

Momentum and collisions

AQA GCSE 8463 Physics / 8464 Combined Science Trilogy | Higher only

Worked solutions | Higher only | Route-specific sections labelled

Specification points covered

8463 4.5.7.1 / 8464 6.5.5.1: momentum, $p = mv$, and its direction
8463 4.5.7.2 / 8464 6.5.5.2: conservation of momentum in a closed system
8463 4.5.7.2: numerical collision and separation calculations (Separate only)
8463 4.5.7.3: force and rate of momentum change (optional, Separate only)
Graph skills: 8463 4.5.6.1.5 / 8464 6.5.4.1.5; energy: 4.1.2.1 / 6.1.2.1

A warehouse tests low-speed carts and protective packaging for optical instruments. Each test is separate. Take right as positive and left as negative throughout. Use $p = mv$, with p in kg m s^{-1} , m in kg and v in m s^{-1} . Mass stays constant during each test.

Shared Higher core: Questions 1–4, 42 marks. Separate Higher main route: Questions 1–5, 55 marks. Optional Question 6: 7 extra marks. Accept equivalent precise wording and consistent follow-through. Suggested timings are not classroom-tested. Original PhysicsUK practice, not an official AQA paper or mark scheme.

1 Getting momentum right

The warehouse team checks the meaning of momentum before testing the carts.

1(a) Define momentum. **[1 mark]**

Answer / mark points: The product of an object's mass and velocity, $p = mv$. [1]

1(b) Why is momentum a vector quantity? **[1 mark]**

Answer / mark points: It has magnitude and direction because velocity is a vector (mass is a scalar). [1]

1(c) An empty 12 kg carrier moves at 3.0 m s^{-1} . A different 18 kg carrier moves at 2.0 m s^{-1} in the same direction. A trainee says the heavier one must have more momentum. Use calculations to assess this claim. **[2 marks]**

Answer / mark points: First carrier: $p = 12 \times 3.0 = 36 \text{ kg m s}^{-1}$. Second: $p = 18 \times 2.0 = 36 \text{ kg m s}^{-1}$. [1 for both]

The claim is wrong: their momenta are equal; both mass and velocity matter. [1]

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2 Checking the cart settings

Use the data from each independent test. All velocities in this section are to the right.

2(a) A loaded cart has a total mass of 24 kg and a velocity of 1.5 m s^{-1} . Calculate its momentum. **[1 mark]**

Answer / mark points: $p = mv = 24 \times 1.5 = +36 \text{ kg m s}^{-1}$, to the right. [1]

2(b) A heavier cart has a total mass of 48 kg and a velocity of 0.75 m s^{-1} . Calculate its momentum. **[1 mark]**

Answer / mark points: $p = 48 \times 0.75 = +36 \text{ kg m s}^{-1}$, to the right. [1]

2(c) A small crate has a mass of 6000 g and moves at 0.80 m s^{-1} . Calculate its momentum. **[2 marks]**

Answer / mark points: $m = 6000 / 1000 = 6.0 \text{ kg}$. [1]

$p = 6.0 \times 0.80 = +4.8 \text{ kg m s}^{-1}$, to the right. [1]

2(d) A 120 kg pallet cart has a momentum of 84 kg m s^{-1} to the right. Calculate its velocity. **[1 mark]**

Answer / mark points: $v = p / m = 84 / 120 = +0.70 \text{ m s}^{-1}$, to the right. [1]

2(e) A carrier has a momentum of 18 kg m s^{-1} to the right at a velocity of 0.60 m s^{-1} . Calculate its mass. **[1 mark]**

Answer / mark points: $m = p / v = 18 / 0.60 = 30 \text{ kg}$. [1]

2(f) A 2.50 kg sample cart moves at 150 cm s^{-1} . Calculate its momentum in SI units. **[2 marks]**

Answer / mark points: $v = 150 / 100 = 1.50 \text{ m s}^{-1}$. [1]

$p = 2.50 \times 1.50 = +3.75 \text{ kg m s}^{-1}$, to the right (3.8 kg m s^{-1} to 2 s.f.). [1]



2 Checking the cart settings continued

2(g) A 12 kg empty cart will carry either a 25 kg load or a 26 kg load at 0.80 m s^{-1} . Its momentum magnitude must not exceed 30 kg m s^{-1} . Select the heavier permitted load and justify your choice using both options.

