Class – IX (Science)

Chapter – Work, Energy & Simple Machines

Revise, Reflect, Refine Solution

1. State whether True or False.

(i) Work is said to be done when a force is applied, even if the object does not move.

(ii) Lifting a bucket vertically upward results in positive work done on the bucket.

(iii) The SI unit for both work and energy is joule (J).

(iv) A motionless stretched rubber band has kinetic energy.

(v) Energy can change from one form to another.

Solution:

Statement	True/False	Reason
(i) Work is said to be done when a force is applied, even if the object does not move.	False	Work is done only when a force causes displacement of the object.
(ii) Lifting a bucket vertically upward results in positive work done on the bucket.	True	The applied force and displacement are in the same direction, so the work done is positive.
(iii) The SI unit for both work and energy is joule (J).	True	Both work and energy are measured in joules (J).
(iv) A motionless stretched rubber band has kinetic energy.	False	Since it is not moving, it has no kinetic energy; it possesses elastic potential energy.
(v) Energy can change from one form to another.	True	Energy can be transformed from one form to another (e.g., potential energy to kinetic energy).

2. Fill in the blanks.

(i) Work done = ______ × ______ (in the direction of force).

(ii) 1 joule of work is done when a force of ______ newton displaces an object by 1 metre in the direction of the force.

(iii) The expression for kinetic energy of a body of mass m and velocity v is ______.

(iv) The potential energy of an object of mass m at a small height h from the Earth's surface is ______.

(v) Power is defined as the ______ at which work is done.

Solution:

(i) Work done = Force × Displacement (in the direction of force).

(ii) 1 joule of work is done when a force of 1 newton displaces an object by 1 metre in the direction of the force.

(iii) The expression for kinetic energy of a body of mass m and velocity v is

$$\boxed{\frac{1}{2}mv^2}$$

(iv) The potential energy of an object of mass m at a small height h from the Earth's surface is

$$\boxed{mgh}$$

(v) Power is defined as the rate at which work is done.

3. When a ball thrown upwards reaches its highest point, tick which of the following statement(s) are correct?

(i) The force acting on the ball is zero.

(ii) The acceleration of the ball is zero.

(iii) Its kinetic energy is zero.

(iv) Its potential energy is maximum.

Solution:

At the highest point of its motion:

- The velocity of the ball becomes zero momentarily.
- The gravitational force (weight) still acts downward.

- Therefore, the acceleration due to gravity g is not zero.

Let's examine each statement:

(i) The force acting on the ball is zero.

False. Gravity acts on the ball at all times, including at the highest point.

(ii) The acceleration of the ball is zero.

False. The acceleration is equal to g downward.

(iii) Its kinetic energy is zero.

True. Since the velocity is zero,

$$KE = \frac{1}{2}mv^2 = 0$$

(iv) Its potential energy is maximum.

True. At the highest point, the ball is at its maximum height, so its potential energy is maximum.

4. For each of the following situations, identify the energy transformation that takes place:

(i) a truck moving uphill,
(ii) unwinding of a watch spring,
(iii) photosynthesis in green leaves,
(iv) water flowing from a dam,
(v) burning of a matchstick,
(vi) explosion of a fire cracker,
(vii) speaking into a microphone,
(viii) a glowing electric bulb, and
(ix) a solar panel.

Solution:

Situation	**Energy Transformation**
(i) A truck moving uphill	Chemical energy (fuel) → Kinetic energy → Gravitational potential energy

Situation	Energy Transformation
(ii) Unwinding of a watch spring	Elastic potential energy → Kinetic energy
(iii) Photosynthesis in green leaves	Solar (light) energy → Chemical energy
(iv) Water flowing from a dam	Gravitational potential energy → Kinetic energy
(v) Burning of a matchstick	Chemical energy → Heat energy and Light energy
(vi) Explosion of a fire cracker	Chemical energy → Heat energy, Light energy, Sound energy and Kinetic energy
(vii) Speaking into a microphone	Sound energy → Electrical energy
(viii) A glowing electric bulb	Electrical energy → Light energy and Heat energy
(ix) A solar panel	Solar (light) energy → Electrical energy

5. A student is slowly lifted straight up in an elevator from the ground level to the top floor of a building. Later, the same student climbs the staircase, all the way to the top. Given that the height of the building is $h = 72.5$ m, acceleration due to gravity is $g = 10$ m s^{-2}, and the student's mass is $m = 50$ kg.

