Chapter 5: Work, Energy and Power - Answer Key

NCERT Physics Class 11

BACK EXERCISES - SOLUTIONS

5.1 Sign of Work Analysis

Determine if the following work quantities are positive or negative:

(a) **Work done by man lifting bucket out of well**
Answer: POSITIVE - Man's force is upward, displacement is upward. Force and displacement in same direction ($\theta = 0°$).

(b) **Work done by gravitational force in above case**
Answer: NEGATIVE - Gravitational force is downward, displacement is upward. Force and displacement in opposite directions ($\theta = 180°$).

(c) **Work done by friction on body sliding down inclined plane**
Answer: NEGATIVE - Friction opposes motion, acts up the plane while displacement is down the plane ($\theta = 180°$).

(d) **Work done by applied force on body moving with uniform velocity on rough horizontal plane**
Answer: POSITIVE - Applied force is in direction of motion to overcome friction and maintain constant velocity.

(e) **Work done by resistive force on vibrating pendulum coming to rest**
Answer: NEGATIVE - Air resistance always opposes motion, reducing pendulum's energy until it stops.

5.2 Body Motion with Friction

Given: $m = 2$ kg, Applied force $F = 7$ N, $\mu = 0.1$, $t = 10$ s

Solution: First find acceleration:

- Friction force: $f = \mu mg = 0.1 \times 2 \times 10 = 2$ N
- Net force: $F_{net} = 7 - 2 = 5$ N
- Acceleration: $a = F_{net}/m = 5/2 = 2.5$ m/s^2
- Displacement in 10 s: $s = \frac{1}{2}at^2 = \frac{1}{2} \times 2.5 \times 100 = 125$ m

(a) **Work by applied force:** $W_F = F \times s = 7 \times 125 =$ **875 J** (b) **Work by friction:** $W_f = -f \times s = -2 \times 125 =$ **-250 J**
(c) **Work by net force:** $W_{net} = F_{net} \times s = 5 \times 125 =$ **625 J** (d) **Change in KE:** $\Delta K = \frac{1}{2}mv^2 = \frac{1}{2} \times 2 \times (25)^2 =$ **625 J**

Interpretation: Work-energy theorem verified: $W_{net} = \Delta K$

5.3 Potential Energy Analysis

For given potential energy graphs, identify forbidden regions and minimum energies:

Analysis method: Particle cannot exist where Total Energy < Potential Energy

(a) **V-shaped potential:** Forbidden regions where $E < V(x)$. Minimum energy at vertex. (b) **Parabolic potential:** No forbidden regions if $E >$ minimum. Minimum at turning points. (c) **Double well potential:** Forbidden region between wells if energy is low. Two stable positions.

5.4 Simple Harmonic Oscillator

Given: $V(x) = kx^2/2$, $k = 0.5$ N/m, Total energy $E = 1$ J

Solution: At turning points: $E = V(x)$, so $KE = 0$ $1 = \frac{1}{2} \times 0.5 \times x^2$ $x^2 = 4$ $x = \pm 2$ m

Answer: Particle must turn back at $x = \pm 2$ m because beyond these points, $V(x) > E$, which is physically impossible.

5.5 Conceptual Questions

(a) **Rocket casing burning:** Heat energy comes from **rocket's kinetic energy**. Friction converts mechanical energy to thermal energy.

(b) **Comet orbital work:** Work = 0 over complete orbit because gravitational force is conservative. Work depends only on initial and final positions, which are same for closed orbit.

(c) **Satellite losing energy:** As satellite loses energy, it moves to lower orbit where gravitational PE decreases. By energy conservation, KE must increase, hence speed increases.

(d) **Man carrying vs pulling mass:**

- **Carrying:** Work = 0 (force perpendicular to displacement)
- **Pulling:** Work > 0 (force has component along displacement)
- **Answer:** Work is greater when pulling.

5.6 Choose Correct Alternative

(a) When conservative force does positive work: potential energy **decreases** (b) Work against friction results in loss of **kinetic** energy
(c) Rate of change of momentum proportional to **external force** (d) In inelastic collision, **total linear momentum** remains unchanged

5.7 True/False Analysis

(a) **FALSE** - In elastic collision, total momentum and total energy conserved, but individual body values change. (b) **TRUE** - Total energy always conserved (including all forms). (c) **FALSE** - Only true for conservative forces. Non-conservative forces like friction give non-zero work over closed loops. (d) **TRUE** - Some kinetic energy converted to other forms in inelastic collision.

