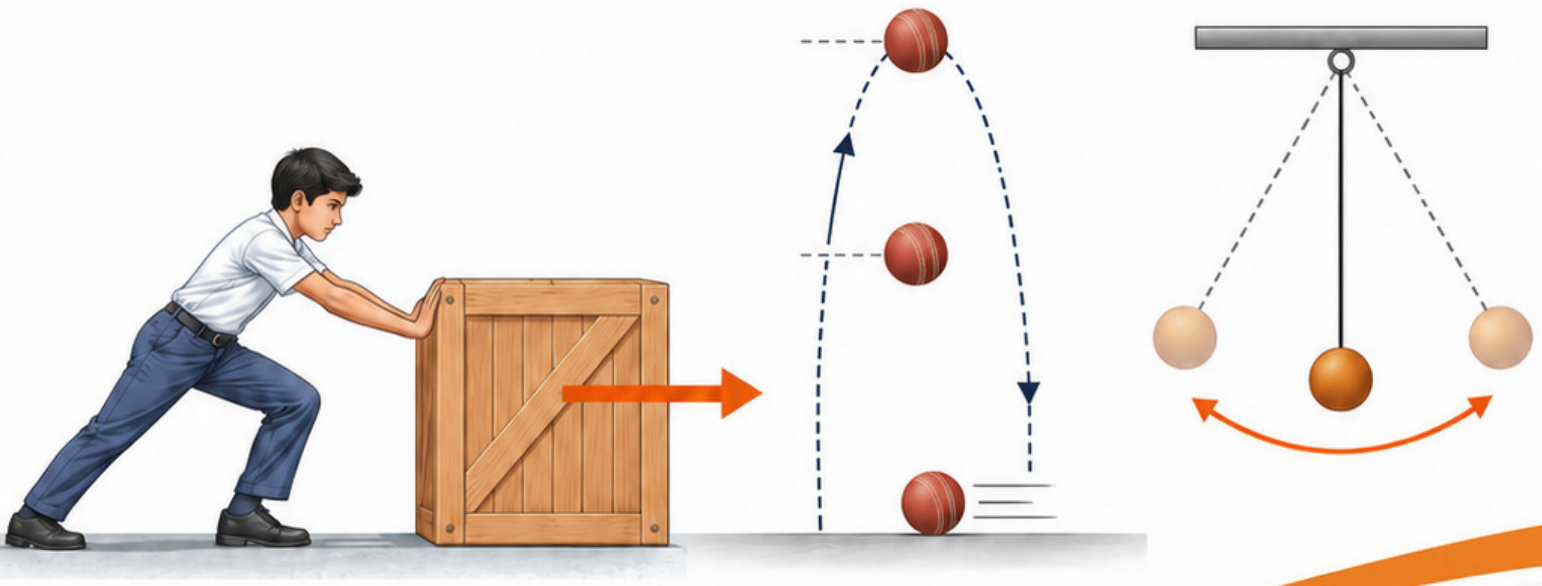
NEXTGEN ACADEMY

WORK AND ENERGY

CLASS 9 • CBSE SCIENCE

Concept Notes • NCERT Solutions • Exam Questions • Solved Numericals



CHAPTER MAP

Scope: Work and Energy Only

Concept Notes

1. Scientific Meaning of Work

- Work is said to be done when a force applied on a body produces a displacement in the direction of the force.
- SI unit: joule (J).

2. Work Done by a Constant Force

- Work done, $W = F \times s$, when a constant force F produces a displacement s in its direction.
- Unit: 1 J = 1 N m.

3. Positive, Negative and Zero Work

- **Positive work**: force and displacement are in the same direction.
- **Negative work**: force and displacement are in opposite directions.
- **Zero work**: force produces no displacement (e.g., carrying a load on a level road).

4. Work from Force–Displacement Graphs

- For a constant force, work done is the area under the F–s graph.
- For variable force, work done equals the total area under the graph between the given limits.

5. Work–Energy Theorem

- The work done by the net force on a body equals the change in its kinetic energy.
- $W = \Delta K = K_f - K_i$.

6. Kinetic and Potential Energy

- Kinetic energy: energy due to motion, $K = \frac{1}{2} m v^2$.
- Potential energy: energy due to position or configuration (e.g., gravitational P.E., $U = mgh$).

7. Mechanical Energy and Conservation

- Mechanical energy = $K + U$.
- In the absence of non-conservative forces (e.g., friction), mechanical energy remains constant (conservation of mechanical energy).

8. Power and Commercial Unit of Energy

- Power is the rate of doing work: $P = \frac{W}{t}$.
- SI unit of power: watt (W) = J s^{-1}.
- Commercial unit of energy: kilowatt-hour (kWh).
- 1 kWh = 3.6×10^6 J.

Practice Sections

- NCERT In-text Questions and Exercise Solutions
- MCQs, Assertion–Reason and Case-based Questions
- Very Short, Short and Long Answer Questions
- Solved Numericals and Competency Practice

Simple Machines is excluded and will be prepared separately.

1. SCIENTIFIC MEANING OF WORK

Definition

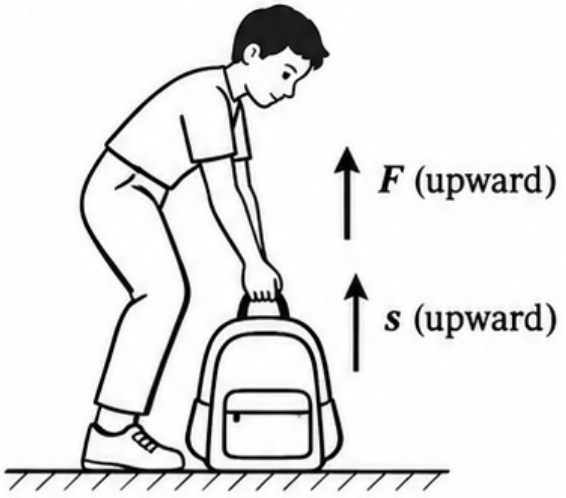
In science, work is done only when a force acting on an object produces displacement.

Essential conditions

1. A force must act on the object.
2. The object must undergo displacement.
3. At least part of the force must act along the displacement.

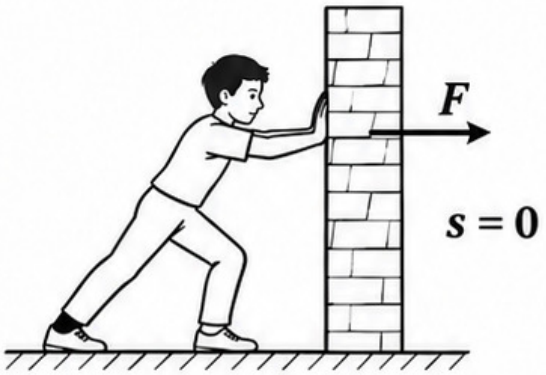
Examples where work is done

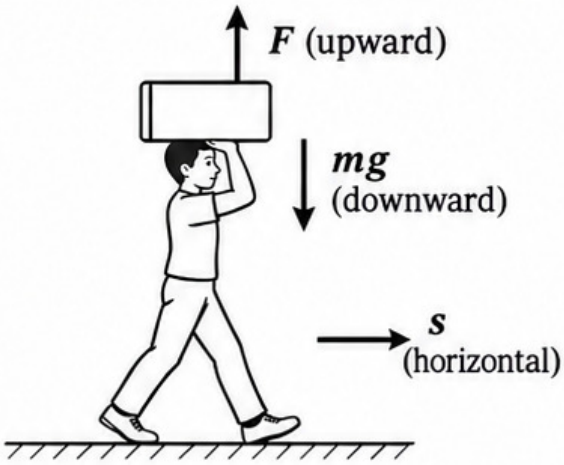
- A student lifts a bag from the floor.
- A horse pulls a cart forward.
- Gravity displaces a falling stone.



Examples where work is zero

- A person pushes a rigid wall that does not move.
- A weightlifter holds a barbell stationary.
- A porter carries a load horizontally at constant height; gravity is perpendicular to displacement.





Exam Tip

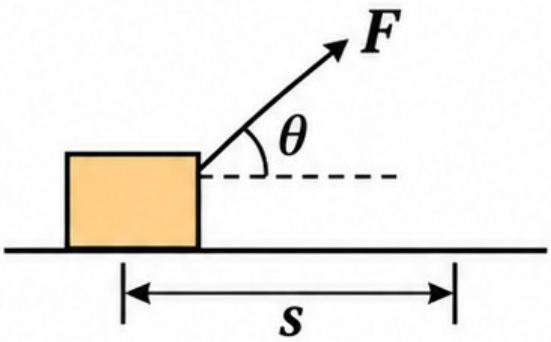
Feeling tired does not by itself mean that mechanical work has been done on an object.

2. WORK DONE BY A CONSTANT FORCE

General expression

$$W = Fs\cos\theta$$

- W = work done in joule (J)
- F = force in newton (N)
- s = displacement in metre (m)
- θ = angle between force and displacement



Same direction

- If force and displacement are parallel, $\theta = 0°$ and $\cos 0° = 1$.

$$W = Fs$$

SI Unit

- One joule is the work done when a force of 1 N displaces an object by 1 m in the direction of the force.

$$1\ \text{J} = 1\ \text{N m}$$

$$1\ \text{kJ} = 1000\ \text{J}$$

Worked Example

- A force of 7 N moves a box through 8 m in its own direction.

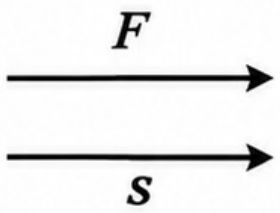
$$W = Fs = 7 \times 8 = 56\ \text{J}$$

3. POSITIVE, NEGATIVE AND ZERO WORK

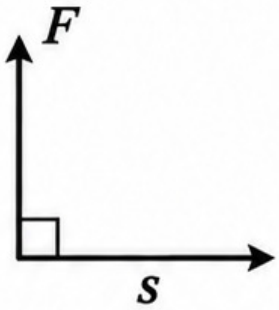
Type	Angle	Sign	Example
Positive	$0° \le \theta < 90°$	$W > 0$	Gravity acting on a falling stone
Zero	$\theta = 90°$ or $s = 0$	$W = 0$	Centripetal force on a satellite; holding a load still
Negative	$90° < \theta \le 180°$	$W < 0$	Friction on a sliding object; gravity on a rising ball

Important Cases

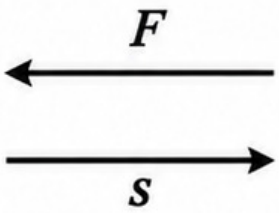
- $\theta = 0° \rightarrow W = +Fs$
- $\theta = 90° \rightarrow W = 0$
- $\theta = 180° \rightarrow W = -Fs$



Parallel ($\theta = 0°$)



Perpendicular ($\theta = 90°$)



Opposite ($\theta = 180°$)

Meaning of the sign

- Positive work transfers energy to the object. Negative work removes mechanical energy from it.

Round trip under gravity

- Gravity is a conservative force. If an object returns to its starting height, the net work done by gravity over the complete trip is zero.

4. WORK FROM A FORCE–DISPLACEMENT GRAPH

Graph Rule

- The work done between two positions is the signed area under the force–displacement (F–s) graph.

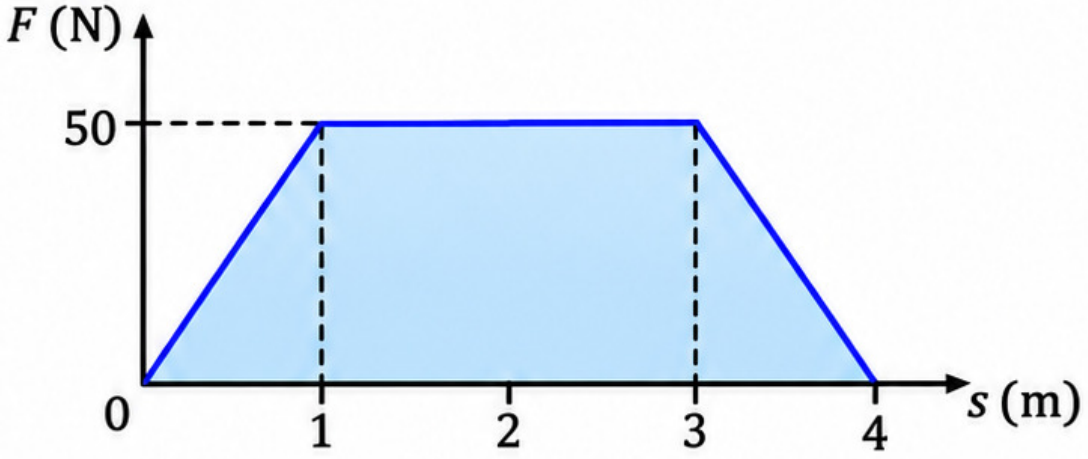
$$W = \text{area under the } F\text{–}s \text{ graph}$$

Useful Areas

- **Rectangle:** W = length × breadth
- **Triangle:** W = ½ × base × height
- **Trapezium:** W = ½ × (sum of parallel sides) × separation
- Area below the displacement axis represents negative work.

Worked Example

- A force rises uniformly from 0 to 50 N over 1 m, remains 50 N for 2 m, and falls uniformly to zero over the next 1 m.



- $W = ½(1)(50) + (2)(50) + ½(1)(50)$
- $W = 25 + 100 + 25 = 150$ J

Note For a variable force, divide the graph into simple shapes and add their signed areas.

5. THE WORK–ENERGY THEOREM

Statement

The net work done on an object equals the change in its kinetic energy.

$$W_{net} = \Delta K = K_f - K_i$$

Derivation for a constant force

1. Let a body of mass m change speed from u to v under a constant force F through displacement s.
2. From $v^2 - u^2 = 2as$, we obtain $s = \dfrac{v^2 - u^2}{2a}$.
3. $W = Fs = mas$.
4. Therefore, $W = ma\left[\dfrac{v^2 - u^2}{2a}\right]$.
5. Hence, $W = \tfrac{1}{2}mv^2 - \tfrac{1}{2}mu^2$.

Special cases

- If $u = 0$, then $W = \tfrac{1}{2}mv^2$.
- If $v = 0$, then $W = -\tfrac{1}{2}mu^2$. The negative sign shows that the stopping force opposes motion.

Worked Example

A 20 kg body slows from 5 m s^{-1} to 2 m s^{-1}.

$W = \tfrac{1}{2}m(v^2 - u^2) = 10(4 - 25) = -210$ J

6. ENERGY AND ITS FORMS

Energy

Energy is the capacity to do work. Work is a mode of energy transfer. Both have the SI unit joule (J).

Form	Meaning or example
Kinetic	Energy due to motion
Potential	Stored energy due to position or configuration
Chemical	Food, fuel, battery and matchstick
Electrical	Energy associated with electric charges
Thermal	Internal energy observed as heating
Light	Energy carried by electromagnetic radiation
Sound	Energy carried by vibrations

Common Energy Transformations

-  Muscular → kinetic + heat: riding a bicycle
-  Chemical → light + heat + sound: firecracker
-  Electrical → light + heat: glowing bulb
-  Light → chemical: photosynthesis
-  Potential → kinetic: water falling from a dam
-  Kinetic → electrical: generator

Principle

Energy may change form or pass from one object to another, but total energy is conserved.

7. KINETIC ENERGY

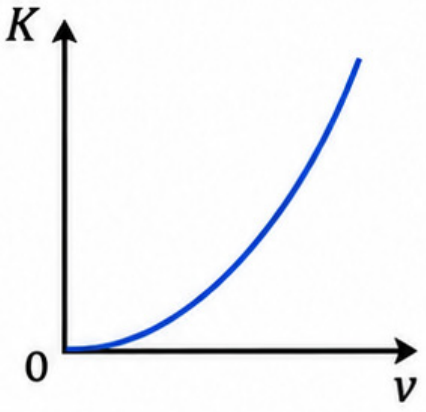
Definition

Kinetic energy is the energy possessed by an object because of its motion.

$$K = \tfrac{1}{2}mv^2$$

Dependence

- $K \propto m$ when speed is constant.
- $K \propto v^2$ when mass is constant.
- Doubling speed makes kinetic energy four times.
- Tripling speed makes kinetic energy nine times.

