P.E is defined as:

Energy in a body is due to its position (with respect to the surface of earth)

If m is mass, g is acceleration due to gravity and h is height of body from surface of earth, then:

$$P.E = mgh \qquad (4.5)$$

This dolphin has lots of kinetic energy as it leaves the water. At its highest point its energy is mostly potential energy Figure 4.10.

FIGURE 4.10

Dolphin

POINT TO PONDER

The pyramids in Egypt are thought to have been built by slaves hauling loads to height by inclined planes. It was the first use of inclined plane in construction happened around 2600BC.A pyramid at Egypt, believed to have been built by hauling stones up inclined planes.

4.5 IMPLICATION OF ENERGY LOSSES IN PRACTICAL DEVICES AND EFFICIENCY

Mechanical efficiency is the ratio of work output to work input. It is often expressed as a percentage. The efficiency of an ideal machine is 100 percent but an actual machine's efficiency will always be less than 100%. This means that some of the work put into the system is transformed (lost) into thermal energy (heat). In a mechanical system, friction is the most common cause of the energy lost to heat.

FIGURE 4.11

Crane

The crane is a machine that is used in our daily life to lift heavy loads. The crane uses 3 simple machines, it has a pulley, lever, as well as a wheel and axle.

Suppose using a pulley if a weight *W* is raised when an effort/Force *E* is applied.

Output: If a machine moves a load *W* through a distance *h* then the useful work done by the machine is called output.

Output= Load x distance *h* through which the load moves

$= F_{out} x D_{out}$

In put: If an effort F_{in} acts through a distance D_{in} then the work done on the machine is called input.

In put= Effort force x Effort distance.

In put= $F_{in} x D_{in}$

Efficiency: the ratio of out put to the input of a machine is called its efficiency.

Mathematically

$$\text{Efficiency} = \frac{\text{out put work}}{\text{in put work}}$$

$$= \frac{\text{Load force} \times \text{Load distance}}{\text{Effort force} \times \text{Effort distance}}$$

$$\boxed{\text{Efficiency} = \frac{F_{out} \times D_{out}}{F_{in} \times D_{in}}} \quad (4.6)$$

The equation for percentage efficiency is

$$\text{Percentage Efficiency} = \frac{\text{Output work}}{\text{Input work}} \times 100\% = \frac{W_{out}}{W_{in}} \times 100\%$$

$$\boxed{= \frac{F_{out} \times D_{out}}{F_{in} \times D_{in}} \times 100\%} \quad (4.7)$$

Even a very efficient device will waste some of its input energy in the form of heat due to the friction forces between different parts of machine.

An incline is used as a simple machine. Which is a flate surface tilted at an angle. Which is commonly used to load truck, planes and trains. The efficiency of some practical devices are given in the table 4.1.

Table: 4.1

Practical devices	Efficiency
Petrol heat engine	(25-30)%
Diesel engine	(34-40)%
Steam locomotive	(35-40)%
Incandescent lamp	5%
Fluorescent lamp	20%
Steam turbine	(34-46)%
Air craft gas turbine	36%
Nuclear power plant	(30-35)%
Fossil fuel power plant	(30-40)%
Electric generator	(70-98)%
Electric motor	(50-92)%
Dry cell battery	90%
Battery	90%
'Home coal furnace	55%

FOR YOUR INFORMATION

Efficiency of some electrical equipments: LED light bulbs have been introduced to replace ordinary light bulbs, as they are much more efficient. Let's take a look at a standard 50-watt. The energy consumption to use a light bulb like this would cost about 1278 Rs in a year. An LED, running over the course of 1 year would cost only 260Rs to operate. Using these causes less energy to be wasted as heat. Recently developed, AC/DC fans can operate on less energy while producing a high airflow. In fact, they can cut down your power consumption by up to 65% and can operate on solar penal. AC/DC fans are designed to run on 12V and consume around 26-35W. Ordinary Fan consume 75watt while AC/DC fans consume about 35 to 40watt so AC/DC fans are more efficient.

AC/DC Fan

Example 4.3

EFFICIENCY OF MACHINE

A machine needed 1000J of energy to raise a 10 kg block at a distance of 6.0m . What is the machine efficiency?

GIVEN

Input work =1000J, mass m=10kg , distance d=6.0m

REQUIRED

machine efficiency h =?

SOLUTION

First, find the work done to raise the block: W = $m\,g\,h$

$$= 10\ \text{kg} \times 9.8\ \text{m/s}^2 \times 6.0\ \text{m} = 588\ \text{J}$$

$$\text{Efficiency}=h = \frac{\text{Output work}}{\text{Input work}} \times 100\% = \frac{588}{1000} \times 100\% = 58.8\% = 59\%$$

Pulleys are machines used to lift heavy loads. Modern cranes are complicated form of pulley system.