(i) Find the gain in the potential energy if the student is lifted straight up to the top.
(ii) Find the gain in the potential energy when the student climbs the stairs to the same top.
(iii) What do you conclude about the dependence of the potential energy on the path taken.

Solution:

Given:

- Mass of student, $m = 50$ kg
- Height of building, $h = 72.5$ m
- Acceleration due to gravity, $g = 10$ m s^{-2}

The gain in potential energy is given by:

$$PE = mgh$$
$$PE = 50 \times 10 \times 72.5$$
$$PE = 36{,}250 \text{ J}$$

(i) Gain in potential energy when lifted straight up

$$\Delta PE = 36{,}250 \text{ J}$$

(ii) Gain in potential energy when climbing the stairs

The initial and final heights are the same, so

$$\Delta PE = mgh$$
$$\Delta PE = 50 \times 10 \times 72.5$$
$$\Delta PE = 36{,}250 \text{ J}$$

(iii) Conclusion

The gain in potential energy is the **same** in both cases:

$$\boxed{\Delta PE = 36{,}250 \text{ J}}$$

Hence, the potential energy gained by an object depends only on its **initial and final positions (height difference)** and **does not depend on the path taken** to reach the final position.

6. A crane lifts a mass m to the 10th floor of a building in a certain time. It then raises the same mass to the 20th floor of the same building in double the time. How much more energy and power are required? Assume that the height of all floors is equal.

Solution:

Let the height of each floor be h.

Case 1: Lifting the mass to the 10th floor

Height reached:

$$h_1 = 10h$$

Potential energy gained:

$$E_1 = mg(10h) = 10mgh$$

Let the time taken be t.

Power required:

$$P_1 = \frac{E_1}{t} = \frac{10mgh}{t}$$

Case 2: Lifting the same mass to the 20th floor

Height reached:

$$h_2 = 20h$$

Potential energy gained:

$$E_2 = mg(20h) = 20mgh$$

Time taken:

$$2t$$

Power required:

$$P_2 = \frac{E_2}{2t} = \frac{20mgh}{2t} = \frac{10mgh}{t}$$

$$P_2 = P_1$$

Comparison:

Energy

$$\frac{E_2}{E_1} = \frac{20mgh}{10mgh} = 2$$

So, the energy required is **twice** as much.

Extra energy required:

$$E_2 - E_1 = 20mgh - 10mgh = 10mgh$$

Power

$$P_2 = P_1$$

Therefore, **no additional power is required**.

7. **Which factors determine the energy required to raise a flag from the ground to the top of a tall flagpole using a pulley? Does raising the flag slowly or quickly change the amount of work done? If the speed at which the flag is raised is doubled, how does the power requirement change? Explain your answers.**

Solution:

The energy required to raise a flag is equal to the gain in its gravitational potential energy.

$$E = mgh$$

where:

- m= mass of the flag
- g= acceleration due to gravity
- h= height of the flagpole

Therefore, the energy required depends on:

1. The mass of the flag (m)
2. The height through which it is raised (h)
3. The acceleration due to gravity (g)

Does raising the flag slowly or quickly change the work done?

No.

The work done in raising the flag is

$$W = mgh$$

which depends only on the mass of the flag and the height through which it is raised. It does not depend on the time taken.

Therefore, whether the flag is raised slowly or quickly, the amount of work done remains the same.

Effect of doubling the speed on power

Power is defined as the rate of doing work:

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

If the flag is raised at double the speed, the time taken becomes half.

Let the original power be

$$P_1 = \frac{W}{t}$$

When the speed is doubled,

$$t' = \frac{t}{2}$$

Hence,

$$P_2 = \frac{W}{t/2} = \frac{2W}{t} = 2P_1$$

Thus, the power requirement doubles.