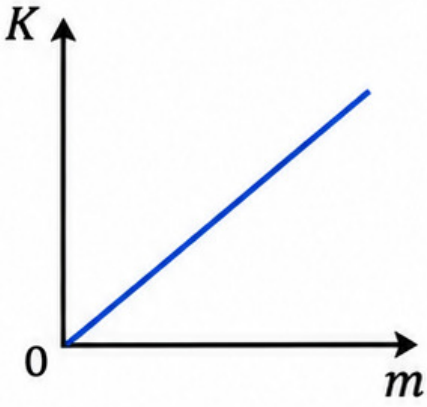


Relation with Momentum

Since $p = mv$, then $v = \frac{p}{m}$.

$$K = \frac{p^2}{2m}$$

For equal momentum, the lighter body has greater kinetic energy.



Worked Example

A 5 kg object moving at 10 m s^{-1} has:

$$K = \tfrac{1}{2} \times 5 \times 10^2 = 250\ J$$

Important

Kinetic energy cannot be negative because mass and v^2 are non-negative.

8. POTENTIAL ENERGY

Meaning

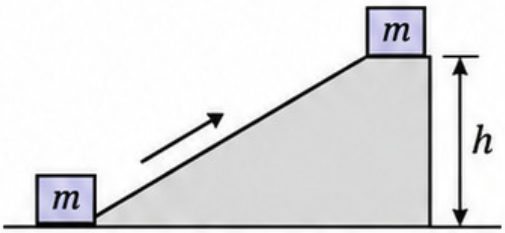
Potential energy is stored energy associated with position or configuration.

Gravitational Potential Energy

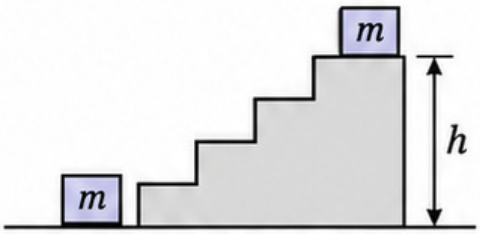
- Near the Earth's surface:

$$U = mgh$$

- m = mass in kg
- g = acceleration due to gravity in m s^{-2}
- h = vertical height above the chosen reference level
- It depends on vertical height, not on the path taken.



By a ramp

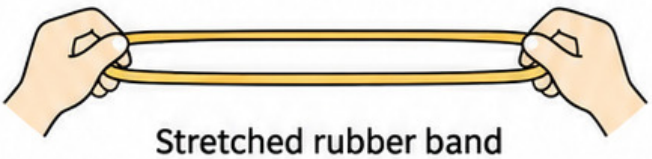


By steps

Elastic Potential Energy

- A stretched rubber band, a compressed spring and a wound watch spring store energy because their shape is changed.
- At its natural length, a spring's elastic potential energy is minimum.


Natural rubber band


Stretched rubber band

Choice of Reference

- The zero level of potential energy is selected for convenience. Therefore, potential energy may be positive, zero or negative relative to the chosen level.

Horizontal Motion

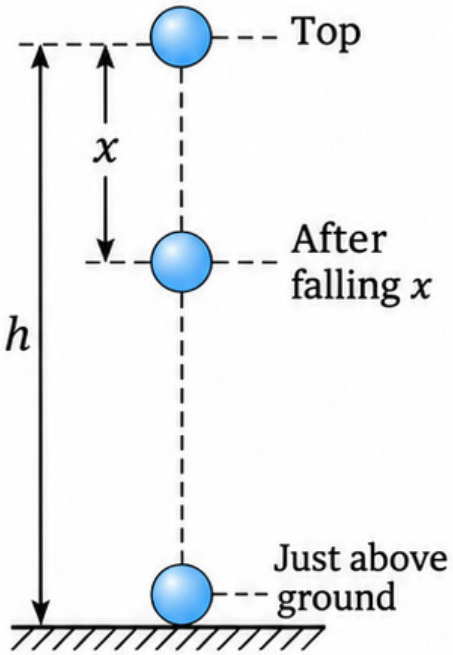
- If height remains constant, gravitational potential energy does not change.

9. MECHANICAL ENERGY AND CONSERVATION

Mechanical Energy

$$E = K + U$$

Mechanical energy is the sum of kinetic energy and potential energy.



Law of Conservation of Energy

Energy can neither be created nor destroyed. It can only be transformed from one form to another; the total energy of an isolated system remains constant.

Freely Falling Body (air resistance neglected)

Position	Potential Energy	Kinetic Energy	Total
Top, height h	mgh	0	mgh
After falling x	$mg(h-x)$	mgx	mgh
Just above ground	0	mgh	mgh

As the body falls, potential energy decreases by exactly the amount by which kinetic energy increases.

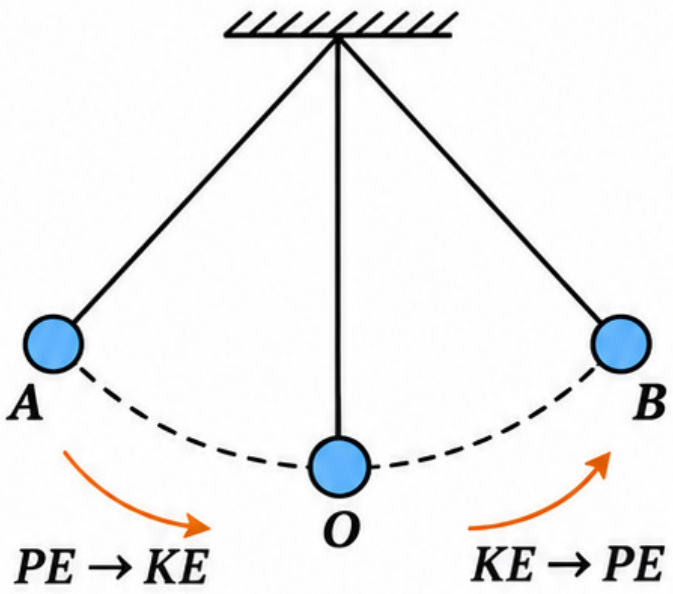
With Friction or Air Resistance

Mechanical energy decreases, but total energy remains conserved because part of it becomes heat, sound or internal energy.

10. CONSERVATION OF ENERGY IN A PENDULUM

At Extreme Position A

Speed = 0; kinetic energy = 0; potential energy is maximum.



From A to O

Potential energy changes into kinetic energy. Speed increases as height decreases.

At Mean Position O

Speed and kinetic energy are maximum; potential energy is minimum.

From O to B

Kinetic energy changes back into potential energy. Speed decreases as height increases.

At Extreme Position B

Speed = 0; kinetic energy = 0; potential energy is maximum.

Why does a real pendulum stop?

Air resistance and friction at the support transfer mechanical energy into heat and sound. Energy is not destroyed, so the law of conservation of energy is not violated.

At every point: $K + U$ = **constant** (ideal pendulum)

11. POWER

Definition

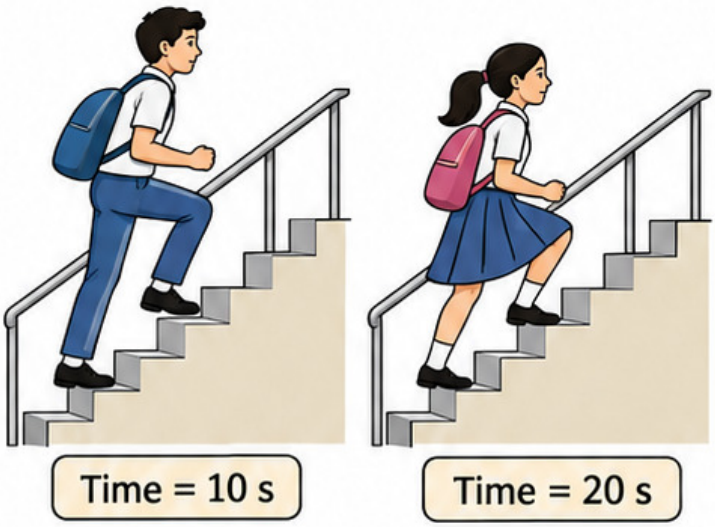
Power is the rate at which work is done or energy is transferred.

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

SI Unit

The SI unit of power is watt (W).

- $1\ \text{W} = 1\ \text{J s}^{-1}$
- $1\ \text{kW} = 1000\ \text{W}$
- 1 horsepower (hp) ≈ 746 W



Useful Forms

- If force and velocity are parallel: $P = Fv$
- Average power = $\frac{\text{total work}}{\text{total time}}$

Work and Power

Two people may do the same work but have different power. The person who completes the work in less time develops greater power.

Worked Example 1

A horse does 5000 J of work in 100 s.

$$P = \frac{5000}{100} = 50\ \text{W}$$

Worked Example 2

A 50 kg girl climbs vertically through 10 m in 20 s. Taking $g = 9.8\ \text{m s}^{-2}$:

$$P = \frac{mgh}{t} = \frac{(50 \times 9.8 \times 10)}{20} = 245\ \text{W}$$

12. COMMERCIAL UNIT OF ENERGY

Kilowatt-hour



The joule is too small for household electrical consumption. Electrical energy is therefore measured in kilowatt-hour (kWh), commonly called one unit.

$$1\ \text{kWh} = 3.6 \times 10^6\ \text{J}$$

Derivation



$$\begin{aligned} 1\ \text{kWh} &= 1000\ \text{W} \times 1\ \text{h} \\ &= 1000\ \text{J s}^{-1} \times 3600\ \text{s} \\ &= 3.6 \times 10^6\ \text{J} \end{aligned}$$

Energy Used by an Appliance

$$E = Pt$$

Use kW and h to obtain kWh. Use W and s to obtain joule.

Worked Example

A 100 W bulb operates for 5 h.

$$E = 0.1\ \text{kW} \times 5\ \text{h} = 0.5\ \text{kWh} = 0.5\ \text{unit}$$

Another Example

$$250\ \text{units} = 250 \times 3.6 \times 10^6\ \text{J} = 9 \times 10^8\ \text{J}$$

Efficiency of Energy Transfer

$$\text{Efficiency} = \frac{\text{useful output energy}}{\text{input energy}} \times 100\%$$

Energy is conserved, but useful output is often smaller because some energy becomes heat or sound.

FORMULA AND EXAM CHECKLIST

Quantity	Formula	SI Unit
Work	$W = Fs\cos\theta$	joule (J)
Kinetic energy	$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$	joule (J)
Potential energy	$U = mgh$	joule (J)
Mechanical energy	$E = K + U$	joule (J)
Power	$P = \frac{W}{t} = \frac{E}{t} = Fv$	watt (W)
Commercial energy	$1\ \text{kWh} = 3.6 \times 10^6\ \text{J}$	kWh

Sign Checklist

- Same direction → positive work
- Opposite directions → negative work
- Perpendicular directions or zero displacement → zero work
- Work done by a stopping force equals negative initial kinetic energy

Numerical Method

1. Convert all values into SI units.
2. Write the appropriate formula.
3. Substitute values with units.
4. State magnitude and sign clearly.
5. Check whether the result is physically reasonable.

Common Mistakes

- Using distance instead of displacement.
- Ignoring the angle between force and displacement.
- Forgetting to square velocity in kinetic energy.
- Treating kW as kWh.
- Assuming that feeling tired always means mechanical work is done.

NCERT IN-TEXT QUESTIONS — SET 1

1. A weightlifter holds a barbell steady above her head. Is mechanical work being done on the barbell?

Answer: No. The upward force balances the weight, but the barbell has zero displacement. Therefore $W = Fs = 0$.

2. A stack of coins slides on a rough surface. Is the work done by friction positive, negative or zero?

Answer: Negative. Friction acts opposite to the displacement, so $\theta = 180°$ and $W = -Fs$.

3. While riding a bicycle on a level road, into which forms does muscular energy change?

Answer: Mainly into the kinetic energy of the bicycle and rider. A part becomes heat because of friction and body processes.

4. Does gravitational potential energy change during horizontal motion at constant height? What happens when the object is raised?

Answer: It remains unchanged during horizontal motion because height is constant. When raised, it increases by mgh.

5. A ball falls from height *h*. Show that its mechanical energy just before reaching the ground is *mgh*.

Answer: Initially $E = mgh$. Just before the ground $U \approx 0$ and $K = mgh$; hence $E = K + U = mgh$.

6. Why do successive peaks of a rolling ball on an undulating track become lower?

Answer: Friction and air resistance convert part of the mechanical energy into heat and sound, so less mechanical energy remains for the next rise.

NCERT EXERCISE SOLUTIONS — SET 1

Q1. Decide whether scientific work is done in each activity.

(a) A student swims in a pond.

Work is done because force applied by the swimmer produces displacement.

(b) A donkey carries a load on a level road.

Work done by gravity on the load is zero because weight is perpendicular to horizontal displacement.

(c) A windmill lifts water from a well.

Work is done because the water is displaced upward by a force.

(d) A green plant performs photosynthesis.

No mechanical work is considered because there is no mechanical force–displacement pair.

(e) An engine pulls a train.

Work is done because the engine's force produces displacement.

(f) Food grains dry in sunlight.

No mechanical work is done on the grains; energy transfer occurs as heating.

(g) A sailboat moves because of wind.

Work is done because wind force displaces the boat.

Q2. Prove that the increase in kinetic energy equals work done by a constant force.

Using $v^2 - u^2 = 2as$ and $F = ma$:

$$W = Fs = mas = ma\left[\frac{v^2 - u^2}{2a}\right]$$

Therefore, $W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = K_f - K_i$.

NCERT EXERCISE SOLUTIONS — SET 2

Q3. A freely falling object stops on reaching the ground. Where does its kinetic energy go?

Answer: It is transformed mainly into heat, sound and deformation energy of the object and ground.

Q4. A motorcycle and a car have equal kinetic energy and are stopped by equal braking forces. Which travels a shorter distance?

Answer: W = Fs = change in kinetic energy. Since both kinetic energy and braking force are equal, both stopping distances are equal.

Q5. Explain conservation of energy using a pendulum.

Answer: At an extreme position, potential energy is maximum and kinetic energy is zero. During descent, potential energy changes into kinetic energy. At the mean position, kinetic energy is maximum. During ascent, kinetic energy changes back into potential energy. Friction transfers some mechanical energy to heat and sound, but total energy remains conserved.

Q6. A freely falling body loses potential energy. Does this violate conservation of energy?

Answer: No. The decrease in potential energy equals the increase in kinetic energy when air resistance is neglected.

Q7. State the SI unit of energy and define it.

Answer: Joule (J). One joule is the energy transferred when 1 J of work is done.

Q8. A person carries ten bricks of 2.5 kg each to a height of 20 m in 50 s. Take $g = 10\ m\ s^{-2}$.

Total mass = 25 kg

$W = mgh = 25 \times 10 \times 20 = 5000$ J

$P = W/t = 5000/50 = 100$ W

MULTIPLE-CHOICE QUESTIONS — SET 1

Q1. **A horse pulls a cart along a road. Who does work on the cart?**

A. The cart
B. The horse
C. The road
D. The wheels

Ans. **B.** The horse, because it applies a force on the cart and causes its displacement.

Q2. **A force of 10 N is applied on an object, but the object does not move. The work done is**

A. 10 J
B. 1 J
C. 0 J
D. 100 J

Ans. **C.** Zero, because work done $W = Fs$ and the displacement $s = 0$.

Q3. **Work done does not depend on the**

A. Initial velocity of the body
B. Magnitude of the force
C. Displacement of the body
D. Angle between force and displacement

Ans. **A.** Work done depends on force, displacement and the angle between them, not on initial velocity.

