physics UK
Smarter practice. Stronger understanding

SOLUTIONS
ATTEMPT | CHECK | CORRECT | IMPROVE

Kinetic and gravitational potential energy solutions

AQA AS 7407 and first-year A Level 7408 | OCR A AS H156 and A Level H556

Matching solutions and teaching prompts for the class review | 38 marks

Specification points covered

- AQA 7407 / 7408: 3.4.1.7 selected work–energy links; 3.4.1.8 kinetic energy, uniform-field gravitational energy and full or partial transfers.
- OCR A H156 / H556: 3.3.2(a)–(c), including both first-principles derivations; 3.3.1(c)–(e) selected conservation and transfers. No inverse-square gravity is required.

Mission assumptions

Project Asteria is an asteroid-deflection and sample-return mission. For every stated height change, use the supplied uniform field $g = 0.24\ N\ kg^{-1}$. Heights refer to changes in centre-of-mass position.

Treat bodies as particles, neglect rotation and use the stated transfer model. Show calculation working in blank spaces; use ruled lines for written explanations.

Class review: model complete energy accounts, use precise quantity language and accept equivalent valid methods.

1. Deriving the equations from first principles [6 marks]

The mission team checks that its energy model follows from earlier mechanics rather than treating the equations as facts to memorise.

(a) Starting with $W = Fs$, $F = ma$ and $v^2 = u^2 + 2as$, derive $\Delta E_k = \frac{1}{2}m(v^2 - u^2)$. Here F is a constant resultant force on a body of constant mass and W is its net work. Show the algebraic steps. [3 marks]

(b) A payload is lifted through a vertical height Δh at constant speed with negligible resistance. Starting with $W = Fs$ and the weight mg, derive $\Delta E_p = mg\Delta h$. Explain why the lifting work increases gravitational potential energy. [3 marks]

Answer / mark points: (a) $v^2 - u^2 = 2as$ gives $as = (v^2 - u^2)/2$. [1] Using the constant resultant force, $W = Fs = mas$. [1] Therefore $\Delta E_k = W = \frac{1}{2}m(v^2 - u^2)$. [1] (b) Constant speed and negligible resistance give lifting force $F = mg$. [1] $W = F\Delta h = mg\Delta h$. [1] Kinetic energy is unchanged, so the lifting work equals the gravitational energy increase: $\Delta E_p = mg\Delta h$. [1]

Teacher prompt / common error: The kinetic-energy expression uses net work, not work by any one arbitrary force. The gravitational result assumes uniform g and no other transfer in this derivation.

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

2. Calibration calculations [5 marks]

Before descent, three systems are checked close to the asteroid surface. Use g = 0.24 N kg^{-1}.

(a) A 24.0 kg mapping drone moves at 6.50 m s^{-1}. Its approach kinetic energy must not exceed 500 J. Calculate its kinetic energy and decide whether this limit is met. [2 marks]

(b) A 27.0 kg inspection unit has kinetic energy 864 J. Calculate its speed. [2 marks]

(c) An 18.0 kg instrument is lifted vertically through 75.0 m. Calculate its increase in gravitational potential energy. [1 mark]

Answer / mark points: (a) $E_k = ½ \times 24.0 \times 6.50^2 = 507$ J. [1] This exceeds 500 J, so the approach limit is not met. [1] (b) $v = \sqrt{(2E_k/m)} = \sqrt{(2 \times 864/27.0)}$. [1] v = 8.00 m s^{-1}. [1] (c) $\Delta E_p = 18.0 \times 0.24 \times 75.0 = 324$ J. [1]

Teacher prompt / common error: Square speed, not mass. Keep the energy result unrounded when comparing with a limit. Speed is the positive square root.

