Forces on slopes 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

Specification points covered

AQA 7407 / 7408: 3.4.1.1 selected vector resolution, inclined-plane forces and equilibrium; 3.4.1.5 selected constant-mass second-law applications.
OCR A H156 / H556: 2.3.1(d); 3.2.1(a), (c), (d) tension, normal force and friction only, (e), (f) resolved straight-line motion. Upthrust is not assessed here.

Main scenario

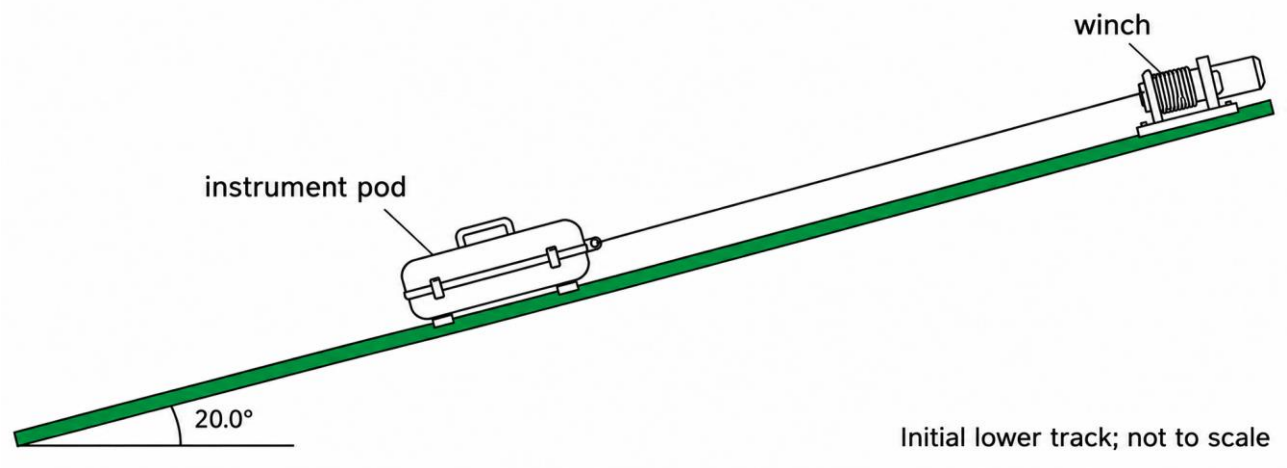
A field team winches a 30.0 kg instrument pod up the access track to a cliffside weather station. The lower track is at 20.0° to the horizontal. The cable is always parallel to the local track.

Take uphill as positive and g = 9.81 m s^{-2}. Neglect air resistance. Friction is negligible unless a force is supplied. Keep guard digits when using earlier results.

Teaching focus

31 marks. Resolve forces before applying the second law. Keep guard digits and distinguish individual forces, resultants and acceleration. Accept equivalent methods and consistent consequential work.

A The lower-track model



1. Calculate the weight of the instrument pod. [1 mark]

Answer / mark points: W = mg = 30.0 × 9.81 = 294.3 N, or 294 N to 3 s.f. [1]
Teacher prompt / common error: Weight is a force, not a mass. Use 294.3 N internally in later calculations.

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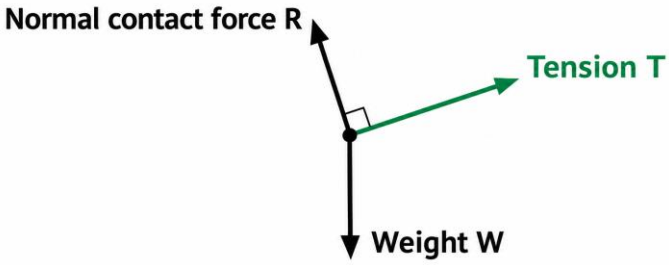
A Forces and motion on the lower track

2. In the blank space below, draw a free-body diagram for the pod. Include and label all the forces acting on it. Friction is negligible. [3 marks]

Answer / mark points: Weight W acts vertically downwards. [1] Cable tension T acts uphill along the cable, parallel to this track. [1] Normal contact force R acts perpendicular to the track, away from its surface. [1]
Teacher prompt / common error: Draw only forces on the pod: no friction in this model and no acceleration or separate resolved-weight arrows. Tension follows the actual cable, parallel to the track here.