Q4. **Which of the following is a correct example of work (in scientific sense)?**

A. Pushing a wall without moving it
B. Standing with a load on the head
C. Climbing a flight of stairs
D. Reading a book

Ans. **C.** Climbing stairs involves applying a force against gravity and moving through a distance.

Q5. **Negative work is done when**

A. force and displacement are in the same direction
B. force and displacement are in opposite directions (angle 180°)
C. the angle between them is 90°
D. no force is applied

Ans. **B.** When force and displacement are opposite ($\theta = 180°$), $W = Fs\cos 180° = -Fs$, i.e. negative.

Q6. **A schoolbag of mass 3 kg is carried by a student through 200 m on a horizontal road. The work done against gravity is**

A. 6000 J
B. 200 J
C. 60 J
D. 0 J

Ans. **D.** Zero, because displacement is horizontal while the gravitational force is vertical ($\theta = 90°$, $W = Fs\cos 90° = 0$).

Q7. **If a force acts opposite to the displacement of a body, the work done is**

A. $W = Fs$
B. $W = -Fs$
C. $W = 0$
D. $W = Fs\cos 90°$

Ans. **B.** For opposite directions, $\theta = 180°$, so $W = Fs\cos 180° = -Fs$.

Q8. **Which of the following statements is incorrect?**

A. Work and energy have different units.
B. Both work and energy are measured in joule (J).
C. Unequal masses dropped freely from a height have equal acceleration.
D. Work is the product of force and displacement (in the direction of force).

Ans. **A.** It is incorrect; work and energy have the same unit, the joule (J).

Q9. **At the halfway point during the free fall of a body from a height, it has**

A. only potential energy
B. only kinetic energy
C. both potential and kinetic energy
D. neither potential nor kinetic energy

Ans. **C.** During the fall, the body still has some height (PE) and also gains speed (KE), so both are present.

Q10. **Iron and aluminium spheres are dropped simultaneously from the same height. Their accelerations are**

A. greater for iron
B. greater for aluminium
C. the same for both
D. zero for both

Ans. **C.** In free fall, all bodies have the same acceleration due to gravity ($g \approx 9.8$ m s^{-2}), independent of their masses.

Q11. **If the speed of a body is tripled, its kinetic energy becomes**

A. 3 times
B. 6 times
C. 9 times
D. 12 times

Ans. **C.** Since $KE = \frac{1}{2}mv^2$, if $v \to 3v$, then $KE' = \frac{1}{2}m(3v)^2 = 9(\frac{1}{2}mv^2)$, i.e. nine times.

Q12. **Two stones of unequal masses are dropped from the same height. Just before hitting the ground, the heavier stone has**

A. smaller kinetic energy
B. the same kinetic energy
C. greater kinetic energy
D. zero kinetic energy

Ans. **C.** At the same height, both have the same speed ($v = \sqrt{2gh}$), so $KE = \frac{1}{2}mv^2$ is greater for the heavier stone (larger mass).

MULTIPLE-CHOICE QUESTIONS — SET 2

Q13 **For a body of mass m, which change in speed causes a larger change in kinetic energy (KE)?**

A. Increasing speed by 50%
B. Doubling the speed
C. Tripling the speed
D. Decreasing speed by half

Ans. B. Since $KE = \frac{1}{2}mv^2$, doubling the speed ($v \to 2v$) makes KE four times (KE → 4KE), giving the larger change.

Q14 **Two bodies of masses 20 g and 50 g have equal kinetic energy. The ratio $p_1^2 : p_2^2$ of their momenta is**

A. 5 : 2
B. 2 : 5
C. 1 : 1
D. 4 : 25

Ans. B. For equal KE, $p^2 = 2mKE \Rightarrow p^2 \propto m$, so $p_1^2 : p_2^2 = 20 : 50 = 2 : 5$.

Q15 **If the kinetic energy of a body is increased by 800%, its momentum increases by**

A. 100%
B. 150%
C. 200%
D. 300%

Ans. C. An 800% increase makes KE = $9KE_0$; since $p \propto \sqrt{KE}$, p becomes $3p_0$, i.e. an increase of 200%.

Q16 **A ball of mass m at a height h above the ground has a potential energy equal to**

A. mv
B. $\frac{1}{2}mv^2$
C. mgh
D. $\frac{mg}{h}$

Ans. C. Gravitational potential energy at height h is $PE = mgh$.

Q17 **The energy of water stored in a dam is**

A. Kinetic energy
B. Potential energy
C. Electrical energy
D. Chemical energy

Ans. B. Water stored at a height has gravitational potential energy due to its position.

Q18 **An aircraft of mass 10^5 kg has a potential energy of 1.5×10^8 J at a certain height above the ground ($g = 10\ m\ s^{-2}$). The height of the aircraft is**

A. 100 m
B. 150 m
C. 200 m
D. 300 m

Ans. B. Using $PE = mgh$, $h = \frac{1.5 \times 10^8}{10^5 \times 10} = 150$ m.

Q19 **A body falls from rest through half of a height h. Then at this point, it has**

A. zero PE and full KE
B. half PE and half KE
C. full PE and zero KE
D. one-fourth PE and three-fourths KE

Ans. B. After falling through $\frac{h}{2}$, the remaining height is $\frac{h}{2}$, so $PE = mg\left(\frac{h}{2}\right)$ (half of initial); by conservation of energy, $KE = mg\left(h - \frac{h}{2}\right) = mg\left(\frac{h}{2}\right)$ (half).

Q20 **For a freely falling body (neglecting air resistance), its total mechanical energy**

A. increases
B. decreases
C. remains constant
D. becomes zero

Ans. C. Mechanical energy (PE + KE) is conserved during free fall.

Q21 **A flying bird has**

A. only kinetic energy
B. only potential energy
C. both kinetic and potential energy
D. neither kinetic nor potential energy

Ans. C. It has kinetic energy due to its motion and potential energy due to its height above the ground.

Q22 **A solar cell converts**

A. chemical energy to electrical energy
B. light (solar) energy to electrical energy
C. electrical energy to light energy
D. mechanical energy to electrical energy

Ans. B. A solar cell converts light (solar) energy into electrical energy.

Q23 **A horse does 5000 J of work in 100 s. Its power is**

A. 5 W
B. 25 W
C. 50 W
D. 500 W

Ans. C. Power $P = \frac{W}{t} = \frac{5000}{100} = 50$ W.

Q24 **Two bulbs of 15 W and 10 W are connected to their rated supply. Which bulb glows brighter?**

A. 10 W bulb
B. 15 W bulb
C. Both glow equally
D. Neither glows

Ans. B. At the same supply voltage, the bulb with higher power (15 W) converts more electrical energy per second into light, so it is brighter.

ASSERTION–REASON QUESTIONS

Directions: For each of the following questions, two statements are given: Assertion (A) and Reason (R).

A: Both A and R are true and R is the correct explanation of A.

B: Both A and R are true but R does not explain A.

C: A is true but R is false.

D: A is false but R is true.

1. **Assertion (A):** A force opposing motion does zero work.

Reason (R): The angle between the force and displacement is 180°.

Answer: D

Explanation: A force opposing motion does negative work, $W = Fs\cos 180° = -Fs \neq 0$; so A is false. The reason is true, as the angle between the force and displacement is 180°.

2. **Assertion (A):** A moving hammer can drive a nail into a wooden block.

Reason (R): The work done on the nail by the hammer is positive.

Answer: A

Explanation: Both A and R are true, and R correctly explains A. The hammer exerts a force on the nail in the direction of its displacement into the wood, so the work done on the nail is positive ($W = Fs\cos 0° = Fs$), which drives it in.

3. **Assertion (A):** A rider speeds up before reaching an uphill road.

Reason (R): This is to give more potential energy to the rider immediately.

Answer: C

Explanation: A is true, but R is false. The rider increases speed to gain extra kinetic energy, which is later converted into gravitational potential energy (PE = mgh) while climbing the hill, not immediately.

4. **Assertion (A):** The kinetic energy of a body is always non-negative.

Reason (R): The potential energy of a body can be positive or negative depending on the chosen reference level.

Answer: B

Explanation: Both A and R are true, but R does not explain A. Kinetic energy $K = \frac{1}{2}mv^2 \geq 0$ for any real v, whereas potential energy (PE = mgh) can be positive, zero or negative depending on the reference level. The truth of R is independent of A.

5. **Assertion (A):** The total energy of a freely falling body remains constant.

Reason (R): Its kinetic energy is minimum (at zero) at the ground.

Answer: C

Explanation: A is true as, in free fall (neglecting air resistance), mechanical energy (KE + PE) remains constant. R is false because the kinetic energy is maximum, not minimum, at the ground (KE = $\frac{1}{2}mv^2$).

6. **Assertion (A):** An electric motor converts electrical energy into mechanical energy.

Reason (R): The mechanical energy of the motor is equal to its kinetic energy only.

Answer: C

Explanation: A is true, but R is false. The mechanical energy of a body is the sum of its kinetic and potential energies, i.e., Mechanical energy = KE + PE. Hence, it is not equal to kinetic energy only.

7. **Assertion (A):** A truck and a bus do the same work, but the truck takes 40 s and the bus 60 s. The truck is more powerful.

Reason (R): Power is given by $P = \frac{W}{t}$.

Answer: A

Explanation: Both A and R are true, and R correctly explains A. For the same work W, power is inversely proportional to time: $P = \frac{W}{t}$. Since the truck takes less time (40 s) than the bus (60 s), $P_{truck} > P_{bus}$; hence, the truck is more powerful.

8. **Assertion (A):** A bulb uses 200 J of energy in 10 s, so its power is 20 W.

Reason (R): Power is the amount of energy used divided by the time taken, i.e., $P = \frac{\text{energy}}{\text{time}}$.

Answer: A

Explanation: Both A and R are true, and R explains A. Using $P = \frac{E}{t}$, with $E = 200$ J and $t = 10$ s,

$P = \frac{200}{10} = 20$ W.

CASE-BASED QUESTIONS — SET 1

CASE 1

A crane lifts a 100 kg load vertically upward. The motor supplied to the crane has an input power of 2.5 kW and its efficiency is 80%. Take $g = 10\ \text{m s}^{-2}$. The height of the load at different times is given below.

Time (s)	0	10	20	30	40
Height (m)	0	20	40	60	80

Questions

(i) Find the work done by the crane in lifting the load to a height of 80 m.

(ii) Calculate the velocity with which the load is being lifted.

(iii) Find (a) the useful output power of the crane and (b) the total input energy supplied in 40 s.

(iv) Calculate the work done by the crane in lifting the load between 20 s and 30 s.

Answers

(i) Work to lift the load to 80 m:

Work against gravity = increase in potential energy

$$W = mgh = 100 \times 10 \times 80$$
$$= \mathbf{80{,}000\ J.}$$

(ii) Velocity of the load:

The height increases by 20 m in 10 s (from table).

$$\text{So, } v = \frac{\Delta h}{\Delta t} = \frac{20}{10} = \mathbf{2\ m\ s^{-1}.}$$

(iii) (a) Useful output power:

$$P_{\text{out}} = \eta P_{\text{in}} = 0.80 \times 2.5\ \text{kW}$$
$$= 2.0\ \text{kW} = \mathbf{2000\ W.}$$

(b) Total input energy in 40 s:

$$E_{\text{in}} = P_{\text{in}}\, t = 2.5\ \text{kW} \times 40\ \text{s}$$
$$= 2500\ \text{W} \times 40\ \text{s}$$
$$= \mathbf{100{,}000\ J.}$$

(iv) Work between 20 s and 30 s:

Height increases from 40 m to 60 m, so $\Delta h = 20$ m.

$$W = mg\,\Delta h = 100 \times 10 \times 20$$
$$= \mathbf{20{,}000\ J.}$$

CASE 2

A ball is thrown vertically upward with some initial speed. It rises to a maximum height h and then falls back to the point from where it was thrown. Consider the work done by gravity on the ball during the upward and downward motions and for the complete (round) trip.

Questions

(i) Find the work done by gravity on the ball when it moves upward through a height h.

(ii) Why is the work done by gravity negative during the upward motion?

(iii) What is the net work done by gravity on the ball during the complete trip (up and down)?

(iv) Which energy remains conserved during the entire motion of the ball? Explain.

Answers

(i) Work done by gravity (upward):

The gravitational force on the ball is $F = mg$ downward, while the displacement is upward by h.

$$W_{\text{up}} = Fs\cos 180^\circ = mg \times h \times (-1)$$
$$= \mathbf{-mgh.}$$

(ii) Reason for negative work (upward):

The work is negative because the force due to gravity (downward) is opposite to the direction of displacement (upward).

(iii) Net work by gravity (round trip):

Work during downward motion from height h to the launch point:

$$W_{\text{down}} = Fs\cos 0^\circ = mg \times h \times 1 = mgh.$$

Net work, $W_{\text{net}} = W_{\text{up}} + W_{\text{down}}$

$$= (-mgh) + mgh = \mathbf{0.}$$

(iv) Energy conserved:

The mechanical energy of the ball, i.e. the sum of its potential energy and kinetic energy, remains conserved (neglecting air resistance):

$$E = PE + KE = mgh + \frac{1}{2}mv^2,$$

which remains constant throughout the motion.

CASE-BASED QUESTIONS — SET 2

CASE 3 Mechanical Energy with External Work

A trolley moves from point P to point Q. Its potential energy at Q is 50 kJ less than at P. The kinetic energy at P is 5 kJ. During the motion, 10 kJ of mechanical energy is lost against friction.

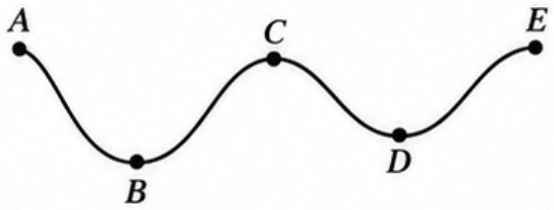
(i) Find the kinetic energy of the trolley at Q.

(ii) Answer the following conceptual questions:

(a) A car travels from P to Q downhill at constant speed. What is the change in its kinetic energy? Explain, even though its potential energy decreases and brakes dissipate energy.

(b) An object of weight 10 N is dropped from a height of 4 m. What is its total mechanical energy after it has fallen through 1 m?

(c) The figure shows a frictionless track A, B, C, D, E with point B at the lowest level. At which point is the potential energy minimum and the kinetic energy maximum? Give a reason.



Solution

(i) Kinetic energy at Q

Decrease in potential energy (energy released) = 50 kJ
Initial kinetic energy at P = 5 kJ
Energy lost against friction = 10 kJ
By conservation of energy (with loss),

$$\text{KE at Q} = (\text{decrease in PE}) + (\text{initial KE}) - (\text{loss})$$
$$= 50 + 5 - 10 = 45 \text{ kJ}$$

Ans. KE at Q = 45 kJ.

(ii) (a) Change in kinetic energy = 0.

Explanation: The car moves at constant speed, so its kinetic energy does not change ($\Delta KE = 0$). Its potential energy decreases as it goes downhill. The loss in potential energy is dissipated as heat due to the work done by the brakes (against friction).

(b) Total mechanical energy after falling 1 m

Weight = 10 N, initial height = 4 m.
Total mechanical energy (conserved) = $mgh = 10 \times 4 = 40$ J.
After falling 1 m: PE = $10 \times (4 - 1) = 30$ J, KE = $40 - 30 = 10$ J.
Hence, total mechanical energy = 40 J.

Ans. Total mechanical energy = 40 J.

(c) Point of minimum PE and maximum KE

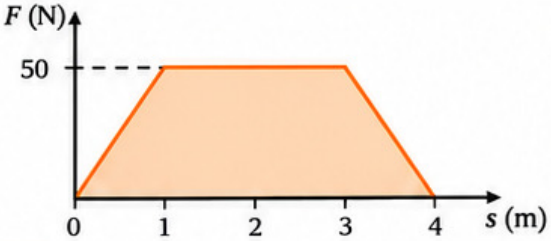
At the lowest point B, the height is minimum, so potential energy (PE) is minimum. On a frictionless track, total mechanical energy is conserved; therefore, kinetic energy (KE) is maximum at B.