[2 marks]

Answer / mark points: 25 kg load: total mass = 37 kg, so $p = 37 \times 0.80 = 29.6 \text{ kg m s}^{-1}$, within the limit. [1]

26 kg load: total mass = 38 kg, so $p = 30.4 \text{ kg m s}^{-1}$, above the limit. The heavier permitted load is therefore 25 kg. [1]

Teacher prompt: Use the mass of cart plus load, not the load alone. The limit is inclusive.

3 Reading a reversing cart's motion

A cart has a constant mass of 15 kg. Figure 1 shows its velocity during one test. Use the signed velocity, not just the speed, when calculating momentum.

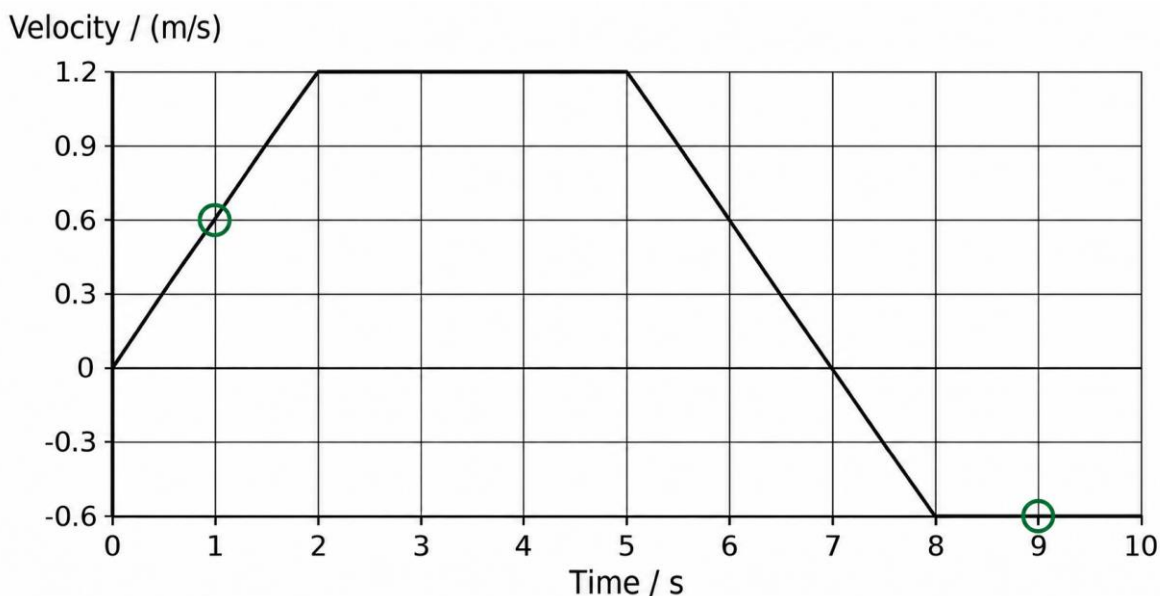


Figure 1

3(a) Read the velocity at 1.0 s from Figure 1 and calculate the cart's momentum at that time. **[2 marks]**

Answer / mark points: $v = +0.60 \text{ m s}^{-1}$. [1]

$p = 15 \times 0.60 = +9.0 \text{ kg m s}^{-1}$, to the right. [1]

3(b) Read the velocity at 9.0 s and calculate the cart's momentum, including its direction. **[2 marks]**

Answer / mark points: $v = -0.60 \text{ m s}^{-1}$. [1]

$p = 15 \times (-0.60) = -9.0 \text{ kg m s}^{-1}$, or 9.0 kg m s^{-1} to the left. [1]

Teacher prompt: The magnitude is 9.0, not -9.0; the signed momentum is -9.0.

3(c) State the time after the start when the cart's momentum is zero. **[1 mark]**

Answer / mark points: 7.0 s. [1] The mass is non-zero, so zero momentum requires zero velocity.