3. A complete energy transfer [4 marks]

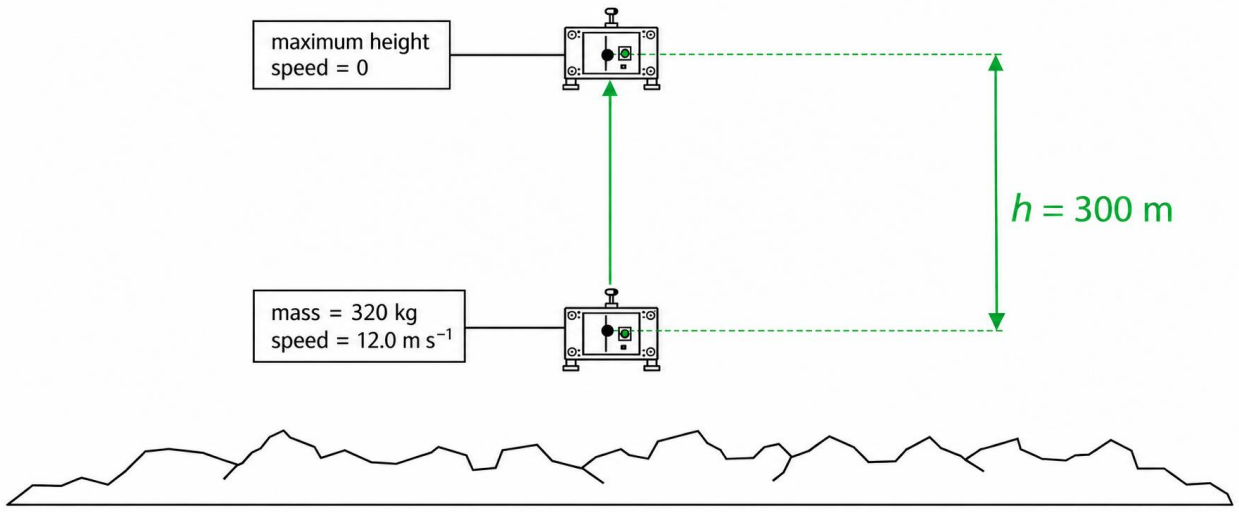
A 320 kg kinetic impactor fires its thrusters close to the asteroid surface until it is moving vertically upwards at 12.0 m s^{-1}. Its engines then switch off. Resistive forces are negligible and g = 0.24 N kg^{-1} is uniform.

(a) Calculate the impactor's kinetic energy when the engines switch off. [1 mark]

(b) Calculate the maximum height reached above the switch-off point. [2 marks]

(c) Describe the exchange between kinetic energy and gravitational potential energy as the impactor rises. [1 mark]

Impactor ascent above the asteroid surface not to scale



Near the surface, take g = 0.24 N kg^{-1} and ignore resistive forces.

Answer / mark points: (a) $E_k = ½ \times 320 \times 12.0^2 = 23040$ J, approximately 23.0 kJ. [1] (b) Complete transfer gives $mg\Delta h = E_k$. [1] $\Delta h = 23040/(320 \times 0.24) = 300$ m. [1] (c) Kinetic energy decreases and gravitational potential energy increases by the same amount as the impactor rises. [1]

Teacher prompt / common error: Use kinetic energy decreases, not velocity is decelerating. At the highest point the stated vertical launch has zero speed and zero kinetic energy. No energy is transferred to thermal stores in this model.

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

4. Does mass affect the maximum height? [3 marks]

Two sample hoppers have different masses. Both launch vertically upwards from the same point at 9.60 m s^{-1}. Resistive forces are negligible and g = 0.24 N kg^{-1} is uniform.

(a) State which hopper reaches the greater maximum height. [1 mark]

(b) Use the kinetic and gravitational potential energy equations to show that mass cancels, then calculate the maximum height. [2 marks]

Answer / mark points: (a) Both hoppers reach the same maximum height. [1] (b) $\frac{1}{2}mv^2 = mg\Delta h$, so cancelling m gives $\Delta h = v^2/(2g)$. [1] $\Delta h = 9.60^2/(2 \times 0.24) = 192$ m. [1]

Teacher prompt / common error: The more massive hopper has proportionally greater initial kinetic energy but also needs proportionally more energy per metre gained; these mass factors cancel.

5. A tethered canister: partial transfer while rising [4 marks]

A 48.0 kg sample canister leaves the surface vertically at 10.0 m s^{-1}. A magnetic brake on its tether transfers energy to thermal stores. At the highest point, 72% of the initial kinetic energy has increased the gravitational potential energy store. Use g = 0.24 N kg^{-1}.