Ans. PE minimum and KE maximum at point B.

CASE 4 Work–Energy Graph

A 10 kg block has an initial kinetic energy of 180 J. A force acts on it, and the force–displacement (F–s) graph from 0 m to 4 m is a trapezium with parallel sides 4 m and 2 m and height 50 N (as shown).

(i) Find the work done by the force from 0 m to 4 m.
(ii) Find the speed of the block at 0 m.
(iii) Find the final kinetic energy and the speed at 4 m.
(iv) Is the acceleration ever negative in 0–4 m? Give reason.



Solution

(i) Work done by the force

Area of trapezium, $W = \frac{1}{2}(a + b) \times h$
$= \frac{1}{2}(4 + 2) \times 50 = 150$ J.

Ans. Work done = 150 J.

(ii) Speed at 0 m

Initial KE, $K_0 = 180$ J, $m = 10$ kg

$$K_0 = \frac{1}{2}mv_0^2 \Rightarrow v_0 = \sqrt{\frac{2K_0}{m}} = \sqrt{\frac{2 \times 180}{10}} = \sqrt{36} = 6 \text{ m/s}.$$

Ans. Speed at 0 m = 6 m/s.

(iii) Final kinetic energy and speed at 4 m

Final KE, $K = K_0 + W = 180 + 150 = 330$ J.

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2 \times 330}{10}} = \sqrt{66} \approx 8.12 \text{ m/s}.$$

Ans. Final KE = 330 J; speed at 4 m = $\sqrt{66} \approx 8.12$ m/s.

(iv) Is the acceleration ever negative?

No. From the graph, the force is non-negative ($F \geq 0$) in 0–4 m. Since $a = F/m$, the acceleration is zero at $s = 0$ and $s = 4$, positive in between, and never negative.

Ans. No, acceleration is never negative.

CASE 5 Coconut Falling into Wet Sand

A coconut of mass 1.5 kg falls freely from a height of 10 m and gets embedded in wet sand. Take $g = 10$ m s^{-2} and the average resistance offered by the sand to be 3000 N. Find (i) its speed just before impact, (ii) the kinetic energy at impact, and (iii) the depth of depression in the sand.

Solution

(i) Speed before impact

$$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 10} = \sqrt{200} \approx 14.14 \text{ m/s}.$$

(ii) Kinetic energy at impact

$$K = \frac{1}{2}mv^2 = \frac{1}{2} \times 1.5 \times 200 = 150 \text{ J}.$$

(iii) Depth of depression

Work done by resistance = $K \Rightarrow F \times d = 150$

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

Ans. Speed ≈ 14.14 m/s; impact energy = 150 J; depth = 5 cm.

VERY SHORT ANSWER QUESTIONS — SET 1

Q1. When is work done?

Ans. Work is done when a force acts on a body and produces a displacement in the direction of the force (or has a component along it).

Q2. What is the expression for work done when the force is along the displacement?

Ans. W = Fs, where F is the force and *s* is the displacement.

Q3. Define 1 joule (J) of work.

Ans. One joule is the work done when a force of 1 newton produces a displacement of 1 metre in its direction (1 J = 1 N × 1 m).

Q4. What is the work done by gravity on a satellite moving in a circular orbit?

Ans. Zero. The gravitational force is directed towards the centre (radially), while the displacement is tangential; hence, the force is perpendicular to the displacement.

Q5. Can a body have displacement without a net force acting on it?

Ans. Yes. A body can move with constant velocity (in a straight line) under balanced forces, i.e., when the net force is zero.

Q6. A person holds a bundle of hay overhead. What is the work done on the hay?

Ans. Zero. The hay does not undergo any displacement, so no work is done on it.

Q7. Can the acceleration of a body be zero even when several forces act on it?

Ans. Yes. If the forces acting on the body balance each other, the net force is zero and hence the acceleration is zero.

Q8. What is the work done by gravity when a body moves upward?

Ans. The work done by gravity is negative, because the gravitational force acts downward while the displacement is upward, i.e., in opposite directions.

Q9. A projectile is thrown and returns to the same level. What is the net work done by gravity on it?

Ans. Zero. Over the complete motion, the upward (negative) and downward (positive) works by gravity are equal in magnitude and cancel each other.

Q10. A mass is moved horizontally on a surface. Does gravity do any work on it?

Ans. Zero. The gravitational force acts vertically downward, while the displacement is horizontal, so the force is perpendicular to the displacement.

Q11. Is any work done on a suitcase when you hold it at rest?

Ans. Zero. The suitcase is at rest and has no displacement, so no work is done on it.

Q12. A cricket ball is thrown horizontally for a distance of 20 m. What is the work done by gravity on the ball?

Ans. The work done by gravity depends on the vertical displacement of the ball. For an ideal horizontal displacement at the same level (no change in height), the work done by gravity is zero.

Q13. In an accelerated circular motion, does the centripetal force do any work on the body?

Ans. No. The centripetal force is always perpendicular to the instantaneous displacement, so it does no work.

Q14. Define kinetic energy.

Ans. Kinetic energy is the energy possessed by a body due to its motion.

Q15. What is the expression for kinetic energy of a body?

Ans. KE = $\frac{1}{2}mv^2$, where m is the mass of the body and v is its velocity.

Q16. How does changing the velocity or mass of a body affect its kinetic energy?

Ans. Kinetic energy varies as the square of the velocity (KE $\propto v^2$) and varies linearly with the mass (KE $\propto$ m).

VERY SHORT ANSWER QUESTIONS — SET 2

Q17 What is the relation between kinetic energy and momentum of a body?

Ans. Kinetic energy (KE) and momentum (p) are related as $KE = \frac{p^2}{2m}$, where m is the mass of the body.

Q18 What are the kinetic and potential energies of a body thrown vertically upward at the highest point of its motion?

Ans. At the highest point, the velocity $v = 0$, so kinetic energy is zero. The potential energy is maximum.

Q19 At what position is the potential energy of a spring minimum?

Ans. The potential energy of a spring is minimum (zero) at its natural length (when it is neither stretched nor compressed).

Q20 Can the potential energy of a body be negative?

Ans. Yes. Potential energy can be negative, as it is defined relative to a chosen zero level.

Q21 Can a body have mechanical energy even when its momentum is zero?

Ans. Yes. When momentum is zero, the kinetic energy is zero, but the body may still have non-zero potential energy, so its mechanical energy can exist.

Q22 What type of energy is stored in the spring of a watch?

Ans. The spring of a watch stores elastic potential energy.

Q23 Are work and energy the same? Justify briefly.

Ans. No. Work is the transfer of energy from one body to another due to a force acting through a distance. Work and energy are different, though both are measured in joules (J).

Q24 What energy transformation takes place when a person rides a bicycle?

Ans. The chemical energy in the person's body (converted into muscular energy) changes mainly to the kinetic energy of the bicycle, with some energy also converted to heat due to friction.

Q25 Why does an electric bulb become hot when it glows?

Ans. When an electric bulb glows, the electrical energy is partly converted into heat energy (in addition to light energy), so the bulb becomes hot.

Q26 How does a battery make an electric bulb glow?

Ans. A battery converts chemical energy into electrical energy. The electrical energy then changes into light energy and heat energy in the bulb, making it glow.

Q27 Give one example each of (i) conversion of light energy to chemical energy and (ii) mechanical energy to heat energy.

Ans. (i) Photosynthesis in green plants (light energy → chemical energy).
(ii) Rubbing our hands (mechanical energy → heat energy).

Q28 Define power and write its formula.

Ans. Power is the rate of doing work, i.e. the amount of work done per unit time. Its formula is $P = \frac{W}{t}$, where W is the work done and t is the time.

Q29 Define 1 watt.

Ans. 1 watt is the power when 1 joule of work is done in 1 second.
1 watt = 1 J s^{-1} (or 1 W = 1 J/s).

Q30 What is the expression for average power?

Ans. Average power is the total work done divided by the total time taken. $P_{avg} = \frac{\text{Total work}}{\text{Total time}}$.

Q31 If you try to push a heavy rock that does not move, is any work done? What happens to the energy in your body?

Ans. No, no work is done on the rock because there is no displacement. However, the chemical energy in the body is used up and is mainly converted into internal (thermal) energy of the body (we feel hot).

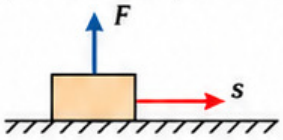
Q32 A falling object eventually comes to rest after hitting the ground. Where does its kinetic energy go?

Ans. The kinetic energy of the object is mainly converted into heat energy, sound energy and the energy used in deformation (change in shape) of the object and the ground.

SHORT-ANSWER QUESTIONS — SET 1

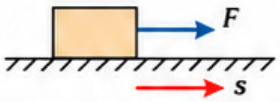
Q1 **Show with diagrams that (i) when the force is perpendicular to displacement, the work done is zero, (ii) when the force is in the same direction as displacement, the work done is positive, and (iii) when the force is opposite to displacement, the work done is negative.**

Ans. **(i) Force ⊥ displacement → zero work**



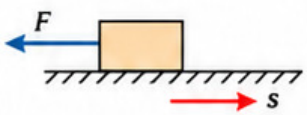
$\theta = 90°$
$W = Fs\cos 90° = 0$
$\therefore$ Work done is zero.

(ii) Force in same direction → positive work



$\theta = 0°$
$W = Fs\cos 0° = Fs\ (>0)$
$\therefore$ Work done is positive.

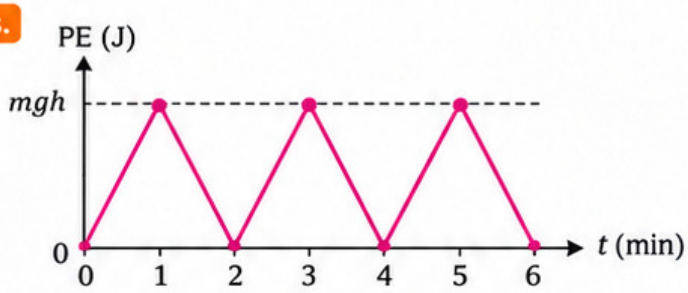
(iii) Force opposite to displacement → negative work



$\theta = 180°$
$W = Fs\cos 180° = -Fs$
$\therefore$ Work done is negative.

Q2 **A girl repeatedly sits and stands for 6 min. Sketch a potential energy (PE)–time graph if the peaks are at 1, 3 and 5 min and the PE is zero at 0, 2, 4 and 6 min. Explain why the PE is zero while sitting and equal to mgh while standing.**

Ans.



- While sitting, the girl is at the chosen reference level (ground/floor), so her height $h = 0$ and $PE = mgh = 0$.
- While standing, her centre of mass is at a height h above this level, so $PE = mgh$. Repeated sitting and standing makes PE rise from 0 to mgh (0–1 min), fall to 0 (1–2 min), and repeat, giving peaks at 1, 3, 5 min and zero at 0, 2, 4, 6 min.

Q3 **A body of mass m moving with speed v is brought to rest. Find the work done on it and the magnitude of the stopping work.**

Ans. Initial kinetic energy, $K_i = \frac{1}{2}mv^2$; final kinetic energy, $K_f = 0$.
Work done on the body,

$$\Delta K = K_f - K_i = 0 - \frac{1}{2}mv^2 = -\frac{1}{2}mv^2.$$

Magnitude of the stopping work $= \frac{1}{2}mv^2$.

Q4 **Define potential energy. Give an example of a wound spring. A skier of mass 50 kg moves from a height of 75 m to 60 m. Find the decrease in his potential energy. Take $g = 10\ \text{m s}^{-2}$.**

Ans.

Potential energy: The energy possessed by a body due to its position or configuration is called potential energy.

Example (wound spring): A compressed or stretched spring (e.g. in a spring toy or a watch) possesses elastic potential energy.

For the skier:

Mass, $m = 50$ kg; initial height $h_1 = 75$ m; final height $h_2 = 60$ m; $g = 10\ \text{m s}^{-2}$.

Decrease in potential energy,

$$\Delta PE = mg(h_1 - h_2) = 50 \times 10 \times (75 - 60)$$
$$= 50 \times 10 \times 15 = 7500\ \text{J}.$$

Q5 **The same body of mass m is raised through a vertical height h along two different paths. What is the change in its potential energy in each case? Is it dependent on the path? Also, find the ratio of potential energies of two equal masses placed at heights $2h$ and $5h$.**

Ans.

- Change in potential energy in each case: $\Delta PE = mgh$.
- It is not dependent on the path, because potential energy depends only on the vertical height (final position) with respect to the reference level.
- For equal masses, at heights $2h$ and $5h$:

$$PE_1 = mg(2h) = 2mgh, \quad PE_2 = mg(5h) = 5mgh.$$
$$\therefore \quad PE_1 : PE_2 = 2mgh : 5mgh = 2 : 5.$$

Q6 **Why does the decrease in potential energy during free fall not violate the law of conservation of energy?**

Ans.

During free fall (neglecting air resistance), the body's potential energy decreases by mgh, and at the same time its kinetic energy increases by an equal amount mgh. Thus, the loss in potential energy is exactly converted into a gain in kinetic energy, so the total mechanical energy,

$$E = PE + KE,$$

remains constant. Hence, there is no violation of the law of conservation of energy.

LONG-ANSWER QUESTIONS

Q1. **Decide whether scientific work occurs in each of the following cases, giving a reason for your answer:**

(i) A swimmer displaces water. (ii) A donkey carries a load on a horizontal road. (iii) A windmill is used to lift water. (iv) A green plant carries out photosynthesis. (v) An engine pulls a train. (vi) Grains dry in the sun. (vii) A sailboat is moved by wind.

Ans.

(i) **A swimmer displaces water: Yes.** The swimmer applies a force on the water and causes its displacement; hence, scientific work is done.

(ii) **A donkey carries a load on a horizontal road: No.** The force exerted by gravity on the load is vertically downward, while the displacement is horizontal. Since the angle between force and displacement is 90°, work done by gravity is zero ($W = Fs \cos 90° = 0$).

(iii) **A windmill is used to lift water: Yes.** The windmill (through its mechanism) applies an upward force on water and displaces it through a vertical height; hence, work is done.

(iv) **A green plant carries out photosynthesis: No (as mechanical work).** Photosynthesis involves a chemical change in which light energy is converted into chemical energy (stored in food). There is no mechanical displacement against a force, so no mechanical work is done.

(v) **An engine pulls a train: Yes.** The engine exerts a force on the train and causes its displacement; hence, scientific work is done.

(vi) **Grains dry in the sun: No (as mechanical work).** Drying is a physical (evaporation) process involving a change of state due to heat from the sun; there is no displacement of the grains against a force.

(vii) **A sailboat is moved by wind: Yes.** The wind exerts a force on the sail, causing the boat to displace; hence, work is done.

Q2. **Derive the work–energy theorem using the equations $v^2 - u^2 = 2as$ and $F = ma$.**

Ans. Let a body of mass m move with initial velocity u and final velocity v under a constant force F through a displacement s.

From the equation of motion, $v^2 - u^2 = 2as$ ... (1)

Also, $F = ma \Rightarrow a = \frac{F}{m}$ ... (2)

Substituting (2) in (1):

$$v^2 - u^2 = 2\frac{F}{m}s \Rightarrow Fs = \frac{1}{2}m(v^2 - u^2)$$

But work done, $W = Fs$. Hence,

$$W = Fs = \frac{1}{2}m(v^2 - u^2) = K_f - K_i$$

Thus, the work done by a net force on a body is equal to the change in its kinetic energy. This is the work–energy theorem.

