physics UK
Smarter practice. Stronger understanding

SOLUTIONS
ATTEMPT | CHECK | CORRECT | IMPROVE

Power and efficiency 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 | 36 marks

Specification points covered

- AQA 7407 / 7408: 3.4.1.7 selected power and efficiency; 3.4.1.8 selected energy transfers.
- OCR A H156 / H556: 3.3.3(a)–(c) power, P = Fv derivation and mechanical efficiency.

The Kepler Ridge transport system

An observatory tests an instrument carrier and hoist. Motor output is work by traction; useful hoist output is defined per task.

1. From work done to power [4 marks]

(a) State what is meant by power and state what it means for a device to have a power of one watt. [2 marks]

(b) Starting with P = W/t, W = Fs and v = s/t, derive P = Fv for a constant force acting parallel to motion at constant speed. [2 marks]

Answer / mark points: Power is the rate of energy transfer or work done. [1] One watt is one joule transferred per second. [1] For the stated parallel constant force and constant speed: P = W/t = Fs/t [1] = F(s/t) = Fv. [1]

Teacher prompt / common error: P = Fv describes work by a specified force. For an angled force, use its component parallel to the velocity. Over a changing-speed interval the finite-time derivation gives average power and average speed.

2. Power and efficiency check [5 marks]

Two separate bench tests check the carrier's actuator at different operating points.

(a) Test A transfers 72.0 kJ in 45.0 s. Calculate the average power and decide if it exceeds 1.50 kW. [2 marks]

(b) In test B, traction is 850 N at 3.60 m s^{-1}. Calculate the mechanical output power. [1 mark]

(c) Test B input is 4.20 kW. Calculate efficiency and assess the claim that it is at least 80%. [2 marks]

Answer / mark points: (a) P = 72000/45.0 = 1600 W = 1.60 kW. [1] It exceeds 1.50 kW, so the test-A limit is not met. [1] (b) P = 850 × 3.60 = 3060 W = 3.06 kW. [1] (c) Efficiency = 3.06/4.20 = 0.72857… = 72.9%. [1] This is below 80%, so the claim is not supported at this operating point. [1]

Teacher prompt / common error: Do not combine the test-A average power with the test-B input power. Use useful output and total input from the same operating point.

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

3. Constant-speed climb [5 marks]

The Kepler Ridge instrument carrier transports telescope equipment up a 12.0° service rail at a constant speed of 3.20 m s^{-1}. Its mass is 1800 kg and the total resistance is 1.60 kN. Use g = 9.81 N kg^{-1}. The schematic omits the normal contact force; it is not a complete free-body diagram.

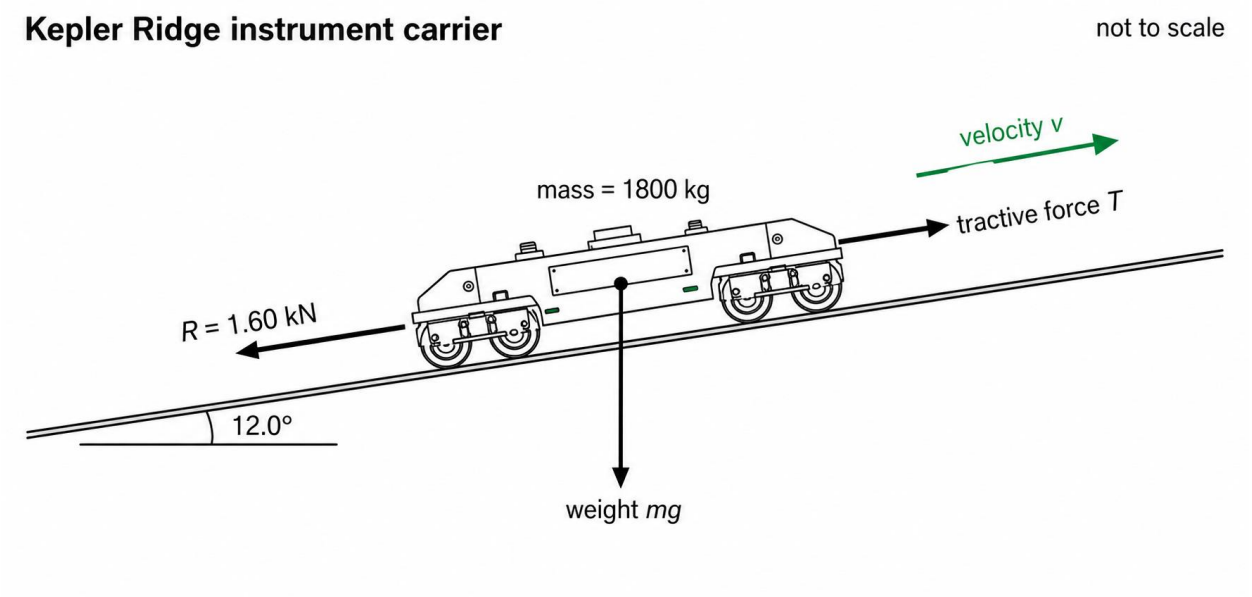
(a) Calculate the component of the carrier's weight acting down the slope. [1 mark]