$h = 59\%$ **Answer**

Example 4.4 **SYSTEM OF PULLEYS**

Block and tackle system of pulleys is used to raise a load of 500N through a height of 20m. The work done against friction is 2000J. Calculate the (a) work done by the effort (b) the efficiency of the system.

GIVEN

Load=w=500N, height h=20m,
work against friction=2000J

REQUIRED

worked done by effort=?,
efficiency h=?

SOLUTION

(a) Work done by effort=work done in raising load + work done against friction

=500x20+2000 = 12000J

(b) $$\text{Efficiency}=h = \frac{\text{Output work}}{\text{Input work}} \times 100\% = \frac{500 \subset 20}{12000} \times 100\% = 83\%$$

12000J, & $h = 83\%$ **Answer**

4.6 ABSOLUTE POTENTIAL ENERGY

Consider a body of mass m at a certain height h in gravitational field. Thus potential energy is P.E = mgh.

When the height h of body of mass m is greater than the radius of the earth then the above equation is not applicable. Thus the absolute value of the potential energy of a body in gravitational field is needed. For this purpose zero point for the potential energy is fixed. Zero point is a point so far away from the earth that the force of gravity is negligible small not attracted by the earth. Hence its potential energy is zero.

To compute the work done in moving the body from earth surface (beyond the earth surface) to very far off distance from earth where the force of gravity reduces. Figure shows a body of mass at pint 1 at distance r_1 from the centre of earth. As the body is moved from point 1 to far off point n the gravitational force does not remain constant. Therefore we divide the whole distance into a number of small distances each of magnitude Δr. So that force during each interval remains constant.

(i) Work done between point 1 and '2' will be:

$$\Delta W_{1\to 2} = F_{av} \quad \Delta r = F_{av} \quad (r_2 - r_1) \qquad (i)$$

But $F_{av} = \dfrac{GmM_e}{r_{av}^2}$, where $r_{av} = \dfrac{r_1 + r_2}{2}$

Then (i) becomes,

$$\Delta W_{1\to 2} = \frac{GmM_e}{r_{av}^2} (r_2 - r_1) \qquad (ii)$$

$\Delta W_{1\to 2} = \dfrac{GmM_e}{r_1 r_2} (r_2 - r_1)$, putting the values then

$$\Delta W_{1\to 2} = GmM_e \left\{\frac{1}{r_1} - \frac{1}{r_2}\right\}$$

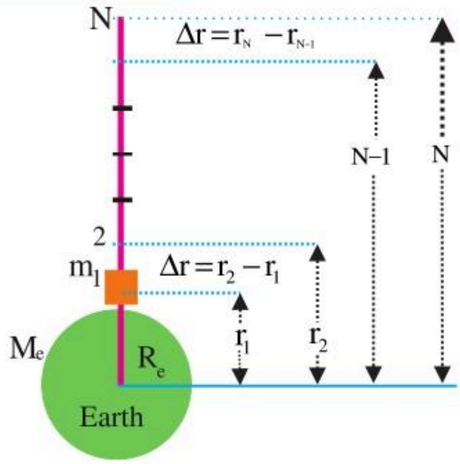
Similarly, $\Delta W_{2\to 3} = GmM_e \left\{\dfrac{1}{r_2} - \dfrac{1}{r_3}\right\}$

And $\Delta W_{3\to 4} = GmM_e \left\{\dfrac{1}{r_3} - \dfrac{1}{r_4}\right\}$

....

....

FIGURE 4.12



The work done in moving the body of mass m from earth surface to very far off distance from earth where the force of gravity reduces.

FORMULA DERIVATION

As $r_{av} = \dfrac{r_1 + r_2}{2}$

But $\Delta r = r_2 - r_1$

and $r_2 = r_1 + \Delta r$

Then $r_{av} = \dfrac{2r_1 + \Delta r}{2}$

Squaring both the sides and neglecting Δr^2 we get $r_{av}^2 = r_1 r_2$

$$\Delta W_{N-2\to N-1} = GmM_e \left\{\frac{1}{r_{N-2}} - \frac{1}{r_{N-1}}\right\}$$

$$\Delta W_{N-1\to N} = GmM_e \left\{\frac{1}{r_{N-1}} - \frac{1}{r_N}\right\}$$

Adding all these, we get: -

$$\Delta W_{1\to N} = \Delta W_{1\to 2} + \Delta W_{2\to 3} + \Delta W_{3\to 4} + \ldots\ldots + \Delta W_{N-2\to N-1} + \Delta W_{N-1\to N}$$