Q3. **Where does the kinetic energy of a falling body go after it hits the ground?**

Ans. When a falling body hits the ground, its kinetic energy does not disappear. It is transformed into other forms, mainly:

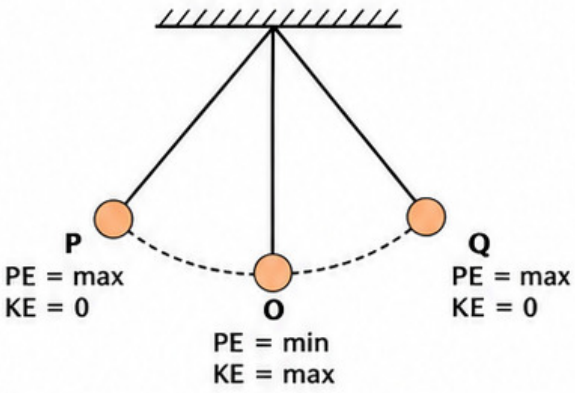
- **Heat energy:** due to friction between the body and the ground, and internal friction within the body and the ground.
- **Sound energy:** some of the kinetic energy appears as sound (e.g., a thud).
- **Energy of deformation (internal energy):** the body and the ground may get slightly deformed, so part of the kinetic energy is stored as internal (elastic) energy (in case of an elastic body, it may be partly converted back to kinetic energy).

Thus, the total energy is conserved, but the mechanical energy (kinetic energy) of the body is dissipated into heat, sound and internal energy of the body and the ground.

Q4. **Explain the changes in energy in a simple pendulum as it oscillates. Support your answer with a labeled diagram. Why does the pendulum eventually come to rest?**

Ans. A simple pendulum consists of a small heavy bob suspended by a light, inextensible string from a fixed point. As it oscillates, there is a continuous interchange between potential energy (PE) and kinetic energy (KE):

- **At an extreme position P:** The bob is at the highest position. PE is maximum (mgh) and KE is zero ($v = 0$).
- **At the mean position O:** The bob is at the lowest position. PE is minimum (≈ 0, taking this level as reference) and KE is maximum $\left(\frac{1}{2}mv^2\right)$.
- **At the opposite extreme position Q:** The bob again comes to the highest position on the other side. PE is maximum and KE is zero.



The pendulum eventually comes to rest because of friction at the point of suspension and air resistance. These resistive forces do negative work on the pendulum, so its mechanical energy (PE + KE) is gradually converted into heat and sound energy. The bob loses energy in each oscillation and finally stops at the mean position. This does not violate the law of conservation of energy, as the total energy is conserved; it is only transformed from mechanical energy to other forms (mainly heat and sound).

NUMERICAL PRACTICE — SET 1

N1 A force of 7 N acts on a body and it moves 8 m in the same direction. Calculate the work done.

Given:	$F = 7$ N, $s = 8$ m (Force and displacement in the same direction)
Formula:	$W = F \times s$
Substitution:	$W = 7\ \text{N} \times 8\ \text{m}$ $= 56\ \text{N m}$ $= 56\ \text{J}$
Answer:	$W = \mathbf{56\ J}$ (positive, since force and displacement are in the same direction).

N2 A pair of bullocks exert a force of 140 N to pull a cart through 15 m. Calculate the work done by the bullocks.

Given:	$F = 140$ N, $s = 15$ m
Formula:	$W = F \times s$
Substitution:	$W = 140\ \text{N} \times 15\ \text{m}$ $= 2100\ \text{N m}$ $= 2100\ \text{J}$
Answer:	$W = \mathbf{2100\ J}$ (positive).

N3 A car and a truck move with the same speed. If the ratio of their masses is 1 : 4, find the ratio of their kinetic energies.

Given:	$m_{car} : m_{truck} = 1 : 4$, $v_{car} = v_{truck} = v$ (same speed)
Formula:	$K = \frac{1}{2} m v^2 \Rightarrow K \propto m$ (for same v)
Substitution:	$K_{car} : K_{truck} = m_{car} : m_{truck}$ $= 1 : 4$
Answer:	Ratio of kinetic energies = **1 : 4.**

N4 A body of mass 5 kg has a kinetic energy of 250 J. Find its speed.

Given:	$m = 5$ kg, $K = 250$ J
Formula:	$K = \frac{1}{2} m v^2 \Rightarrow v = \sqrt{\frac{2K}{m}}$
Substitution:	$v = \sqrt{\frac{2 \times 250\ \text{J}}{5\ \text{kg}}}$ $= \sqrt{100\ m^2 s^{-2}}$ $= 10\ \text{m s}^{-1}$
Answer:	**$v = 10$ m/s.**

N5 A truck of mass 1200 kg is moving with a speed of 25 km/h. Calculate the stopping energy (i.e., the kinetic energy to be removed) and the work done by the brakes.

Given:	$m = 1200$ kg, $v = 25$ km/h
Formula:	Stopping energy (initial KE): $K = \frac{1}{2} m v^2$ Work by brakes: $W = -K$
Substitution:	Convert speed: $25\ \text{km/h} = \frac{25 \times 1000}{3600}\ \text{m/s}$ $= 6.94\ \text{m/s}$ (approx.) $K = \frac{1}{2} \times 1200\ \text{kg} \times (6.94\ \text{m/s})^2$ $= 600 \times 48.16\ \text{J}$ $\approx 2.89 \times 10^4\ \text{J}$
Answer:	Stopping energy (magnitude of KE to be removed) $\approx \mathbf{2.89 \times 10^4\ J}$. Work done by the brakes: $W \approx \mathbf{-2.89 \times 10^4\ J}$ (negative, since the brakes oppose the motion and reduce the kinetic energy to zero).

N6 A body has a kinetic energy of 25 J when its speed is 5 m/s. If its speed becomes three times (15 m/s), find its new kinetic energy.

Given:	$K_1 = 25$ J at $v_1 = 5$ m/s, new speed $v_2 = 3v_1 = 15$ m/s
Formula:	$K \propto v^2 \Rightarrow K_2 = \left(\frac{v_2}{v_1}\right)^2 K_1$
Substitution:	$K_2 = (3)^2 \times 25\ \text{J}$ $= 9 \times 25\ \text{J}$ $= 225\ \text{J}$
Answer:	New kinetic energy, $K_2 = \mathbf{225\ J}$.

N7 A body of mass 20 kg has its speed reduced from 5 m s^{-1} to 2 m s^{-1}. Calculate the work done on the body.

Given: m = 20 kg, u = 5 m s^{-1}, v = 2 m s^{-1}

Formula / Method: Work done (change in KE), $W = \frac{1}{2} m (v^2 - u^2)$

Substitution:

$$W = \frac{1}{2} \times 20 \times (2^2 - 5^2)$$
$$= 10 \times (4 - 25)$$
$$= 10 \times (-21)$$
$$= -210 \text{ J}$$

Answer: $W = -210$ J

N8 A car of mass 1500 kg is moving at 60 km h^{-1}. What work must be done to stop it? Also, find the stopping energy.

Given: m = 1500 kg, speed = 60 km h^{-1}, final speed v = 0

Formula / Method: Convert speed to m s^{-1}; work done $W = \frac{1}{2} m (v^2 - u^2)$; stopping energy = $|W|$.

Substitution:

$$60 \text{ km h}^{-1} = \frac{60 \times 1000}{3600} \approx 16.67 \text{ m s}^{-1}$$
$$W = \frac{1}{2} \times 1500 \times (0^2 - 16.67^2)$$
$$= 750 \times (-277.8889)$$
$$\approx -2.083 \times 10^5 \text{ J}$$

Answer: **Work done = -2.083×10^5 J; Stopping energy = 2.083×10^5 J**

N9 A body of mass 2 kg is dropped from a height of 1 m. Calculate its kinetic energy when it reaches the ground. Take g = 9.8 m s^{-2}.

Given: m = 2 kg, h = 1 m, g = 9.8 m s^{-2}

Formula / Method: Loss of PE = gain in KE; KE = mgh

Substitution:

$$\text{KE} = 2 \times 9.8 \times 1$$
$$= 19.6 \text{ J}$$

Answer: KE = 19.6 J

N10 A stone of mass 3 kg is thrown vertically upwards with a speed of 30 m s^{-1}. Calculate the maximum potential energy it attains.

Given: m = 3 kg, u = 30 m s^{-1}

Formula / Method: At the highest point, KE = 0 and PE is maximum; hence PE_{max} = initial KE = $\frac{1}{2} mu^2$.

Substitution:

$$PE_{max} = \frac{1}{2} \times 3 \times 30^2$$
$$= 1.5 \times 900$$
$$= 1350 \text{ J}$$

Answer: **Maximum potential energy = 1350 J**

N11 An electric iron of power 1200 W is used for 30 minutes daily. Find the total electrical energy used in 30 days.

Given: P = 1200 W, time per day = 30 min, number of days = 30

Formula / Method: $E = Pt$ (t in s); also, E (in kWh) = P (kW) × t (h) × number of days.

Substitution: Time per day, t = 30 min = 30 × 60 = 1800 s

$$E = 1200 \times 1800 \times 30$$
$$= 6.48 \times 10^7 \text{ J}$$

(Alternatively: P = 1.2 kW, t = 0.5 h per day; E = 1.2 × 0.5 × 30 = 18 kWh)

Answer: **Total energy = 6.48×10^7 J (= 18 kWh)**

N12 A girl of mass 50 kg climbs up a height of 10 m in 20 s. Calculate the power developed by her. Take g = 9.8 m s^{-2}.

Given: m = 50 kg, h = 10 m, t = 20 s, g = 9.8 m s^{-2}

Formula / Method: Power, $P = \frac{\text{Work done}}{\text{time}} = \frac{mgh}{t}$

Substitution:

$$P = \frac{50 \times 9.8 \times 10}{20}$$
$$= \frac{4900}{20}$$
$$= 245 \text{ W}$$

Answer: $P = 245$ W

NUMERICAL PRACTICE — SET 3

N13 An elevator together with its load has a mass of 700 kg and descends with a constant speed of 0.5 m s^{-1}. Find the magnitude of the power associated with its weight. Also express it in horsepower (1 hp = 746 W).

Given: $m = 700$ kg, $v = 0.5$ m s^{-1}, $g = 10$ m s^{-2}, 1 hp = 746 W

Formula/Method: Power associated with weight: $P = mgv$

Substitution:
$$P = (700\text{ kg})(10\text{ m s}^{-2})(0.5\text{ m s}^{-1}) = 3500\text{ W}$$
$$P\text{ (in hp)} = \frac{3500}{746} = 4.69\text{ hp}$$

Note: Direction/sign depends on motor operation; magnitude is asked.

Answer: $P = 3500$ W = 4.69 hp (magnitude)

N14 A household consumes 250 electrical units of energy. Express this energy in joules.

Given: Electrical energy = 250 units, 1 unit = 1 kWh = 3.6×10^6 J

Formula/Method: E = (No. of units) × (3.6×10^6 J)

Substitution:
$$E = 250 \times 3.6 \times 10^6\text{ J} = 9 \times 10^8\text{ J}$$

Answer: $E = 9 \times 10^8$ J

N15 A heater of power 1500 W is used for 10 h. Find the energy consumed in joules and in kilowatt-hour.

Given: $P = 1500$ W, $t = 10$ h ($= 10 \times 3600\text{ s} = 3.6 \times 10^4$ s)

Formula/Method: $E = Pt$

Substitution:
$$E = (1500\text{ W})(3.6 \times 10^4\text{ s}) = 5.4 \times 10^7\text{ J} = 54 \times 10^6\text{ J}$$
In kWh: E = (P in kW) × (t in h) = (1.5 kW) × (10 h) = 15 kWh

Answer: $E = 54 \times 10^6$ J = 15 kWh

N16 Water of mass 6000 kg per hour falls from a height of 60 m. Taking g = 10 m s^{-2}, find the energy released per hour and the power.

Given: $m = 6000$ kg (per hour), $h = 60$ m, $g = 10$ m s^{-2}

Formula/Method: Energy released in 1 h: $E = mgh$
Power: $P = \frac{E}{t}$, $t = 1\text{ h} = 3600\text{ s}$

Substitution:
$$E = (6000\text{ kg})(10\text{ m s}^{-2})(60\text{ m}) = 3.6 \times 10^6\text{ J (per hour)}$$
$$P = \frac{3.6 \times 10^6\text{ J}}{3600\text{ s}} = 1000\text{ W}$$

Answer: $E = 3.6 \times 10^6$ J per hour, $P = 1000$ W

N17 A lamp uses 1000 J of energy in 10 s. Find its power.

Given: $E = 1000$ J, $t = 10$ s

Formula/Method: $P = \frac{E}{t}$

Substitution:
$$P = \frac{1000\text{ J}}{10\text{ s}} = 100\text{ W}$$

Answer: P = 100 W

N18 A lift carries a load of 5000 kg through 12 floors, each of height 9 m, in 30 s. Taking g = 10 m s^{-2}, find the power of the lift.

Given: $m = 5000$ kg, $n = 12$, height per floor = 9 m, $t = 30$ s, $g = 10$ m s^{-2}

Formula/Method: Total height: $h = n \times$ (height per floor)
Power: $P = \frac{mgh}{t}$

Substitution:
$$h = 12 \times 9\text{ m} = 108\text{ m}$$
$$P = \frac{(5000\text{ kg})(10\text{ m s}^{-2})(108\text{ m})}{30\text{ s}} = 1.8 \times 10^5\text{ W} = 180\text{ kW}$$

Answer: P = 1.8×10^5 W = 180 kW

NUMERICAL PRACTICE — SET 4

N19 An athlete of mass 55 kg accelerates from rest to 12 m s^{-1} in 4 s. Find the work done on the athlete and the average power.

Given: $m = 55$ kg, $u = 0$, $v = 12$ m s^{-1}, $t = 4$ s

Formula: Work, $W = \Delta K = \frac{1}{2} m(v^2 - u^2)$

Average power, $P_{avg} = \frac{W}{t}$

Substitution:

$W = \frac{1}{2} \times 55 \times (12^2 - 0^2)$

$= 27.5 \times 144 = 3960$ J

$P_{avg} = \frac{3960}{4} = 990$ W

Answer: **Work = 3960 J; Average power = 990 W**

N20 A girl holds a bucket with an upward force of 15 N, walks 10 m on a horizontal path and then climbs 20 m vertically. Find the work done by the upward supporting force.

Given: $F = 15$ N (upward), $s_h = 10$ m (horizontal), $s_v = 20$ m vertical)

Formula: Work, $W = Fs \cos\theta$

Substitution:

Horizontal: $\theta = 90° \Rightarrow W_h = 15 \times 10 \times \cos 90° = 0$ J

Vertical: $\theta = 0° \Rightarrow W_v = 15 \times 20 \times \cos 0° = 300$ J

Total work (by this force) $= W_h + W_v = 0 + 300 = 300$ J

Answer: **Horizontal work = 0 J; Vertical work = 300 J; Total work = 300 J**

Common misconception (corrected): Students often add 15 × (10 + 20). This is wrong because work depends on the component of force along the displacement; for the horizontal part the upward force is perpendicular to motion, so it does no work.

N21 A labourer of total mass 110 kg climbs a height of 15 m (take $g = 10$ m s^{-2}). He also carries an additional 10 kg block to the same height. Find the work done (i) on the labourer, (ii) on the block, and (iii) the total work.

Given: $m_L = 110$ kg, $m_b = 10$ kg, $h = 15$ m, $g = 10$ m s^{-2}

Formula: Work against gravity, $W = m\,g\,h$

Substitution:

(i) Labourer: $W_L = 110 \times 10 \times 15 = 16500$ J $= 16.5$ kJ

(ii) Block: $W_b = 10 \times 10 \times 15 = 1500$ J

(iii) Total: $W_{total} = (110 + 10) \times 10 \times 15 = 18000$ J

Answer: **$W_L = 16500$ J (16.5 kJ); $W_b = 1500$ J; Total work = 18000 J (18.0 kJ)**

N22 A trolley and a girl (together of mass 40 kg) move at 4 m s^{-1} and are brought to rest. Find (i) their initial kinetic energy and (ii) the work done on the trolley–girl system.