(b) Calculate the tractive force provided by the motor. [1 mark]

(c) Calculate the useful mechanical output power of the motor. [1 mark]

(d) The resultant force on the carrier is zero. Explain why the motor's useful output power is not zero. [2 marks]

Kepler Ridge instrument carrier not to scale



Answer / mark points: (a) $W_{parallel}$ = 1800 × 9.81 × sin 12.0° = 3671.3046… N, approximately 3.67 kN down the rail. [1] (b) T = $W_{parallel}$ + R = 5271.3046… N, approximately 5.27 kN. [1] (c) P_{motor} = Tv = 16868.17… W, approximately 16.9 kW. [1] (d) The zero resultant means the kinetic energy is unchanged, not that the motor's traction is zero. [1] Its non-zero output increases gravitational energy and supplies the transfer against resistance. [1]

Teacher prompt / common error: Use traction, not resultant force, for motor mechanical output. As a check, 11.748… kW increases gravitational energy and 5.120 kW is transferred against resistance; together they equal the 16.868… kW output.

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

4. Which force belongs in P = Fv? [4 marks]

The carrier continues up the slope at the constant speed described in Question 3. For each transfer rate, identify the force that should be used in P = Fv.

(a) The useful mechanical output power of the motor. [1 mark]

(b) The rate at which the carrier's gravitational energy store increases. [1 mark]

(c) The rate at which energy is transferred to thermal stores by resistance. [1 mark]

(d) The rate of change of the carrier's kinetic energy. [1 mark]

Answer / mark points: (a) Motor tractive force T. [1] (b) Magnitude of the component of weight down the rail, mg sin 12.0°. [1] (c) Resistance magnitude R. [1] (d) Resultant force along the rail, which is zero here. [1]

Teacher prompt / common error: For (b) and (c), these positive magnitudes give the rates of gravitational increase and dissipation. The work rates of gravity and resistance on the carrier itself are negative for uphill motion. The net work rate is the kinetic-energy change rate.

5. Accelerating uphill [4 marks]

The 1800 kg carrier is now travelling uphill at 2.40 m s^{-1} and accelerating at 0.300 m s^{-2}. The resistance is 1.90 kN. The slope angle remains 12.0°. Use g = 9.81 N kg^{-1}.

(a) Calculate the resultant force on the carrier. [1 mark]

(b) Calculate the tractive force provided by the motor. [1 mark]

(c) Calculate the useful mechanical output power of the motor at this instant. [1 mark]

(d) Calculate the rate at which the carrier's kinetic energy is increasing at this instant. [1 mark]

Answer / mark points: (a) $F_{resultant}$ = ma = 1800 × 0.300 = 540 N uphill. [1] (b) T = 540 + 1900 + 3671.3046… = 6111.3046… N, approximately 6.11 kN. [1] (c) P_{motor} = T × 2.40 = 14667.13… W, approximately 14.7 kW. [1] (d) Rate of kinetic-energy increase = $F_{resultant}$ × v = 540 × 2.40 = 1296 W, approximately 1.30 kW. [1]

Teacher prompt / common error: Only the net work rate changes kinetic energy. The remaining motor output increases gravitational energy and transfers energy against resistance. Keep unrounded forces for later calculations.

