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SOLUTIONS
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Work done and energy transfers 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 | 37 marks

Specification points covered

- AQA 7407 / 7408: 3.4.1.7 selected work and force–displacement areas; 3.4.1.8 selected conservation of energy, gravitational energy and resistance.
- OCR A H156 / H556: 3.3.1(a)–(e) work and energy conservation; 3.3.2(b) selected uniform-field gravitational energy. Power and efficiency are not assessed here.

The Lumen Line installation

A team installs a moving light sculpture in a former railway tunnel. Different stages involve a rail trolley, a counterweight and a display carriage. Treat stated forces as constant unless a graph shows otherwise.

Show working and signs. Use g = 9.81 N kg^{-1} and keep guard digits. The 37 marks reward distinct outcomes. Accept equivalent valid methods and consistent consequential work.

A Language and direction

1. Define work done by a force. State what it means for one joule of work to be done. [2 marks]

Answer / mark points: Work is the product of a force and the displacement of its point of application in the force direction. [1] One joule is the work done by a force of 1 N moving its point of application 1 m in that direction. [1]

Teacher prompt / common error: Accept force component along the displacement multiplied by displacement. A force acting without the required displacement does no work.

2. A technician walks 25 m horizontally while supporting equipment with an upward force of 180 N. Calculate the work done by this upward force and explain your answer. [2 marks]

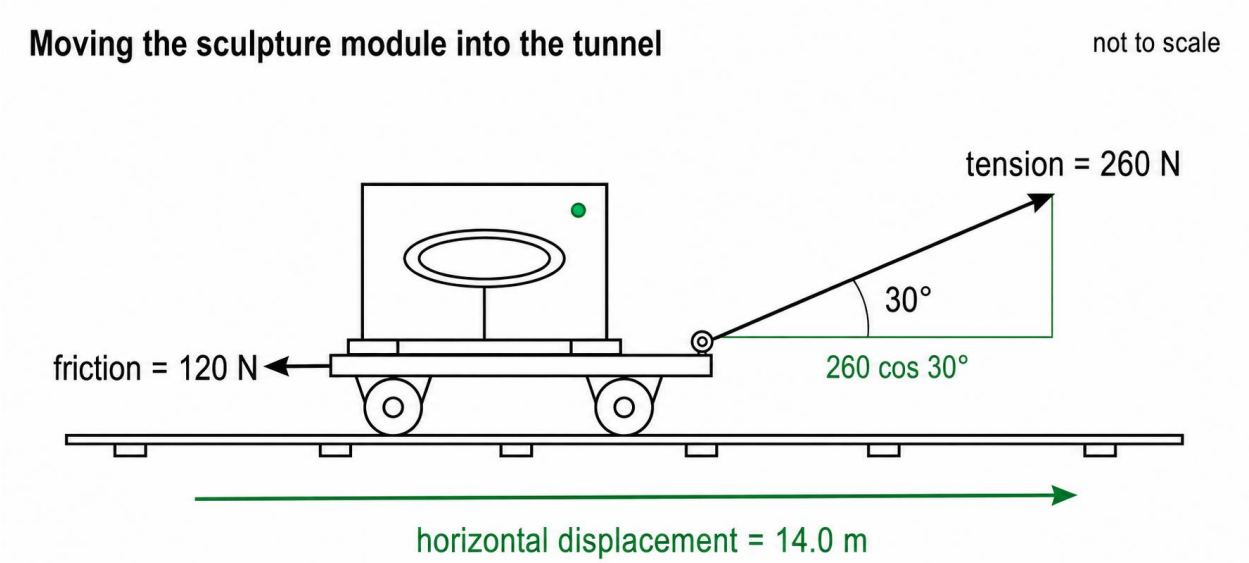
Answer / mark points: W = 180 × 25 × cos 90° = 0 J. [1] The upward support force is perpendicular to the horizontal displacement. [1]

Teacher prompt / common error: The question asks about this force, not the technician's total metabolic energy expenditure.

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B Moving the sculpture module

The trolley moves horizontally. The diagram shows the cable tension, friction and displacement. Its weight and normal contact force are vertical.



3. Use the trolley diagram. Calculate the work done on the trolley by the cable tension during the 14.0 m movement. [2 marks]

Answer / mark points: W = Fs cos θ = 260 × 14.0 × cos 30° [1] = 3152.33… J, approximately 3.15 kJ. [1]

Teacher prompt / common error: The displacement is horizontal; use the component of tension along it.

4. Calculate the work done on the trolley by the 120 N frictional force during this movement. Include its sign. [1 mark]

Answer / mark points: W = −120 × 14.0 = −1680 J, or −1.68 kJ. [1]

Teacher prompt / common error: Friction acts opposite to the displacement. Its work on the trolley is negative.

