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# Conservation of momentum and collisions 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 | 35 marks*

## Specification points covered

- AQA 7407 / 7408: 3.4.1.6 selected one-dimensional momentum conservation, elastic/inelastic collisions, separation and mean impact force; 3.4.1.8 selected kinetic-energy accounts.
- OCR A H156 / H556: 3.5.2(a)–(c), restricted here to one-dimensional interactions; 3.5.1(c)–(d) selected momentum change and impulse. No two-dimensional questions are included.

HarbourLine's parcel-carrier team tests joining, rebound and emergency separation on straight level tracks. Small carts model the full carriers. Treat each body as a particle, keep a consistent sign convention and identify the isolated horizontal system for each event. Account separately for total momentum and total kinetic energy.

### 1. Principles and collision types [4 marks]

*Use precise wording that identifies the system and the quantity that is conserved.*

(a) State the principle of conservation of momentum, including the condition required for it to apply. [2 marks]

(b) State what is meant by a perfectly elastic collision. [1 mark]

(c) State what is meant by an inelastic collision. [1 mark]

Answer / mark points: (a) The total momentum of a system remains constant [1] provided the resultant external force on the system is zero. [1] (b) The total kinetic energy of the system is conserved in a perfectly elastic collision. [1] (c) The total kinetic energy of the system is not conserved in an inelastic collision. [1] Total energy is still conserved.

Teacher prompt / common error: Do not accept 'momentum before equals momentum after' without identifying total momentum of the system and the absence of a resultant external force. Inelastic does not mean that energy disappears.

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## 2. A joined one-dimensional collision [4 marks]

*Take motion to the right as positive. Cart A has mass 0.40 kg and velocity +3.0 m $s^{-1}$. It collides with stationary cart B of mass 0.60 kg. The carts stick together. External horizontal forces during contact are negligible.*

(a) Calculate the velocity of the joined carts immediately after the collision. [2 marks]

(b) Calculate the kinetic energy transferred from the kinetic store during the collision. [2 marks]

Answer / mark points: (a) $0.40 \times 3.0 + 0.60 \times 0 = (0.40 + 0.60)v$ [1], so $v = +1.20$ m $s^{-1}$. [1] (b) $E_{k,before} = \frac{1}{2} \times 0.40 \times 3.0^2 = 1.80$ J and $E_{k,after} = \frac{1}{2} \times 1.00 \times 1.20^2 = 0.720$ J. [1] Energy transferred = 1.80 - 0.720 = 1.08 J (about 1.1 J). [1]

Teacher prompt / common error: Do not average the initial velocities. Use total momentum; any decrease in kinetic energy is transferred to internal energy, sound and deformation.

## 3. A rebound collision [6 marks]

*Take motion to the right as positive. Cart A has mass 0.20 kg and initial velocity +3.0 m $s^{-1}$. It collides head-on with stationary cart B of mass 0.30 kg. After the collision, A has velocity -0.60 m $s^{-1}$. External horizontal forces during contact are negligible.*

(a) Calculate the velocity of cart B after the collision. [2 marks]

(b) Calculate the total kinetic energy before and after the collision. [2 marks]

(c) Classify the collision and justify your answer. [1 mark]

(d) State the relationship between the changes in momentum of carts A and B. [1 mark]

Answer / mark points: (a) $0.20 \times 3.0 = 0.20 \times (-0.60) + 0.30v_B$. [1] Hence $v_B = +2.40$ m $s^{-1}$. [1] (b) $E_{k,before} = \frac{1}{2} \times 0.20 \times 3.0^2 = 0.900$ J. [1] $E_{k,after} = \frac{1}{2} \times 0.20 \times 0.60^2 + \frac{1}{2} \times 0.30 \times 2.40^2 = 0.036 + 0.864 = 0.900$ J. [1] (c) The collision is perfectly elastic because total kinetic energy is conserved. [1] (d) $\Delta p_A = 0.20(-0.60 - 3.0) = -0.720$ kg m $s^{-1}$ and $\Delta p_B = +0.720$ kg m $s^{-1}$: the changes are equal in magnitude and opposite in direction. [1]

Teacher prompt / common error: A rebound velocity must carry a negative sign when right is positive. Compare total kinetic energy, not the kinetic energy of one cart.

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## 4. An internal separation [4 marks]

*Two carts are initially stationary and held together by a compressed spring. When released, cart A of mass 0.45 kg moves left at 2.2 m $s^{-1}$. Cart B has mass 0.75 kg. External horizontal forces are negligible.*

(a) Calculate the velocity of cart B. [2 marks]

(b) Explain why the total kinetic energy increases while total momentum remains zero. [2 marks]

Answer / mark points: (a) $0 = 0.45 \times (-2.2) + 0.75v_B$ [1], so $v_B = +1.32$ m $s^{-1}$ (to the right). [1] (b) Elastic potential energy in the compressed spring is transferred to kinetic energy. [1] The spring forces are internal and the resultant external horizontal force is zero, so the equal and opposite momenta keep the total momentum at zero. [1]

Teacher prompt / common error: Momentum conservation applies to interactions as well as collisions. Energy can change store while total energy and total momentum remain conserved.

