Chapter 7: Work, Energy and Simple Machines

Exercises — Revise, Reflect, Refine

Q1 State whether True or False.

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

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

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

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

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

SOLUTION

(i) FALSE.

Work is done only when a force causes displacement in an object. If the object does not move (displacement = 0), the work done $W = F \times s = F \times 0 = 0$, regardless of the force applied.

(ii) TRUE.

When a bucket is lifted vertically upward, the applied force acts upward and the displacement is also upward (same direction). Since $W = F \times s \times \cos\theta$ with $\theta = 0°$, $W = F \times s > 0$, so work done on the bucket is positive.

(iii) TRUE.

Both work and energy are measured in joules (J). $1\ J = 1\ N \times 1\ m = 1\ kg\ m^2\ s^{-2}$.

(iv) FALSE.

A motionless stretched rubber band has elastic potential energy (stored due to deformation), not kinetic energy. Kinetic energy requires the object to be in motion ($KE = \frac{1}{2}mv^2$).

(v) TRUE.

Energy can be converted from one form to another, for example chemical energy in fuel → kinetic energy of a vehicle, or potential energy of water → electrical energy in a hydroelectric plant.

Answer: (i) False (ii) True (iii) True (iv) False (v) True

Q2 Fill in the blanks.
(i) Work done = _____ × _____ (in the direction of force).
(ii) 1 joule of work is done when a force of _____ newton displaces an object by 1 metre in the direction of the force.
(iii) The expression for kinetic energy of a body of mass m and velocity v is _____.
(iv) The potential energy of an object of mass m at a small height h from the Earth's surface is _____.
(v) Power is defined as the _____ at which work is done.

SOLUTION

(i) Work done = Force × Displacement (in the direction of force).
The formula $W = F \times s$ applies when the force and displacement are in the same direction.

(ii) 1 joule of work is done when a force of 1 newton displaces an object by 1 metre.
By definition: $1\ J = 1\ N \times 1\ m$.

(iii) The expression for kinetic energy is $KE = \frac{1}{2}mv^2$.
This is derived from the work-energy theorem: work done accelerating a mass m from rest to speed v equals $\frac{1}{2}mv^2$.

(iv) The gravitational potential energy at height h is $PE = mgh$.
This comes from the work done against gravity to lift the object through height h.

(v) Power is defined as the rate at which work is done.
$P = W/t$, measured in watts (W), where $1\ W = 1\ J\ s^{-1}$.

Answer: (i) Force, Displacement (ii) 1 (iii) $\frac{1}{2}mv^2$ (iv) mgh (v) rate

Q3 When a ball thrown upwards reaches its highest point, tick which of the following statement(s) are correct?
(i) The force acting on the ball is zero.
(ii) The acceleration of the ball is zero.
(iii) Its kinetic energy is zero.
(iv) Its potential energy is maximum.

SOLUTION

At the highest point of the ball's trajectory, the ball is momentarily at rest ($v = 0$).

(i) INCORRECT. Gravity ($W = mg$, downward) still acts on the ball at the highest

point. The force is not zero.

(ii) INCORRECT. The acceleration due to gravity g = 10 m s^{-2} acts downward throughout the flight, including at the highest point. Acceleration is not zero.

(iii) CORRECT. At the highest point the ball is momentarily at rest (v = 0), so KE = ½mv^2 = 0.

(iv) CORRECT. At the highest point, the height h is maximum, so gravitational potential energy PE = mgh is at its maximum value.

Both (iii) and (iv) are correct. These are consistent with energy conservation: total mechanical energy is constant, and at the highest point all of it is potential energy.

Answer: Statements (iii) and (iv) are correct.

Q4 For each of the following situations, identify the energy transformation that takes place: (i) a truck moving uphill, (ii) unwinding of a watch spring, (iii) photosynthesis in green leaves, (iv) water flowing from a dam, (v) burning of a matchstick, (vi) explosion of a fire cracker, (vii) speaking into a microphone, (viii) a glowing electric bulb, and (ix) a solar panel.

SOLUTION

(i) Truck moving uphill: Chemical energy (fuel) → Kinetic energy → Gravitational potential energy.

(ii) Unwinding of a watch spring: Elastic potential energy (stored in coiled spring) → Kinetic energy (movement of watch gears/hands).

(iii) Photosynthesis in green leaves: Light energy (solar) → Chemical energy (stored in glucose/food).

(iv) Water flowing from a dam: Gravitational potential energy (stored water at height) → Kinetic energy (flowing water) → Electrical energy (in turbines/generators).

