OCR A A Level Physics | Power and efficiency solutions

Matching solutions and teaching prompts for the class review | 34 marks

Specification points covered

- 3.3.3(a) Define power, the unit watt, and use P = W / t.
- 3.3.3(b) Use and derive P = Fv from first principles.
- 3.3.3(c) Calculate the efficiency of a mechanical system.

Class review
Reveal working one step at a time. Before using P = Fv, require pupils to name the energy transfer and identify the force responsible for that transfer.

1. From work done to power [4 marks]

Begin with the definitions that connect energy transfer, force and motion.

(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 the motion. **[2 marks]**

Answer / mark points: (a) Power is the rate of energy transfer, or the rate of doing work. [1] One watt is one joule transferred per second. [1]
(b) P = W / t = Fs / t [1] = F(s / t) = Fv. [1]

Teacher prompt / common error: The derivation assumes that F is the constant force component parallel to the velocity. If the force is angled, use its component along the motion.

2. Power and efficiency check [3 marks]

An engineering team checks three values in the specification for an electric actuator.

(a) The actuator transfers 72.0 kJ of energy in 45.0 s. Calculate its power. **[1 mark]**

(b) It provides a tractive force of 850 N while moving at 3.60 m s^{-1}. Calculate its useful mechanical output power. **[1 mark]**

(c) Its electrical input power is 4.20 kW. Calculate its efficiency at this operating point. **[1 mark]**

Answer / mark points: (a) P = W / t = 72.0 × 10^3 / 45.0 = 1.60 kW. [1]
(b) P = Fv = 850 × 3.60 = 3.06 kW. [1]
(c) efficiency = useful output power / input power × 100 = 3.06 / 4.20 × 100 = 72.9%. [1]

Teacher prompt / common error: Efficiency compares useful output with total input. Power alone does not describe how efficiently a device transfers energy.

3. Constant-speed climb [6 marks]

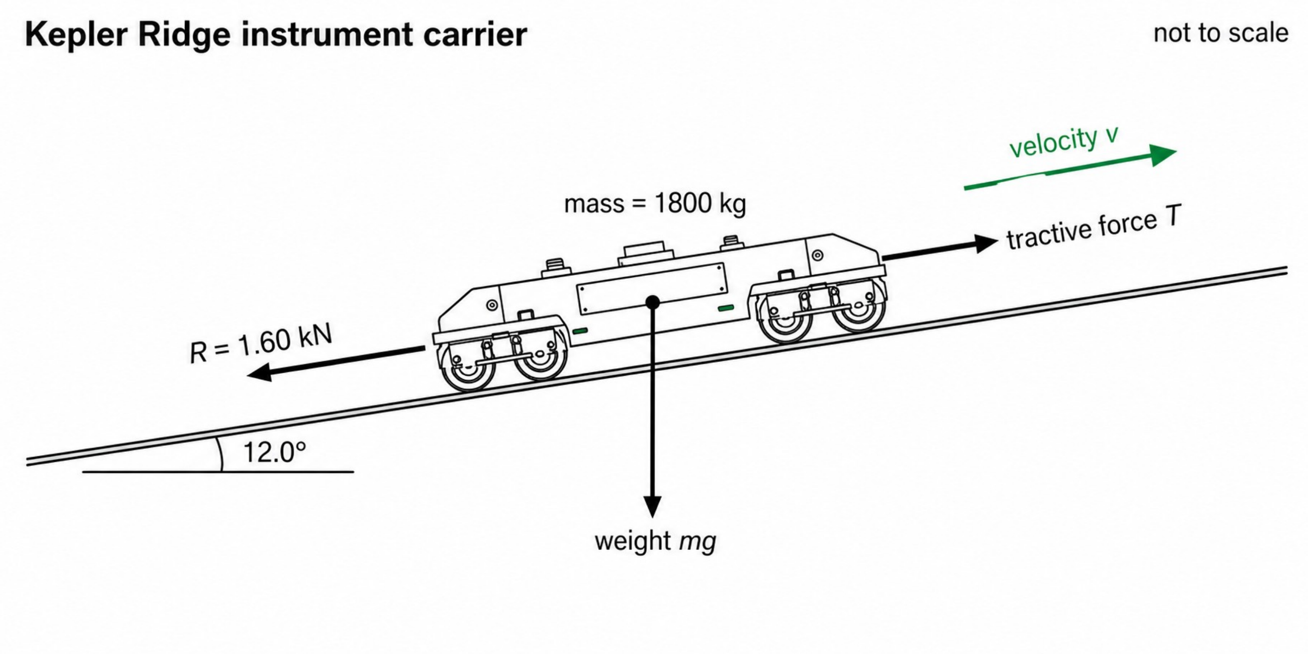
The Kepler Ridge instrument carrier transports telescope equipment up a 12.0° service rail at a constant speed of 3.20 m s⁻¹. The carrier has mass 1800 kg and the total resistance to motion is 1.60 kN. Use g = 9.81 N kg⁻¹.