## 5. Rebound and contact force [5 marks]

*Take motion to the right as positive. Autonomous parcel carrier A has mass 1.50 kg and moves at +2.40 m $s^{-1}$. It collides with stationary carrier B of mass 2.50 kg. After the collision A rebounds at -0.40 m $s^{-1}$. The carriers are in contact for 0.080 s. External horizontal forces are negligible during the collision.*

(a) Calculate the velocity of carrier B immediately after the collision. [2 marks]

(b) Calculate the change in momentum of carrier A. [1 mark]

(c) Calculate the average force exerted on carrier A during the collision. [1 mark]

(d) State the average force exerted on carrier B, including its direction. [1 mark]

Answer / mark points: (a) $1.50 \times 2.40 = 1.50 \times (-0.40) + 2.50v_B$. [1] Hence $v_B = +1.68$ m $s^{-1}$. [1] (b) $\Delta p_A = 1.50[-0.40 - (+2.40)] = -4.20$ kg m $s^{-1}$. [1] (c) $F_{average}$ on A $= \Delta p_A/\Delta t = -4.20/0.080 = -52.5$ N. [1] The negative sign means the force is to the left. (d) The average force on B is 52.5 N to the right. [1] It is equal in magnitude and opposite in direction to the force on A.

Teacher prompt / common error: Keep the rebound velocity negative throughout. The force pair acts on different carriers; equal and opposite forces produce equal and opposite momentum changes during the same contact time.

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## 6. A sequence of one-dimensional collisions [8 marks]

*Three test carts P, Q and R move along the same straight, level track. Take motion to the right as positive. Cart P has mass 0.40 kg and initially moves at +3.0 m $s^{-1}$; cart Q of mass 0.80 kg is stationary. After P collides with Q, P continues to the right at +0.40 m $s^{-1}$. Cart Q then collides with stationary cart R of mass 0.50 kg and the two carts couple together. External horizontal forces are negligible during both collisions.*

(a) Calculate the velocity of cart Q immediately after the first collision. [2 marks]

(b) Calculate the kinetic energy transferred from the kinetic store in the first collision and classify this collision. [3 marks]

(c) Calculate the velocity of the coupled Q-R carts after the second collision. [2 marks]

(d) Calculate the total kinetic energy transferred from the start of the sequence to the end of the second collision. [1 mark]

Answer / mark points: (a) $0.40 \times 3.0 = 0.40 \times 0.40 + 0.80v_Q$. [1] Hence $v_Q = (1.20 - 0.160)/0.80 = +1.30$ m $s^{-1}$. [1] (b) $E_{k,before} = ½ \times 0.40 \times 3.0^2 = 1.80$ J. $E_{k,after} = ½ \times 0.40 \times 0.40^2 + ½ \times 0.80 \times 1.30^2 = 0.032 + 0.676 = 0.708$ J. [1] Energy transferred = 1.80 - 0.708 = 1.09 J. [1] The collision is inelastic because total kinetic energy decreases. [1] (c) $0.80 \times 1.30 + 0 = (0.80 + 0.50)v$. [1] Therefore v = +0.800 m $s^{-1}$. [1] (d) Final $E_k = ½ \times 0.40 \times 0.40^2 + ½ \times 1.30 \times 0.800^2 = 0.032 + 0.416 = 0.448$ J, so total energy transferred = 1.80 - 0.448 = 1.35 J. [1]

Teacher prompt / common error: Treat the two collisions separately for momentum, then include every moving cart when comparing the initial and final kinetic energy of the complete P-Q-R system.

## 7. Collision language corrections [4 marks]

*For each statement, give a precise scientific correction.*

(a) "The collision lost momentum because the kinetic energy decreased." [2 marks]

(b) "An inelastic collision always makes the objects stick together." [2 marks]

Answer / mark points: (a) The total momentum of the complete collision system is conserved because the resultant external force is negligible. [1] Kinetic energy is transferred to other stores, such as internal energy, deformation and sound; it is not momentum that is lost. [1] (b) Inelastic means that total kinetic energy is not conserved. [1] The objects may separate after the collision; sticking together is only one possible inelastic outcome. [1]

Teacher prompt / common error: Require pupils to name 'total momentum of the system' and 'total kinetic energy'. Momentum is a vector quantity; kinetic energy is a scalar energy store.

*Review: conserve signed total momentum for an isolated system, then compare total kinetic energy to classify the event. Inelastic objects need not remain joined.*

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