8. A man of mass 60 kg rides a scooter of mass 100 kg. He accelerates the scooter to a velocity v. The next day, his son with a mass of 40 kg joins him as a passenger. If the scooter reaches the same speed on both days in the same time interval, what is the ratio of the fuel of the tank used on the two days? Assume that the energy transfer to the scooter happens entirely due to fuel, and no other losses occur due to air resistance and friction.

Solution:

The fuel consumed is proportional to the energy supplied by the fuel.

Since there are no losses due to friction or air resistance, all the fuel energy is converted into the kinetic energy of the scooter and its riders.

The kinetic energy is given by:

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

Since the final speed v is the same on both days, the fuel consumed is proportional to the total mass being accelerated.

Day 1

Total mass:

$$m_1 = 100 + 60 = 160 \text{ kg}$$

Kinetic energy gained:

$$KE_1 = \frac{1}{2}(160)v^2$$
$$KE_1 = 80v^2$$

Day 2

Total mass:

$$m_2 = 100 + 60 + 40 = 200 \text{ kg}$$

Kinetic energy gained:

$$KE_2 = \frac{1}{2}(200)v^2$$
$$KE_2 = 100v^2$$

Ratio of fuel used

$$\text{Fuel ratio} = \frac{KE_1}{KE_2} = \frac{80v^2}{100v^2} = \frac{4}{5}$$

Therefore,

$$\boxed{\text{Fuel used on Day 1 : Fuel used on Day 2} = 4:5}$$

9. **On a seesaw with sliding seats, a child is sitting on one side and an adult on the other side. The adult weighs twice that of the child. The seesaw, however, is balanced. Draw a figure which depicts this situation showing the distances from the fulcrum where the child and the adult are seated.**

Solution:

For a balanced seesaw, the clockwise moment must equal the anticlockwise moment.

Weight of child × Distance of child from fulcrum
= Weight of adult × Distance of adult from fulcrum

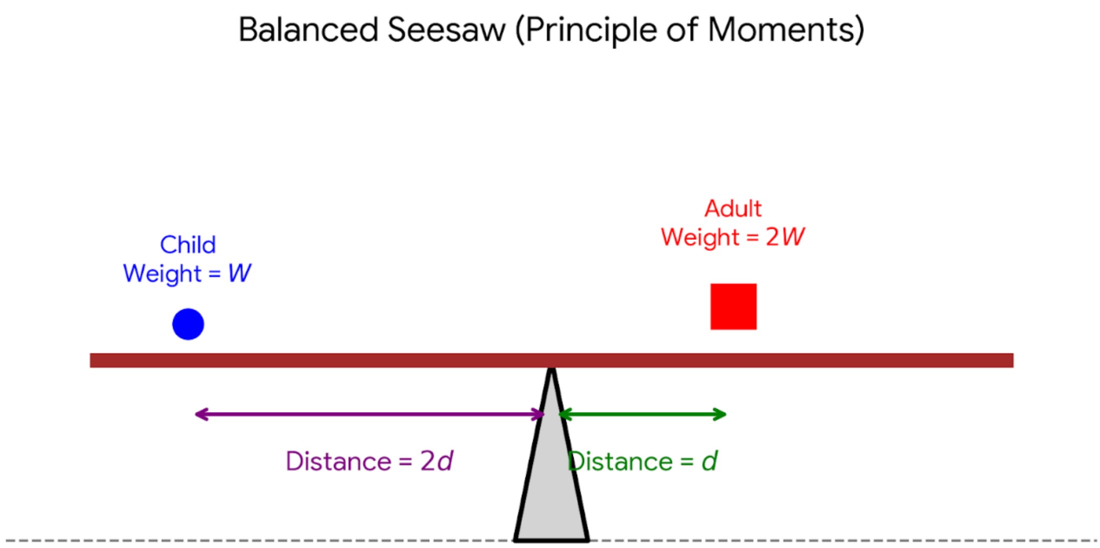
Let the child's weight be W.

Then the adult's weight is $2W$.

If the child sits at a distance d from the fulcrum and the adult sits at a distance x, then

$$W \times d = 2W \times x$$
$$d = 2x$$
$$x = \frac{d}{2}$$

Thus, the **adult must sit at half the distance from the fulcrum as the child**.