Given: $m = 40$ kg, $u = 4$ m s^{-1}, $v = 0$

Formula: $K = \frac{1}{2} m v^2$, $W = \Delta K = K_f - K_i$

Substitution:

(i) $K_i = \frac{1}{2} \times 40 \times 4^2 = 20 \times 16 = 320$ J

(ii) $W = 0 - 320 = -320$ J

Answer: **Initial KE = 320 J; Work on the system = −320 J**

Note: The work done by the girl on the trolley depends on the actual contact force she exerts (e.g., a backward push) and the displacement during stopping. If she is merely riding and no separate applied force is considered, we take the work on the trolley–girl system as −320 J (done by external retarding force such as friction).

N23 A constant frictional force of 5 N acts opposite to the motion along a route consisting of a 1.5 km straight path, one complete circular path of radius 100 m, and a 2.0 km straight path. Find the work done by friction.

Given: $F_f = 5$ N (opposing), $d_1 = 1.5$ km $= 1500$ m, $r = 100$ m, $d_3 = 2.0$ km $= 2000$ m

Formula: Total distance, $d = d_1 + 2\pi r + d_3$

Work by friction, $W_f = -F_f d$

Substitution:

$d = 1500 + 2\pi(100) + 2000$

$= 1500 + 200\pi + 2000$

$\approx 1500 + 628.3 + 2000$

≈ 4128 m

$W_f = -5 \times 4128 \approx -2.064 \times 10^4$ J

Answer: **Work by friction $\approx -2.064 \times 10^4$ J**

Note: Work done by friction depends on the actual path length (distance covered), not on the net displacement between the initial and final positions.

N24 A scooter with its rider has a mass of 150 kg and slows down from 54 km h^{-1} to 36 km h^{-1}. Find the change in kinetic energy.

Given: $m = 150$ kg, $u = 54$ km h^{-1} $= 15$ m s^{-1}, $v = 36$ km h^{-1} $= 10$ m s^{-1}

Formula: $\Delta K = \frac{1}{2} m (v^2 - u^2)$

Substitution:

$\Delta K = \frac{1}{2} \times 150 \times (10^2 - 15^2)$

$= 75 \times (100 - 225)$

$= 75 \times (-125)$

$= -9375$ J

Answer: **Change in KE = −9375 J**

NUMERICAL PRACTICE — SET 5

N25 Four men lift a 250 kg box through a height of 1 m. Take $g = 10\ \text{m s}^{-2}$. Find (i) the total work done, (ii) the work done by each man (equal share), and (iii) the work done in holding the box at that height.

Given: $m = 250$ kg, $h = 1$ m, $g = 10\ \text{m s}^{-2}$, no. of men = 4

Formula: $W = mgh$

Substitution: $W = 250 \times 10 \times 1 = 2500$ J

Answer:
(i) **Total work = 2500 J**
(ii) **Work by each man** $= \frac{2500}{4} = 625$ **J**
(iii) **Work in holding at height = 0 J** (no displacement of the box)

N26 A light and a heavy object have the same momentum p. Which object has greater kinetic energy? What is the ratio of their kinetic energies?

Given: Momentum of both objects: p (same)
m_1 (lighter), m_2 (heavier), $m_1 < m_2$

Formula: $K = \frac{p^2}{2m}$

Substitution: For the two objects:

$$K_1 = \frac{p^2}{2m_1}, \quad K_2 = \frac{p^2}{2m_2}$$

$$\Rightarrow \frac{K_1}{K_2} = \frac{p^2/2m_1}{p^2/2m_2} = \frac{m_2}{m_1}$$

Answer: **The lighter object has greater kinetic energy.** $K_1 : K_2 = m_2 : m_1$
(i.e., KE is inversely proportional to mass).

N27 A body of mass 0.25 kg has a kinetic energy of 30 J. Find its speed.

Given: $m = 0.25$ kg, $K = 30$ J

Formula: $K = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2K}{m}}$

Substitution:

$$v = \sqrt{\frac{2 \times 30}{0.25}} = \sqrt{\frac{60}{0.25}}$$

$$= \sqrt{240} \approx 15.49\ \text{m s}^{-1}$$

Answer: **Speed, $v \approx 15.49\ \text{m s}^{-1}$.**

N28 The speed of a body of mass M and speed v is reduced to $v/2$. Find the work done on the body.

Given: Mass = M, initial speed = v, final speed = $\frac{v}{2}$

Formula: Work done $= \Delta K = K_f - K_i$

$$= \frac{1}{2}Mv_f^2 - \frac{1}{2}Mv_i^2$$

Substitution:

$$W = \frac{1}{2}M\left(\frac{v}{2}\right)^2 - \frac{1}{2}Mv^2$$

$$= \frac{1}{2}M\left(\frac{v^2}{4} - v^2\right) = -\frac{3}{8}Mv^2$$

Answer: **Work done on the body, $W = -\frac{3}{8}Mv^2$.**

N29 A body of mass 5 kg is thrown vertically upward with a speed of 50 m s^{-2}. Find its speed, height and potential energy after 5 s. (Take $g = 10\ \text{m s}^{-2}$.)

Given: $m = 5$ kg, $u = 50\ \text{m s}^{-1}$, $t = 5$ s, $g = 10\ \text{m s}^{-2}$

Formula: $v = u - gt$, $h = ut - \frac{1}{2}gt^2$, $PE = mgh$

Substitution:

$$v = 50 - 10 \times 5 = 0\ \text{m s}^{-1}$$

$$h = 50 \times 5 - \frac{1}{2} \times 10 \times 5^2$$

$$= 250 - 125 = 125\ \text{m}$$

$$\text{PE} = 5 \times 10 \times 125 = 6250\ \text{J}$$

Answer: **Speed after 5 s = 0 m s^{-1}, Height = 125 m, Potential energy = 6250 J.**

N30 A person can jump to a height of 0.4 m on Earth. On a planet where his weight is half of that on Earth, what height can he jump to if he takes off with the same energy?

Given: Height on Earth, $h_1 = 0.4$ m,
Weight on planet is half $\Rightarrow g' = \frac{g}{2}$
(Same takeoff energy, i.e., same KE)

Formula: At highes point, KE = PE $\Rightarrow K = mgh$
Since K is same: $mgh_1 = mg'h_2$

Substitution:

$$mg \times 0.4 = m\left(\frac{g}{2}\right) \times h_2$$

$$\Rightarrow h_2 = 2 \times 0.4 = 0.8\ \text{m}$$

Answer: **The person can jump to a height of 0.8 m on that planet.**

NUMERICAL PRACTICE — SET 6

N31

A 5 kg bag is raised through 4 m with a total work of 300 J. If $g = 10\ \text{m s}^{-2}$, find the upward acceleration.

Data: $m = 5\ \text{kg},\ h = 4\ \text{m},\ W = 300\ \text{J},\ g = 10\ \text{m s}^{-2}$

Formula: $W = m(g + a)h$

Substitution:

$$300 = 5(10 + a) \times 4$$
$$300 = 20(10 + a)$$
$$10 + a = \frac{300}{20} = 15$$
$$a = 15 - 10 = 5\ \text{m s}^{-2}$$

Answer: $a = 5\ \text{m s}^{-2}$

N32

A 40 kg object is raised to a height of 5 m ($g = 10\ \text{m s}^{-2}$) and then falls freely. Find its initial potential energy. What is its kinetic energy when it has fallen halfway (2.5 m)?

Data: $m = 40\ \text{kg},\ h = 5\ \text{m},\ g = 10\ \text{m s}^{-2}$

Formula: $PE = mgh$

Substitution:

Initial PE: $PE = 40 \times 10 \times 5 = 2000\ \text{J}$

At halfway (height = 2.5 m):

$PE_{\text{remaining}} = 40 \times 10 \times 2.5 = 1000\ \text{J}$

PE lost $= 2000 - 1000 = 1000\ \text{J}$

$\therefore\ KE = 1000\ \text{J}$

Answer: Initial PE = 2000 J; KE (at halfway) = 1000 J

N33

Person X runs at 8 m s^{-1} against a resisting force of 10 N. Person Y runs at 3 m s^{-1} against a resisting force of 20 N. Find the power of each and their ratio.

Data:

For X: $F_x = 10\ \text{N},\ v_x = 8\ \text{m s}^{-1}$

For Y: $F_y = 20\ \text{N},\ v_y = 3\ \text{m s}^{-1}$

Formula: $P = Fv$

Substitution:

$P_x = 10 \times 8 = 80\ \text{W}$

$P_y = 20 \times 3 = 60\ \text{W}$

Ratio: $P_x : P_y = 80 : 60 = 4 : 3$

Answer: $P_x = 80\ \text{W},\ P_y = 60\ \text{W}$; ratio = 4 : 3

N34

An object of mass m is at a height h. A second object has mass $3m$ and is at a height $2h$. Find the ratio of their potential energies and the ratio of the work done by gravity in bringing each to the ground.

Data:

Case 1: mass = m, height = h

Case 2: mass = $3m$, height = $2h$

Formula: $PE = mgh$; Work by gravity to ground, $W = mgh$

Substitution:

$PE_1 = mgh$

$PE_2 = (3m)g(2h) = 6mgh$

$\therefore\ PE_1 : PE_2 = mgh : 6mgh = 1 : 6$

$W_1 = mgh$

$W_2 = (3m)g(2h) = 6mgh$

$\therefore\ W_1 : W_2 = mgh : 6mgh = 1 : 6$

Answer: PE ratio = 1 : 6; work by gravity ratio = 1 : 6

N35

A 10 kg object falls from a height of 0.9 m ($g = 9.8\ \text{m s}^{-2}$). Find its total mechanical energy, its kinetic energy at halfway (0.45 m), and its kinetic energy just before hitting the ground.

Data: $m = 10\ \text{kg},\ h = 0.9\ \text{m},\ g = 9.8\ \text{m s}^{-2}$

Formula: $ME = PE = mgh$ (energy conserved)

KE at height $h' = mgh - mgh'$

Substitution:

Total mechanical energy: $ME = 10 \times 9.8 \times 0.9 = 88.2\ \text{J}$

At halfway ($h' = 0.45\ \text{m}$):

$KE = 10 \times 9.8 \times (0.9 - 0.45) = 10 \times 9.8 \times 0.45$

$= 44.1\ \text{J}$

Just before hitting ground ($h' = 0$):

$KE = 10 \times 9.8 \times 0.9 = 88.2\ \text{J}$

Answer: Total energy = 88.2 J; KE (at halfway) = 44.1 J; KE (at ground) = 88.2 J

N36

A 4 kg body hits the ground at 20 m s^{-1} and does not rebound. Find the kinetic energy at the impact and state into what forms it is mainly converted. The given height is 20 m; check its consistency with $g = 10\ \text{m s}^{-2}$.

Data: $m = 4\ \text{kg},\ v = 20\ \text{m s}^{-1},\ h = 20\ \text{m}$ (given), $g = 10\ \text{m s}^{-2}$

Formula: $KE = \frac{1}{2}mv^2$; using $v^2 = 2gh$ (for consistency check)

Substitution:

KE **(at impact):** $KE = \frac{1}{2} \times 4 \times (20)^2$

$= 2 \times 400 = 800\ \text{J}$

Consistency: $v^2 = 2gh = 2 \times 10 \times 20 = 400 \Rightarrow v = 20\ \text{m s}^{-1}$

(Hence, the given height 20 m is consistent with $g = 10\ \text{m s}^{-2}$.)

Answer: KE at impact = 800 J; converted mainly into heat, sound and deformation (of the body and ground). The given height 20 m is consistent with $g = 10\ \text{m s}^{-2}$.

NUMERICAL PRACTICE — SET 7

N37

A hammer of mass 1 kg falls through 3 m ($g = 10\ m\ s^{-2}$). Find the decrease in its potential energy and state the energy changes on impact. A woman (together with the hammer) of total weight 600 N climbs 2 m in 7 s. Find the useful power.

Data: (i) $m = 1$ kg, $h = 3$ m, $g = 10\ m\ s^{-2}$
(ii) Total weight, $W = 600$ N, height $= 2$ m, time, $t = 7$ s

Formula: (i) $\Delta PE = mgh$
(ii) $P = \frac{W}{t}$

Substitution: (i) $\Delta PE = 1 \times 10 \times 3 = 30$ J (decrease)
(ii) $P = \frac{600 \times 2}{7} = \frac{1200}{7} \approx 171.4$ W

Answer: Decrease in PE = 30 J; energy changes: PE → KE → heat and sound on impact; Useful power = 1200 7 ≈ 171.4 W.

N38

A cellphone of mass m is lifted through 1 m in 1 s and then through 2 m in 2 s. Find the power in each case and state whether the power is the same.

Data: Mass $= m$, $g = 10\ m\ s^{-2}$
(i) $h_1 = 1$ m, $t_1 = 1$ s
(ii) $h_2 = 2$ m, $t_2 = 2$ s

Formula: $P = \frac{mgh}{t}$

Substitution: (i) $P_1 = \frac{m \times 10 \times 1}{1} = 10m\ \text{W} = mg$
(ii) $P_2 = \frac{m \times 10 \times 2}{2} = 10m\ \text{W} = mg$

Answer: $P_1 = mg$, $P_2 = mg$; hence, the power is the same in both cases.

N39

A bucket of mass 3 kg is drawn from a 10 m deep well in 25 s ($g = 10\ m\ s^{-2}$). Find the work done and the power.

Data: $m = 3$ kg, $h = 10$ m, $t = 25$ s, $g = 10\ m\ s^{-2}$

Formula: $W = mgh$, $P = \frac{W}{t}$

Substitution: $W = 3 \times 10 \times 10 = 300$ J
$P = \frac{300}{25} = 12$ W

Answer: Work done = 300 J; Power = 12 W.

N40

A boy of mass 50 kg climbs 45 steps, each of height 15 cm, in 9 s ($g = 10\ m\ s^{-2}$). Find the work done and the power.

Data: $m = 50$ kg, number of steps $= 45$, height of each step $= 15$ cm $= 0.15$ m, $t = 9$ s, $g = 10\ m\ s^{-2}$

Formula: $h = n \times$ (step height), $W = mgh$, $P = \frac{W}{t}$

Substitution: $h = 45 \times 0.15 = 6.75$ m
$W = 50 \times 10 \times 6.75 = 3375$ J
$P = \frac{3375}{9} = 375$ W

Answer: Work done = 3375 J; Power = 375 W.

N41

A machine gun fires 30 bullets, each of mass 0.10 kg, at a speed of 500 m s^{-1} in 10 s. Find the total kinetic energy of the bullets and the average power of the gun.

Data: Number of bullets, $n = 30$, mass of each bullet, $m = 0.10$ kg, speed, $v = 500\ m\ s^{-1}$, time, $t = 10$ s

Formula: KE (one bullet) $= \frac{1}{2}mv^2$,
Total KE $= n \times \frac{1}{2}mv^2$,
$P = \frac{\text{Total KE}}{t}$

Substitution: Total KE $= 30 \times \frac{1}{2} \times 0.10 \times (500)^2$
$= 30 \times 0.05 \times 250000$
$= 375000$ J
$P = \frac{375000}{10} = 37500$ W $= 37.5$ kW

Answer: Total kinetic energy = 375000 J; Average power = 37500 W = 37.5 kW.

N42

A pump of power 2 kW raises water through a height of 10 m in 1 minute ($g = 10\ m\ s^{-2}$). Find the mass of water raised per minute.

Data: $P = 2$ kW $= 2000$ W, $h = 10$ m, $t = 1$ min $= 60$ s, $g = 10\ m\ s^{-2}$

Formula: $P = \frac{mgh}{t} \Rightarrow m = \frac{Pt}{gh}$

Substitution: $m = \frac{2000 \times 60}{10 \times 10}$
$= \frac{120000}{100}$
$= 1200$ kg

Answer: Mass of water raised = 1200 kg per minute.

NUMERICAL PRACTICE — SET 8

N43

A car engine develops a power of 500 W. If the car moves with a constant speed of 20 m s^{-1}, find the driving force.

Method: Use the relation between power, force and velocity for motion at constant speed.