5.8 Collision Analysis

(a) **During elastic collision:** KE not conserved instantaneously (bodies deform), but conserved before and after. (b) **Linear momentum:** Always conserved at every instant due to Newton's Third Law. (c) **Inelastic collision:** Same as elastic - momentum always conserved, KE only conserved before and after (not during). (d) **Potential energy collision:** If PE depends only on separation, collision is **elastic**.

5.9 Power and Motion

Body initially at rest, constant acceleration:

$P = F \cdot v = ma \cdot (at) = ma^2t$

Since a is constant, $P \propto t$

Answer: (ii) t

5.10 Constant Power Motion

$P = F \cdot v = \text{constant}$

For constant power: $F = P/v$

From $F = ma$: $ma = P/v$, so $a = P/(mv)$

Using $v = ds/dt$ and $a = dv/dt$:

$dv/dt = P/(mv)$

Solving: $v\, dv = (P/m)\, dt$

Integration gives: $v^2 \propto t$, so $v \propto t^{(1/2)}$

Since $v = ds/dt$: $s \propto t^{(3/2)}$

Answer: (iii) t^(3/2)

5.11 Work by Constrained Force

Given: $\vec{F} = -\hat{i} + 2\hat{j} + 3\hat{k}$ N, displacement = 4 m along z-axis

$\vec{d} = 4\hat{k}$ m

Solution: $W = \vec{F}\cdot\vec{d} = (-\hat{i} + 2\hat{j} + 3\hat{k})\cdot(4\hat{k}) = 3 \times 4 =$ **12 J**

5.12 Electron vs Proton Speed

Given: Electron KE = 10 keV, Proton KE = 100 keV

Solution: For electron: $\frac{1}{2}m_e v_e^2 = 10$ keV For proton: $\frac{1}{2}m_p v_p^2 = 100$ keV

Taking ratio: $(v_e/v_p)^2 = (KE_e/KE_p) \times (m_p/m_e) = (10/100) \times (1.67\times10^{-27})/(9.11\times10^{-31}) = 1833$
$v_e/v_p = 42.8$

Answer: Electron is faster by factor of **42.8**

5.13 Raindrop Analysis

Given: r = 2 mm, h = 500 m, terminal velocity at h/2, final speed = 10 m/s

Solution: Mass: $m = (4/3)\pi r^3\rho = (4/3)\pi(2\times10^{-3})^3 \times 10^3 = 3.35\times10^{-5}$ kg

(a) **Work by gravity:**

- First half: $W_{g1} = mgh/2 = 3.35\times10^{-5} \times 10 \times 250 =$ **0.084 J**
- Second half: $W_{g2} = mgh/2 =$ **0.084 J**

(b) **Work by air resistance:** Total gravitational work = mgh = 0.168 J Final KE = $\frac{1}{2}mv^2 = \frac{1}{2} \times 3.35\times10^{-5} \times 100 = 1.68\times10^{-3}$ J Work by air resistance = Final KE - Total gravitational work = **-0.166 J**

5.14 Molecular Collision

Given: v = 200 m/s, θ = 30° with normal, elastic collision

Analysis:

- Momentum component parallel to wall: unchanged

- Momentum component perpendicular to wall: reversed
- Total momentum of molecule changes
- But momentum of (molecule + wall) system conserved

Answers:

- Momentum conserved for **system**: YES
- Collision is **elastic** (same speed before and after)

5.15 Water Pump Efficiency

Given: Volume = 30 m^3, time = 15 min, height = 40 m, efficiency = 30%

Solution: Mass of water: $m = 30 \times 10^3 = 30{,}000$ kg Work done against gravity: $W = mgh = 30{,}000 \times 10 \times 40 = 1.2\times10^7$ J Power output: $P_{out} = W/t = 1.2\times10^7/900 = 13{,}333$ W Power input: $P_{in} = P_{out}/\text{efficiency} = 13{,}333/0.3 =$ **44.4 kW**

5.16 Three Ball Collision

Initial: Two balls at rest, one moving with speed V
After elastic collision: Momentum and energy must be conserved

Analysis of options: Only **(a)** satisfies both conservation laws:

- Momentum: $MV = M(0) + M(V) + M(0)$ ✓
- Energy: $\frac{1}{2}MV^2 = 0 + \frac{1}{2}MV^2 + 0$ ✓

5.17 Pendulum Collision

Given: Pendulum released from 30°, elastic collision

Solution: Before collision: $mgh = \frac{1}{2}mv_1^2$ $h = L(1 - \cos 30°) = L(1 - \sqrt{3}/2)$ $v_1^2 = 2gL(1 - \sqrt{3}/2)$

After elastic collision between equal masses with one at rest:
First ball stops, second ball moves with v_1

Height reached by bob A after collision: **0 m** (it stops)

5.18 Pendulum with Air Resistance

Given: L = 1.5 m, 5% energy loss, released from horizontal

Solution: Initial energy: $E_0 = mgL$ Final energy: $E_f = 0.95mgL = \frac{1}{2}mv^2$ $mgL - 0.05mgL = \frac{1}{2}mv^2$ $0.95mgL = \frac{1}{2}mv^2$ $v^2 = 1.9gL = 1.9 \times 10 \times 1.5 = 28.5$ v = **5.34 m/s**

5.19 Leaking Sand Trolley

Given: Trolley mass = 300 kg, sand = 25 kg, initial speed = 27 km/h = 7.5 m/s
Sand leaking rate = 0.05 kg/s

Solution: No external horizontal forces, so horizontal momentum conserved: Initial momentum = Final momentum $(300 + 25) \times 7.5 = 300 \times v_f$ $v_f = 325 \times 7.5/300 =$ **8.125 m/s**

5.20 Variable Velocity Work

Given: m = 0.5 kg, v = ax^(3/2), a = 5 m^(-1/2)s^(-1), x: 0 to 2 m

Solution: KE at x = 0: $K_0 = 0$ KE at x = 2: $K_2 = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.5 \times (5 \times 2^{3/2})^2 = \frac{1}{2} \times 0.5 \times (5 \times 2\sqrt{2})^2 = \frac{1}{2} \times 0.5 \times 800 =$ **200 J**

Work done = ΔKE = **200 J**

5.21 Windmill Power

Given: Area A = 30 m^2, v = 36 km/h = 10 m/s, ρ = 1.2 kg/m^3, efficiency = 25%

Solution: (a) **Mass flow rate:** $dm/dt = \rho Av = 1.2 \times 30 \times 10 =$ **360 kg/s** (b) **KE of air per second:** $P = \frac{1}{2}(dm/dt)v^2 = \frac{1}{2} \times 360 \times 100 =$ **18,000 W**

(c) **Electrical power:** Pe = 0.25 × 18,000 = **4.5 kW**

5.22 Weight Loss Exercise

Given: m = 10 kg, h = 0.5 m, repetitions = 1000, efficiency = 20%

Solution: (a) **Work against gravity:** W = nmgh = 1000 × 10 × 10 × 0.5 = **50,000 J** (b) **Fat consumption:**

- Energy from fat needed = W/efficiency = 50,000/0.2 = 250,000 J
- Fat mass = 250,000/(3.8×10^7) = **6.58×10^{-3} kg = 6.58 g**

5.23 Solar Panel Area

Given: Power needed = 8 kW, solar intensity = 200 W/m^2, efficiency = 20%

Solution: (a) **Required area:**

- Usable power density = 200 × 0.2 = 40 W/m^2
- Area = 8000/40 = **200 m^2**

(b) **Comparison:** Typical house roof ≈ 100-150 m^2, so solar area is **larger than typical roof**.

KEY FORMULAS REFERENCE

Work and Energy

- W = F⃗·d⃗ = Fd cosθ
- K = ½mv^2
- ΔK = Wnet (Work-Energy Theorem)

Potential Energy

- Gravitational: V = mgh

- Elastic: $V = \frac{1}{2}kx^2$
- Conservative force: $F = -dV/dx$

Power

- Average: $P = W/t$
- Instantaneous: $P = \vec{F}\cdot\vec{v}$

Collisions

- Momentum conservation: $\vec{p}_i = \vec{p}f$
- Elastic collision: $KE_i = KEf$
- 1D elastic (m_2 at rest): $v_1f = (m_1-m_2)v_{1i}/(m_1+m_2)$

Answer Key Complete - All exercise problems solved with detailed explanations for JEE/NEET preparation.