(v) Burning of a matchstick: Chemical energy → Heat energy + Light energy.

(vi) Explosion of a firecracker: Chemical energy → Heat energy + Light energy + Sound energy + Kinetic energy (of fragments).

(vii) Speaking into a microphone: Sound energy (mechanical/kinetic energy of air) → Electrical energy.

(viii) A glowing electric bulb: Electrical energy → Light energy + Heat energy.

(ix) A solar panel: Light energy (solar) → Electrical energy.

Answer: (i) Chemical→KE→PE (ii) Elastic PE→KE (iii) Light→Chemical (iv) Gravitational PE→KE→Electrical (v) Chemical→Heat+Light (vi) Chemical→Heat+Light+Sound+KE (vii) Sound→Electrical (viii) Electrical→Light+Heat (ix) Light→Electrical

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Q5 A student is slowly lifted straight up in an elevator from the ground level to the top floor of a building. Later, the same student climbs the staircase, all the way to the top. Given that the height of the building is h = 72.5 m, acceleration due to gravity is g = 10 m s^{-2}, and student's mass is m = 50 kg.
(i) Find the gain in the potential energy if the student is lifted straight up to the top.
(ii) Find the gain in the potential energy when the student climbs the stairs to the same top.
(iii) What do you conclude about the dependence of the potential energy on the path taken?

SOLUTION

Given: m = 50 kg, g = 10 m s^{-2}, h = 72.5 m.

(i) Gain in PE going up in elevator:
PE = mgh = 50 × 10 × 72.5
PE = 36 250 J = 36.25 kJ

(ii) Gain in PE climbing stairs to the same height:
PE = mgh = 50 × 10 × 72.5
PE = 36 250 J = 36.25 kJ

(iii) In both cases the change in gravitational potential energy is the same: 36 250 J.
Conclusion: Gravitational potential energy depends only on the height gained (h) and not on the path taken to reach that height. Whether the student takes the elevator (direct vertical path) or the staircase (longer zigzag path), the gain in PE is identical.

Answer: (i) 36 250 J (ii) 36 250 J (iii) Gravitational PE depends only on height, not on the path taken.

Q6 A crane lifts a mass m to the 10th floor of a building in a certain time. It then raises the same mass to the 20th floor of the same building in double the time. How much more energy and power are required? Assume that the height of all floors is equal.

SOLUTION

Let the height of each floor = H, so:
Height to 10th floor = 10H.
Height to 20th floor = 20H.

Let the time to reach the 10th floor = t, so time to reach 20th floor = 2t.

Energy to lift to 10th floor: $E_1 = mg(10H)$
Energy to lift to 20th floor: $E_2 = mg(20H) = 2 \times mg(10H) = 2E_1$

Extra energy required = $E_2 - E_1 = 2E_1 - E_1 = E_1 = mg(10H)$.
The crane needs exactly as much MORE energy as it used for the first lift.

Power for 10th floor: $P_1 = E_1/t = mg(10H)/t$
Power for 20th floor: $P_2 = E_2/(2t) = mg(20H)/(2t) = mg(10H)/t = P_1$

The power required is the same in both cases.

Answer: The crane needs one additional amount of energy equal to mg(10H) — the same as the first lift. The power required is the same in both cases ($P_1 = P_2 = mg \cdot 10H/t$).

Q7 Which factors determine the energy required to raise a flag from the ground to the top of a tall flagpole using a pulley? Does raising the flag slowly or quickly change the amount of work done? If the speed at which the flag is raised is doubled, how does the power requirement change? Explain your answers.

SOLUTION

Factors determining the energy (work done) to raise the flag:
W = mgh, where m = mass (weight) of the flag, g = acceleration due to gravity, h = height of the flagpole.
The two factors are: (1) the weight of the flag (mg) and (2) the height of the flagpole (h).
The pulley is a simple machine that changes the direction of the applied force; it does not reduce the work done.

Does speed affect the work done?

No. The work done W = mgh depends only on the weight of the flag and the height through which it is raised. Whether the flag is raised slowly or quickly does not change W.

Effect of doubling the speed on power:
Power P = W/t. If speed doubles, the same height h is covered in half the time (t → t/2).
New power P' = W/(t/2) = 2W/t = 2P.
Doubling the speed doubles the power required.

Answer: Energy required = mgh; factors are the weight (mg) of the flag and height (h) of the pole. Raising speed does not change work done. Doubling the speed doubles the power requirement.