Putting the corresponding values, then: -

$$\Delta W_{1\to N} = GmM_e \left\{\frac{1}{r_1} - \frac{1}{r_2}\right\} + GmM_e \left\{\frac{1}{r_2} - \frac{1}{r_3}\right\} + GmM_e \left\{\frac{1}{r_3} - \frac{1}{r_4}\right\}$$

$$+ \ldots\ldots\ldots + GmM_e \left\{\frac{1}{r_{N-2}} - \frac{1}{r_{N-1}}\right\} + GmM_e \left\{\frac{1}{r_{N-1}} - \frac{1}{r_N}\right\}$$

$$\Delta W_{1\to N} = GmM_e \left\{\frac{1}{r_1} - \frac{1}{r_2} + \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_3} - \frac{1}{r_4} + \ldots\ldots + \frac{1}{r_{N-2}} - \frac{1}{r_{N-1}} + \frac{1}{r_{N-1}} - \frac{1}{r_N}\right\}$$

Resulting

$$\Delta W_{1\to N} = GmM_e \left\{\frac{1}{r_1} - \frac{1}{r_N}\right\} \qquad \text{(iii)}$$

If the nth; point 'N' lies on infinity, then $r_N = \infty$ (infinity) and then (iii) becomes

$$\Delta W_{1\to\infty} = GmM_e \left\{\frac{1}{r_1} - \frac{1}{\infty}\right\}$$

$$\Delta W_{1\to\infty} = GmM_e \left\{\frac{1}{r_1} - 0\right\}$$

$$\Delta W_{1\to\infty} = \frac{GmM_e}{r_1} \qquad \text{(iv)}$$

If we displace the body from surface of Earth of radius 'R_e', then we replace 'r_1' by 'R_e' and (iv) becomes,

$$\Delta W = \frac{GmM_e}{R_e}$$

Thus from the surface of earth up to infinity

$$\text{Absolute potential energy} = \frac{GmM_e}{R_e}$$

Actually it is the work done against gravity, so its value is always taken as negative so

$$\text{Absolute potential energy} = -\frac{GmM_e}{R_e} \qquad (4.8)$$

Now gravitational potential at any point is defined as

The amount of work done in moving a body at a certain point in a gravitational field to a position of zero potential such that the body is never accelerated is called Absolute potential energy.

Now gravitational potential at any point is defined as

The potential energy per unit mass at that point which is at distance r from the center of earth and is shown as

$$V_{(r)} = -\frac{GM_e}{R_e} \qquad (4.9)$$

4.7 ESCAPE VELOCITY

If a body is projected up, it returns to the ground due to the action of gravity. If the initial velocity of the object is increased, the body takes a longer time to fall back. If we continue to increase the initial velocity, a stage will reach when the body will never come back, but will escape out of the influence of gravity.

The initial velocity, which a projectile must have at the earth's surface in order to go out of earth's gravitational field, is known as escape velocity.

As the earth's gravitational field extends to infinity, escape velocity is apparently the velocity a projectile must have at the earth's surface so as to be projected to an infinite distance in space.

In this chapter we have already seen that

FOR YOUR INFORMATION

A Delta II rocket blasting off. A rocket going into space needs large amount of energy to achieve escape velocity in order to make it off Earth and get into space the work done in lifting a body from earth's surface to a very far off distance into space which we call as the absolute potential energy of a body at the earth's surface is given by $\frac{GM_e m}{R_e}$

Where 'M_e' is mass of earth and 'R_e' is radius of earth.

If a projectile is given an initial kinetic energy equal to $\frac{GM_e m}{R_e}$, it will reach an infinite distance from the earth.

Such a projectile will have escape velocity. The value of escape velocity can be computed by equating the initial K.E with absolute potential energy.

$$\frac{1}{2}mv_{esc}^2 = \frac{GM_e m}{R_e}$$

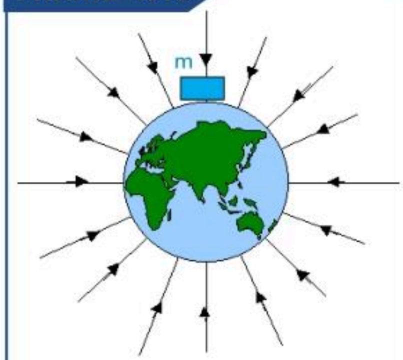
$$\boxed{v_{esc} = \sqrt{\frac{2GM_e}{R_e}}} \quad (4.10)$$

As $\frac{GM_e m}{R_e^2} = mg \Rightarrow GM_e = gR_e^2$

Putting its value in Eq 4.10 we get

$$\boxed{v_{esc} = \sqrt{2gR_e}} \quad (4.11)$$

FIGURE 4.13



Gravitational field around the earth

Substituting the value of $G = 6.67 \times 10^{-11}\ Nm^2\ kg^{-2}$

$R_e = 6.4 \times 10^6$ m and $M_e = 6 \times 10^{24}$ kg.

