11

Work and Energy

In the Chapter

- Work done on an object is termed as the magnitude of the force multiplied by the distance moved by the object in the direction of the applied force. The unit of work is joule: 1 joule = 1 newton × 1 metre.
- Work done on an object by a force would be zero if the displacement of the object is zero.
- An object having capability to do work is said to possess energy. Energy has the same unit as that of work.
- An object in motion possesses what is known as the kinetic energy of the object. An object of mass, m moving with velocity, v has a kinetic energy of $1/2\ mv^2$.
- The energy possessed by a body due to its change in position or shape is known as the potential energy. The gravitational potential energy of an object of mass, m raised through a height, h from the earth's surface is expressed by m g h.
- According to the law of conservation of energy, energy can only be transformed from one form to another; it can neither be created nor destroyed. The total energy before and after the transformation always remains constant.
- Energy exists in nature in several forms like kinetic energy, heat energy, potential energy, chemical energy, etc. The sum of the kinetic and potential energies of an object is known as its mechanical energy.
- Power is defined as the rate of doing work. The SI unit of power is watt. 1 W = 1 J/s.
- The energy used in one hour at the rate of 1kW is called 1 kW h.

Intext Exercises

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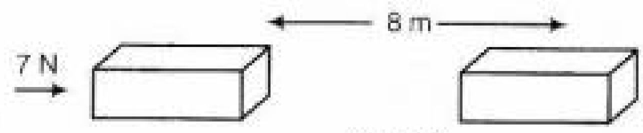
1. **A force of 7 N acts on an object. The displacement is, say 8 m, in the direction of the force (as given in the figure). Let us take it that the force acts on the object through the displacement. What is the work done in this case ?**



Ans. Force, $F = 7\,N$
Displacement, $S = 8\,m$
Work, $W = F \times S$
$W = 7N \times 8\,m = 56\,Nm$

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1. When do we say that work is done?

Ans. Work is said to be done when force is applied on an object and the object moves through a distance in the direction of application of force.

It is equal to the product of force and displacement.

Work done = Force × Displacement

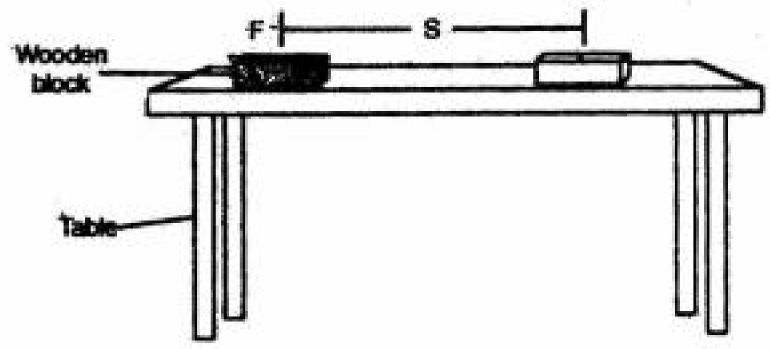
Or $W = F \times S$

2. Write an expression for the work done when a force is acting on an object in the direction of its displacement.

Ans. When a force F is applied on a body, and it moves the body by a distance S in its direction, then the amount of work done is described by the relationship,

Work done = Force × Distance through which the body moves

Or, $W = F \times S$



3. Define 1 J of work.

Ans. Work done is described as,

Work = Force x Distance

So, the unit of work depends upon the unit of force and distance. In SI units force is expressed in newton (N) unit, while the distance is measured in metre (m) unit. So,

1 unit of work done = 1 Newton x 1 Metre

The unit, $1\,N \times 1\,m$ is called joule (J)

Thus, the SI unit of work is joule (J).

Joule is defined as follows:

The amount of work done when a force of 1 N moves a body by a distance of 1 M in its own direction is equal to 1 joule.

4. A pair of bullocks exerts a force of 140 N on a plough. The field being ploughed is 15 m long. How much work is done in ploughing the length of the field?

Ans. Force, F = 140 N

Displacement, S = 15 m

Work done = $F \times S$

$W = 140\,N \times 15\,m$

$W = 2100\,Nm$

$W = 2100\,J$

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1. What is the kinetic energy of an object ?

Ans. The energy possessed by a body by virtue of its motion is called kinetic energy. So a moving object can do some work due to its kinetic energy.

Examples : (i) A speeding bullet has kinetic energy.

(ii) Wind has kinetic energy. It is due to this energy that the wind can turn the blades of a windmill.

(iii) Flowing river water has kinetic energy.