Q8 A man of mass 60 kg rides a scooter of mass 100 kg. He accelerates the scooter to a velocity v. The next day, his son with a mass of 40 kg joins him as a passenger. If the scooter reaches the same speed on both days in the same time interval, what is the ratio of the fuel of the tank used on the two days? Assume that the energy transfer to the scooter happens entirely due to fuel, and no other losses occur due to air resistance and friction.

SOLUTION

Day 1: Total mass = mass of scooter + man = 100 + 60 = 160 kg.
Day 2: Total mass = mass of scooter + man + son = 100 + 60 + 40 = 200 kg.

Both days: same final speed v, starting from rest (u = 0).

Since all energy from fuel converts to kinetic energy (no losses):
Fuel used ∝ KE gained = ½ × total mass × v^2

Day 1: $KE_1 = ½ \times 160 \times v^2$
Day 2: $KE_2 = ½ \times 200 \times v^2$

Ratio of fuel used (Day 2 to Day 1):
$KE_2/KE_1 = (½ \times 200 \times v^2) / (½ \times 160 \times v^2) = 200/160 = 5/4$

The ratio of fuel used on Day 2 to Day 1 is 5 : 4.

Answer: Ratio of fuel used (Day 2 : Day 1) = 5 : 4.

Q9 On a seesaw with sliding seats, a child is sitting on one side and an adult on the other side. The adult weighs twice that of the child. The seesaw however is balanced. Draw a figure which depicts this situation showing the distances from the fulcrum where the child and the adult are seated.

SOLUTION

Let the weight of the child = W_c.
Weight of the adult = W_a = 2W_c (given).

For the seesaw to be balanced, the torques about the fulcrum must be equal:
W_c × d_c = W_a × d_a
W_c × d_c = 2W_c × d_a
d_c = 2 × d_a

The child must sit at twice the distance from the fulcrum compared to the adult.

Example: if the adult sits 1 m from the fulcrum, the child sits 2 m from the fulcrum on the opposite side.

Figure description: A horizontal seesaw beam balanced on a central fulcrum (triangle). The adult is seated 1 unit from the fulcrum on the left side; the child is seated 2 units from the fulcrum on the right side. Both sides balance because: W_adult × 1 = 2W_child × 1 = W_child × 2.

Answer: The child must sit twice as far from the fulcrum as the adult. If adult is at distance d from the fulcrum, the child sits at distance 2d on the opposite side.

Q10 A ball of mass 2 kg is thrown up with a velocity of 20 m s^{-1}.
(i) Identify the sign of the work done by gravity on the ball during its upward motion and its downward motion.
(ii) If the ball reaches a height of 19.4 m, how much work was done by air resistance (assume g = 10 m s^{-2}).

SOLUTION

Given: m = 2 kg, u = 20 m s^{-1} (upward), h = 19.4 m, g = 10 m s^{-2}.

(i) Sign of work done by gravity:
Gravity always acts downward (force = mg = 20 N, downward).

Upward motion: displacement is upward, force is downward → they are in opposite directions (θ = 180°).
W_gravity (upward) = −mgh = −2 × 10 × 19.4 = −388 J (NEGATIVE).

Downward motion: displacement is downward, force is also downward → same direction (θ = 0°).
W_gravity (downward) = +mgh = +388 J (POSITIVE).

(ii) Work done by air resistance during upward motion:
Initial KE = ½mv² = ½ × 2 × 20² = ½ × 2 × 400 = 400 J.
Final KE at height 19.4 m = 0 J (ball momentarily at rest at highest point).

By the work-energy theorem: W_net = ΔKE
W_gravity + W_air = KE_final − KE_initial
−388 + W_air = 0 − 400
W_air = −400 + 388 = −12 J

Air resistance did −12 J of work (negative, as expected — it opposes motion).

Answer: (i) Work by gravity is negative during upward motion, positive during downward motion. (ii) Work done by air resistance = −12 J.

Q11 A 10.0 kg block is moving on a horizontal floor with negligible friction. As shown in Fig. 7.37, a variable force is applied on the block in its direction of motion from its position at 0 m till 4 m. If the block had a kinetic energy of 180 J when it was at 0 m, find the block's speed (i) at 0 m, and (ii) at 4 m. Does the block have negative acceleration in any portion of its motion?
[Fig. 7.37: Force vs Displacement graph (trapezoid) — force increases linearly from 0 N at x = 0 m to 50 N at x = 1 m, stays constant at 50 N from x = 1 m to x = 3 m, then decreases linearly back to 0 N at x = 4 m.]

SOLUTION

Given: m = 10.0 kg, KE at 0 m = 180 J.
From Fig. 7.37: the force-displacement graph is a trapezoid — F rises 0 → 50 N over x = 0 to 1 m, stays flat at 50 N from x = 1 to 3 m, then falls 50 → 0 N from x = 3 to 4 m.