10. A ball of mass 2 kg is thrown up with a velocity of 20 m s^{-1}.

(i) Identify the sign of the work done by gravity on the ball during its upward motion and its downward motion.

(ii) If the ball reaches a height of 19.4 m, how much work was done by air resistance (assume $g = 10$ m s^{-2}).

Solution:

Given:

- Mass of ball, $m = 2$ kg

- Initial velocity, $u = 20 \text{ m s}^{-1}$
- Maximum height reached, $h = 19.4 \text{ m}$
- Acceleration due to gravity, $g = 10 \text{ m s}^{-2}$

(i) Sign of the work done by gravity

During upward motion:

The gravitational force acts downward while the displacement is upward. Therefore, the angle between force and displacement is 180°.

$$W = Fs\cos\ 180^\circ$$

Hence, the work done by gravity is negative.

During downward motion:

Both gravitational force and displacement are downward. Therefore, the angle between force and displacement is 0°.

$$W = Fs\cos\ 0^\circ$$

Hence, the work done by gravity is positive.

Answer (i):

- **Upward motion: Negative**
- **Downward motion: Positive**

(ii) Work done by air resistance

Initial kinetic energy:

$$KE_i = \frac{1}{2}mu^2$$
$$KE_i = \frac{1}{2} \times 2 \times (20)^2$$
$$KE_i = 400 \text{ J}$$

Potential energy at the highest point:

$$PE = mgh$$
$$PE = 2 \times 10 \times 19.4$$
$$PE = 388 \text{ J}$$

If there were no air resistance, the entire kinetic energy would be converted into potential energy. The loss in mechanical energy is therefore

$$400 - 388 = 12 \text{ J}$$

This energy is the work done by air resistance.

$$\boxed{W_{\text{air}} = -12 \text{ J}}$$

(The negative sign indicates that air resistance opposes the motion.)

11. A 10.0 kg block is moving on a horizontal floor with negligible friction. As shown in Fig. 7.37, a variable force is applied on the block in its direction of motion from its position at 0 m till 4 m. If the block had a kinetic energy of 180 J when it was at 0 m, find the block's speed (i) at 0 m, and (ii) at 4 m. Does the block have negative acceleration in any portion of its motion?

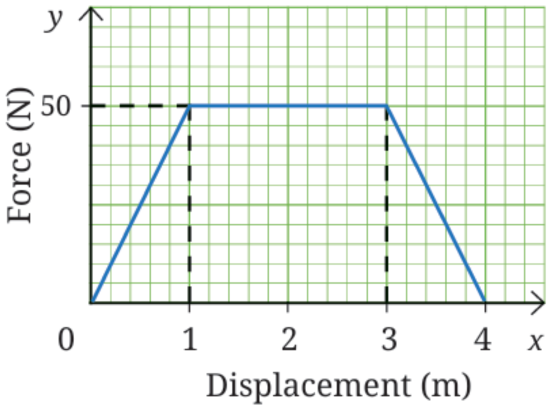


Fig. 7.37

Solution:

Given:

- Mass of block, $m = 10$ kg
- Initial kinetic energy at $x = 0$,

$$KE_0 = 180 \text{ J}$$

(i) Speed of the block at 0 m

Using

$$KE = \frac{1}{2}mv^2$$
$$180 = \frac{1}{2}(10)v^2$$
$$180 = 5v^2$$
$$v^2 = 36$$
$$v = 6 \text{ m s}^{-1}$$

Therefore,

$$\boxed{v_0 = 6\ \text{m s}^{-1}}$$

(ii) Speed of the block at 4 m

The work done by the variable force equals the area under the force-displacement graph.

Area from 0 to 4 m (trapezium)

$$W = \frac{1}{2} \times (4 + 2) \times 50 = 150\ \text{J}$$

By the Work-Energy Theorem,

$$KE_4 = KE_0 + W$$
$$KE_4 = 180 + 150$$
$$KE_4 = 330\ \text{J}$$

Now,

$$330 = \frac{1}{2}(10)v^2$$
$$330 = 5v^2$$
$$v^2 = 66$$
$$v = \sqrt{66}$$

Therefore,

$$\boxed{v_4 = \sqrt{66}\ \text{m s}^{-1}}$$

(iii) Does the block have negative acceleration anywhere?