2. Write an expression for the kinetic energy of an object.

Ans. Let a body of mass 'm' starting from rest accelerate uniformly to attain a velocity v after having covered a distance of s. Then,

$v^2 - u^2 = 2as$

Or, $v^2 = 2as$ $(vu = 0)$

Or, $a = v2/2s$

So, the force (F) acting on the body is,

$F = m \times a = m \times v^2/2s$

Or, $F \times s = \frac{1}{2}mv^2$

But, $F \times s =$ Work done on the body,

So,

Work done on the body $= \frac{1}{2}mv^2$.

Kinetic energy of the body when it is in motion is equal to amount of work done on it. Therefore,

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

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

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

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

where, m = mass of object

v - velocity of the object

Here, mass (m) is same in both cases (since object is same)

$$\therefore \quad \frac{K_1}{K_2} = \left(\frac{V_1}{V_2}\right)^2$$

Initial kinetic energy $K_1 = 25$ J

Initial velocity $V_1 = 5$ mg–1

New kinetic energy $K_2 = ?$

New velocity $V_2 = 3V_1 = 3 \times 5 = 15 ms^{-1}$

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

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

$\Rightarrow$ K2 = 225J

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1. **What is power ?**

Ans. Power is the rate of doing work or the rate of utilizing energy. The power of an agent may vary with time.

2. **Define 1 watt of power.**

Ans. 1 watt is the power of an agent, which does work at the rat of 1 joule per second.

Or

Power is 1 watt when the rate of consumption of energy is 1 joule per second.

3. **A lamp consumes 1000 J of electrical energy in 10 seconds. What is its power ?**

Ans. Electrical energy = 1000 J

Time = 10 seconds

Power = Electrical energy consumed / Time taken

P = 1000J / 10s

P = 100 Js^{-1} or 100 W

4. **Define average power.**

Ans. We obtain the average power by diving the energy consumed by the total time taken.

Power = Total work done / Time taken

P = W / t

Exercise

1. **Look at the activities listed below. Reason out whether or not work is done in the light of your understanding of the term 'work'.**
   (a) Suma is swimming in a pond.
   (b) A donkey is carrying a load on its back.
   (c) A wind -mill is lifting water from a well.
   (d) A green plant is carrying out photosynthesis.
   (e) An engine is pulling a train.
   (f) A sailboat is moving due to wind energy.

Ans. (a) Yes, work is being done in this case. But the work done is negative since the force is being applied backwards but the displacement (motion of Suma) is in the forward direction.

(b) No, work is being done in this case because the force (load on its back) is acting downwards whereas the displacement (motion of the donkey) is in forward direction. For work to be done, displacement should be in the direction of application of force.

(c) Yes, work is being done in this case because the force is being applied upwards and the water is also being lifted upward.

(d) No, work is being done in this case because neither there is any force applied nor there is any displacement.

(e) Yes, work is being done because the engine is applying a force on the train and the train is showing displacement in the direction of force (moving forward).

(f) Yes, work is being done in this case because the wind energy is applying a force and the sailboat is getting displaced in the direction of application of force.

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

Ans. The work done by the force of gravity on the objet will be zero. This is because

Work done against gravity = $m \times g \times h$

The mass and acceleration due to gravity remains constant but the height becomes zero since the initial and final points of the path of the object lie on the same horizontal line.

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

Ans. The chemical energy of the battery is converted into electrical energy which is further converted into heat and light energies.

4. Certain force acting on a 20 kg mass changes its velocity from 5 ms-1 to 2ms-1. Calculate the work done by the force.

Ans.

Mass $m = 20\text{ kg}$

Initial velocity, $u = 5\text{ ms}^{-1}$

Final velocity, $v = 2\text{ ms}^{-1}$

Work done by the force = change in kinetic energy

= Final kinetic energy – Initial kinetic energy

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

$$= \frac{1}{2}m(v^2 - u^2) = \frac{1}{2} \times 20(2)^2 - (5)^2$$

$$= 10(4 - 25) = 10 \times -21 = -210\text{J}$$

5. A mass of 10 kg is at a point A on a table. It is moved to a point B. If the line joining A and B is horizontal, what is the work done on the object by the gravitational force ? Explain your answer.

Ans. Mass, $m = 10\text{ kg}$

Acceleration due to gravity $g = 10\text{ ms}^{-2}$

Work done by force of gravity = $m \times g \times h$

In this case, the work done on the object by the force of gravity is zero because the line joining A and B is horizontal, hence the height 'h' is zero, i.e., there is no component of the force of gravity in the direction of displacement.