5. Calculate the net work done on the trolley by all forces. State which of the trolley's energy stores increases. [2 marks]

Answer / mark points: Net work = 3152.33… − 1680 = 1472.33… J, approximately +1.47 kJ. [1] The trolley's kinetic energy increases. [1]

Teacher prompt / common error: Use unrounded working. Work by the cable is not the same as net work.

6. Explain why the weight and normal contact force each do zero work on the trolley during its horizontal movement. [1 mark]

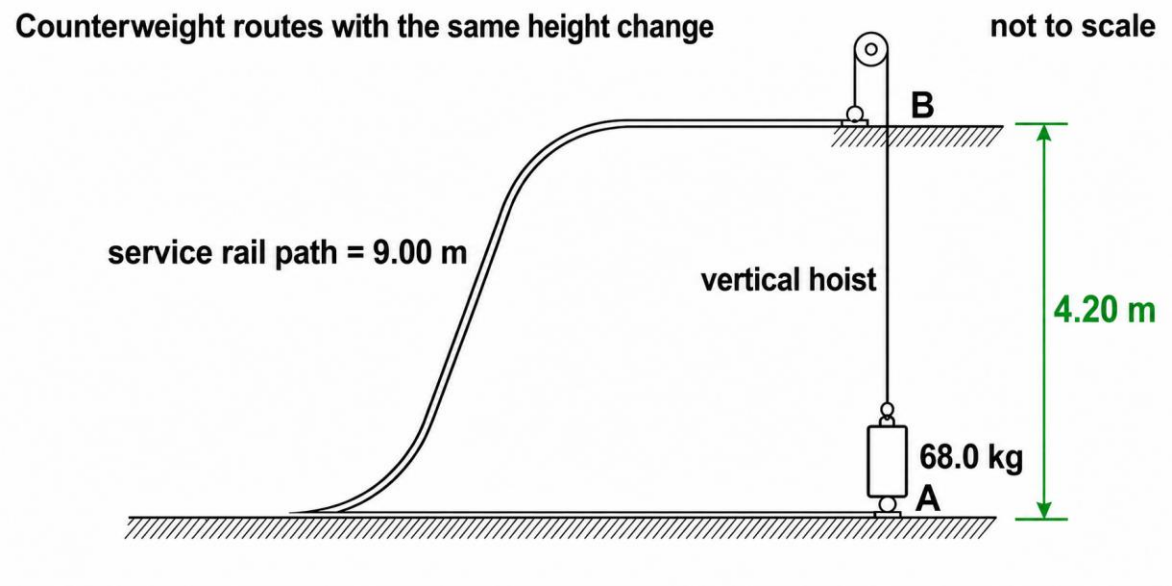
Answer / mark points: Both forces act perpendicular to the displacement, so their components along the displacement are zero. [1]

Teacher prompt / common error: One clear perpendicular-force argument covers both forces; do not award twice for repeating it.

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C Raising the counterweight

The two routes connect the same lower point A and upper point B. The counterweight gains the same vertical height by either route.



7. The 68.0 kg counterweight moves from A to B. Identify the distance relevant to its weight, then calculate the work done against gravity. Use g = 9.81 N kg^{-1}. [2 marks]

Answer / mark points: Use the vertical height change, 4.20 m, not the 9.00 m service-rail path. [1] Work against gravity = mgΔh = 68.0 × 9.81 × 4.20 = 2801.736 J, approximately 2.80 kJ. [1]

Teacher prompt / common error: The relevant displacement is measured parallel to the weight. Work by gravity itself is −2.80 kJ for the ascent.

8. During the vertical lift, the hoist pulls upwards with a constant force of 760 N through 4.20 m. The counterweight moves at constant speed against resistance. Apart from the gravitational increase, all energy supplied by the hoist is transferred to thermal stores. Calculate that thermal transfer. [2 marks]

Answer / mark points: Work by the hoist = 760 × 4.20 = 3192 J. [1] Constant speed gives $\Delta E_k = 0$, so thermal transfer = 3192 − 2801.736 = 390.264 J, approximately 390 J. [1]

Teacher prompt / common error: The constant-speed condition is essential. Equivalently, resistance = 760 − 68.0 × 9.81 = 92.92 N, and resistance × distance = 390.264 J.

9. If resistive forces are ignored, explain why the work done against gravity is the same for the vertical route and the longer service-rail route. Does that prove that total hoist work is always the same for the two real routes? [2 marks]

Answer / mark points: The gravitational energy increase depends on the same vertical height change, not route length. [1] No: real routes may have different work against resistance or different kinetic-energy changes, changing total hoist work. [1]

Teacher prompt / common error: Separate work against gravity from work by a particular drive; the latter can include other energy changes.