No.

The applied force is always positive (in the direction of motion) throughout the interval 0m to 4m.

Since

$$a = \frac{F}{m}$$

and $F > 0$ everywhere,

$$a > 0$$

throughout the motion.

Therefore,

The block does not have negative acceleration in any portion of its motion.

12. The gravitational attraction on the surface of the Moon (lunar surface) is about $\frac{1}{6}$th of that on the surface of the Earth. An astronaut can throw a ball up to a height of 8 m from the surface of the Earth. How far up will the ball thrown with the same upward velocity travel from the surface of the Moon?

Solution:

Let the initial velocity with which the ball is thrown be u.

At the maximum height, the final velocity is

$$v = 0$$

Using the equation of motion,

$$v^2 = u^2 - 2gh$$

On the Earth

Maximum height reached:

$$h_E = 8 \text{ m}$$

So,

$$0 = u^2 - 2g(8)$$
$$u^2 = 16g$$

On the Moon

The acceleration due to gravity on the Moon is

$$g_M = \frac{g}{6}$$

Let the maximum height reached on the Moon be h_M.

Using the same initial velocity u,

$$0 = u^2 - 2g_M h_M$$

Substituting $u^2 = 16g$ and $g_M = \frac{g}{6}$,

$$16g = 2\left(\frac{g}{6}\right) h_M$$
$$16 = \frac{h_M}{3}$$
$$h_M = 48 \text{ m}$$

13. A 1000 kg car is moving along a road at a constant speed. Suddenly, the driver notices some obstruction ahead and applies the brakes to come to a complete stop. The graphical representation of motion of the car starting from the instant the driver spots the traffic ahead is shown in Fig. 7.38.

(i) Describe how the car moves between positions A and B.
(ii) Calculate the kinetic energy of the car at A.
(iii) State the work done by the brakes in bringing the car to a halt between B and C.
(iv) What does the kinetic energy of the car transform into?

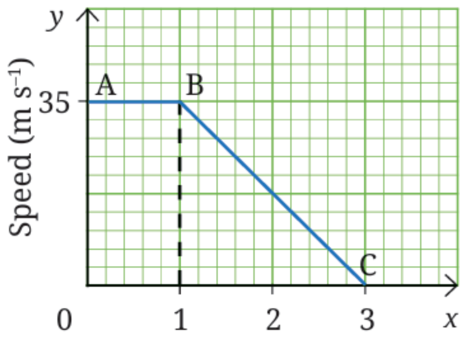


Fig. 7.38

Solution:

Given:

- Mass of car, $m = 1000$ kg
- Speed at A and B = 35 m s^{-1}
- Speed at C = 0 m s^{-1}

(i) Describe how the car moves between A and B.

From the speed-time graph, the speed remains constant at 35 m s^{-1}between A and B.

Therefore, the car moves with **uniform velocity (constant speed)** and has **zero acceleration** during this interval.

(ii) Calculate the kinetic energy of the car at A.

Kinetic energy is given by

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

Substituting the values,

$$KE = \frac{1}{2} \times 1000 \times (35)^2$$
$$KE = 500 \times 1225$$
$$KE = 612500 \text{ J}$$
$$\boxed{KE = 6.125 \times 10^5 \text{ J}}$$

(iii) State the work done by the brakes in bringing the car to a halt between B and C.

The work done by the brakes equals the change in kinetic energy.

Initial kinetic energy at B:

$$KE_B = 612500 \text{ J}$$

Final kinetic energy at C:

$$KE_C = 0$$

Therefore,

$$W = KE_C - KE_B$$
$$W = 0 - 612500$$
$$W = -612500 \text{ J}$$
$$\boxed{W = -6.125 \times 10^5 \text{ J}}$$

The negative sign indicates that the brakes do work opposite to the direction of motion.

(iv) What does the kinetic energy of the car transform into?

The kinetic energy of the car is mainly converted into:

- **Heat energy** due to friction between the brake pads and wheels.
- A small amount into **sound energy**.

14. The potential energy-displacement graph of a 0.5 kg ball moving along a frictionless track is shown in Fig. 7.39. At O, the velocity of the ball is 0 m s^{-1} and potential energy is 30 J. Calculate the velocity of the ball at P, Q and R.