Continue your physics journey

Videos, practice and support for your next step

www.physicsuk.co.uk

6. Hoisting a calibration package [4 marks]

A winch raises a 620 kg calibration package vertically through 18.0 m in 34.0 s. The package begins and ends at rest. Its electrical input power is 4.20 kW. The only useful transfer is the package's gravitational energy increase; all remaining input energy is dissipated to thermal stores. Use g = 9.81 N kg^{-1}.

(a) Calculate the useful energy transferred to the package's gravitational energy store. [1 mark]

(b) Calculate the electrical energy supplied to the winch. [1 mark]

(c) Calculate the efficiency of the winch. [1 mark]

(d) Calculate the energy dissipated during the lift. [1 mark]

Answer / mark points: (a) $\Delta E_p = 620 \times 9.81 \times 18.0 = 109479.6$ J, approximately 109 kJ. [1] (b) $E_{input} = 4200 \times 34.0 = 142800$ J, approximately 143 kJ. [1] (c) Efficiency = 109479.6/142800 × 100 = 76.666…%, approximately 76.7%. [1] (d) $E_{thermal} = 142800 - 109479.6 = 33320.4$ J, approximately 33.3 kJ. [1]

Teacher prompt / common error: The start/end-at-rest condition removes any net kinetic-energy change. The stated energy account makes the remaining input a thermal transfer. Use guard digits, not rounded 109 kJ and 143 kJ.

7. Choosing an operating mode [5 marks]

The hoist must complete 240 kJ of useful work. In Quiet mode it takes 60.0 s with an input power of 5.00 kW. In Fast mode it takes 40.0 s and receives 320 kJ of input energy.

(a) Calculate the efficiency in each mode. [2 marks]

(b) Calculate the useful output power in each mode. [2 marks]

(c) A technician says, 'Fast mode is better because it is more powerful.' Evaluate this statement. [1 mark]

Answer / mark points: (a) Quiet input = 5.00 × 60.0 = 300 kJ, so efficiency = 240/300 = 80%. [1] Fast efficiency = 240/320 = 75%. [1] (b) Quiet useful output power = 240/60.0 = 4.00 kW. [1] Fast useful output power = 240/40.0 = 6.00 kW. [1] (c) Fast completes the work sooner but is less efficient and uses more energy; the preferred mode depends on whether time or energy use is the priority. [1]

Teacher prompt / common error: Higher power is a greater transfer rate, not automatically a greater efficiency. Credit a justified choice consistent with an explicitly stated priority.

Continue your physics journey

Videos, practice and support for your next step

www.physicsuk.co.uk

8. Constant-power upper section [5 marks]

On a level upper section, the 1800 kg carrier's motor has a constant mechanical output power of 24.0 kW. Resistance does not decrease as speed increases. The values below describe this operating range.

(a) At 4.00 m s^{-1}, calculate the tractive force provided by the motor. [1 mark]

(b) The resistance is 2.40 kN at this speed. Calculate the resultant force and the acceleration. [2 marks]

(c) At 8.00 m s^{-1}, calculate the tractive force. The resistance is now 3.00 kN. [1 mark]

(d) Explain why the carrier has reached its maximum constant speed at 8.00 m s^{-1}. [1 mark]

Answer / mark points: (a) $T = P/v = 24000/4.00 = 6000$ N = 6.00 kN. [1] (b) $F_{resultant} = 6000 - 2400 = 3600$ N. [1] $a = 3600/1800 = 2.00$ m s^{-2}. [1] (c) $T = 24000/8.00 = 3000$ N = 3.00 kN. [1] (d) At 8.00 m s^{-1} traction balances resistance, so acceleration is zero; at greater speeds constant-power traction would be lower while resistance would not be lower, preventing a greater steady speed. [1]

Teacher prompt / common error: At the maximum steady speed the motor still does work. The statement about resistance is needed to justify a maximum, not merely an instantaneous balance.

Review emphasis

Full-credit explanations identify which force is doing the work, distinguish that force from the resultant force, and keep power separate from efficiency.

Continue your physics journey

Videos, practice and support for your next step

www.physicsuk.co.uk