Science - Class 9

Chapter 11 - Work and Energy

WORK

- Work done on an object is defined as the magnitude of Force (F) multiplied by distance moved (s) by the object in the direction of the applied force.

- $W = F \times s$ (or) $F \times d$

- If displacement is 0, work done will also be 0.

- Work has only magnitude and no direction.

- Work done by a force can be either positive or negative.

- SI unit of work is Nm or Joule (J)
  1 Joule (J) = 1 Newton × 1 metre

Example: A force of 5 N is acting on an object. The object is displaced through 2 m in the direction of the force.

If the force acts on the object all through the displacement, then work done is 5N × 2m = 10 Nm or 10 J.

- Work done is negative when the force acts opposite to the direction of displacement.

- Work done is positive when the force is in the direction of displacement.

Example: A force of 7 N acts on an object. The displacement is, say 8 m, in the direction of the force. What is the work done in this case.

Soln: Work Done = Force × Displacement

$= F \times S$

$F = 7\,N \quad S = 8\,m$

$\therefore$ Work Done $W = 7 \times 8$

$= 56\,J.$

Example: A porter lifts a luggage of 15 kg from the ground and puts it on his head 1·5 m above the ground. Calculate the work done by him on the luggage.

Soln: $m = 15\,kg$ displacement $s = 1.5\,m$

$W = F \times S = mg \times S = 15 \times 10 \times 1.5 = 225\,J.$

Work done is 225 J.

Q) When do we say that work is done?

ANS) Work is done whenever the given conditions are satisfied.

(i) A force acts on a body

(ii) There is a displacement of the body caused by the applied force along the direction of the applied force.

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

ANS) Work Done = Force x Displacement.

Q) Define 1 J of work

ANS) 1 J is the amount of work done by a force of 1 N on an object that displaces it through a distance of 1 m in the direction of the applied force.

Q) 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) Work Done = Force x Displacement

$W = F \times S$

$F = 140\ N \quad S = 15\ m$

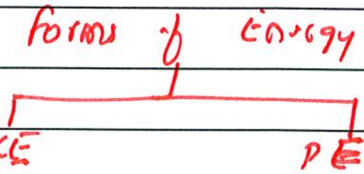
$W = 140 \times 15$

$= 2100\ J.$

Hence, 2100 J of work is done in ploughing the field.

Energy

- Defined as the capability to do work
- Object which does the work loses energy and the object on which the work is done gain energy.
- SI unit : Joule (J)



Forms of Energy

Kinetic energy is the energy of motion

Energy which a body possesses because of its motion, which occurs anywhere from an atomic level to that of a whole organism.

Energy possessed by an object by virtue of its motion. KE of a body of mass (m) moving with a certain velocity (v) is equal to the work done on it to make it acquire that velocity.

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

Unit : Watt (W)   1 watt = 1 Joule / 1 second

1 kW = 1000 W

Examples:

- Electrical - The movement of atoms
- Electromagnetic or Radiant - The movement of waves
- Thermal or Heat - The movement of molecules.
- Motion - The movement of objects
- Sound - The movement through wave.

Potential Energy:

Stored energy or gravitational energy

Energy possed by an object by virtue of its position or configuration.

Gravitational PE is work done in raising an object from the ground to point above the ground against gravity.

$$PE = mgh$$

Potential Energy is maximum at the maximum HEIGHT.

Derive the KE equation $KE = \frac{1}{2}mv^2$

Consider an object of mass (m) moving with uniform velocity (v). Let it be displaced through distance S when a constant force f acts on it in the direction of displacement.

Using motion equation $v^2 - u^2 = 2as$

$$S = \frac{v^2 - u^2}{2a} \qquad f = ma$$

$$W = F \times S = ma \times \frac{v^2 - u^2}{2a} = \frac{1}{2}m(v^2 - u^2)$$

If the object is starting from its stationary position, that is, $u = 0$, then

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

It is clear that the work done is equal to the change in KE of the object.