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3 Reading a reversing cart's motion continued

3(d) Compare the cart's momentum at 2.0 s and at 4.0 s. Explain your comparison. **[1 mark]**

Answer / mark points: It is the same at both times ($+18 \text{ kg m s}^{-1}$): mass and velocity are both unchanged. [1]

3(e) Describe how the momentum changes from 0 to 2.0 s and explain the shape of this change. **[2 marks]**

Answer / mark points: The momentum increases linearly from zero. [1]
The velocity increases linearly and mass is constant, so $p = mv$ is proportional to v . [1]

Teacher prompt: Say momentum increases linearly, not momentum accelerates.

3(f) A trainee says the negative momentum at 9.0 s means the cart's mass is negative. Explain the correct interpretation. **[2 marks]**

Answer / mark points: Its mass remains positive (15 kg). [1]
The negative sign means the velocity and momentum are to the left, opposite to the chosen positive direction. [1]

4 Testing conservation with a pair of carts

Cart K moves right towards stationary cart L. They couple on a level low-friction track. Their drives and brakes are off. Unless a different test is stated, compare the instants immediately before and after contact and neglect the resultant external horizontal force on the pair.

4(a) Define the system used to test conservation in this collision and explain why its horizontal momentum can be treated as conserved. **[2 marks]**

Answer / mark points: The system is carts K and L together. [1]
The resultant external horizontal force on that system is negligible over the collision, so total horizontal momentum is conserved. [1]

Teacher prompt: Closed means no resultant external force, not no forces at all. Vertical weight and support balance; internal contact forces can be large.

4(b) K slows down and L begins to move right. Explain how K can lose momentum without violating conservation of momentum. **[2 marks]**

Answer / mark points: K transfers momentum to L through their interaction. [1]
K's individual momentum decreases, but the total momentum of K and L stays the same. [1]

4(c) Predict whether the coupled pair's common speed is greater than, equal to or less than K's speed just before contact. Explain without doing a numerical collision calculation. **[2 marks]**

Answer / mark points: The common speed is less than K's initial speed. [1]
The same total momentum is now carried by the greater combined mass, so $p = mv$ requires a smaller velocity magnitude. [1]

4(d) In a different test, the brakes act during contact. The pair's total momentum changes from 30 kg m s^{-1} right to 24 kg m s^{-1} right. Does this disprove conservation in a closed system? Explain. **[2 marks]**

Answer / mark points: No: the cart pair is not horizontally closed in this test, because the track exerts an external braking force. [1]
Momentum is transferred to the track and Earth; conservation applies to a suitably larger closed system. [1]

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4 Testing conservation with a pair of carts continued

4(e) In another test, two carts start at rest with a compressed spring between them. When released, they move apart. Explain how both can gain momentum while the total remains zero. **[2 marks]**

Answer / mark points: The carts gain equal-magnitude momenta in opposite directions. [1]
Their signed momenta add to zero, matching the initial total; neither cart has to remain at rest. [1]

4(f) Plan a safe small-scale cart experiment to test conservation of horizontal momentum during coupling. Describe the measurements, how to minimise unwanted external effects and how to use repeated results. **[4 marks]**

Answer / mark points: Measure each cart's total mass, including its secured load, with a balance. [1]
Use light gates and flags of known length to find velocities (flag length / interruption time), recording directions immediately before and after coupling. A calibrated video method with distances and times is equivalent. [1]
Use a level low-friction track with drives and brakes off; keep measurements close to contact to reduce external-force effects. Use small carts and secured loads with end stops or a catch tray. [1]
For each run, calculate signed total mv before and after, compare within measurement precision, and repeat at several initial settings to judge consistency. [1]

Teacher prompt: Credit a coherent method, not isolated apparatus names. Measure total masses and velocities, not speed alone with unknown direction. This is not a numbered required practical.