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D Cable alignment and energy recovery

10. During cable alignment, a force of 190 N does 870 J of work while the module moves 8.50 m. Determine the angle between this force and the displacement. [2 marks]

Answer / mark points: cos θ = W/(Fs) = 870/(190 × 8.50). [1] θ = 57.404…°, approximately 57.4°. [1]

Teacher prompt / common error: Check that the ratio is dimensionless and lies between −1 and +1 before taking inverse cosine.

11. A 95 N braking force then acts directly opposite to the module's motion over 2.60 m. Calculate the work done by this force. [1 mark]

Answer / mark points: W = 95 × 2.60 × cos 180° = −247 J. [1]

Teacher prompt / common error: The negative sign describes energy transferred away from the moving module by this force.

12. In a separate constant-speed regenerative descent, the counterweight's gravitational energy decreases by 5.60 kJ. The battery gains 4.10 kJ. All remaining energy is transferred to thermal stores. Calculate this transfer and explain why the remaining energy has not been destroyed. [2 marks]

Answer / mark points: Thermal transfer = 5.60 − 4.10 = 1.50 kJ. [1] This energy is dispersed to thermal stores in the apparatus and surroundings; total energy remains conserved. [1]

Teacher prompt / common error: The battery gains chemical energy. Do not describe energy as used up or destroyed.

13. Two arrangements tow a display carriage through the same horizontal distance of 16.0 m. A uses 310 N at 20° to the motion; B uses 360 N at 42°. Calculate the work done by each and decide which transfers more energy to the carriage. [3 marks]

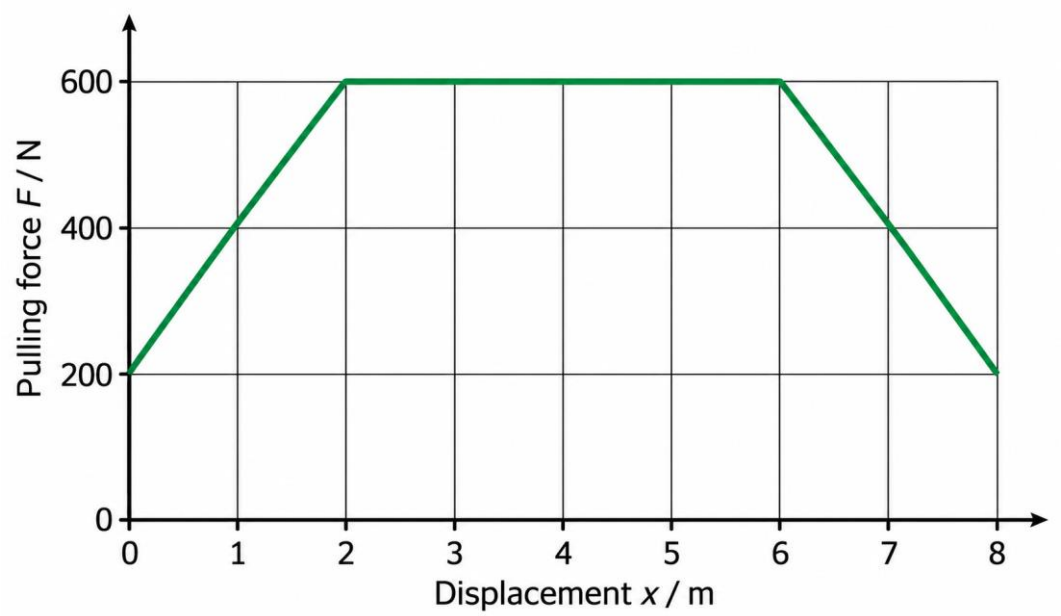
Answer / mark points: A: W = 310 × 16.0 × cos 20° = 4660.88… J, approximately 4.66 kJ. [1] B: W = 360 × 16.0 × cos 42° = 4280.51… J, approximately 4.28 kJ. [1] Choose A for greater work: its larger component along the displacement outweighs its smaller force magnitude. [1]

Teacher prompt / common error: Comparing force magnitudes alone gives the wrong decision.

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E A variable-force pull

In a separate horizontal test, the controller varies its pulling force with displacement as shown. The plotted force is parallel to the carriage's displacement and is not the resultant force.



14. For the variable-force test shown, determine the work done by the pulling force from x = 0 to x = 8.0 m. Show how you divide the graph into areas. [3 marks]

Answer / mark points: Work equals the area under the force–displacement graph. End trapezia: each ½ × (200 + 600) × 2 = 800 J. [1] Middle rectangle: 600 × 4 = 2400 J. [1] Total = 800 + 2400 + 800 = 4000 J = 4.00 kJ. [1]

Teacher prompt / common error: Accept a 200 × 8 rectangle plus the area above it: 1600 + 400 + 1600 + 400 = 4000 J. Area has units N m = J, not N s.