Example: An object of mass 15 kg is moving with a uniform velocity of 4 m/s. What is the KE possessed by the object.

Sol^n: $m = 15$ kg $v = 4$ m/s

$$KE \quad E_K = \frac{1}{2} mv^2 = \frac{1}{2} \times 15 \times 4 \times 4$$

$$E_K = 120 \text{ J}$$

KE of the object is 120 J.

Example: What is the work done to increase the velocity of a car from 30 km/h to 60 km/h if the mass of the car is 1500 kg?

Sol^n: Mass of the car, $m = 1500$ kg

$$u = 30 \text{ km/h} = 30 \times \frac{5}{18} = 8.33 \text{ m/s}$$

$$v = 60 \text{ km/h} = 60 \times \frac{5}{18} = 16.67 \text{ m/s}$$

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

$$KE = \frac{1}{2} \times 1500 (16.67 + 8.33)(16.67 - 8.33)$$

$$= \frac{1}{2} \times 1500 \times 25 \times 8.33$$

$$= 156,187.5 \text{ J}$$

156375 J

Q> The KE of an object of mass, m moving with a velocity of 5 m/s is 25 J. What will be its KE when its velocity is doubled? What will be its KE when its velocity is increased three times?

Soln : $E_K = \frac{1}{2} mv^2$

$m =$

$v = 5$ m/s

$E_K = 25$ J

$25 = \frac{1}{2} m v^2$

$m = \frac{25 \times 2}{5 \times 5} = 2$ kg

(i) If velocity is doubled $v = 5 \times 2 = 10$ m/s

$KE = \frac{1}{2} \times 2 \times 10 \times 10$

$= 100$ J

KE = 4 times

(ii)

$KE = \frac{1}{2} mv^2 = \frac{1}{2} \times 2 \times 15 \times 15$

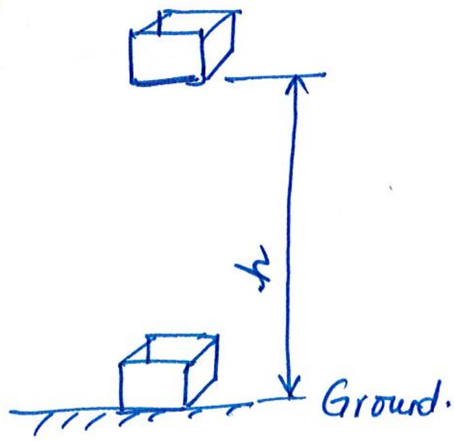
$= 225$ J

Q> If a 100 J of work was done, when a force of 12.5 N acts, what was the distance moved by the force? [S = 8 m]

Q> A 1800 kg car is moving at 30 m/s. When brakes are applied. If the average force exerted by the brakes is 6000 N, find the distance travelled by the car before it comes to rest.

[Hint: KE = Work done by car = F×S] [S = 135 m]

P.E. of an object at a height



An object increases its energy when raised through a height.

This is because work is done on it against gravity while it is being raised.

The energy present in such an object is the gravitational potential energy.

Consider an object of mass, m. Let it be raised through a height, h from the ground.
The minimum force required to raise the object is equal to the weight of the object mg.

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

$W = mgh$

$E_p = mgh$.

Example:
Find the energy possessed by an object of mass 10 kg when it is at height of 6 m above the ground. $g = 9.8\ m/s^2$

Soln: $m = 10\ kg \quad g = 9.8 \quad h = 6\ m$

$E_p = mgh = 10 \times 9.8 \times 6\ J$
$= 588\ J$

Example - An object of mass 12 kg is at certain height above the ground. If the PE of the object is 480 J. Find the height at which the object is with respect to the ground. $g = 10\ m/s^2$

Soln: $m = 12\ kg \quad E_p = 480\ J$

$$E_p = mgh \Rightarrow 480 = 12 \times 10 \times h$$

$$h = \frac{480}{12 \times 10} = 4\ m$$

The object is at the height of 4 m.