We get $v_{esc} = 11.2 \times 10^3 m\ s^{-1}$

Thus the value of escape velocity is $11.2 \times 10^3 m\ s^{-1}$. For any other planet the value of escape velocity will be different and can be computed on the value of mass and radius of the planet.

Example 4.5 MOON RADIUS

The moon's radius is 1.74×10^6m and the acceleration due to gravity, $g = 1.6\ ms^{-2}$ on its surface. Find out the escape velocity from moon's surface.

GIVEN

Radius of moon = $R_m = 1.74 \times 10^6$ m
Acceleration due to gravity = $g_m = 1.6 ms^{-2}$

REQUIRED

Escape velocity = v_{esc} = ?

SOLUTION

$$v_{esc} = \sqrt{\frac{2GM_m}{R_m}}$$

$$v_{esc} = \sqrt{2g_m R_m}$$ putting the values

$$v_{esc} = \sqrt{2 \subset 1.6 \times 1.74 \times 10^6}$$

$v_{esc} = 2.360 \times 10^3\ ms^{-1}$ Answer

Example 4.6 ESCAPE SPEED

Compare the escape speed of a rocket launched from the moon with Earth. The mass of the moon is 7.35×10^{22} kg and the radius is 1.74×10^6 m.

GIVEN

Mass of moon=M_m=7.35×10^{22}kg
Radius R=1.74×10^6m

REQUIRED

speed v=?

SOLUTION

$$v = \sqrt{\frac{2GM_m}{R}} = \sqrt{\frac{2(6.67\times10^{-11}N.m^2/kg^2)(7.35\times10^{22}kg)}{1.74\times10^6 m}} = 2370\,ms^{-1}$$

Notice that you can escape from the moon by traveling much more slowly than you must travel to escape the gravitational pull of Earth. This is why launching a Lunar Module from the moon's surface was so much easier than launching an Apollo spacecraft from Earth.

$v = 2.370 \times 10^3\ ms^{-1}$ Answer

Assignment 4.2 GRAVITATION PULL OF EARTH

How fast would the moon need to travel in order to escape the gravitational pull of Earth, if Earth has a mass of 5.98×10^{24} kg and the distance from Earth to the moon is 3.84×10^8 m?

(1441 ms^{-1}).

4.8 WORK ENERGY THEOREM IN RESISTIVE MEDIUM

Energy can be stored into one of the two basic types: kinetic energy and potential energy. One form can be converted into other. When a hammer is raised to a certain height h it acquires gravitational potential energy. Its gravitational potential energy can be used to drive nail into the wood. If a hammer of weight w is released, it will fall under the force of gravity F and will do work on the nail by driving it into the wood block Figure 4.14 .

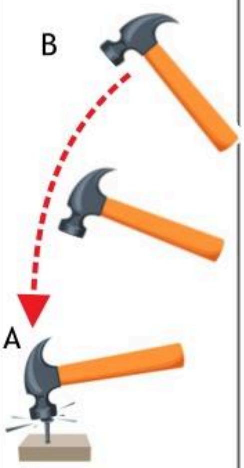
Hence work done = wxh

Under the action of gravitational force a hammer loses its potential energy and acquiring Kinetic energy while falling downward. Just before hitting the ground the potential energy of the hammer is minimum and kinetic energy maximum. We will use the assumption that energy transformation is frictionless.

Acquiring kinetic energy =loss in potential energy

$$=\text{work done}= wxh=mgh \quad (4.12)$$

FIGURE 4.14



Hammer falling on the nail by driving it into the wood

Thus we see that the potential energy lost by the body in falling from B to A is equal to the kinetic energy gained by it when it reaches A. This means potential energy of a body decreases when an equal increase in kinetic energy occur.

In many situations friction cannot be ignored. Because frictional forces reduce the mechanical energy (but not the total energy), they are called dissipative forces. Because of the work done by the friction, the energy transformation is never perfect. Friction causes the loss of energy.

A part of potential energy is used in work done against friction (fh) and remaining potential energy is converted into kinetic energy.

Hence $$mgh = fh + \frac{1}{2}mv^2 \quad (4.13)$$

Loss in potential energy = gain in kinetic energy + work done against friction.

This is a very important work-energy equation. Similarly, when the body moves up, then

Loss in k.E at A = Gain in P.E at B + work done against friction.

This leads us to the law of conservation of energy in terms of K.E and P.E.

4.9 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,

$$\text{Total Energy} = \text{P.E.} + \text{K.E} = \text{Constant}$$

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

Energy can neither be created nor destroyed. It can be transformed from one kind into other, but the total amount of energy remains constant.

That 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 seems in an energy transfer that some energy has disappeared, the lost energy is often converted into heat.

This appears to be the fate of all available energies and is one reason why new sources of useful energy have to be developed.

