Work, energy and power

Physics 18

18.1 Work

You have learnt before, that an object is said to have done work if its position or shape changed under the action of a force applied on it. Let us investigate further about work.

If we place an object on a horizontal plane as shown in Figure 18.1 and apply a constant force of 1 N on it until it moves a distance of 1 m along the direction of the force, the work done by the force is defined to be one Joule (1 J).

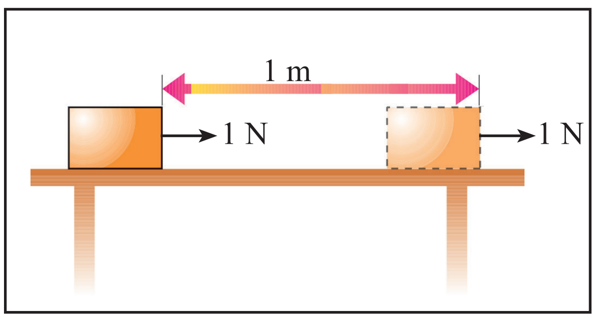


Figure 18.1 – Moving an object by 1 m under the action of a force of 1 N

If a constant force of 2 N acts on the object until it moves by 1 m in the direction of the force, then the work done on the object is 2 J.

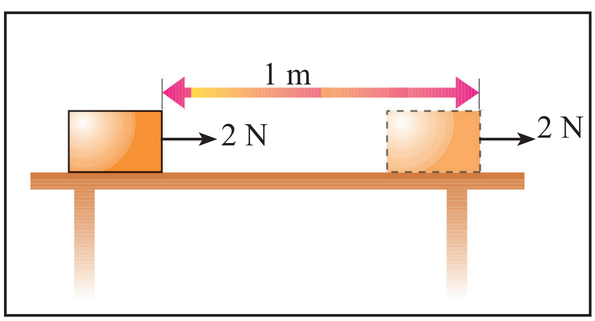


Figure 18.2 – Moving an object by 1 m under the action of a force of 2 N

Similarly, if a constant force of 3 N acts on the object until it moves by 1 m in the direction of the force as shown in Figure 18.3, then the work done on the object is 3 J.

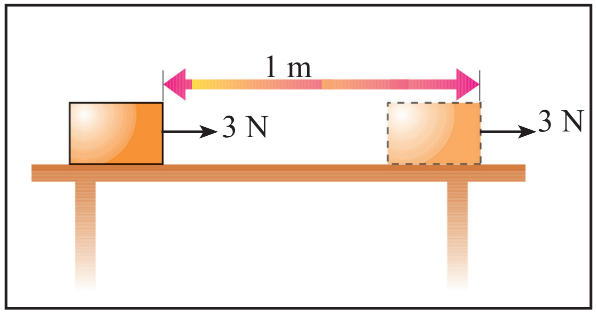


Figure 18.3 – Moving an object by 1 m under the action of a force of 3 N

Therefore,
Work done by a force = force × displacement in the direction of the force

Example 1

What is the work done, if a force of 7.5 N acts on an object and displaces it by 8 m in the direction of the force?

Work done = force × displacement in the direction of the force
= 7.5 N × 8 m
= 60 J

Example 2

The weight of an object is 40 N. What is the work done in lifting the object by a vertical distance of 2 m?

Force that mast be applied vertically upwards to lift the 40 N weight = 40 N
Displacement along the direction of the force = 2 m
Work done = 40 N × 2 m
= 80 J

Example 3

The mass of an object is 5 kg. Find the work done in lifting it upwards by 3 m.

Mass of the object = 5 kg

Weight of the object = mg

$= 5 \text{ kg} \times 10 \text{ m s}^{-2}$

$= 50 \text{ N}$

Force needed to lift the weight = 50 N

Height to be lifted = 3 m

Work done $= 50 \text{ N} \times 3 \text{ m}$

$= 150 \text{ J}$

Exercise 18.1

Copy the table given below in your exercise book and fill in the blanks.

Force	Displacement of force	Work done
20 N	2 m	....
....	80 cm	24 J
15 N	....	22.5 J
0.75 N	8 m	....

18.2 Energy

Energy is the ability to do work. The unit for measuring energy is the same unit Joule that is used to measure the work done. We need energy to do various tasks. There are different forms of energy that help us to do work.