Law of conservation of energy

Whenever energy gets transformed, the total energy remains unchanged. This is the law of conservation of energy. According to this law, energy can only be converted from one form to another; it can neither be created or destroyed.

The total energy before and after the transformation remain the same.

Let an object of mass m be made to fall freely from a height h. At the start, PE is mgh and KE is zero, since $u=0$.

Total Energy $= mgh$.

As the object falls, its PE will change to KE. If v is the velocity $KE = \frac{1}{2}mv^2$. When $h=0$ v is max.

$$PE + KE = \text{constant}.$$

$$mgh + \frac{1}{2}mv^2 = \text{constant}.$$

Rate of Doing Work (Power)

Power measures the speed of work done, that is, how fast or slow work is done.

Power is defined as rate of doing work (or) the rate of transfer of energy.

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

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

1 watt = 1 J/s   1 kW = 1000 W

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

Types of Power : (1) Electrical Power

(2) Mechanical Power

(3) Fluid Power

kWh - Energy used in 1 hour at the rate of 1 kW is called 1 kWh.

1 kWh = 3.6×10^6 J.

1 unit = 1 kWh.

Example: Two girls, each of weight 400 N climb up a rope through a height of 8 m. Girl A takes 20 s while Girl B take 50 s. Find the power expended by each girl.

Soln: (i) Power expended by girl A

Weight of girl, $mg = 400 \, N$

$h = 8 \, m \qquad t = 20 \, sec$

$$P = \frac{mgh}{t} = \frac{400 \times 8}{20} = 160 \, W$$

(ii) Girl B $\quad P = \frac{mgh}{t} = \frac{400 \times 8}{50} = 64 \, W.$

Example: A boy of mass 50 kg runs up a staircase of 45 steps in 9 sec. If the height of each step is 15 cm. Find its power. $g = 10 \, m/s$.

Soln: $m = 50 \, kg \qquad h = \frac{45 \times 15}{100} = 6.75 \, m$

$$P = \frac{mgh}{t} = \frac{50 \times 10 \times 6.75}{9} = 375 \, W.$$

Q) A lamp consumes 1000 J of electrical energy in 10 s. What is its power.

[Ans 100 W]

Important Points for Work Problems:

- Always draw a free-body diagram, choosing the positive x-axis in the same direction as the displacement.
- Work is negative if a component of the force is opposite displacement direction
- Work done by any force that is at right angles with displacement will be zero (0).
- For resultant work, you can add the works of each force, or multiply the resultant force times the net displacement.
- Energy is the ability to move
- Potential is stored energy (Statics)
- Dependant on height
- Kinetic is moving energy (Dynamics)
- Dependant on velocity
- Springs store energy dependant on distance and constant

Class IX: Science

Chapter 11: Work and Energy

Chapter notes

Key Learning:

1. Work is done when force acting on a body produces displacement in it.
2. Work done = Force $\times$ displacement in the direction of force
3. Work is a scalar quantity.
4. The SI unit of work is joule (j).
5. Work done is positive if the angle between force and displacement is acute.
6. Work done is negative if the angle between force and displacement is obtuse.
7. Work done on an object by a force would be zero if the displacement of the object is zero.
8. When a body moves along a circular path, the force acts along the radius of the circular path and the motion of the body is along the tangential direction. Therefore, the angle between the direction of motion and the force is 90°. Hence, no work is done on a body when it moves in a circular path.
9. An object having a capability to do work is said to possess energy.
10. The energy possessed by a body by virtue of its motion is called kinetic energy.
11. The energy possessed by a body by virtue of its position or change in configuration is called potential energy.
12. Power is defined as the rate at which work is done.
13. The change of one form of energy into another is called transformation of energy.
14. Law of conservation of energy states that energy can neither be created nor be destroyed but can be transformed from one form to another.
15. Energy exists in nature in several forms such as kinetic energy, potential energy, heat energy, chemical energy etc. The sum of the

kinetic and potential energies of an object is called its mechanical energy.