Equations: $P = Fv \Rightarrow F = \dfrac{P}{v}$

Substitution: $F = \dfrac{500\ \text{W}}{20\ \text{m s}^{-1}} = 25\ \text{N}$

Answer: $F = 25\ \text{N}$ (in the direction of motion)

N44

A body is lifted vertically at a constant speed of 1 m s^{-1} by a power of 1100 W. Find the mass of the body. Take $g = 10\ \text{m s}^{-2}$.

Method: At constant speed, the lifting force equals the weight ($F = mg$). Use $P = Fv = mgv$.

Equations: $P = mgv \Rightarrow m = \dfrac{P}{gv}$

Substitution: $m = \dfrac{1100\ \text{W}}{10\ \text{m s}^{-2} \times 1\ \text{m s}^{-1}} = 110\ \text{kg}$

Answer: $m = 110\ \text{kg}$

N45

A butterfly of mass 1 g rises vertically with a speed of 0.5 m s^{-1}. Find the power developed by the butterfly. Take $g = 10\ \text{m s}^{-2}$.

Method: The power required to rise at constant speed is the rate of gain of gravitational potential energy: $P = mgv$.

Equations: $P = mgv$

Substitution: $m = 1\ g = 1 \times 10^{-3}\ \text{kg}$

$$P = (1 \times 10^{-3}\ \text{kg}) \times (10\ \text{m s}^{-2}) \times (0.5\ \text{m s}^{-1})$$
$$= 0.005\ \text{W}$$

Answer: $P = 0.005\ \text{W} = 5.0 \times 10^{-3}\ \text{W}$

N46

A bus of mass 4000 kg moving with a speed of 80 m s^{-1} is brought to rest by a constant braking force of 30000 N. Find (i) the stopping distance and (ii) the work done by the brakes.

Method: (i) Use work–energy theorem: the work done by the brakes equals the loss of kinetic energy, $W = -\text{KE}$. The stopping distance is $s = \dfrac{KE}{F}$.

Equations: $KE = \dfrac{1}{2}mv^2;\quad s = \dfrac{KE}{F};\quad W = -KE$

Substitution: $KE = \dfrac{1}{2} \times 4000\ \text{kg} \times (80\ \text{m s}^{-1})^2$

$$= 0.5 \times 4000 \times 6400 = 1.28 \times 10^7\ \text{J}$$
$$s = \frac{1.28 \times 10^7\ \text{J}}{30000\ \text{N}} = 426.666\ldots\ \text{m} \approx 426.7\ \text{m}$$
$$W = -1.28 \times 10^7\ \text{J}$$

Answer:
(i) Stopping distance, $s \approx 426.7\ \text{m}$
(ii) Work done by the brakes, $W = -1.28 \times 10^7\ \text{J}$

N47

A man holds a 5 kg suitcase stationary in his hand for 2 min. Calculate the mechanical work done on the suitcase.

Method: Mechanical work is $W = F \cdot s = Fs\cos\theta$. As the suitcase remains stationary, its displacement $s = 0$.

Equations: $W = Fs\cos\theta$

Substitution: $s = 0 \Rightarrow W = F \times 0 \times \cos\theta = 0$

Answer: $W = 0\ \text{J}$

Note: The mechanical work on the suitcase is zero, though the man's muscles consume energy (chemical energy) to maintain the hold.

N48

A vehicle of mass 1000 kg moving with a speed of 60 m s^{-1} is brought to rest uniformly in 9 m. Find (i) its acceleration, (ii) the retarding force, (iii) the time taken to stop and (iv) the work done by the retarding force.

Method: Use $v^2 = u^2 + 2as$, $F = ma$, $v = u + at$ and $W = -KE$ (loss of kinetic energy).

Equations: $v^2 = u^2 + 2as;\ F = ma;\ v = u + at;\ W = -\dfrac{1}{2}mu^2$

Substitution: Given: $u = 60\ \text{m s}^{-1}$, $v = 0$, $s = 9\ \text{m}$, $m = 1000\ \text{kg}$

(i) $0 = (60)^2 + 2a(9) \Rightarrow a = -\dfrac{60^2}{2 \times 9} = -200\ \text{m s}^{-2}$

(ii) $F = ma = 1000 \times (-200) = -2.0 \times 10^5\ \text{N}$

(iii) $t = \dfrac{v - u}{a} = \dfrac{0 - 60}{-200} = 0.30\ \text{s}$

(iv) $W = -\dfrac{1}{2} \times 1000 \times 60^2 = -1.8 \times 10^6\ \text{J}$

Answer:
(i) $a = -200\ \text{m s}^{-2}$
(ii) $F = -2.0 \times 10^5\ \text{N}$
(iii) $t = 0.30\ \text{s}$
(iv) $W = -1.8 \times 10^6\ \text{J}$

NUMERICAL PRACTICE — SET 9

N49

A ball of mass 2 kg is thrown upward with speed 20 m s^{-1}. It reaches a height of 19.4 m. Take $g = 10$ m s^{-2}. Find (i) initial KE, (ii) PE at top, (iii) work done by air resistance.

Given: $m = 2$ kg, $u = 20$ m s^{-1}, $h = 19.4$ m, $g = 10$ m s^{-2}

Method: Use $KE = \frac{1}{2}mv^2$ and $PE = mgh$. Work by air resistance = final mechanical energy − initial.

Eqns.: $KE = \frac{1}{2}mv^2$, $PE = mgh$, $W_{air} = E_f - E_i$

Calculation:

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

(ii) $PE_{top} = 2 \times 10 \times 19.4 = 388$ J

(iii) $W_{air} = E_f - E_i = 388 - 400 = -12$ J

Answer: $KE_i = 400$ J, $PE_{top} = 388$ J, $W_{air} = -12$ J.

N50

The acceleration due to gravity on the Moon is $\frac{1}{6}$ of that on the Earth. A body, thrown vertically upward with the same speed, reaches a height of 8 m on the Earth. To what height will it rise on the Moon?

Given: $g_{Moon} = \frac{1}{6} g_{Earth}$, $h_E = 8$ m, same launch speed (u)

Method: Use $h = \frac{u^2}{2g}$. For same u, height $\propto \frac{1}{g}$.

Eqns.: $h = \frac{u^2}{2g}$, $h_M = \frac{g_E}{g_M} h_E$

Calculation: $h_M = \frac{g_E}{g_E/6} \times 8 = 6 \times 8 = 48$ m

Answer: Height on the Moon = 48 m.

N51

A car of mass 1000 kg moves with a speed of 35 m s^{-1}. The driver reacts for 1 s (A to B) and then the car is brought to rest by 3 s (B to C). Find (i) KE at A, (ii) work done by brakes from B to C, and (iii) the form in which this KE appears.

Given: $m = 1000$ kg, $v = 35$ m s^{-1}; reaction time = 1 s; car stops by $t = 3$ s.

Method: Compute initial KE; from A to B speed is constant, so no work is done. From B to C, final KE = 0, so work by brakes = ΔKE = 0 − KE. The KE is converted mainly into heat and sound.

Eqns.: $KE = \frac{1}{2}mv^2$, $W_{B-C} = KE_f - KE_i$

Calculation:

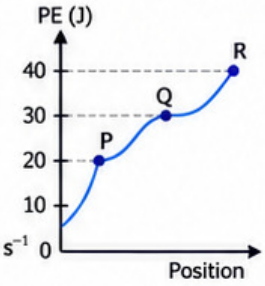
(i) $KE_A = \frac{1}{2} \times 1000 \times (35)^2 = 612500$ J

(ii) $W_{B-C} = 0 - 612500 = -612500$ J

Answer: KE at A = 612500 J; work by brakes (B to C) = −612500 J; KE appears mainly as heat (due to friction in brakes) and sound.

N52

The potential–energy (PE) of a 0.5 kg ball at different positions is shown below. The total mechanical energy of the ball is 30 J. Find (i) KE and speed at P, (ii) speed at Q, (iii) whether the ball can reach R.



Given: $m = 0.5$ kg, $E_{ttoal} = 30$ J.

Method: Use $E_{ttoal} = KE + PE$ and $v = \sqrt{\frac{2KE}{m}}$.

Eqns.: $KE = E_{ttoal} - PE$, $v = \sqrt{\frac{2KE}{m}}$

Calculation:

(i) At P: PE = 20 J

KE = 30 − 20 = 10 J

$v = \sqrt{\frac{2 \times 10}{0.5}} = \sqrt{40} \approx 6.32$ m s^{-1}

(ii) At Q: PE = 30 J

KE = 30 − 30 = 0 ⇒ $v = 0$

(iii) At R: PE = 40 J > 30 J

⇒ Not reachable.

Answer: (i) $KE_P = 10$ J, $v_P \approx 6.32$ m s^{-1}; (ii) $v_Q = 0$; (iii) R cannot be reached (PE at $R = 40$ J > $E_{ttoal} = 30$ J).

N53

A crane raises a certain mass to the 10th floor in time t and to the 20th floor in time $2t$. Compare (i) the potential energy gained in the two cases, and (ii) the power in the two cases.

Given: Same mass m; height to 10th floor = h in time t; height to 20th floor = $2h$ in time $2t$.

Method: Use $PE = mgh$. Power $P = \frac{Work}{time} = \frac{\Delta PE}{time}$.

Eqns.: $E_1 = mgh$, $E_2 = mg(2h)$, $P_1 = \frac{E_1}{t}$, $P_2 = \frac{E_2}{2t}$

Calculation:

(i) $E_2 = mg(2h) = 2mgh = 2E_1$ (energy doubles).

(ii) $P_1 = \frac{mgh}{t}$, $P_2 = \frac{2mgh}{2t} = \frac{mgh}{t} = P_1$.

Answer: (i) Potential energy doubles ($E_2 = 2E_1$). (ii) Power remains the same ($P_2 = P_1$).

N54

A flag of mass m is raised to a height h. (i) Find the work done in raising it, (ii) show that it is independent of the speed of raising, and (iii) if the speed is doubled, what happens to the time and the power?

Given: Mass m, height h; let raising speed be v (then $v' = 2v$).

Method: Work against gravity gives gain in PE, which does not depend on speed. Use $t = h/v$ and $P = W/t$.

Eqns.: $W = mgh$, $t = \frac{h}{v}$, $P = \frac{W}{t} = \frac{mgh}{t}$

Calculation:

(i) $W = mgh$.

(ii) W depends only on m, g and h (independent of speed).

(iii) If $v' = 2v$, then $t' = \frac{h}{2v} = \frac{t}{2}$,

$P' = \frac{mgh}{t/2} = \frac{mgh}{t} = 2P$.

Answer: (i) Work done = mgh. (ii) It is independent of speed. (iii) On doubling speed: time halves ($t' = t/2$) and power doubles ($P' = 2P$).

ADDITIONAL PRACTICE BANK — SET 1

AP1 A boy pushes a book with a force of 40 N through 25 cm. Find the work done.

Given:
$F = 40$ N, $s = 25$ cm $= 0.25$ m

Working:
Work done, $W = F \times s$
$= 40 \times 0.25$
$= 10$ J

Answer: $W = 10$ J.

AP2 A ball of mass 1 kg rises vertically through 4 m. Take $g = 10\ \text{m s}^{-2}$. Find (i) work done by gravity and (ii) work done against gravity.

Given:
$m = 1$ kg, $h = 4$ m, $g = 10\ \text{m s}^{-2}$

Working:
(i) Work done by gravity:
$W_g = -mgh = -1 \times 10 \times 4$
$= -40$ J

(ii) Work done against gravity:
$W_{\text{against}} = +mgh = +1 \times 10 \times 4$
$= +40$ J

Answer: $W_g = -40$ J; $W_{\text{against}} = +40$ J.

AP3 A labourer carries n bricks, each of mass m, to a roof of height h. Find the work done.

Given:
Number of bricks $= n$, mass of each brick $= m$, height $= h$, acceleration due to gravity $= g$

Working:
Total mass lifted $= nm$
Work done, $W = (nm)gh$
$= nmgh$

Answer: $W = nmgh$.

AP4 A train moves 1 km at constant speed against a resistance of 5×10^5 N. Find (i) work done by the engine and (ii) work done by friction.

Given: $s = 1\ \text{km} = 10^3$ m, resistance $F = 5 \times 10^5$ N

Working:
(i) At constant speed, engine force = resistance.
Work done by engine:
$W_{\text{engine}} = F \times s = (5 \times 10^5) \times (10^3)$
$= 5 \times 10^8$ J.

(ii) Work done by friction (opposite to motion):
$W_{\text{friction}} = -F \times s = -(5 \times 10^5) \times (10^3)$
$= -5 \times 10^8$ J.

Answer: $W_{\text{engine}} = +5 \times 10^8$ J;
$W_{\text{friction}} = -5 \times 10^8$ J.

AP5 A man of mass 70 kg carries a load of 10 kg up a vertical height of 100 m. Take $g = 10\ \text{m s}^{-2}$. Find (i) total work done on the man + load, (ii) work done on the load alone. State the interpretation of the result.

Given: $m_{\text{man}} = 70$ kg, $m_{\text{load}} = 10$ kg, $h = 100$ m, $g = 10\ \text{m s}^{-2}$

Working:
(i) Total mass $= 70 + 10 = 80$ kg
Total work, $W_{\text{total}} = (80)gh = 80 \times 10 \times 100$
$= 80000$ J.

(ii) Work on load alone:
$W_{\text{load}} = (10)gh = 10 \times 10 \times 100$
$= 10000$ J.

Interpretation: Of the total 80000 J, 10000 J increases the potential energy of the load. The remaining 70000 J increases the potential energy of the man (does not raise the load).

Answer: (i) 80000 J; (ii) 10000 J.

AP6 A man of mass 60 kg needs a kinetic energy of 750 J. Find his speed.

Given:
$m = 60$ kg, $K = 750$ J

Working:
$$K = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2 \times 750}{60}}$$
$$= \sqrt{25} = 5\ \text{m s}^{-1}.$$

Answer: $v = 5\ \text{m s}^{-1}$.

ADDITIONAL PRACTICE BANK — SET 2

AP7

A body has a kinetic energy of 5 J and moves with a speed of 2 m s^{-1}. Find its mass.

Given: $K = 5$ J, $v = 2$ m s^{-1}

Working:

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

$$5 = \frac{1}{2} \times m \times (2)^2$$

$$5 = 2m$$

$$m = \frac{5}{2} = 2.5 \text{ kg}$$

Answer: Mass = 2.5 kg.

AP8

A football of mass 0.25 kg is kicked from rest to a speed of 10 m s^{-1}. Find the work done on the football.

Given: $m = 0.25$ kg, $u = 0$, $v = 10$ m s^{-1}

Working:

Work done = change in kinetic energy

$$W = \Delta K = \frac{1}{2}m(v^2 - u^2)$$

$$= \frac{1}{2} \times 0.25 \times (10^2 - 0^2)$$

$$= 0.125 \times 100$$

$$= 12.5 \text{ J}$$

Answer: Work done = 12.5 J.

AP9

A body of mass 5 kg, initially at rest, is acted upon by a force of 20 N for 10 s. Find its acceleration, final speed and kinetic energy.

Given: $m = 5$ kg, $u = 0$, $F = 20$ N, $t = 10$ s

Working:

(i) Acceleration: $a = \frac{F}{m} = \frac{20}{5} = 4 \text{ m s}^{-2}$

(ii) Final speed: $v = u + at = 0 + 4 \times 10$

$= 40 \text{ m s}^{-1}$

(iii) Kinetic energy: $K = \frac{1}{2}mv^2$

$$= \frac{1}{2} \times 5 \times (40)^2$$

$$= 2.5 \times 1600$$

$$= 4000 \text{ J}$$

Answer: $a = 4$ m s^{-2}, $v = 40$ m s^{-1}, $K = 4000$ J.

AP10

A bullet of mass 0.02 kg slows down from 500 m s^{-1} to 400 m s^{-1} after passing through a tree. Find (i) the change in kinetic energy of the bullet and (ii) the work done by the bullet on the tree. Also, clearly distinguish between the work on the bullet and the work by the bullet.