Example 4.7 **WORK DONE**

A ball of mass 100 g is thrown vertically upward at a speed of 25 ms^{-1}. If no energy is lost, determine the height it would reach. If the ball only rises to 25m, calculate the work done against air resistance. Also calculate the force of friction.

GIVEN

Friction = $f = 0$
Mass = m = 100 g = 0.1 kg, Speed = v = 25 m s^{-1}
Height = h = 25 m

REQUIRED

Height = h =?
Work done against air resistance = f h = ?
Force of friction= f=?

SOLUTION

1. As $f = 0$ so
   Loss in k.E = Gain in P.E
   $\frac{1}{2} mv^2 = mgh \Rightarrow h = v^2/2g$
   Putting the values then: $h = (25 \times 25) / (2 \times 9.8) = 31.9\text{m}$

2. Loss in k.E = Gain in P.E + $f\,h$

$\frac{1}{2}mv^2 = mgh + f\,h$ $\qquad f\,h = \frac{1}{2}mv^2 - mgh$

$f\,h = 0.5 \times 0.1 \times 25 \times 25 - 0.1 \times 9.8 \times 25 = 6.75$ J

Putting the value of h we get $f = \dfrac{6.75}{25} = 0.27$ N

Force of friction= f=0.27 N — **Answer**

Assignment 4.3 **FRICTION**

Consider a person on a sled sliding down a 100 m long hill on a 30° incline. The mass is 20 kg, and the person has a velocity of 2 ms^{-1} down the hill when they're at the top. (a) How fast is the person traveling at the bottom of the hill? (b) If, the velocity at the bottom of the hill is 10 m s^{-1}, because of friction. How much work is done by friction? (a. 31.3 m s^{-1}, b. -8840 J)

DO YOU KNOW?

The pull of the moon does not only pull the sea up and down but it pulls land up and down by as much as 0.25m.

4.10 NON RENEWABLE RESOURCES

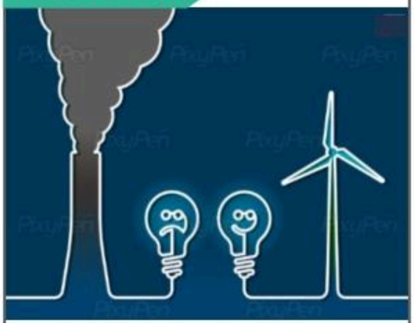
There are two major types of energy sources, conventional and non-conventional. Conventional' sources of energy are also called Non-Renewable resources. These resources cannot be renewed or replenished in short duration.

It took thousands of years of time to form the non-renewable resources which exist inside the earth in the form of coal, fossil fuels, etc. Over 85% of the energy used in the world is from conventional supplies. Most developed nations are dependent on conventional energy sources such as fossil fuels (coal, oil and gas) and nuclear power. These sources are called conventional because they cannot be renewed.

Industrialized societies depend on conventional energy sources. Fossil fuels are the most commonly used types of conventional energy. They were formed when incompletely decomposed plant and animal matter was buried in the earth's crust. This process occurred over millions of years. The three main types of fossil fuels are coal, oil, and natural gas.

Coal: Coal is the most abundant form of fossil fuel available on earth. Coal is mostly found below the earth and is major source of fuel for electricity generation as of today. Coal formed slowly over millions of years from the buried remains of ancient swamp plants. Currently, the world is consuming coal at a rate of about 5 billion metric tons per year. In addition to electricity production, coal is sometimes used for heating and cooking in less developed countries and in rural areas of developed countries. If consumption continues at the same rate, the current reserves will last for more than 200 years. The burning of coal results insignificant atmospheric pollution.

FIGURE 4.15



Energy from fossil fuels

Oil: Oil is available in abundance in most of the middle east countries such as Saudi Arabia, Kuwait, Iran, Iraq and UAE etc. Like coal, it was also made out of dead plants and animals that had lived millions of years ago. When plants and animals died they were covered with thick layer of mud and sand which created huge pressure and temperature.

Most known oil reserves are already being exploited, and oil is being used at a rate that exceeds the rate of discovery of new sources. If the consumption rate continues to increase and no significant new sources are found, oil supplies may be exhausted in another 50 years or so.

Natural Gas: Natural Gas is the gaseous form of fossil fuels. It is a mixture of several gases including methane, ethane, propane and butane. It burns completely and leaves no ashes. It causes almost no pollution and is one the cleanest form of fossil fuel.

The use of natural gas is growing rapidly. Natural gas is easy and inexpensive to transport once pipelines are in place. In developed countries, natural gas is used primarily for heating, cooking, and powering vehicles. It is also used in a process for making ammonia fertilizer. The current estimate of natural gas reserves is about 100 million metric tons. At current usage levels, this supply will last an estimated 100 years.