16. The energy used in one hour at the rate of 1kW is called 1 kW h.

Top Formulae:

1. The amount of work done, $W = FS \cos \theta$
2. If $\theta = 90°$, $W = FS \cos 90°$

$$= 0, \text{ as } \cos 90° = 0$$

3. Kinetic energy of an object of mass m and moving with velocity v

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

4. Gravitational potential energy of an object of mass m at height h

$$P.\,E. = m\,g\,h$$

5. Law of conservation of energy

$$\frac{1}{2}mv^2 + m\,g\,h = \text{constant}$$

6. $\text{Power (P)} = \dfrac{\text{Energy spent (E)}}{\text{Time taken (t)}}$

7. 1 watt = 1 joule/second or 1 W = 1 J / s
8. 1 kilowatt = 1000 watts
9. 1 kW = 1000 W
10. 1 kW = 1000 J / s
11. 1 KWh = 3.6×10^6 J
12. 1 hp = 746 W = 0.746 KW

Numerical Problem

Work and energy

1) A porter lifts a luggage of 15 kg from the ground and puts it on his head 1.5 m above the ground. Calculate the work done by him on luggage.

2) 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?

3) Derive an expression for the K.E. of the body? Calculate the K.E for a body of mass 5 kg moving a velocity 2.5 m/s^2.

4) An object of mass 15 kg is moving with uniform velocity of 4 m/s. What is the KE possessed by the object?

5) What is the work to be done to increase the velocity of a car from 30 km/h to 60 km/h if the mass of the car is 1500 kg?

6) The KE of an object of mass m, moving with a velocity of 5 m/s is 25 J. What will be its KE when its velocity is doubled?

7) A stone is thrown vertically upwards with a velocity 40 m/s.
   (a) At what height will its KE and PE are equal.
   (b) Calculate the PE of the body if its mass = 10 kg.

8) Find the energy possessed by an object of mass 10 kg, when it is at height of 6 m above the ground. Given $g = 9.8\ m/s^2$

9) An object of mass 12 kg is at certain height above ground. If the PE of the object is 480 J, find the height at which the object is with respect to the ground. Given $g = 10\ m/s^2$

10) A 1800 kg car is moving at 30 m/s. When brakes are applied. If the average force exerted by the brakes is 6000 N, find the distance travelled by the car before it comes to rest?

11) Derive an expression for the PE of the body. Calculate P.E of the body of mass 10 kg at height of 10 m.

12) What is Power? Show that power = Force X Velocity? Calculate power of a body of Mass 10 kg accelerating with $10\ m/s^2$ acquires a velocity of 5 m/s?

13) A boy of mass 50 kg runs up a staircase of 45 steps in 9 sec. If the height of each step is 15 cm, find his power. $g = 10\ m/s^2$.

14) An electric bulb of 60 W is used for 6 h per day. Calculate the 'unit' of energy consumed in one day by the bulb.

15) Certain force acting on a 20 kg mass changes its velocity from 5 m/s to 2 m/s. Calculate the work done by the force.

16) An object of mass 40 kg is raised to a height of 5 m above the ground. What is its P.E. If the object is allowed to fall, find its KE when its is half-way down.

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

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

19) Find the energy in kWh consumed in 10 hours by four devices of power 500 W each.

20) A girl having mass of 35 kg sits on a trolley of mass 5 kg. The trolley is given an initial velocity of 4 m/s by applying a force.

Answer

1) 225 J.
2) 2100 J
3) KE = 15.625 J.
4) 120 J
5) 156 375 J.
6) 4 times
7) (a) h = 80 m (b) 8000 J
8) 588 J.
9) H = 4 m.
10) Displacement - 135 m
11) 1000 J.
12) P = 500W.
13) Power P = 375 W.
14) 0.36 units.
15) -210 J.
16) PE = 1960 J , Half-way = 980 J.
17) 15 kWh.
18) 20.8×10^4 J of work is required to stop the car.
19) 4×5 kWh.
20) 0 J.