Examples

Heat energy
Electric energy
Magnetic energy
Mechanical energy
Light energy
Sound energy

Out of these different forms of energy, we will discuss mechanical energy here. There are two forms of mechanical energy and they are known as potential energy and kinetic energy.

Kinetic energy

The energy possessed by an object due to its motion is known as kinetic energy.

As shown in Figure 18.4, project an object (*A*) with a certain velocity along a horizontal floor so that it collides with a light trolley (*B*). After the collision, the trolley would move some distance before coming to rest. Next, project the object with a higher velocity. Now the trolley will move a longer distance before coming to rest.

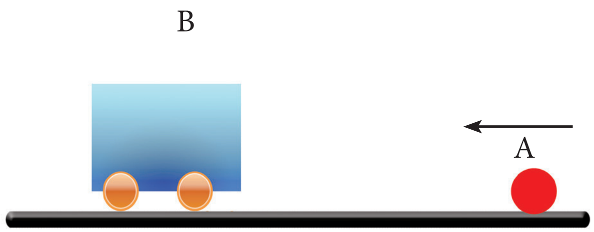


Figure 18.4 – Pushing an object with a velocity

In this case, part of the kinetic energy of the moving object is transferred to the trolley setting the trolley in motion. When a higher initial velocity is given to the object, more energy is transferred to the trolley and it moves a longer distance.

Similarly, push objects of various masses with the same velocity towards the trolley. You will observe that the trolley would move further when knocked on by larger masses.

From these results, it is clear that the kinetic energy depends on the two factors, velocity and mass.

The following equation, which involves the two factors velocity and mass is used to calculate the kinetic energy of a moving object.

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

Where, m = mass of the object

v = velocity of the object

E_k = kinetic energy

When the unit of mass is kg, and the unit of velocity is m s^{-1}, the unit of kinetic energy is J (Joule).

Example 1

The mass of an object is 6 kg. Calculate its kinetic energy when it is moving at a velocity of 4 m s^{-1}.

$$\text{Kinetic energy} = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times 6 \times 4^2$$
$$= 48 \text{ J}$$

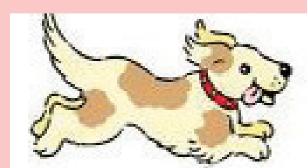
Example 2

Calculate the kinetic energy of an object of mass 4 kg at an instant that it is moving with a velocity of 2 m s^{-1}.

$$\text{Kinetic energy} = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times 4 \times 2^2$$
$$= 8 \text{ J}$$

Exercise 18.2

1) The mass of a dog is 10 kg. If its kinetic energy is 20 J at a certain instant, what would be the velocity it is running at?



(2) The kinetic energy of an object of mass 500 g is 9 J when it is moving with a certain velocity. Calculate the velocity of the object at that instant.

Potential energy

The energy stored in an object due to its position or due to a change in its form is known as potential energy.

When we lift an object upwards by a certain distance, we perform work on the object. That is, we expend some energy to bring the object to its new position. That energy is stored in the object as potential energy.
Let us find the energy required to lift an object of mass 3 kg by a distance of 2 m as shown in Figure 18.5 .

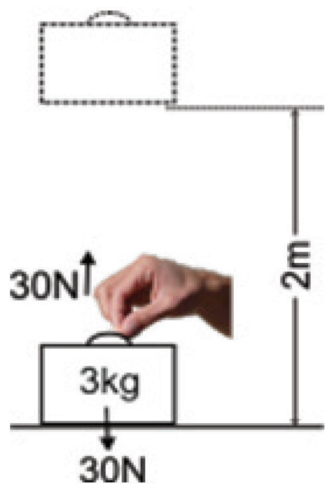


Figure 18.5 - Doing work against gravity

Weight of the 3 kg mass = 3 kg $\times$ 10 m s^{-2} = 30 N
Force required to lift the object = 30 N
Height that the object is lifted = 2 m
Work done on the object = 30 N $\times$ 2 m
= 60 J

Work done = mass of the object $\times$ gravitational acceleration $\times$ vertical distance lifted

Work done = Weight of the object $\times$ vertical distance lifted

Weight of the object = mass of the object $\times$ gravitational acceleration

Since the work done is 60 J the energy stored in the object at a height of 2 m is 60 J. That is the potential energy of the object at a height of 2 m is 60 J.

Since work is done against gravitational attraction, this potential energy is known as gravitational potential energy.