6. The potential energy of a freely falling object decreases progressively. Does this violate the law of conservation of energy ? Why?

Ans. This does not violate the law of conservation of energy because as the potential energy of the freely falling object decreases, its kinetic energy increases. Hence, the total energy remains the same.

7. What are the various energy transformations that occur when you are riding a bicycle ?

Ans. The various energy transformations are :

Potential energy to muscular energy to mechanical energy.

8. Does the transfer of energy take place when you push a huge rock with all your might and fail to move it ? Where is the energy you spend going ?

Ans. No, transfer of energy does not take place when we push a huge rock with all our might. When we push the rock, the muscles are stretched and blood is displaced to the strained muscles more rapidly. These changes consume energy and we feel tired.

9. A certain household has consumed 250 units of energy during month. How much energy is this in joules ?

Ans. Energy consumption during a month = 250 units

1 unit = 1 kWh

250 units	=	250 kWh
Now 1 kWh	=	36,00,000J
250 kWh	=	36,00,000 J × 250
	=	90,00,00,000 J

10. An object of mass 40 kg is raised to a height of 5m above the ground. What is its potential energy? If the object is allowed to fall, find its kinetic energy when it is half way down.

Ans. Given mass $m = 40$ kg, height $h = 5$,
Potential energy PE = mgh = 40 × 9.8 × 5 = 1960 J
KE at half-way down = PE at half way down

$$= mg\frac{h}{2}$$

$$= 40 \times 9.8 \times \frac{5}{2} = 980\text{J}$$

11. What is the work done by the force of gravity on a satellite moving round the earth ? Justify your answer.

Ans. The work done on a satellite moving round the earth is zero.
When the satellite moves in a circular path, then the centripetal force acts towards the centre along the radium and the direction of motion is tangential to the circle. The two are thus perpendicular to each other (Fig. 12.12). So,

Work done	=	$F \times S \times \cos\theta$
W	=	$FS \cos 90\theta = 0$

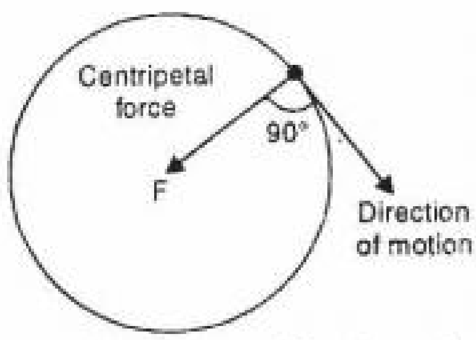


Fig. 12.12. Motion of a satellite in a circular path.

So, in the case of uniform circular motion, the work done is zero.

12. Can there be displacement of an object in the absence of any force acting on it ? Think. Discuss this question with your friends and teacher.

Ans. When the body is at rest, by Newton's first law of motion, it continues to remain at rest unless an external unbalanced force acts on it. Hence, no displacement takes place in the absence of force. However, when the body is in motion, say a moving bus, a force is required to stop. So, in this case, the displacement takes place in the absence of force.

13. A person holds a bundle of hay over his head for 30 minutes and gets tried. Has he done some work or not ? Justify your answer.

Ans. No, the person has not done any work on the bundle of hay because there is no displacement of the bundle.

14. An electric heater is rated 1500 W. How much energy does it use in 10 hours ?

Ans. Power = 1500 W = 1500 / 1000 kW

= 1.5 kW

Time = 10 h

Power = Work done / Time taken

Or

Power = Electrical energy consumed / Time taken

Electrical energy = Power × Time taken

Electrical energy = 1.5 kW × 10 h

= 15 kWh

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

Ans. (i) The bob eventually comes to rest because the friction at the point of support of the pendulum and friction of air acting on the swinging bob converts the mechanical energy of the oscillating pendulum into heat energy slowly.

(ii) Eventually, this heat energy goes into the environment.

(iii) No, it is not a violation of the law of conservation of energy.

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

Ans. Mass = m

Constant velocity = v

Energy of the body = $\frac{1}{2}mv^2$

(Since the body is in motion)

Thus an equivalent amount of work should be done on the body in order to bring it to rest.