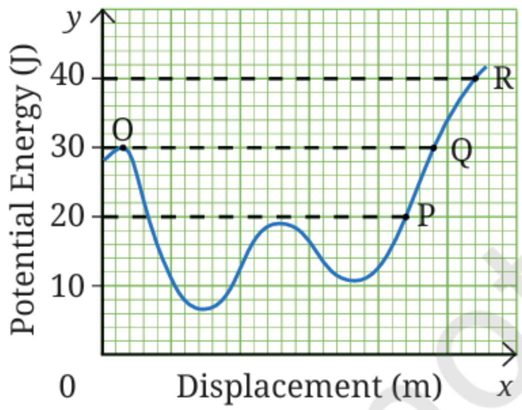


Fig.7.39

Solution:

Given:

- Mass of ball, $m = 0.5$ kg
- At O:
  - Velocity $= 0$ m s^{-1}
  - Potential Energy $= 30$ J

Since the track is frictionless, **total mechanical energy remains constant**.

At O,

$$KE_O = \frac{1}{2}mv^2 = 0$$

Therefore,

$$E_{\text{total}} = PE_O + KE_O = 30 + 0 = 30 \text{ J}$$

From the graph:

- $PE_P = 20$ J
- $PE_Q = 30$ J
- $PE_R = 40$ J

Using

$$KE = E_{\text{total}} - PE$$

and

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

At P

$$KE_P = 30 - 20 = 10\text{ J}$$
$$\frac{1}{2}(0.5)v_P^2 = 10$$
$$0.25v_P^2 = 10$$
$$v_P^2 = 40$$
$$v_P = \sqrt{40} = 2\sqrt{10}\text{ m s}^{-1}$$
$$\boxed{v_P = 2\sqrt{10}\text{ m s}^{-1}}$$

At Q

$$KE_Q = 30 - 30 = 0$$
$$v_Q = 0$$
$$\boxed{v_Q = 0\text{ m s}^{-1}}$$

At R

$$KE_R = 30 - 40 = -10\text{ J}$$

A negative kinetic energy is not possible.

Therefore, the ball **cannot reach point R** because its total mechanical energy is only 30 J, whereas the potential energy at R is 40 J.

$$\boxed{\text{The ball cannot reach } R}$$

15. A coconut of mass 1.5 kg falls from the top of a coconut tree onto the wet sand on a beach. The height of the tree is 10 m. On impact, the coconut comes to rest by making a depression in the sand.

(i)	**Calculate the velocity of the coconut just before it hits the sand.**
(ii)	**Assume that the average resistive force of sand is** 3000 N **and all of the coconut's energy is used to create the depression in the sand. Calculate the depth of the depression the coconut makes in the sand. Assume $g = 10 \text{ m s}^{-2}$.**

Solution:

Given:

- Mass of coconut, $m = 1.5$ kg
- Height of tree, $h = 10$ m
- Acceleration due to gravity, $g = 10 \text{ m s}^{-2}$
- Resistive force of sand, $F = 3000$ N

(i) Velocity just before hitting the sand

Using the equation of motion:

$$v^2 = u^2 + 2gh$$

Since the coconut is dropped from rest,

$$u = 0$$
$$v^2 = 0 + 2(10)(10)$$
$$v^2 = 200$$
$$v = \sqrt{200}$$
$$v = 10\sqrt{2} \text{ m s}^{-1}$$

Therefore,

$$\boxed{v = 10\sqrt{2} \text{ m s}^{-1}}$$

(ii) Depth of the depression in the sand

The kinetic energy of the coconut just before impact is

$$KE = \frac{1}{2}mv^2$$
$$KE = \frac{1}{2}(1.5)(200)$$
$$KE = 150 \text{ J}$$

This energy is used to do work against the resistive force of the sand.

$$W = Fd$$

where d is the depth of the depression.

$$150 = 3000d$$
$$d = \frac{150}{3000}$$
$$d = 0.05 \text{ m}$$
$$d = 5 \text{ cm}$$

Therefore,

$$\boxed{d = 0.05 \text{ m} = 5 \text{ cm}}$$