15. In that same 8.0 m horizontal test, a constant 150 N resistance also acts opposite to the motion. Other forces do no work. Calculate the change in the carriage's kinetic energy. [2 marks]

Answer / mark points: Work by resistance = −150 × 8.0 = −1200 J. [1] ΔE_k = net work = 4000 − 1200 = +2800 J, so kinetic energy increases by 2.80 kJ. [1]

Teacher prompt / common error: The plotted force is the pulling force, not the resultant. Do not equate its area alone to the kinetic-energy change.

16. A technician models the variable pull by 200 N, the mean of its endpoint values. Explain why this underestimates the work. Determine the constant force that would do the same work over 8.0 m. [2 marks]

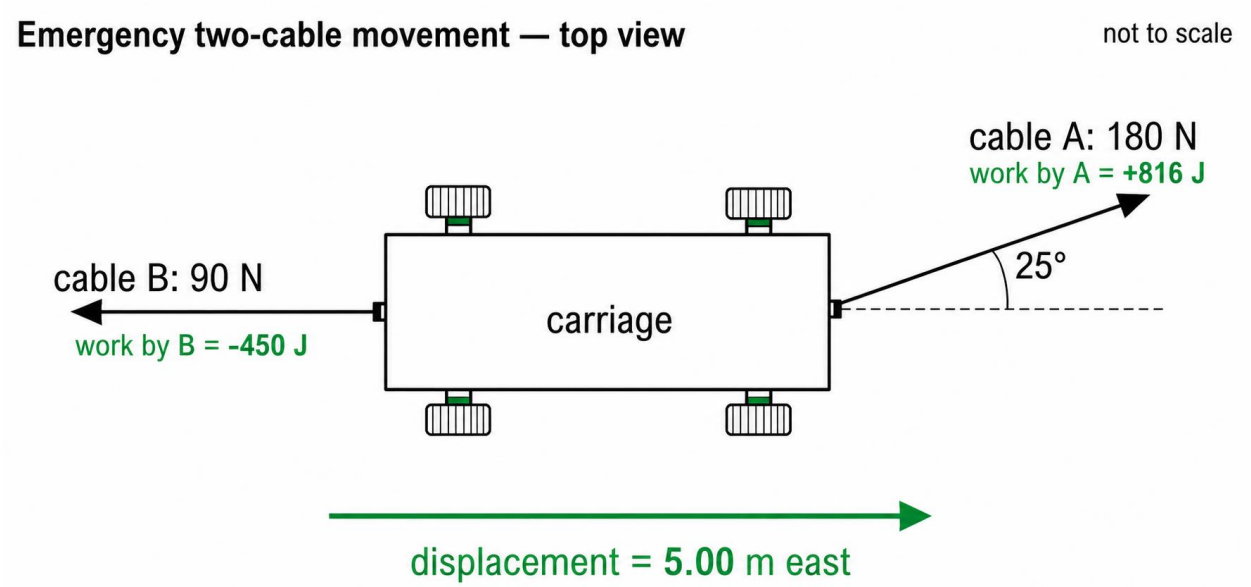
Answer / mark points: The force exceeds 200 N throughout the interior of the interval and remains at 600 N for 4 m, so the endpoint mean misses substantial area. [1] Correct equivalent constant force = W/s = 4000/8.0 = 500 N. [1]

Teacher prompt / common error: Averaging endpoint values works for a straight-line force variation over the whole interval, not this three-segment graph.

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F The emergency two-cable test

This top view shows two cable forces acting while the carriage moves east. Determine the work done by each cable, then evaluate the technician's claim.



17. In the emergency two-cable diagram, the carriage moves 5.00 m east. Calculate the work done by cable A. [2 marks]

Answer / mark points: $W_A = 180 \times 5.00 \times \cos 25° $ [1] = 815.677… J, approximately +816 J. [1]

Teacher prompt / common error: This is a top view. The 25° angle is measured from the eastward displacement.

18. Calculate the work done by cable B and hence the total work done by the two cables on the carriage. [2 marks]

Answer / mark points: $W_B = 90 \times 5.00 \times \cos 180° = -450$ J. [1] $W_A + W_B = 815.677… - 450 = +365.677…$ J, approximately +366 J. [1]

Teacher prompt / common error: This is work by these two cables, not automatically net work if other forces also do work.

19. A technician says, "Both cables transfer energy to the carriage because both exert a force on it." Evaluate this statement using the force and displacement directions. [2 marks]

Answer / mark points: Cable A has a component along the displacement and does positive work, transferring energy to the carriage. [1] Cable B acts opposite to the displacement and does negative work, transferring energy away from the carriage. [1]

Teacher prompt / common error: Describe the work done by each force, not a force as having or using up energy.

Review: identify the force, its direction and the displacement before calculating work. Net work changes kinetic energy; energy transferred by one force may have several destinations.

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