Table 1

Test	Total before / (kg m s^{-1})	Total after / (kg m s^{-1})
U	+30.0	+29.8
V	+30.0	-30.0

4(g) Table 1 shows measured totals from two independent cart-pair tests. Each true value may differ from its measurement by up to 0.5 kg m s^{-1} . Which test is consistent with conserved total momentum? Use the values and directions. **[2 marks]**

Answer / mark points: U is consistent: the positive totals differ by only 0.2 kg m s^{-1} , with overlapping possible ranges (29.5–30.5 and 29.3–30.3). [1]
V is not consistent for the cart pair: +30.0 and -30.0 have opposite directions and do not agree within the stated limits. [1]

Teacher prompt: Equal magnitudes alone are not equal vector momenta. Agreement within measurement limits does not prove exact equality.

4(h) In a further collision, total momentum is unchanged but the carts' total kinetic energy decreases from 22 J to 14 J. Can both statements be true? Explain what happens to the energy. **[2 marks]**

Answer / mark points: Yes: conservation of momentum does not require conservation of kinetic energy. [1]
The 8 J is transferred to other energy stores or surroundings, for example internal energy through deformation/heating and sound. Total energy is conserved. [1]

Teacher prompt: Do not say energy is destroyed or used up. The quoted kinetic energies describe a separate test.



5 Separate Physics only: calculating collisions

All parts of Question 5 are for Separate Physics Higher only. In every test, the resultant external horizontal force is negligible during the collision or separation. Take right as positive. Figure 2 applies to part (a) only.

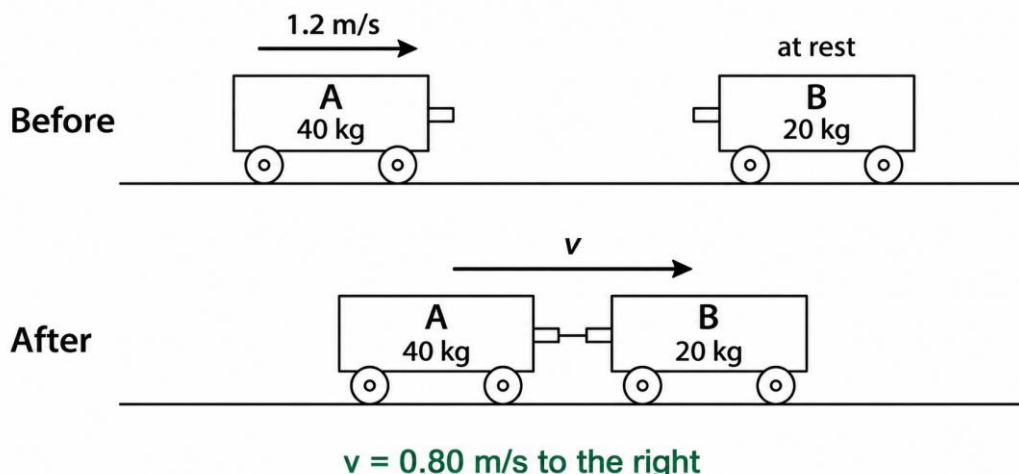


Figure 2

5(a) Separate Physics only: use Figure 2 to calculate the common velocity after A and B couple. **[2 marks]**

Answer / mark points: Initial total momentum = $(40 \times 1.2) + (20 \times 0) = 48 \text{ kg m s}^{-1}$. [1]
 Combined mass = 60 kg; $60v = 48$, so $v = +0.80 \text{ m s}^{-1}$, to the right. [1]

5(b) Separate Physics only: in a new test, A is 40 kg at $+1.2 \text{ m s}^{-1}$ and B is 20 kg at $+0.30 \text{ m s}^{-1}$ before coupling. Calculate their common velocity afterwards. **[2 marks]**

Answer / mark points: Initial total momentum = $(40 \times 1.2) + (20 \times 0.30) = 54 \text{ kg m s}^{-1}$. [1]
 $v = 54 / 60 = +0.90 \text{ m s}^{-1}$, to the right. [1]

5(c) Separate Physics only: repeat the calculation when A is 40 kg at $+1.2 \text{ m s}^{-1}$ but B is 20 kg at -0.60 m s^{-1} before coupling. **[2 marks]**

Answer / mark points: Initial total momentum = $(40 \times 1.2) + (20 \times (-0.60)) = 36 \text{ kg m s}^{-1}$. [1]
 $v = 36 / 60 = +0.60 \text{ m s}^{-1}$, to the right. [1]

Teacher prompt: B initially moves left. Subtract its momentum magnitude rather than adding both magnitudes.