(i) Speed at 0 m:
KE = ½mv²
180 = ½ × 10.0 × v²
v² = 2 × 180 / 10 = 36
v = √36 = 6 m s⁻¹

(ii) Work done by the variable force from 0 to 4 m:

W = area under the F-s graph = area of the trapezoid = ½ × (sum of parallel sides) × height
The parallel sides are the top (flat portion, length 3 − 1 = 2 m) and the bottom (full base 4 − 0 = 4 m); the 'height' is the peak force 50 N.
W = ½ × (2 + 4) × 50 = ½ × 6 × 50 = 150 J

KE at 4 m = KE at 0 m + W = 180 + 150 = 330 J

Speed at 4 m:
330 = ½ × 10.0 × v^2
v^2 = 2 × 330 / 10 = 66
v = √66 ≈ 8.12 m s^{-1}

Negative acceleration?
The applied force is always in the direction of motion (always non-negative from the graph: 0 → 50 → 50 → 0 N). Since friction is negligible and the net force is always ≥ 0, the block's acceleration is always ≥ 0. The block speeds up throughout its motion from 6 m s^{-1} to about 8.12 m s^{-1}. The block does NOT have negative acceleration in any portion.

Answer: (i) v at 0 m = 6 m s^{-1}. (ii) v at 4 m = √66 ≈ 8.12 m s^{-1}. The block does not have negative acceleration at any point.

Q12 The gravitational attraction on the surface of the Moon (lunar surface) is about 1/6th of that on the surface of the Earth. An astronaut can throw a ball up to a height of 8 m from the surface of the Earth. How far up will the ball thrown with the same upward velocity travel from the surface of the Moon?

SOLUTION

Given: g_{Earth} = 10 m s^{-2}, height on Earth h_E = 8 m.
g_{Moon} = g_{Earth} / 6 = 10/6 m s^{-2}.

Same initial upward velocity u on both Earth and Moon.

On Earth, using $v^2 = u^2 - 2g_E \times h_E$, at maximum height v = 0:
$0 = u^2 - 2 \times 10 \times 8$
u^2 = 160 m^2 s^{-2}

On the Moon, with the same u^2 = 160 m^2 s^{-2}:
$0 = u^2 - 2 \times g_{Moon} \times h_{Moon}$
$h_{Moon} = u^2 / (2 \times g_{Moon}) = 160 / (2 \times 10/6) = 160 \times 6 / 20 = 48$ m

Alternatively, since h ∝ 1/g for the same u:
h_Moon = h_Earth × (g_Earth / g_Moon) = 8 × 6 = 48 m

Answer: The ball will travel 48 m upward from the surface of the Moon.

Q13 A 1000 kg car is moving along a road at a constant speed. Suddenly, the driver notices some obstruction ahead and applies the brakes to come to a complete stop. The graphical representation of motion of the car starting from the instant the driver spots the traffic ahead is shown in Fig. 7.38.
[Fig. 7.38: Speed-time graph. Speed (m s^{-1}) on y-axis, Time (s) on x-axis. Point A is at (0 s, 35 m s^{-1}); speed remains constant at 35 m s^{-1} until point B at (1 s, 35 m s^{-1}) — this is the driver's reaction time; speed then decreases linearly from B to C at (3 s, 0 m s^{-1}) — braking phase.]
(i) Describe how the car moves between positions A and B.
(ii) Calculate the kinetic energy of the car at A.
(iii) State the work done by the brakes in bringing the car to a halt between B and C.
(iv) What does the kinetic energy of the car transform into?

SOLUTION

Given: m = 1000 kg. From Fig. 7.38: $v_A = v_B = 35$ m s^{-1}, $v_C = 0$.
A is at t = 0 s, B is at t = 1 s (reaction time), C is at t = 3 s (car stops).

(i) Motion between A and B:
The speed-time graph is horizontal (constant) between A and B. The car moves at a constant speed of 35 m s^{-1}. This interval (0 s to 1 s) represents the driver's reaction time — the brakes have not yet been applied.

(ii) Kinetic energy of the car at A:
$KE_A = \frac{1}{2}mv^2 = \frac{1}{2} \times 1000 \times 35^2$
$= \frac{1}{2} \times 1000 \times 1225$
= 612 500 J = 612.5 kJ

(iii) Work done by brakes from B to C:
At B: $KE_B = KE_A$ = 612 500 J (same speed).
At C: KE_C = 0 J (car is stationary).
By work-energy theorem: $W_{brakes} = \Delta KE = KE_C - KE_B = 0 - 612\,500 = -612\,500$ J
The brakes do −612 500 J of work (negative because braking force opposes motion).