Nuclear Energy

When atoms are split apart, this energy can be used to make electricity. This process is called nuclear fission.In a nuclear power plant, fission takes place inside a reactor. Nuclear power in Pakistan makes a small contribution to total electricity production and requirements, supplying only 6.1 terawatt hour(s) (5.5%) of the electricity in 2015.

4.11 RENEWABLE RESOURCES

Non-Conventional' sources of energy are also called Renewable resources. The resources which are being continuously renewed by nature constantly are called as Renewable Resources. The sun, the winds, tides, geothermal energy, biomass, farm and animal waste including human excreta are the non-conventional sources of energy. They are inexpensive in nature.
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.

1. Energy from Biomass

Biomass energy is energy generated from plants and animals, and it is a renewable source of energy. Biomass is matter usually thought of as garbage. Some of it is just stuff lying around -- dead trees, tree branches, yard clippings, left-over crops, wood chips, and bark and sawdust.

FIGURE 4.16

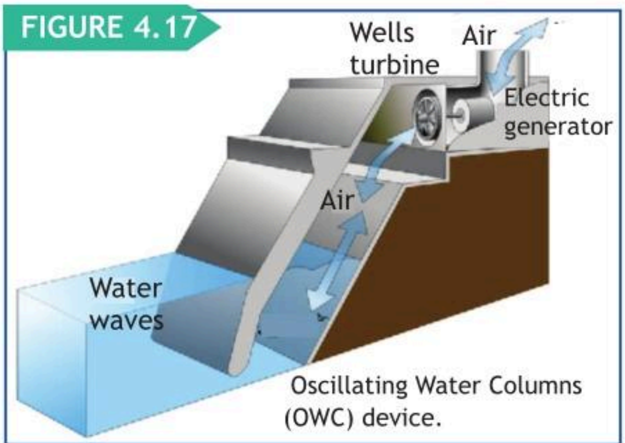
(a) garbage (b) energy from waste.

The trucks bring the waste from factories and from farms to a biomass power plant. This is then fed into a furnace where it is burned. The heat is used to boil water in the boiler, and the energy in the steam is used to turn turbines and generators. Technologies today are able to recover the energy contained in plastics. Plastics have a high energy content that can be converted to electricity, synthetic gas, fuels and recycled feedstocks for new plastics.

About 81 million ton/annum biomass production has a huge potential to produce enough bio-energy by employing different technologies viz. combustion, gasification, pyrolysis, process etc. Similarly, available dung from 72 million animals (cows and buffalos) and available poultry droppings from 785 million poultry birds can produce considerable biogas to produce heat and electricity.

2. Energy from waves

FIGURE 4.17



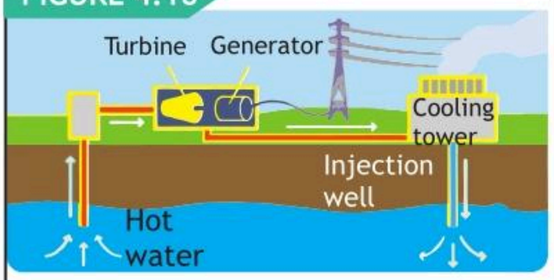
Oscillating Water Columns (OWC) device.

Ocean waves are caused by the wind as it blows across the sea. Waves are a powerful source of renewable energy.

There are many devices which are designed to efficiently convert wave power into electricity. Oscillation Water Columns (OWC) is one of them as shown in Fig 4.17. An Oscillating Water Column (OWC) consists of a partially submerged structure that opens to the ocean below the water surface. When these waves come through the structure it causes the water column to rise and fall with the wave which causes the air in the top structure to pressurize and depressurize. This in turn pushes and pulls air through a connected air turbine at

3. Geothermal Energy

FIGURE 4.18



Geothermal power plant.

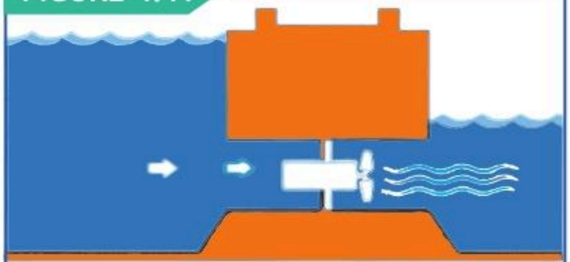
The inside of the Earth is full of heat which can be converted into different forms of energy therefore it is called geothermal energy. Geothermal power plants, which uses heat from deep inside the Earth to generate steam to make electricity as shown in Figure 4.18. At a geothermal power plant, wells are drilled 1 or 2 miles deep into the Earth to pump steam or hot water to the surface.

