Newton’s laws momentum and impulse 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 | 40 marks

Specification points covered

- AQA 7407 / 7408: 3.4.1.5 Newton’s laws; 3.4.1.6 momentum change and force–time area; 3.4.1.3 selected constant-acceleration distance reasoning.
- OCR A H156 / H556: 3.5.1(a)–(e) laws, momentum, resultant force and impulse; 3.1.1(a) selected speed and distance reasoning.

HarbourLine tests a 600 kg loaded cargo tug and trailer on a straight level port lane. Take rightwards as positive. The operating tests are separate; the towbar is rigid and has negligible mass. Use the stated resultant forces and distinguish mutual interaction forces from forces balanced on one system.

1. Newton's laws - precise statements [4 marks]

Use complete statements about the resultant force and the interacting objects.

(a) State Newton's first law of motion. [1 mark]

(b) State Newton's second law of motion. [1 mark]

(c) State Newton's third law of motion. [2 marks]

Answer / mark points: (a) An object remains at rest or continues to move with constant velocity unless acted on by a resultant force. [1] (b) The resultant force on an object is equal to the rate of change of its momentum and acts in the direction of that change. [1] (c) When two objects interact, the force exerted by A on B is equal in magnitude and opposite in direction to the force exerted by B on A. [1] The paired forces are the same type and act on different objects. [1]

Teacher prompt / common error: For the first law, 'constant velocity' includes rest. For the second law, F = ma alone is not the full statement. For the third law, name both objects: the pair never acts on one object.

2. Momentum is a vector [5 marks]

Take motion to the right as positive throughout this question. The total mass of the loaded tug and trailer is 600 kg.

(a) Write the equation that defines linear momentum and state its SI unit. [1 mark]

(b) Calculate the momentum when the vehicle travels at +5.0 m s^{-1}. [1 mark]

(c) During a reversing test, the vehicle travels at -1.20 m s^{-1}. Calculate its momentum. [1 mark]

(d) Calculate the change in momentum from the motion in part (b) to the motion in part (c). Include the sign. [2 marks]

Answer / mark points: (a) $p = mv$; SI unit kg m s^{-1} (equivalently N s). [1] (b) $p = 600 \times (+5.0) = +3.0 \times 10^3$ kg m s^{-1}. [1] (c) $p = 600 \times (-1.20) = -720$ kg m s^{-1}. [1] (d) $\Delta p = p_{final} - p_{initial} = -720 - (+3000)$ [1] $= -3720$ kg m s^{-1}. [1]

Teacher prompt / common error: The minus sign belongs to a chosen direction; it does not mean that the momentum has a negative magnitude. Always calculate final minus initial.

3. Resultant force and acceleration [6 marks]

The loaded tug and trailer have total mass 600 kg. During the first test, the driving force is 1.62 kN to the right and the total resistive force is 420 N to the left.

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

(b) Calculate the acceleration of the vehicle. [1 mark]

(c) Later, the vehicle moves at constant velocity while the resistive force is 900 N to the left. Determine the driving force and explain your answer using Newton's first law. [2 marks]

(d) The trailer is disconnected, so the moving mass becomes 390 kg. In a calibration run the same 1.20 kN net force acts. Calculate the new acceleration and explain why it is greater than in part (b). [2 marks]

Answer / mark points: (a) $F_{net} = 1620 - 420 = 1200$ N to the right. [1] (b) $a = F_{net}/m = 1200/600 = 2.0$ m s^{-2} to the right. [1] (c) Driving force = 900 N to the right. [1] Constant velocity means zero acceleration, so Newton's first law requires zero resultant force. [1] (d) $a = 1200/390 = 3.08$ m s^{-2} to the right. [1] The same resultant force acts on a smaller mass, so acceleration is greater. [1]

Teacher prompt / common error: Net force is the vector sum of all external forces. 'The forces are balanced' is weaker than stating that the resultant force is zero and therefore acceleration is zero.

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4. Why F = ma is a special case [3 marks]

Use the general momentum form of Newton's second law.