20.0° track; directions only, not to scale

3. Calculate the component of the pod's weight parallel to the 20.0° track. State its direction. [1 mark]

Answer / mark points: Parallel component = mg sin 20.0° = 100.6565… N, approximately 101 N down the track. [1]
Teacher prompt / common error: A direct resolved-component result earns one mark. Do not confuse down the track with vertically downward.

4. Calculate the normal contact force exerted by the track on the pod. [1 mark]

Answer / mark points: There is no perpendicular acceleration and the cable has no perpendicular component: R = mg cos 20.0° = 276.5515… N, approximately 277 N. [1]
Teacher prompt / common error: This relationship depends on the stated force geometry. It is not a universal formula for every cable arrangement.

5. The tension in the cable is 165 N. Calculate the acceleration of the pod. Friction is negligible. [2 marks]

Answer / mark points: Taking uphill as positive, F = 165 − mg sin 20.0°. [1] a = F/m = (165 − 100.6565…)/30.0 = +2.14478… m s^{-2}, or 2.14 m s^{-2} uphill. [1]
Teacher prompt / common error: Use unrounded intermediate values. To 3 s.f., 2.14478… rounds to 2.14, not 2.15.

6. A pupil writes, 'the tension causes a 165 N acceleration'. Explain why this is not a correct description. Use the terms tension, resultant force and acceleration. [2 marks]

Answer / mark points: Tension is an individual force measured in N, not an acceleration. [1] Combine all forces to obtain the resultant; acceleration is resultant force divided by mass and has units m s^{-2}. [1]
Teacher prompt / common error: The relevant force in F = ma is the resultant, not the cable tension alone.

7. The cable tension is adjusted so that it equals the component of weight parallel to the track. The pod is moving uphill. Describe its subsequent motion and explain your answer. [2 marks]

Answer / mark points: Tension balances the downhill weight component, giving zero resultant force and zero acceleration. [1] The pod continues uphill at constant velocity. [1]
Teacher prompt / common error: Balanced forces do not require the pod to be stationary. Friction is still negligible in this part.

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B Friction and the winch setting

New condition
During the next haul, a frictional force of 18.0 N acts down the track while the pod moves uphill.

8. The pod now experiences a frictional force of 18.0 N down the track. Calculate the cable tension required for it to move uphill at constant velocity. [2 marks]

Answer / mark points: Constant velocity requires zero resultant: $T - mg \sin 20.0° - 18.0 = 0$. [1] $T = 100.6565\ldots + 18.0 = 118.6565\ldots$ N, approximately 119 N. [1]

Teacher prompt / common error: The tension balances both downhill forces.

9. The cable tension is increased to 160 N while the frictional force remains 18.0 N. Calculate the acceleration of the pod. [2 marks]

Answer / mark points: $F = 160 - mg \sin 20.0° - 18.0$. [1] $a = (160 - 100.6565\ldots - 18.0)/30.0 = +1.37812\ldots$ m s^{-2}, or 1.38 m s^{-2} uphill. [1]

Teacher prompt / common error: Subtract the supplied friction force when uphill is positive. No coefficient of friction is needed.

10. State the direction of the frictional force on the pod while it moves uphill. Explain why friction acts in this direction. [2 marks]

Answer / mark points: Friction acts down the track. [1] It opposes the pod's sliding motion relative to the stationary track surface, which is uphill. [1]

Teacher prompt / common error: Friction opposes relative motion or its tendency at the contact. It does not always act opposite to an object's overall motion; the stated sliding-on-a-fixed-track model matters.