In the above example if we take, m as the mass of the object,

g as the acceleration due to gravity and

h as the vertical distance to the object, then

$$\text{potential energy} = mgh$$

The work done in lifting an object vertically upwards is stored in the object as potential energy. This energy is converted back into kinetic energy when the object is released. Let us do the following activity to show that the potential energy of an object is greater when its vertical position is higher.

Activity 18.1

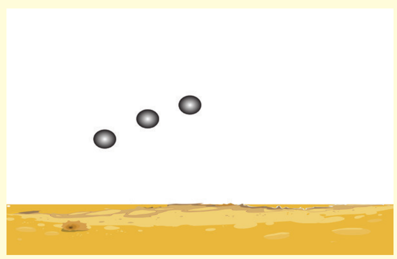


Figure 18.6 – Variation of the potential energy with height

- Spread some clay on the floor, to a thickness of about 3 cm.
- Release a fairly heavy weight from a vertical height of about 0.5 m from the clay surface.
- Observe the depth of the depression caused on the clay surface at the point of contact where the weight fell.
- Repeat the above procedure by releasing the weight from various heights, make sure that the same part of the weight comes in contact with the clay surface each time it falls.
- Each time observe the depth of the depression on the clay surface.

You will observe that the depth of the depression increases as the original height of releasing the weight increases. The energy required to form a depression on the clay surface was given by the falling weight. Your observations will confirm that the energy of the weight increases as the height of the fall increases.

It will be clear to you from this activity that the potential energy stored in an object increases in proportion to the height it is positioned.

Activity 18.2

- Fill about $\frac{1}{4}$th of the height of a plastic bottle with sand and allow it to fall from a height of about 1 m onto the clay surface.
- Observe the depth of the depression formed on the clay surface as before.
- Next fill about ½ of the plastic bottle with sand and release from the same height as before.
- Now fill the plastic bottle completely with sand and release it from the same height.

You will observe that the depth of the depression on the clay surface increases with the mass of the object. It will be clear to you that the potential energy of an object increases with increasing mass.

When the length of a rubber band or a spring is increased by stretching it upon applying a force, its shape changes and the work done by the displacement of the force is stored in the rubber band or the spring. This potential energy is known as **elastic potential energy.**

Figure 18.7 - Stretching a spring

Suppose that the bicycle riding fast along a horizontal road had to climb up a hill as shown in the figure 18.8. Even though the rider might not try to pedal the bicycle now, it is possible for the bicycle to reach the hilltop due to the velocity he had at first. However, his velocity would decrease as the bicycle moves upward. Therefore, the kinetic energy of the bicycle would gradually decrease as it moves up.

If he was able reach the hilltop in this manner, the rider would be able reach the bottom of the hill without pedaling the bicycle. As he moves down the hill, his velocity would increase gradually. In turn, the kinetic energy of the bicycle would increase gradually.

Figure 18.8 - Riding a bicycle up of a hill

When the bicycle reached the bottom of the hill after riding along the flat road, it had some kinetic energy. When it went up the hill, its kinetic energy decreased until it reached a minimum value at the hilltop while its potential energy increased up to a maximum value. When the bicycle started its decent after reaching the hilltop, its potential energy begins to decrease while the kinetic energy begins to increase. From this example, it would be clear to you that kinetic energy can transform into potential energy and potential energy can transform back into kinetic energy.