(a) Starting with p = mv and F = Δp / Δt, show that F = ma for an object of constant mass. [2 marks]

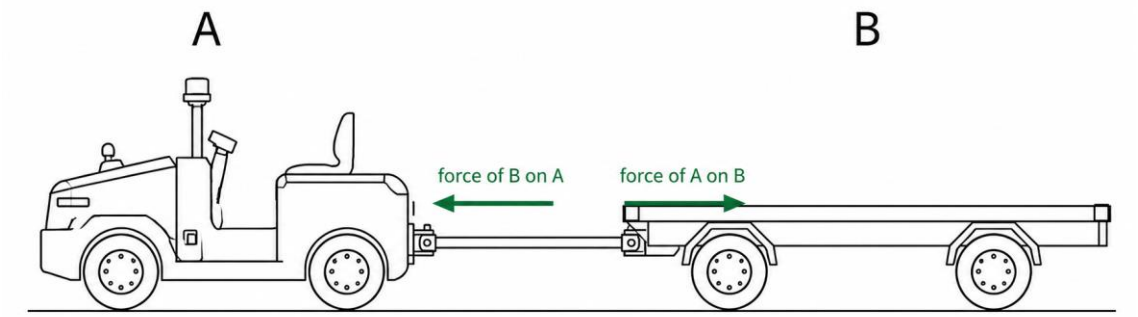
(b) A technician substitutes the 1.62 kN driving force into F = ma for Question 3(b). Explain why this is wrong. [1 mark]

Answer / mark points: (a) For constant mass, Δp = mΔv. [1] Therefore F = Δp/Δt = m(Δv/Δt) = ma. [1] (b) The F in Newton's second law is the net/resultant force, not one individual force; the 420 N resistance must also be included. [1]

Teacher prompt / common error: Do not describe F = ma as a different law. It follows from F = Δp/Δt when the mass is constant.

5. Newton's third law at the towbar [5 marks]

During a separate manoeuvre, tug A pushes trailer B through a rigid, negligible-mass towbar. The towbar exerts a horizontal force of 820 N on B to the right.



(a) State the magnitude, direction and type of the force that B exerts on A. [2 marks]

(b) Explain why the two towbar forces do not cancel when calculating the acceleration of trailer B alone. [1 mark]

(c) At constant velocity, the driving force and total resistance on the complete vehicle are equal and opposite. Give two reasons why these forces are not a Newton's third-law pair. [2 marks]

Answer / mark points: (a) B exerts an 820 N towbar force on A to the left. [1] It is the same type of interaction force as the force of A on B. [1] (b) The pair acts on different objects: only the force of A on B belongs on a free-body diagram of trailer B. [1] (c) Both forces act on the same complete vehicle system. [1] They are not the mutual forces of one interaction: the driving force has a partner on the road, while resistance has partners on the road/air. [1] Do not require different force types; both can involve contact interactions.

Teacher prompt / common error: Equal and opposite is necessary but not sufficient. A third-law pair is the same interaction viewed on two different objects.