11. The track becomes wet and the frictional force decreases to 8.0 N while the tension stays at 160 N. Calculate the new acceleration. State how it compares with your answer to question 9. [2 marks]

Answer / mark points: $a = (160 - mg \sin 20.0° - 8.0)/30.0 = +1.71145\ldots$ m s^{-2}, or 1.71 m s^{-2} uphill. [1] This is greater than Q9 because the smaller opposing friction gives a larger resultant for the same mass. [1]

Teacher prompt / common error: The increase is $10.0/30.0 = 0.333\ldots$ m s^{-2}. Accept equivalent comparisons supported by consistent consequential calculations.

C The steeper upper track

New condition
The pod reaches a straight upper section of track at 30.0° to the horizontal. For questions 12-17, the pod still has a mass of 30.0 kg unless stated otherwise.

12. Calculate the component of the pod's weight parallel to the 30.0° track. State its direction. [1 mark]

Answer / mark points: Parallel component = $mg \sin 30.0° = 147.15$ N, approximately 147 N down the track. [1]

Teacher prompt / common error: The steeper track increases the downhill component, although the weight has not changed.

13. Calculate the normal contact force exerted by the 30.0° track on the pod. [1 mark]

Answer / mark points: $R = mg \cos 30.0° = 254.8713\ldots$ N, approximately 255 N. [1]

Teacher prompt / common error: The normal force decreases as this slope becomes steeper; it is not equal to the full weight.

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C Upper-track operating decisions

Continue on the 30.0° track. Use 30.0 kg except for the sleeved pod in Q16; Q17 explicitly returns to the original pod.

14. The frictional force is 20.0 N and the cable tension is 200 N. Calculate the acceleration of the pod on the 30.0° track. [2 marks]

Answer / mark points: F = 200 − 147.15 − 20.0 = 32.85 N uphill. [1] a = 32.85/30.0 = 1.095 m s^{-2}, or 1.10 m s^{-2} to 3 s.f. [1]
Teacher prompt / common error: Do not round 147.15 N before subtracting. Tension and resultant force are different quantities.

15. The winch has a safe maximum cable tension of 220 N. Determine whether it can accelerate the pod at 1.50 m s^{-2} on the 30.0° track against a frictional force of 20.0 N. Show your reasoning. [3 marks]

Answer / mark points: Required tension satisfies T − mg sin 30.0° − 20.0 = ma. [1] T = 30.0 × 1.50 + 147.15 + 20.0 = 212.15 N, approximately 212 N. [1] This is below 220 N, so the winch can provide the requested acceleration within its stated tension limit. [1]
Teacher prompt / common error: Credit the force-balance method, required tension and justified decision. Comparison and conclusion form one decision point, not two extra marks.

16. A protective sleeve increases the mass of the pod to 38.0 kg. The cable tension is 220 N and friction is 20.0 N. Calculate the acceleration on the 30.0° track. [2 marks]

Answer / mark points: Using the new mass, F = 220 − 38.0 × 9.81 × sin 30.0° − 20.0 = 220 − 186.39 − 20.0 = 13.61 N. [1] a = 13.61/38.0 = +0.358158… m s^{-2}, or 0.358 m s^{-2} uphill. [1]
Teacher prompt / common error: Use 38.0 kg in both the weight component and F = ma. Do not show rounded 186 N in an equation that then uses 186.39 N internally.

17. For the original 30.0 kg pod without the protective sleeve, a pupil says, "At 30.0°, the normal contact force is 30% of the weight because the slope is 30.0°." Explain why this is incorrect. State the correct relationship and use it to calculate the normal contact force. [2 marks]

Answer / mark points: The numerical angle is not a percentage: perpendicular equilibrium gives R/W = cos 30.0°, not 0.30. [1] For the specified original 30.0 kg pod, R = 30.0 × 9.81 × cos 30.0° = 254.8713… N, approximately 255 N. [1] This is about 86.6% of its weight.
Teacher prompt / common error: The question explicitly returns to the original mass. Do not carry the 38.0 kg sleeve mass into this separate comparison.

Review: resolve the actual force directions, use the resultant in F = ma, and state the physical assumptions behind the normal-force calculation.

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