Given: $m = 0.02$ kg, $u = 500$ m s^{-1}, $v = 400$ m s^{-1}

Working:

Initial kinetic energy: $K_i = \frac{1}{2}mu^2$

$$= \frac{1}{2} \times 0.02 \times (500)^2 = 2500 \text{ J}$$

Final kinetic energy: $K_f = \frac{1}{2}mv^2$

$$= \frac{1}{2} \times 0.02 \times (400)^2 = 1600 \text{ J}$$

Change in kinetic energy:

$$\Delta K = K_f - K_i = 1600 - 2500 = -900 \text{ J}$$

Distinguishing the two works:

- **Work on the bullet:** Work done by the tree on the bullet, which reduces its kinetic energy. $W_{\text{on bullet}} = \Delta K = -900$ J.
- **Work by the bullet:** Work done by the bullet on the tree, equal in magnitude and opposite in sign. $W_{\text{by bullet (on tree)}} \approx +900$ J.

Answer: ΔK (bullet) = −900 J;
Work on bullet = −900 J;
Work by bullet on tree ≈ +900 J.

AP11

A body of mass 4 kg is raised from a height of 5 m to 10 m. If $g = 10$ m s^{-2}, find the increase in its potential energy.

Given: $m = 4$ kg, $h_1 = 5$ m, $h_2 = 10$ m, $g = 10$ m s^{-2}

Working: Increase in potential energy,

$$\Delta U = mg(h_2 - h_1)$$

$$= 4 \times 10 \times (10 - 5)$$

$$= 4 \times 10 \times 5$$

$$= 200 \text{ J}$$

Answer: Increase in potential energy = 200 J.

AP12

A 1 kg object gains 1 J of potential energy. If $g = 10$ m s^{-2}, through what height has it been raised?

Given: $m = 1$ kg, $\Delta U = 1$ J, $g = 10$ m s^{-2}

Working: $\Delta U = mgh \Rightarrow h = \frac{\Delta U}{mg}$

$$= \frac{1}{1 \times 10} = 0.1 \text{ m}$$

Answer: Height = 0.1 m.

ADDITIONAL PRACTICE BANK — SET 3

AP13 A ball of mass 5 kg is thrown vertically upward with a speed of 10 m s^{-1}. Take $g = 10$ m s^{-2}. Find (i) the highest potential energy attained and (ii) the maximum height.

Solution:

Given: $m = 5$ kg, $u = 10$ m s^{-1}, $g = 10$ m s^{-2}

(i) At the highest point, initial KE converts to PE.

$$PE_{max} = KE_{initial} = \frac{1}{2}mu^2$$
$$= \frac{1}{2} \times 5 \times (10)^2 = \frac{1}{2} \times 5 \times 100 = 250 \text{ J}$$

(ii) At the highest point, $v = 0$. Using $v^2 = u^2 - 2gh$,

$$0 = (10)^2 - 2 \times 10 \times h \quad \Rightarrow \quad h = \frac{100}{20} = 5 \text{ m}$$

Answer: Highest PE = 250 J; Maximum height = 5 m.

AP14 A ball of mass 5 kg is dropped from a height of 10 m. Take $g = 10$ m s^{-2}. Find (i) its initial potential energy, (ii) its kinetic energy just before reaching the ground, and (iii) its speed on impact.

Solution:

Given: $m = 5$ kg, $h = 10$ m, $g = 10$ m s^{-2}

(i) Initial PE: $PE = mgh = 5 \times 10 \times 10 = 500$ J

(ii) Just before reaching the ground, PE is converted to KE (neglecting air resistance):

$KE = 500$ J

(iii) $v = \sqrt{2gh} = \sqrt{2 \times 10 \times 10} = \sqrt{200}$
≈ 14.14 m s^{-1}

Answer: Initial PE = 500 J; KE (before ground) = 500 J; Impact speed = $\sqrt{200} \approx 14.14$ m s^{-1}.

AP15 A body is thrown vertically upward with a kinetic energy of 10 J and reaches a height of 5 m. Take $g = 10$ m s^{-2}. Find the mass of the body.

Solution:

Given: KE = 10 J, $h = 5$ m, $g = 10$ m s^{-2}

At the highest point, KE converts to PE:

$$10 = mgh = m \times 10 \times 5$$
$$m = \frac{10}{50} = 0.2 \text{ kg}$$

Answer: Mass of the body = 0.2 kg.

AP16 A rocket of mass 3×10^6 kg is moving with a speed of 1 km s^{-1} at an altitude of 25 km. Take $g = 10$ m s^{-2}. Find (i) its potential energy and (ii) its kinetic energy.

Solution:

Given: $m = 3 \times 10^6$ kg, $v = 1$ km $s^{-1} = 1000$ m s^{-1}, $h = 25$ km $= 25 \times 10^3$ m, $g = 10$ m s^{-2}

(i) $PE = mgh$
$= 3 \times 10^6 \times 10 \times 25 \times 10^3$
$= 750 \times 10^9 = 7.5 \times 10^{11}$ J

(ii) $KE = \frac{1}{2}mv^2$
$= \frac{1}{2} \times 3 \times 10^6 \times (1000)^2$
$= 1.5 \times 10^6 \times 10^6 = 1.5 \times 10^{12}$ J

Answer: PE = 7.5×10^{11} J; KE = 1.5×10^{12} J.

AP17 A boy of mass 40 kg climbs 50 steps, each of height 10 cm, in 5 s. Take $g = 10$ m s^{-2}. Find (i) the total vertical height climbed, (ii) the work done against gravity, and (iii) the power.

Solution:

Given: $m = 40$ kg, steps = 50, height per step = 10 cm = 0.10 m, $t = 5$ s, $g = 10$ m s^{-2}

(i) Total height: $h = 50 \times 0.10 = 5.0$ m

(ii) Work against gravity: $W = mgh$
$= 40 \times 10 \times 5 = 2000$ J

(iii) Power: $P = \frac{W}{t} = \frac{2000}{5} = 400$ W

Answer: $h = 5$ m; Work = 2000 J; Power = 400 W.

AP18 An engine lifts 90 metric tonnes of coal per hour through a height of 200 m. Take $g = 10$ m s^{-2}. Find the power of the engine.

Solution:

Given: mass per hour = 90 metric tonnes
$= 90 \times 10^3$ kg $= 9.0 \times 10^4$ kg

$h = 200$ m, $g = 10$ m s^{-2}, time = 1 h = 3600 s

Work done in 1 h: $W = mgh$
$= 9.0 \times 10^4 \times 10 \times 200$
$= 1.8 \times 10^8$ J

Power: $P = \frac{W}{t} = \frac{1.8 \times 10^8}{3600} = 5.0 \times 10^4$ W $= 50$ kW

Answer: Power of the engine = 50 kW.

ADDITIONAL PRACTICE BANK — SET 4

AP19 How much time is required to perform a work of 500 J at a rate of 10 W?

Solution:

Given: Work, $W = 500$ J; Power, $P = 10$ W

Using, $P = \frac{W}{t} \Rightarrow t = \frac{W}{P}$

$$t = \frac{500\ \text{J}}{10\ \text{W}} = 50\ \text{s}$$

Answer: $t = 50$ s.

AP20 A 100 W bulb is used for 5 h. Find the electrical energy consumed in kWh, in units and in joules.

Solution:

Given: Power, $P = 100$ W; Time, $t = 5$ h

Energy, $E = P \times t = 100\ \text{W} \times 5\ \text{h} = 500\ \text{Wh}$
$= 0.5\ \text{kWh}$

1 kWh = 1 unit $\Rightarrow$ $E = 0.5$ unit

In joules: $1\ \text{kWh} = 3.6 \times 10^6\ \text{J}$

$\therefore\ E = 0.5 \times 3.6 \times 10^6\ \text{J} = 1.8 \times 10^6\ \text{J}$

Answer: $E = 0.5$ kWh $= 0.5$ unit $= 1.8 \times 10^6$ J.

AP21 A lift can raise a load of 4000 kg through 10 floors, each of height 6 m, in 10 s. If $g = 10\ \text{m s}^{-2}$, find the power of the lift.

Solution:

Given: $m = 4000$ kg; floors = 10; height per floor = 6 m; total height, $h = 10 \times 6 = 60$ m; time, $t = 10$ s; $g = 10\ \text{m s}^{-2}$

Work done (gain in gravitational potential energy),

$$W = mgh = 4000 \times 10 \times 60\ \text{J} = 2.4 \times 10^6\ \text{J}$$

Power, $P = \frac{W}{t} = \frac{2.4 \times 10^6}{10}\ \text{W}$

$= 2.4 \times 10^5\ \text{W} = 240\ \text{kW}$

Answer: $P = 240$ kW.

AP22 State the energy transformations in the following: (a) at a dam, (b) in a steam engine, (c) in a thermal power station.

Solution:

(a) At a dam: Gravitational potential energy of stored water → kinetic energy of flowing water → mechanical energy (turbine) → electrical energy.

(b) In a steam engine: Chemical energy of fuel → heat energy (steam) → mechanical energy (motion of piston).

(c) In a thermal power station: Chemical energy of fuel → heat energy → mechanical energy (turbine) → electrical energy.

Energy-Transformation Summary

Energy changes from one form to another in various devices and natural processes. Examples:

Case	Energy transformation (in brief)
(a) **Dam**	Water (PE) → kinetic (water) → mechanical (turbine) → electrical
(b) **Steam engine**	Chemical (fuel) → heat (steam) → mechanical
(c) **Thermal power station**	Chemical (fuel) → heat → mechanical (turbine) → electrical

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More Everyday Transformations

- **Truck moving uphill:** Chemical energy (fuel) → kinetic energy (motion) + gravitational potential energy (increase in height) + heat energy (due to friction).
- **Watch (spring):** Elastic potential energy (in wound spring) → kinetic energy (motion of hands).
- **Photosynthesis:** Light energy (sunlight) → chemical energy (food, e.g., glucose).
- **Match stick:** Chemical energy → heat energy + light energy.
- **Firecracker:** Chemical energy → sound energy + light energy + heat energy + kinetic energy (motion of fragments).
- **Microphone:** Sound energy → electrical energy.
- **Electric bulb:** Electrical energy → light energy + heat energy.
- **Solar cell:** Light energy (sunlight) → electrical energy.

REVISION WORKSHEET WITH SOLUTIONS

A Fill in the Blanks

Fill in the blanks with the correct word / expression. The answer is given after a short blank.

1. Work is equal to the product of force and displacement along the force.
   Answer: work = force × displacement along force.
2. The SI unit of work is _____.
   Answer: joule.
3. One joule of work is done when a force of 1 N displaces a body by _____.
   Answer: 1 m.
4. The kinetic energy of a body is _____.
   Answer: $KE = \frac{1}{2}mv^2$.
5. The potential energy of a body at height h is _____.
   Answer: PE = mgh.
6. Power is the _____.
   Answer: rate of doing work.
7. The mechanical energy of a body is the sum of its kinetic and potential energies, i.e. _____.
   Answer: mechanical energy = KE + PE.
8. One commercial unit of energy is equal to _____.
   Answer: 1 kWh = 3.6×10^6 J.

B True / False with Correction

State whether each statement is True or False. If False, write the correct statement.

No.	Statement	True / False	Correction (if False)
1.	A force without displacement always does work.	False	A force without displacement does no work.
2.	Lifting a bucket upward is a positive work done by the lifting force.	True	—
3.	Work and energy both have the SI unit joule.	True	—
4.	A motionless stretched rubber band has kinetic energy.	False	It has elastic potential energy (stored energy due to deformation).
5.	Energy can change from one form to another.	True	—
6.	Work is a scalar quantity.	True	—
7.	Pushing a rigid wall does mechanical work on the wall.	False	No mechanical work is done, as the wall does not undergo displacement.
8.	If the speed of a body is doubled, its kinetic energy becomes four times.	True	—
9.	During horizontal motion at a fixed height, the gravitational potential energy of a body changes.	False	It does not change, as the height remains constant.
10.	For a freely falling body, its total mechanical energy remains constant, neglecting air resistance.	True	—

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FINAL COMPETENCY CHECK

A. Multiple Choice Questions (MCQs)

1. A force of 20 N pulls an object through 5 m at an angle of 60° with the direction of motion. The work done is
   (A) 100 J (B) 50 J (C) 20 J (D) 10 J
2. If the speed of a body is doubled, keeping its mass the same, its kinetic energy becomes
   (A) 2 times (B) 3 times (C) 4 times (D) 8 times
3. The SI unit of power is
   (A) joule (B) newton (C) watt (D) pascal
4. When an object is carried horizontally at a constant height, the work done by the upward support (carrying force) is
   (A) positive (B) negative (C) zero (D) cannot say

B. Assertion–Reason Question

5. **Assertion (A):** The total mechanical energy of a body is conserved during ideal free fall (no air resistance).
   Reason (R): The loss in potential energy of the body is equal to the gain in its kinetic energy.
   Choose the correct option:
   (A) Both A and R are true, and R correctly explains A.
   (B) Both A and R are true, but R does not explain A.
   (C) A is true, but R is false.
   (D) A is false, but R is true.

C. Very Short Answer Questions

6. Distinguish between work and energy.
7. Why does the centripetal force do no work?

D. Numerical Questions

8. A 4 kg body is lifted vertically through 6 m. If $g = 10\ \text{m s}^{-2}$, find the work done.
9. The speed of a 2 kg body increases from $3\ \text{m s}^{-1}$ to $7\ \text{m s}^{-1}$. Find the work done.
10. A device of power 600 W is used for 5 min. Find the energy (work) done.

E. Case-Based Questions

11. A skateboarder starts from rest and goes down a frictionless ramp from a height of 5 m. Take $g = 10\ \text{m s}^{-2}$.
    (i) Find the speed at the bottom of the ramp.
    (ii) Does the speed depend on the mass of the skateboarder? Give reason.
12. A motor raises a 50 kg load through 8 m in 20 s. (Take $g = 10\ \text{m s}^{-2}$.) Find the power of the motor.

Answer Key (with Brief Solutions)

1 **(B) 50 J** — $W = F s \cos\theta = 20 \times 5 \times \cos 60° = 20 \times 5 \times 0.5 = 50$ J.

2 **(C) 4 times** — $K = \tfrac{1}{2}mv^2 \Rightarrow K' = \tfrac{1}{2}m(2v)^2 = 4(\tfrac{1}{2}mv^2)$.

3 **(C) watt** — $P = \dfrac{W}{t}$; SI unit: watt (W) = J s^{-1}.

4 **(C) zero** — Work by support: $W = F s \cos 90° = 0$ (support is vertical, displacement horizontal).

5 **(A)** — In ideal free fall, mechanical energy (PE + KE) remains constant; decrease in PE equals increase in KE.

6 Work: energy transferred when a force causes displacement, $W = F s \cos\theta$ (scalar, unit J). Energy: capacity to do work (unit J).

7 Centripetal force is always perpendicular to the instantaneous displacement (tangential), so $\theta = 90°$ and $W = F s \cos 90° = 0$.

8 **240 J** — $W = mgh = 4 \times 10 \times 6 = 240$ J.

9 **40 J** — $W = \Delta K = \tfrac{1}{2}m(v^2 - u^2) = \tfrac{1}{2} \times 2 \times (7^2 - 3^2) = (49 - 9) = 40$ J.

10 **180 kJ** — $W = Pt = 600 \times (5 \times 60) = 1.8 \times 10^5$ J = 180 kJ.

11 **(i) 10 m s^{-1}** **(ii) No**
(i) $mgh = \tfrac{1}{2}mv^2 \Rightarrow v = \sqrt{2gh} = \sqrt{2 \times 10 \times 5} = 10\ \text{m s}^{-1}$.
(ii) No. $v = \sqrt{2gh}$ is independent of mass.

12 **200 W** — $P = \dfrac{W}{t} = \dfrac{mgh}{t} = \dfrac{50 \times 10 \times 8}{20} = 200$ W.

Self-check: write formula, substitute SI units, state sign (positive/negative/zero) and unit (J or W).