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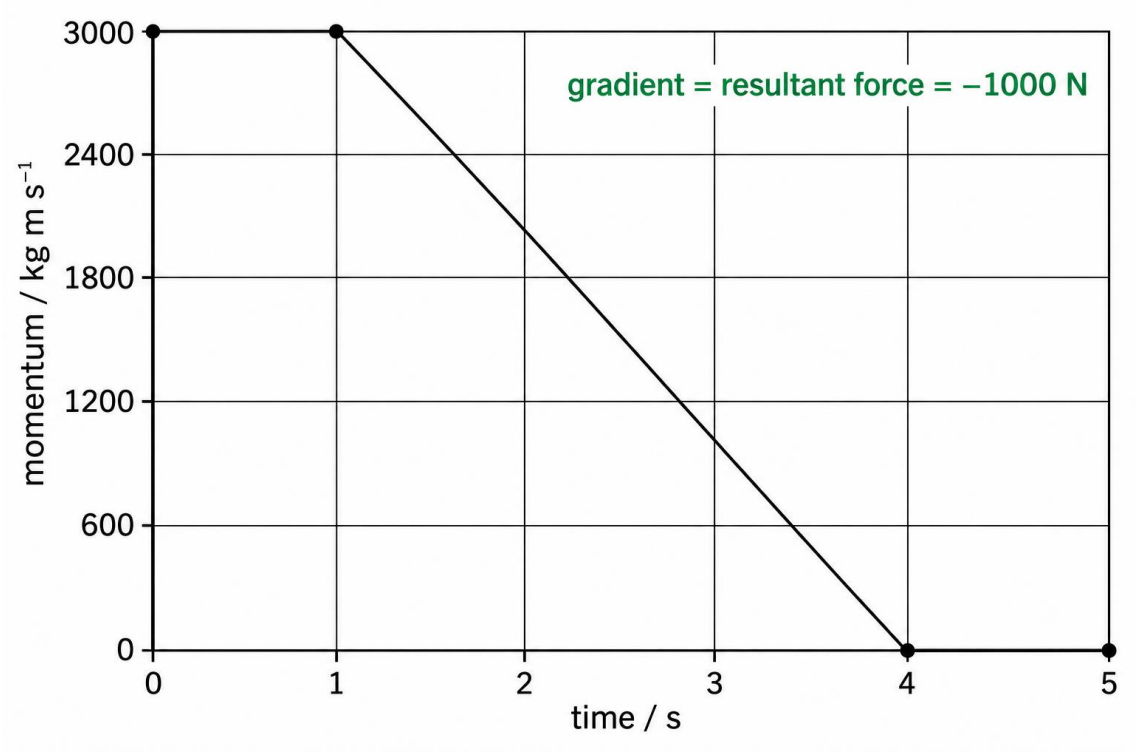
6. Reading a momentum-time graph [7 marks]

The 600 kg loaded vehicle moves to the right. The graph shows its momentum during a controlled braking test.



(a) Determine the net force from t = 0 to t = 1.0 s. [1 mark]

(b) Determine the magnitude and direction of the net force from t = 1.0 s to t = 4.0 s. [2 marks]

(c) Calculate the speed at t = 1.0 s and at t = 4.0 s. [2 marks]

(d) Calculate the distance travelled between t = 1.0 s and t = 4.0 s. [2 marks]

Answer / mark points: (a) The graph is horizontal, so $F_{net} = \Delta p/\Delta t = 0$ N. [1] (b) F_{net} = gradient = (0 - 3000)/(4.0 - 1.0) [1] = -1000 N, so the force has magnitude 1000 N and acts to the left. [1] (c) At 1.0 s, v = p/m = 3000/600 = 5.0 m s^{-1}. At 4.0 s, p = 0 so v = 0 m s^{-1}. [2] (d) Constant mass means velocity decreases linearly from 5.0 to 0 m s^{-1}, so distance = ½(5.0 + 0) × 3.0. [1] Distance = 7.50 m. [1]

Teacher prompt / common error: The gradient of a momentum-time graph is force. The area under this graph is not distance; convert momentum to velocity first because the mass is constant.