Hot water is pumped from deep underground through a well under high pressure. When the water reaches the surface, the pressure is dropped, which causes the water to turn into steam. The steam spins a turbine, which is connected to a generator that produces electricity.
The steam cools off in a cooling tower and condenses back to water.
The cooled water is pumped back into the Earth to begin the process again.
You're most likely to find one of these power plants in an area that has a lot of hot springs, geysers, or volcanic activity, because these are places where the Earth is particularly hot just below the surface.

4. Tidal Energy

Using the power of the tides, energy is produced from the gravitational pull from both the moon and the sun, which pulls water upwards, while the Earth's rotational and gravitational power pulls water down, thus creating high and low tides. This

FIGURE 4.19



Tidal barrages

Tidal barrages are the most efficient tidal energy sources as shown in Figure 4.19. A tidal barrage is a dam that utilizes the potential energy generated by the change in height between high and low tides. This energy turns a turbine or compresses air, which generates electricity. The Oxford University engineers calculated that underwater turbines strung across the entire width of the narrow inlet of the sea could generate a maximum 1.9 GW (giga watt) of power, averaged across the fortnightly tidal cycle. That is equivalent to 16.5 TW/h (terawatt/hour) of electricity a year, almost half Scotland's entire annual electricity consumption in 2011.

FIGURE 4.20

Tidal energy technologies.

5. Solar Energy

Solar energy is the radiant light and heat from the sun that has been harnessed by humans since ancient times using a range of ever-evolving technologies.
According to the International Energy Agency, global capacity of solar PV had

reached 402 gigawatts (GW) at the end of 2017.

The research findings indicate that solar energy is the best renewable energy option for Pakistan due to many factors such as price, operation and maintenance costs and life span. Pakistan is blessed with 5.5 Wh m^{-2} d^{-1} solar exposure with annual mean sunshine duration of 8-10 h d^{-1} throughout the country.

6. Wind Energy

Wind energy describes the process by which wind is used to generate electricity. Wind turbines convert the kinetic energy into mechanical power. An equivalents of 100 billion watts per year of power in the shape of wind energy is available on the earth. In the windy regions, wind mills are installed to produce mechanical energy. This mechanical energy may be used in tube wells or flour mills.

FIGURE 4.21

Wind energy

Wind speed 5-7 m s^{-1} persists in the coastal regions of Sindh and Baluchistan provinces with more than 20,000 MW of economically feasible wind power potential.

KEY POINTS

Work Done: The work done on a body by a constant force is defined as the product of the displacement and the component of the force in the direction of the displacement.

Conservative Field: The work done in the Earth's gravitational field is independent of the path followed, such a force field is called a conservative field.

Power: Power is defined as the rate of doing work.

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

Potential Energy: The potential energy is possessed by a body because of its position in a force field.

Absolute Potential Energy: The amount of work done in moving a body at a certain point in a gravitational field to a position of zero potential such that the body is never accelerated is called Absolute potential energy.

Escape Velocity: The initial velocity of a body with which it should be projected upward so that it does not come back, is called escape velocity.

Non Conventional Energy Sources: Some of the non conventional energy sources are

(a) Energy from the tides (b) Energy from waves
(c) Solar Energy. (d) Energy from biomass
(f) Geothermal energy

Exercise

MULTIPLE CHOICE QUESTIONS

Choose the best possible answer

1. You push a heavy crate down a ramp at a constant velocity. Only four forces act on the crate. Which force does the greatest magnitude of work on the crate?
(a) The force of friction. (b) The force of gravity.
(c) The normal force. (d) The force you pushing.

2. The force constant of a wire is k and that of the another wire is 3k when both the wires are stretched through same distance, if work done are W_1 and W_2, then
(a) $W_2 = W_1$ (b) $W_2 = 9W_1$ (c) $W_1 = 3W_2$ (d) $W_2 = 3W_1$

3. Escape velocity on the surface of the earth is 11.2 kms^{-1}. If the mass of the earth increases to twice its value and the radius of the earth becomes half the escape velocity is
a. 5.6 kms^{-1} b. 11.2 kms^{-1} c. 22.4 kms^{-1} d. 33.6 kms^{-1}

4. An example of non-conservative force is:
a. Electric force b. Gravitational Force
c. Frictional force d. Magnetic force

5. When the speed of your car is doubled, by what factor does its kinetic energy increase?
(a) $\sqrt{2}$. (b) 2. (c) 4. (d) 8.