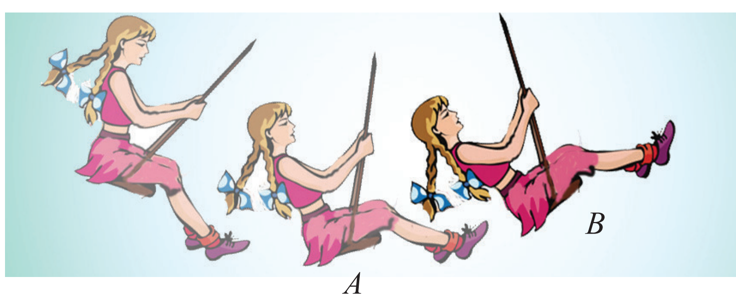


Figure 18.9 - Movement of a swing

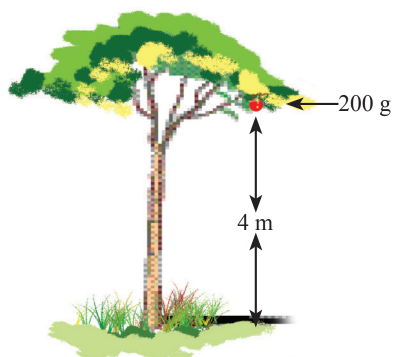
You have seen swings in motion. When the child in the swing shown Figure 18.9, moves from the lowest point *A* to the highest point *B*, the kinetic energy decreases gradually. However, as she reaches a higher vertical level at *B*, the potential energy increases gradually. Therefore, as the child moves from point *A* to *B*, the kinetic energy of the system gets converted into potential energy. At *B* the velocity is zero and all the kinetic energy has transformed into potential energy. Thereafter, when the child swings back to point *A*, the potential energy gets transformed back into kinetic energy.

Example 1

Find the gravitational potential energy of an object of mass 7.5 kg at a vertical height of 4 m.

$$\begin{aligned}\text{Potential energy} &= mgh \\ &= 7.5\text{ kg} \times 10\text{ m s}^{-2} \times 4\text{ m} \\ &= 300\text{ J}\end{aligned}$$

Example 2



A fruit on a tree has a mass of 200 g. The vertical height to the fruit from the ground level is 4 m. Find the gravitational potential energy of the fruit.

$$\begin{aligned}\text{Gravitational potential energy} &= mgh \\ &= \frac{200\text{ kg}}{1000} \times 10\text{ m s}^{-2} \times 4\text{ m} \\ &= 8\text{ J}\end{aligned}$$

Instances where potential energy is used in daily life

1. Water stored in high reservoirs is allowed to fall down to a lower level, transforming the initial potential energy of the water into kinetic energy and this kinetic energy of the falling water is used to rotate a turbine to generate electricity.

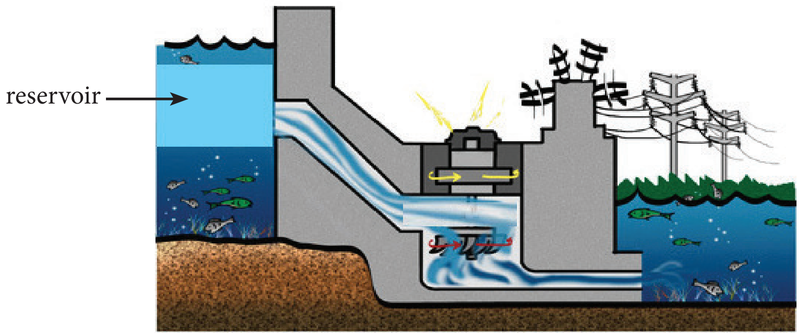


Figure 18.10 - Potential energy is used to generate electricity.

2. Pile and Tower

Pile is used to tighten the loose soil in construction sites before laying the foundation of buildings. This is done by lifting the pile to some height and releasing it to fall down onto the ground below.

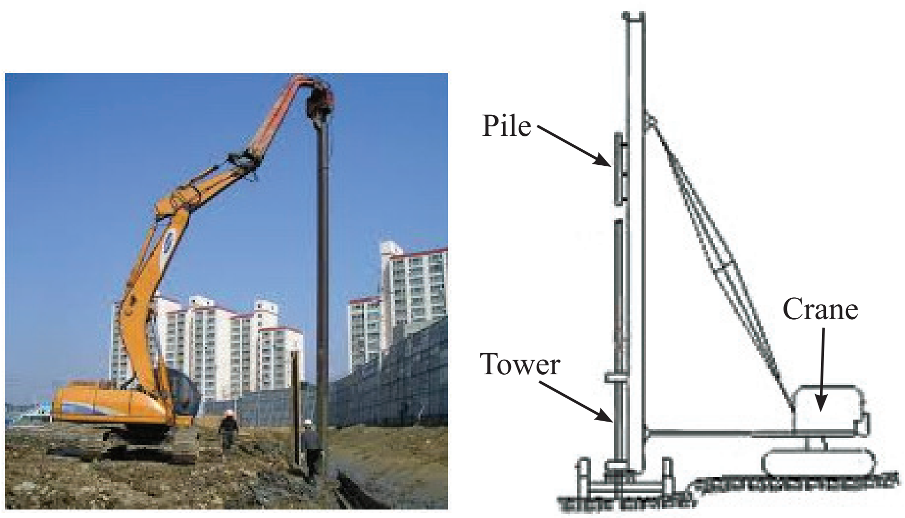


Figure 18.11 - Pile and tower.