(iv) The kinetic energy transforms into heat energy (and a small amount of sound energy) due to friction between the brake pads and wheels, and between the tyres and the road surface.

Answer: (i) Constant speed (35 m s^{-1}) — reaction time before brakes engage. (ii) KE at A = 612 500 J = 612.5 kJ. (iii) Work by brakes = −612 500 J. (iv) KE converts to heat energy (and some sound).

Q14 The potential energy-displacement graph of a 0.5 kg ball moving along a frictionless track is shown in Fig. 7.39. At O, the velocity of the ball is 0 m s^{-1} and potential energy is 30 J. Calculate the velocity of the ball at P, Q and R.
[Fig. 7.39: Potential Energy (J) on y-axis (0, 10, 20, 30, 40) vs Displacement (m) on x-axis. Starting from O on the left at PE = 30 J, the curve dips into a deep well, rises to a small hump, dips again, then climbs steeply up the right side passing through P (PE = 20 J), then Q (PE = 30 J), and reaching R (PE = 40 J) at the top right.]

SOLUTION

Given: m = 0.5 kg, at O: v = 0 m s^{-1}, PE = 30 J.
Track is frictionless, so total mechanical energy is conserved.

Total mechanical energy (set at O where the ball is at rest):
E_{total} = KE + PE = 0 + 30 = 30 J

At any point: KE = E_{total} − PE = 30 − PE
Speed: $v = \sqrt{(2 \times KE / m)} = \sqrt{(2 \times (30 - PE) / 0.5)} = \sqrt{(4 \times (30 - PE))}$

Reading the labelled points off Fig. 7.39: P is at PE = 20 J, Q at PE = 30 J, R at PE = 40 J.

At P (PE = 20 J):
KE_P = 30 − 20 = 10 J
$v_P = \sqrt{(2 \times 10 / 0.5)} = \sqrt{40} = 2\sqrt{10} \approx 6.32$ m s^{-1}

At Q (PE = 30 J):
KE_Q = 30 − 30 = 0 J
$v_Q = \sqrt{0} = 0$ m s^{-1}
Q is a turning point: all of the ball's energy is potential, so it is momentarily at rest, just as at O.

At R (PE = 40 J):
This would require KE_R = 30 − 40 = −10 J, which is impossible (kinetic energy

cannot be negative).

With only 30 J of total mechanical energy, the ball can never reach a point where PE = 40 J. So the ball does NOT reach R — it turns back at Q (PE = 30 J). No velocity can be assigned at R because the ball never gets there.

Answer: $v_P = 2\sqrt{10} \approx 6.32$ m s^{-1}; $v_Q = 0$ m s^{-1} (turning point, PE = 30 J = total energy). The ball cannot reach R (PE = 40 J > 30 J total energy), so it never arrives at R.

Q15 A coconut of mass 1.5 kg falls from the top of a coconut tree onto the wet sand on a beach. The height of the tree is 10 m. On impact, the coconut comes to rest by making a depression in the sand.
(i) Calculate the velocity of the coconut just before it hits the sand.
(ii) Assume that the average resistive force of sand is 3000 N and all of the coconut's energy is used to create the depression in the sand. Calculate the depth of the depression the coconut makes in the sand. Assume g = 10 m s^{-2}.

SOLUTION

Given: m = 1.5 kg, h = 10 m, g = 10 m s^{-2}, F_{sand} = 3000 N.

(i) Velocity just before hitting the sand:
The coconut falls from rest (u = 0) through height h = 10 m.
Using $v^2 = u^2 + 2gh$:
$v^2 = 0 + 2 \times 10 \times 10 = 200$ m^2 s^{-2}
$v = \sqrt{200} = 10\sqrt{2} \approx 14.14$ m s^{-1}

(ii) Depth of depression in sand:
KE of coconut on impact = $\frac{1}{2}mv^2 = \frac{1}{2} \times 1.5 \times 200 = 150$ J
(Alternatively: KE = mgh = 1.5 × 10 × 10 = 150 J, confirming energy conservation.)

All 150 J of kinetic energy is used by the sand's resistive force over depth d:
Work by sand = $F_{sand} \times d = 150$ J
$3000 \times d = 150$
$d = 150 / 3000 = 0.05$ m = 5 cm

Answer: (i) $v = 10\sqrt{2} \approx 14.14$ m s^{-1}. (ii) Depth of depression = 0.05 m = 5 cm.