Hence work done on the object = $\frac{1}{2}mv^3$

17. Calculate the work required to be done to stop a car of 1500 kg moving at a velocity of 60 km/h?

Ans. Mass, m = 1500 kg

Velocity, $v = 60\ \text{kmh}^{-1}$

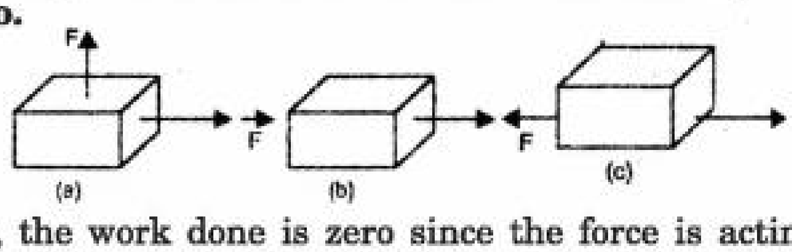
$$= \frac{60 \times 1000\text{m}}{3600\text{s}} = 16.67\ \text{ms}^{-1}$$

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

$$\text{K.E.} = \frac{1}{2} \times 1500\text{kg} \times (16.67\ \text{ms}^{-1})^2$$

$$= 208416.67\ \text{J}$$

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



Ans. (a) In this case, the work done is zero since the force is acting perpendicular to the displacement.

Work done at an angle 0 = F × s × cosθ

W = $F \times s \times \cos 90^\circ$

W = $F \times s \times 0 = 0$ Joule

(b) In this case, the work done is positive because the displacement takes place in the direction of application of force.

(c) In this case, the work done is negative because the displacement takes place in the direction opposite to the direction of application of force.

19. Soni says that the acceleration in an object could be zero even when several forces are acting on it. Do you agree with her? Why?

Ans. Yes, Soni is correct because when the object is at rest, the velocity is zero and in turn the acceleration is zero. Several forces may act on it but they cancel each other. When the object is in motion and moving with a constant velocity, its acceleration is zero. Even in this situation several forces may acts on the object which balance each other.

20. Find the energy in kWh consumed in 10 hours by four devices or power 500 W each.

Ans. Power of each device = 500 W

Power of four devices = 4 × 500 W

= 2000 W

= 2000 / 1000 kW = 2 kW

Time = 100 hours

Power = Work done / Time taken

Or, Power = Electrical energy / Time taken

Or, Electrical energy

= Power × Time taken

Electrical energy

= 2 kW × 10 hrs = 200 kWh

21. A freely falling object eventually stops on reaching the ground. What happens to its kinetic energy?

Ans. When the object stops, the velocity becomes zero. Its kinetic energy also becomes zero (K.E. = $\frac{1}{2}mv^2$) on reaching the ground.

Additional Questions

1. List two essential conditions for work to be done.

Ans. (i) A force should be applied on a body.

(ii) Displacement should be in the direction of force applied.

2. When is 1 joule of work said to be done?

Ans. When a force of 1 newton causes a displacement of 1 m in its own direction, the work done is said to be 1 joule.

3. What will cause greater change in kinetic energy of a body? Changing its mass or changing its velocity.

Ans. Changing velocity of a body will cause greater change in its kinetic energy.

4. What is the SI unit of kinetic energy?

Ans. Joule

5. Water flows down the mountains to the plains. What happens to the potential energy of water?

Ans. Potential energy of water will decrease. It will change to kinetic energy of water.

6. A nail becomes hot when hammered into a plank. Why?

Ans. Because some mechanical energy due to friction is converted into heat energy.

7. An archer stretches his bow to shoot an arrow. Name the energy transformation taking place when the arrow is shot.

Ans. The potential energy changes into kinetic energy.

8. What is the SI unit of power?

Ans. The SI unit of power is Watt.

9. Define 1 kWh.

Ans. One kilowatt hour is the amount of electrical energy consumed when an electrical appliance of 1000 watt is used for 1 hour.

10. What should be the change in velocity of a body required to increase its kinetic energy to four times of its initial value ?

Ans. The velocity of the body should be doubled at constant mass.

11. A labourer, with a load on his head, is going along a horizontal road. Is he doing some work?

Ans. No, the labourer is not doing any work because force and direction of motion are perpendicular to each other.

12. A body is thrown vertically upwards. Its velocity keeps on decreasing. What happens to its kinetic energy as its velocity becomes zero ?

Or

A ball is thrown vertically upwards. Its velocity keeps on decreasing. What happens to its kinetic energy when it reaches the maximum height?

Ans. The kinetic energy of the body changes into its potential energy.

13. Two bodies having equal masses are moving with uniform speed of 2v and 3v, respectively. Find the ratio of their kinetic energies.

Ans. 4: 9 respectively.

14. What change should be affected in the velocity of a body to maintain the same kinetic energy if its mass is increased four times ?

Ans. K.E. = $\frac{1}{2}mv^2$. If mass is increased four times, velocity must be reduced to half to maintain the same K.E.