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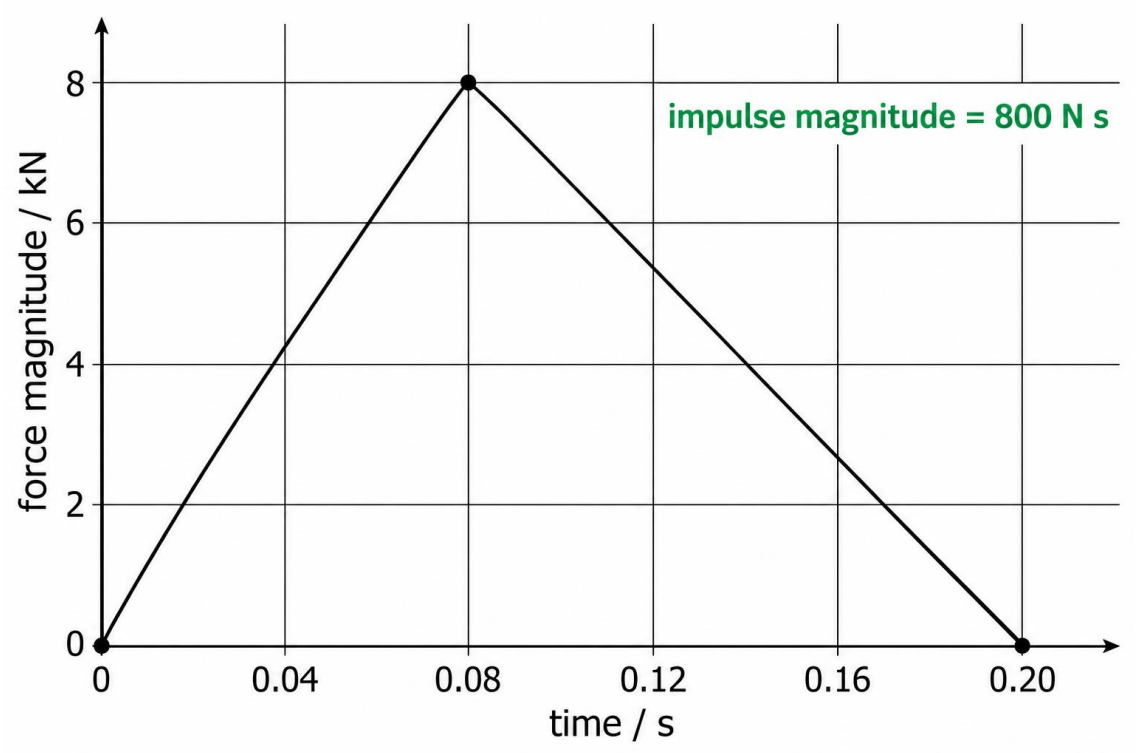
7. Impulse from the pneumatic buffer [6 marks]

The 600 kg vehicle reaches the end-of-lane buffer with momentum +600 kg m s^{-1}. The graph shows the magnitude of the buffer force on the vehicle. This force acts to the left throughout the contact. All other horizontal impulses during contact are negligible. This is a separate test from the braking run.



(a) Use the graph to determine the magnitude of the impulse exerted by the buffer. [2 marks]

(b) Calculate the final momentum of the vehicle, including its sign. [2 marks]

(c) Calculate the velocity after contact and state its direction. [2 marks]

Answer / mark points: (a) Impulse magnitude = area under graph = ½ × 0.20 × (8.0 × 10^3) [1] = 800 N s. [1] (b) The impulse is to the left, so it is -800 N s. $p_{final} = p_{initial}$ + impulse = +600 - 800 [1] = -200 kg m s^{-1}. [1] (c) v = p/m = -200/600 = -0.333 m s^{-1}. [1] The vehicle rebounds to the left. [1]

Teacher prompt / common error: The graph gives the magnitude of force, but the question states its direction. Apply the sign to the impulse before adding it to the initial momentum.

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8. Correct the physics language [4 marks]

For each pupil statement, write one precise correction.

(a) "The momentum is accelerating while the brakes act." [1 mark]

(b) "At constant velocity, no forces act on the vehicle." [1 mark]

(c) "The 1.62 kN driving force in Question 3 is the force used in F = ma." [1 mark]

(d) "A Newton's third-law pair cancels because its forces are equal and opposite." [1 mark]

Answer / mark points: (a) The vehicle accelerates; its momentum decreases or changes while the braking force acts. [1] (b) Forces may act at constant velocity, but their vector sum / resultant force is zero. [1] (c) F in F = ma is the net/resultant force: 1.62 kN - 0.420 kN = 1.20 kN to the right. [1] (d) Third-law forces act on different objects, so they do not cancel on the free-body diagram of either object. [1]

Teacher prompt / common error: Quantities increase, decrease or remain constant; objects accelerate. Encourage pupils to identify the object before naming any force.

Review: name the body, choose a direction, identify the resultant, then use the relevant graph gradient or signed impulse. Third-law forces act on different objects.

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