5 Separate Physics only: calculating collisions continued

5(d) Separate Physics only: cart C is 30 kg at $+0.80 \text{ m s}^{-1}$ and cart D is 20 kg at rest. They collide but do not couple. Afterwards C moves at $+0.20 \text{ m s}^{-1}$. Calculate D's final velocity. **[2 marks]**

Answer / mark points: Initial total = $30 \times 0.80 = 24$; C's final momentum = $30 \times 0.20 = 6.0$. D therefore has $+18 \text{ kg m s}^{-1}$. [1]
 $v = 18 / 20 = +0.90 \text{ m s}^{-1}$, to the right. [1]

5(e) Separate Physics only: in another test, C is 30 kg at $+0.80 \text{ m s}^{-1}$ and D is 20 kg at -1.0 m s^{-1} . Afterwards C moves at -0.40 m s^{-1} . Calculate D's final velocity. **[3 marks]**

Answer / mark points: Initial total = $(30 \times 0.80) + (20 \times (-1.0)) = +4.0 \text{ kg m s}^{-1}$. [1]
 C's final momentum = $30 \times (-0.40) = -12 \text{ kg m s}^{-1}$, so D's final momentum = $4.0 - (-12) = +16 \text{ kg m s}^{-1}$. [1]
 $v = 16 / 20 = +0.80 \text{ m s}^{-1}$, to the right. [1]

5(f) Separate Physics only: two carts start at rest, then a spring pushes them apart. A 25 kg cart moves left at 0.60 m s^{-1} . The other cart is 15 kg. Calculate its velocity. **[2 marks]**

Answer / mark points: Initial total is zero; the first cart has -15 kg m s^{-1} , so the other must have $+15 \text{ kg m s}^{-1}$. [1]
 $v = 15 / 15 = +1.0 \text{ m s}^{-1}$, to the right. [1]

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6 Optional Separate Physics only: protecting an instrument

Question 6 is for Separate Physics Higher only. An 8.0 kg crate moves right at 1.8 m s^{-1} and stops without rebounding. Compare two horizontal stopping tests with the same initial and final velocities. Use mean resultant force = change in momentum / stopping time.

6(a) Optional Separate Physics only: calculate the crate's change in momentum, using final momentum minus initial momentum. **[1 mark]**

Answer / mark points: Change = $0 - (8.0 \times 1.8) = -14.4 \text{ kg m s}^{-1}$, to the left. [1]

6(b) Optional Separate Physics only: a rigid stop brings the crate to rest in 0.120 s. Calculate the mean resultant force on the crate, including its direction. **[2 marks]**

Answer / mark points: Mean resultant force = $-14.4 / 0.120$. [1]
 $F = -120 \text{ N}$, or 120 N to the left. [1]

6(c) Optional Separate Physics only: a thick pad stops the same crate in 0.360 s. Calculate the mean resultant force on the crate. **[1 mark]**

Answer / mark points: $F = -14.4 / 0.360 = -40 \text{ N}$, or 40 N to the left. [1]

6(d) Optional Separate Physics only: explain why the pad reduces the magnitude of the mean resultant force in these tests. Link the motion, momentum change and stopping time. **[3 marks]**

Answer / mark points: The mass and initial and final velocities are the same, so the change in momentum is the same. [1]
 The pad increases the stopping time. [1]
 The same momentum change per longer time gives a smaller magnitude of rate of momentum change, hence a smaller mean resultant force. [1]

Teacher prompt: Use longer time, not slower time. Do not claim a smaller momentum change. These data determine mean force, not peak force.

Review and improve

Momentum is a vector: a negative value indicates direction, not negative mass or a smaller speed. In a closed system the total momentum before an event equals the total afterwards; each cart's momentum can change. For a horizontal collision, consider the resultant external horizontal force. Internal forces transfer momentum between carts. Kinetic energy may decrease while total energy and momentum remain conserved. In the impact extension, a longer stopping time for the same momentum change reduces the magnitude of the mean resultant force; it does not alone establish the peak force.

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