6. One horse power is given by:
a. 746 W b. 746 KW c. 746 MW d. 746 GW

7. Work is said to be negative when $\vec{F}$ and $\vec{d}$ are:
a. Parallel b. Anti Parallel c. Perpendicular d. at 45°

8. Two bodies of masses m_1 and m_2 have equal momentum their kinetic energies E_1 and E_2 are in the ratio
a. $\sqrt{m_1} : \sqrt{m_2}$ b. $m_1 : m_2$ c. $m_2 : m_1$ d. $\sqrt{m_1^2} : \sqrt{m_2^2}$

MULTIPLE CHOICE QUESTIONS

9. The atmosphere is held to the earth by
   a. Winds b. Gravity c. Clouds d. The rotation of earth
10. If momentum is increased by 20% then k.E increases by
    a. 44% b. 55% c. 66% d. 77%
11. If the k.E of a body becomes four times of the initial value, then new momentum will
    a. Become twice its initial value
    b. Become three times, its initial value
    c. Become four times, its initial value
    d. Remains constant.
12. Two bodies with kinetic energies in the ratio of 4 : 1 are moving with equal linear momentum. The ratio of their masses is
    a. 1 : 2 b. 1 : 1 c. 4 : 1 d. 1 : 4
13. A body of mass 5 kg is moving with a momentum of 10 kg ms^{-1}. A force of 0.2 N acts on it in the direction of motion of the body for 10s. The increase in its kinetic energy is
    a. 2.8 J b. 3.2 J c. 3.8 J d. 4.4 J
14. If force and displacement of particle in the direction of force are doubled. Work would be
    a. Double b. 4 times c. Half d. ¼ times

CONCEPTUAL QUESTIONS

Give a short response to the following questions

1. A bucket is taken to the bottom of a well, does the bucket possess any P.E? Explain.
2. When an arrow is shot from its bow, it has k.E. From where does it get the k.E?
3. Does a hydrogen filled balloon possess any P.E? Explain.
4. Is k.E a vector quantity?
5. What happens to k.E of a bullet when it penetrates into a target?
6. Does the tension in the string of a swinging pendulum do any work? Explain.
7. A meteor when enters into the earth's atmosphere burns. What happens to its energy?
8. What type of energy is stored in the spring of watch?

9. A man drops a cup from a certain height, which breaks into pieces. What energy changes are involved?
10. A man rowing boat upstream is at rest with respect to shore, is he doing work?
11. Why energy savers are used instead of normal bulbs?

COMPREHENSIVE QUESTIONS

Give extended response to the following question

1. Define work and show that it is the dot product of force and displacement. At what conditions work done will be maximum or minimum?
2. Define power and show that power is the dot product of force and velocity. What are the different units of power used in our daily life?
3. Explain the work energy principle in the cases of the change in k.E of body.
4. Prove that Absolute P.E = $\frac{GmM_e}{R_e}$
5. Calculate the values of the escape velocity of a body and show that it is equal 11.2 km s^{-1}.
6. Describe briefly various non-conventional sources of energy.

NUMERICAL QUESTIONS

1. A 70 kg man runs up a long flight of stairs in 4 s. The vertical height of the stair is 4.5m. Calculate his power.
   (P = 7.7×10^2 Watts)
2. A body of mass 2.0 kg is dropped from a rest position 5m above the ground. What is its velocity at height of 3.0 m above the ground ? (v = 6.3 m s^{-1})
3. A man pulls a trolley through a distance of 50m by applying a force of 100N which makes an angle of 30° with horizontal. Calculate the work done by the man. (4330 J)

4. The roller-coaster car starts its journey from a vertical height of 40m on the first hill and reaches a vertical height of only 25m on the second hill, where it slows to a momentary stop. It traveled a total distance of 400 m. Determine the thermal energy produced and estimate the average friction force on the car whose mass is 1000 kg. (370N)

5. A man whose mass is 70kg walks up to the third floor of a building which is 12m above the ground in 20s. Find his power in watts and hp. (P = 411.6 watt = 0.55 hp)

6. To what height can a 400W engine lift a 100 kg mass in 3s? (h= 0.122m)

7. A ball of mass 100 g is thrown vertically upward at a speed of 25 ms^{-1}. If no energy is lost, determine the height it would reach. If the ball only rises to 25m, calculate the work done against air resistance. Also calculate the force of friction. (31.9m, 6.7J, 0.3N)

8. An object of mass 1000 g falls from a height of 30m on the sand below. If it penetrates 4cm into the sand, what opposing force is exerted on it by the sand? Neglect air friction. (f = 7350 N)

9. A body of mass '*m*' drops from Bridge into water of the river. The bridge is 10m high from the water surface.
(a). Find the speed of the body 5m above the water surface.
(b). Find the speed of the body before it strikes the water.
((a) 9.9 $m\ s^{-1}$ (b) 14 $m\ s^{-1}$)

10. The engine of a JF-Thunder fighter (made by Pakistan and China) develops a thrust of 3000N. What horsepower does it at a velocity of 600 $m\ s^{-1}$? (2413 hp)

11. The mass of the moon is 1/80 of the mass of the earth and corresponding radius is ¼ of the earth. Calculate the escape velocity on the surface of moon. (2.5 kms^{-1})