(a) Calculate the initial kinetic energy of the canister. [1 mark]

(b) Calculate the increase in gravitational potential energy. [1 mark]

(c) Calculate the maximum height reached. [1 mark]

(d) Calculate the energy transferred to thermal stores by the brake. [1 mark]

Answer / mark points: (a) $E_k = \frac{1}{2} \times 48.0 \times 10.0^2 = 2400$ J. [1] (b) $\Delta E_p = 0.72 \times 2400 = 1728$ J. [1] (c) $\Delta h = 1728/(48.0 \times 0.24) = 150$ m. [1] (d) Thermal transfer = 2400 − 1728 = 672 J. [1]

Teacher prompt / common error: At the highest point the vertical motion has stopped: 72% of initial kinetic energy has increased gravitational energy and 28% has been transferred to thermal stores. Energy has not vanished.

Continue your physics journey

Videos, practice and support for your next step

www.physicsuk.co.uk

6. A landing package: partial transfer while falling [5 marks]

A descent tether brakes a 90.0 kg seismometer package released from rest 160 m above its landing site. Just before contact, 65% of the decrease in gravitational potential energy is kinetic energy. The remainder has been transferred to thermal and internal stores by the tether brake. Use g = 0.24 N kg^{-1}.

(a) Calculate the decrease in gravitational potential energy. [1 mark]

(b) Calculate the kinetic energy just before touchdown. [1 mark]

(c) Calculate the speed just before touchdown. [2 marks]

(d) Calculate the energy transferred to thermal and internal energy stores. [1 mark]

Answer / mark points: (a) Decrease in E_p = 90.0 × 0.24 × 160 = 3456 J. [1] (b) E_k = 0.65 × 3456 = 2246.4 J. [1] (c) v = √(2E_k/m). [1] v = √(2 × 2246.4/90.0) = 7.065… m s^{-1}, approximately 7.07 m s^{-1}. [1] (d) Other transfers = 3456 − 2246.4 = 1209.6 J, approximately 1.21 kJ. [1]

Teacher prompt / common error: This is the speed immediately before contact, not the speed after the package stops. The tether brake removes energy; no atmospheric drag model is assumed.

7. Tracking an ejecta fragment [4 marks]

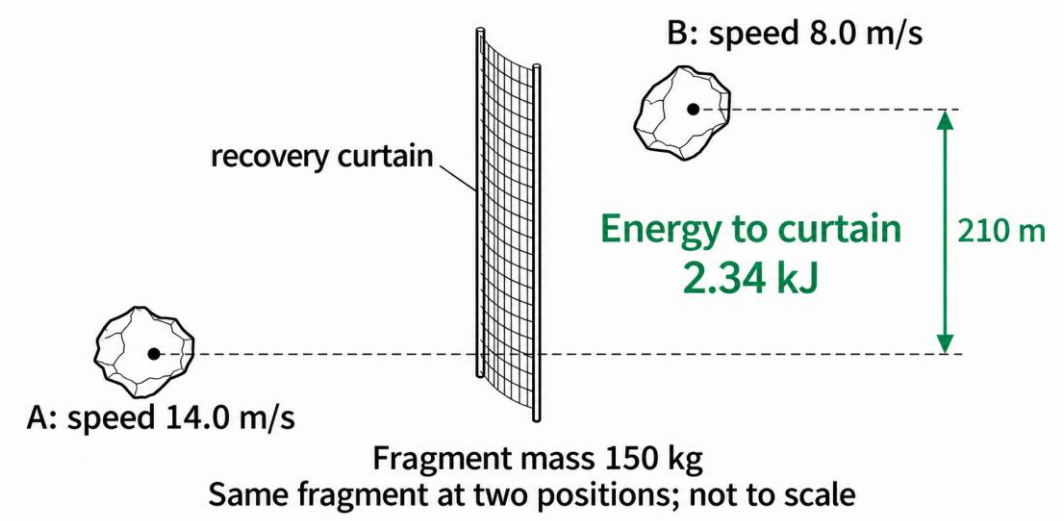
A 150 kg fragment leaves an impact crater at A at 14.0 m s^{-1}. Between A and B it passes through a recovery curtain that exerts resistance. At B it is 210 m higher and moves at 8.0 m s^{-1}. Apart from gravity and this interaction, no other energy transfer occurs. Use g = 0.24 N kg^{-1}.