3. Sledge hammer

In breaking stones and cutting firewood, sledge-hammer is used. When cutting wood, an iron wedge is inserted into the piece of wood to be cut and the lifted sledge-hammer is released on to the wedge. The potential energy of the sledge-hammer at the point of release transforms into kinetic energy whereby it collides on the wedge with a large velocity. The kinetic energy of the sledge-hammer gets transferred to the wedge which passes through the piece of wood, separating it into pieces.

Figure 18.12 - Using sledge hammer

18.3 Power

The amount of work done in a unit time or the rate of doing work is known as power.

If 600 Joules of work is done in 10 s,

rate of doing work or power $= \dfrac{600 \text{ J}}{10 \text{ S}}$

$= 60 \text{ J s}^{-1}$

One Joule per second (1JS^{-1}) is defined as a Watt (1W). Hence the power indicated above is 60W. That is the unit of power is Watt (W) .The following equation is used to calculate the power.

$$\text{Power} = \frac{\text{work done (J)}}{\text{time spent (s)}}$$

Example 1

The time taken to lift a mass of 5 kg to a height of 8 m is 10 s. Calculate the rate of doing work (power).

Mass of object $= 5$ kg

Weight of object $= mg$

$= 5 \text{ kg} \times 10 \text{ m s}^{-2}$

$= 50 \text{ N}$

Therefore, force exerted to lift the object $= 50\ N$

Height lifted $= 8\ m$

Work done $= 50\ N \times 8\ m$

$= 400\ J$

$$\text{Power} = \frac{400\ J}{10\ s}$$

$= 40\ W$

Example 2

What is the work done in a minute by a machine operating with a power output of 100 W?

Power = 100 W

$= 100\ J\ s^{-1}$

Time = 1 minute

= 60 s

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

Work done during 10 s = power × time

$= 100\ W \times 60\ s$

$= 100\ J\ s^{-1} \times 60\ s$

$= 6000\ J$

Miscellaneous exercises

(1) (i) A child lifts a bag of mass 4 kg to a height of 1.5 m. What is the work done? ($g = 10\ m\ s^{-2}$)

(ii) If the child took 3 seconds to do the work above, what is the rate of doing work (power)?

(2) A mass of 800 g was projected vertically upwards at a velocity of $20\ m\ s^{-1}$.

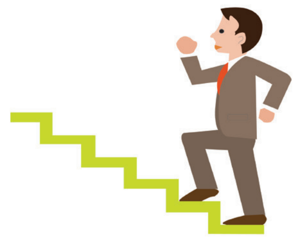
(i) What is the kinetic energy of the object just as it is projected?

(ii) How long will it take to reach the maximum height?

(iii) What is the maximum height it would reach?

(iv) What is its potential energy at the maximum height?

(3) A child of mass 35 kg climbs up a stair case to a vertical height of 4 m.



(i) What is the amount of work he does?

(ii) If he took 1 minute to climb the stairs, what is his rate of doing work or power?

Summary

- The work done by a force is equal to the product of the magnitude of the force and the displacement along the direction of the force.

  That is, work = force × displacement in the direction of the force

- If there is no energy loss, the work done is equal to the energy expended.
- The unit of measuring work and energy is the Joule (J).
- The two forms of mechanical energy are the potential energy and the kinetic energy.
- The kinetic energy of an object depends on its mass and the velocity.

Kinetic energy is calculated using the following equation:

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

m = mass (kg)
v = velocity ($m\ s^{-1}$)

There are three factors that affect the gravitational potential energy.

1. Mass (m)
2. Gravitational acceleration (g)
3. Height (h)

The following equation is used to calculate the gravitational potential energy.

Gravitational potential energy = $m\,g\,h$

- The potential energy of an object changes when its shape changes.
- When an object moves upwards under gravity, there is a loss in its kinetic energy and this lost kinetic energy is transformed into potential energy.

Technical Terms

Work	-	කාර්යය	-	வேலை
Energy	-	ශක්තිය	-	சக்தி
Mechanical energy	-	යාන්ත්‍රික ශක්තිය	-	பொறிமுறை சக்தி
Kinetic energy	-	චාලක ශක්තිය	-	வெப்பசக்தி
Potential energy	-	විභව ශක්තිය	-	அழுத்த சக்தி
Power	-	ජවය	-	வலு