15. A horse and a dog are running with the same speed. If the weight of the horse is ten times that of the dog, what is the ratio of their kinetic energy?

Ans. 10: 1 (i.e., $m_1 : m_2$)

16. Name the term used for the sum of kinetic energy and potential energy of a body.

Ans. Mechanical energy.

17. How many joules make one kilo watt hour?

Ans. 1 kilowatt-hour = 3.6 x 106 J.

18. When displacement is in a direction opposite to the direction of force applied, what is the type of work done?

Ans. Work done is negative.

19. A car and a truck are moving with the same velocity of 60 km/hr. Which one has more kinetic energy? (Mass of truck > Mass of car).

Ans. Truck has more kinetic energy.

20. Give one example each of:

(a) Positive work done by a force.

(b) Negative work done by a force.

Ans. (a) Positive work done by a force: When we hit a ball, the ball starts moving in the direction of force; it is an example of positive work done by a force.

(b) Negative work done by a force: The frictional force always acts in the direction opposite to the movement of the body. Thus, it is an example of negative work done by a force.

21. Is there any difference in the way we use the term 'work' in day to day life and the way we use it in science?

Ans. Yes, in day to day life, any physical or mental exertion is called work, but in science we have a separate definition of work.

22. A student is writing a three-hour science paper. How much work is done by the student? Give reasons to your answer.

Ans. Work done is zero because there is no displacement.

23. Seema tried to push a heavy rock of 100 kg for 200 s but could not move it. Find the work done by Seema at the end of 200 s.

Ans. Work done by Seema is zero because there is no displacement.

24. How much work is done by a weight lifter when he holds a weight of 80 kg on his shoulders for two minutes?

Ans. Work done is zero because there is not displacement.

25. Rupayan lifts a book through a height by applying force.
(i) What happens to the book? Why?
(ii) Is work being done scientifically?

Ans. (i) The book rises up because Rupayan has exerted a force on it.
(ii) Yes, work is being done scientifically because a force is applied on the book and the book has moved.

26. What are the two conditions needed to be satisfied for work to be done?

Ans. (i) A force should act on an object.
(ii) The object must be displaced.
If any of the conditions do not exist, work is not done.

27. What is the work done on an object when the force on the object is zero?

Ans. When force is zero, the work done will be zero.

28. What should be the angle between force and displacement to get minimum work?

Ans. To get minimum work angle should be 90°.

29. On what factors does the work done on a body depend?

Ans. The work done on a body depends on following factors:
(i) Magnitude of the force (F).
(ii) Distance through which the body moves (s) in the direction of force.
(iii) The angle between force and displacement.

30. What do you understand by the statements :
(i) Work done by the force.
(ii) Work done against the force.

Ans. (i) Work is done by a force, if the point of application of the force moves in the direction of the force.
(ii) If the point of application of force moves in a direction opposite to that of the force, work is said to be done against the force.
Consider a body already in motion. When we apply a force to stop it, the force must be applied in the direction opposite to that of the motion.
Thus, the point of application of force moves through a certain distance in a direction opposite to that of the force.
In this situation, the work is said to be done against the force.

Multiple Choice Questions

1. When a body falls freely towards the earth, then its total energy

(a) increases (b) decreases

(c) remains constant (d) first increases and then decreses

Ans. (c)

2. A car is accelerated on a levelled road and attains a velocity four times its initial velocity. In this process the potential energy of the car

(a) becomes twice to that of initial

(b) does not change

(c) becomes four times that of initial

(d) becomes 16 times that of initial

Ans. (b)

3. In case of negative work the angle between the force and displacement is

(a) 90° (b) 45°

(c) 0° (d) 180°

Ans. (d)

4. The kinetic energy of an object is K. If its velocity is doubled, then its kinetic energy will be:

(a) K (b) 2K

(c) 4K (d) 3K

Ans. (c)

5. A stone is thrown vertically upward. It comes to rest momentarily at the highest point. What happens to its kinetic energy?

(a) It converts into elastic potential energy.

(b) It converts into gravitational potential energy.

(c) It converts into chemical energy.

(d) It is completely destroyed.

Ans. (b)

6. The potential energy of a girl is maximum when she is:

(a) standing (b) sitting on the ground

(c) sleeping on the ground (d) sitting in a chair

Ans. (d)

7. A spring is stretched. The potential energy of the stretched spring:

(a) remains the same (b) increase

(c) becomes zero (d) decreases

Ans. (b)

8. In a tug of war, work done by a winning team is :

(a) zero (b) positive

(c) negative (d) None of these

Ans. (b)