(a) Calculate the decrease in kinetic energy from A to B. [1 mark]

(b) Calculate the increase in gravitational potential energy from A to B. [1 mark]

(c) Calculate the energy transferred to other stores between A and B. [1 mark]

(d) Explain why the calculation shows that the transfer from kinetic energy to gravitational potential energy is only partial. [1 mark]



Answer / mark points: (a) Decrease in E_k = ½ × 150 × (14.0^2 − 8.0^2) = 9900 J. [1] (b) Increase in E_p = 150 × 0.24 × 210 = 7560 J. [1] (c) Energy transferred to the recovery curtain = 9900 − 7560 = 2340 J = 2.34 kJ. [1] (d) The gravitational increase is smaller than the kinetic decrease; the difference is transferred through the curtain interaction, so the transfer to gravitational energy is partial. [1]

Teacher prompt / common error: Compare changes in stores. The stated resistance explains the mechanical-energy decrease; do not invent air resistance on the asteroid.

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

8. Two-stage sample-return launch [7 marks]

A launcher transfers 30.0 kJ from a battery. In stage 1, 60% becomes kinetic energy of a 120 kg capsule. In stage 2, 80% of that kinetic energy increases its gravitational potential energy. The capsule rises vertically and is momentarily at rest at the end. All other energy is transferred to thermal and internal stores. Use g = 0.24 N kg^{-1}.

(a) Calculate the kinetic energy of the capsule immediately after launch. [1 mark]

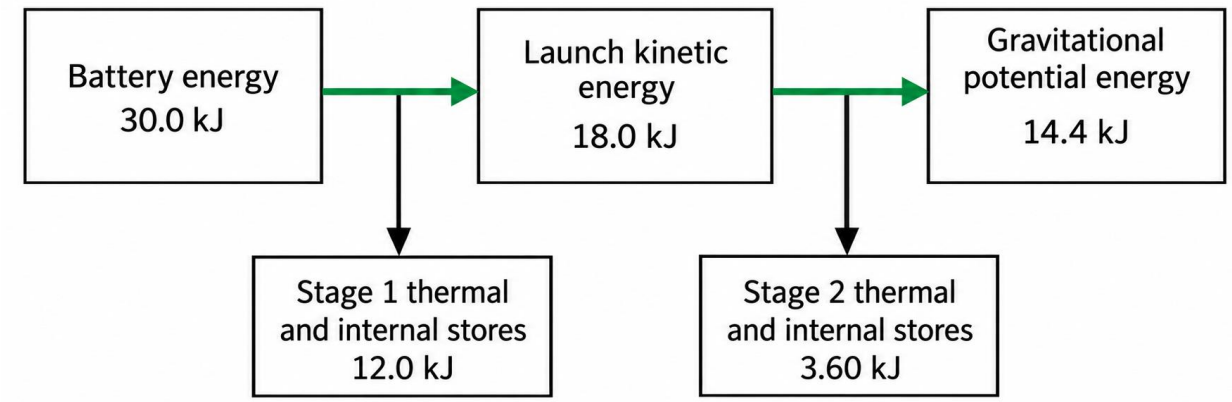
(b) Calculate the launch speed. [2 marks]

(c) Calculate the increase in gravitational potential energy during stage 2. [1 mark]

(d) Calculate the height gained during stage 2. [1 mark]

(e) Calculate the total energy transferred to thermal and internal energy stores across both stages. [1 mark]

(f) Calculate the percentage of the original 30.0 kJ that becomes gravitational potential energy. [1 mark]



Energy transfers; arrows not to scale.

Answer / mark points: (a) Launch E_k = 0.60 × 30.0 = 18.0 kJ. [1] (b) $v = \sqrt{(2E_k/m)}$. [1] $v = \sqrt{(2 \times 18000/120)}$ = 17.320… m s^{-1}, approximately 17.3 m s^{-1}. [1] (c) ΔE_p = 0.80 × 18.0 = 14.4 kJ. [1] (d) Δh = 14400/(120 × 0.24) = 500 m. [1] (e) Stage 1: 12.0 kJ; stage 2: 3.60 kJ; total other transfers = 15.6 kJ. [1] (f) Fraction = 0.60 × 0.80 = 0.48, or 48%. [1]

Teacher prompt / common error: At the end the capsule is at rest, so residual kinetic energy is zero. The final gravitational increase of 14.4 kJ plus other transfers of 15.6 kJ accounts for all 30.0 kJ. Multiply successive fractions, do not add percentages.

Review emphasis

Full-credit energy accounts name the store that decreases, the store that increases and any energy transferred to thermal or internal stores. The total energy before and after must agree.

Continue your physics journey

Videos, practice and support for your next step

www.physicsuk.co.uk