(a) Calculate the component of the carrier's weight acting down the slope. **[2 marks]**

(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]**



Answer / mark points: (a) Component of weight = mg sin 12.0° [1] = 1800 × 9.81 × sin 12.0° = 3.67 kN down the slope. [1]
(b) Constant speed means zero resultant force, so T = 3.67 + 1.60 = 5.27 kN. [1]
(c) Motor output power = Tv = 5271 × 3.20 = 16.9 kW. [1]
(d) Constant speed means zero acceleration and therefore zero resultant force. [1] The motor still provides a tractive force and transfers energy against gravity and resistance, so its useful output power is not zero. [1]

Teacher prompt / common error: Do not insert the zero resultant force into P = Fv when calculating motor output. Use the motor's tractive force because that is the force doing work on the carrier.

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) Use the tractive force T supplied by the motor. [1]
(b) Use the component of weight parallel to the slope, $mg \sin 12.0°$. [1]
(c) Use the resistance R. [1]
(d) Use the resultant force. It is zero here, so the kinetic energy is not changing. [1]

Teacher prompt / common error: $P = Fv$ is a rate of work done by a specified force. Different forces describe different energy-transfer rates in the same motion.

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) Resultant force = $ma = 1800 \times 0.300 = 540$ N uphill. [1]
(b) $T - 1900 - 3671 = 540$, so $T = 6.11$ kN. [1]
(c) Motor output power = $Tv = 6111 \times 2.40 = 14.7$ kW. [1]
(d) Rate of increase of kinetic energy = resultant force × speed = $540 \times 2.40 = 1.30$ kW. [1]

Teacher prompt / common error: Only 1.30 kW increases the kinetic energy. The remainder of the motor output increases gravitational energy and transfers energy thermally against resistance.

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 electrical input power to the winch is 4.20 kW. 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) Useful energy = mgh = 620 × 9.81 × 18.0 = 109 kJ. [1]
(b) Input energy = Pt = 4200 × 34.0 = 143 kJ. [1]
(c) efficiency = 109480 / 142800 × 100 = 76.7%. [1]
(d) Dissipated energy = 142.8 - 109.5 = 33.3 kJ. [1]

Teacher prompt / common error: Keep input and useful quantities in the same units before forming the efficiency ratio. Efficiency has no unit and cannot exceed 100%.

7. Choosing an operating mode [4 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. **[1 mark]**

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

Answer / mark points: (a) Quiet input energy = 5.00 × 60.0 = 300 kJ; efficiency = 240 / 300 × 100 = 80%. [1] Fast efficiency = 240 / 320 × 100 = 75%. [1]
(b) Quiet useful power = 240 / 60.0 = 4.00 kW; Fast useful power = 240 / 40.0 = 6.00 kW. [1]
(c) Fast mode completes the work sooner and has the greater useful output power, but it is less efficient. The better mode depends on whether time or energy use is the priority. [1]

Teacher prompt / common error: More powerful does not mean more efficient. Power is the rate of transfer; efficiency is the fraction of the input transferred usefully.

8. Constant-power upper section [5 marks]

On a level upper section, the carrier's motor has a constant mechanical output power of 24.0 kW. The carrier still has mass 1800 kg.

(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) Tractive force = P / v = 24 000 / 4.00 = 6.00 kN. [1]
(b) Resultant force = 6.00 - 2.40 = 3.60 kN. [1] Acceleration = 3600 / 1800 = 2.00 m s^{-2}. [1]
(c) Tractive force = 24 000 / 8.00 = 3.00 kN. [1]
(d) At constant power, tractive force decreases as speed increases. At 8.00 m s^{-1} the 3.00 kN tractive force balances the 3.00 kN resistance, so the resultant force and acceleration are zero. [1]

Teacher prompt / common error: At maximum speed the motor still transfers energy. The speed stays constant because the forces balance, not because the motor has stopped doing work.

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.