Momentum, impulse and conservation of momentum

85 marks

Hints online, answers free with an account: mathswariz.uk/worksheets/ocr-further-maths-mech-momentum/

Date

A Do Now

Quick questions to start.

A1 From A-Level Maths [2 marks]

A particle of mass $3\ \text{kg}$ accelerates uniformly from $2\ \text{m s}^{-1}$ to $8\ \text{m s}^{-1}$ in $4\ \text{s}$. Find the resultant force on it.

Answer .....

A2 From A-Level Maths [2 marks]

A ball is thrown vertically upwards at $14\ \text{m s}^{-1}$. Taking upwards as positive, find its velocity $2\ \text{s}$ later.

Answer .....

A3 Needed today [2 marks]

Solve $4v + 3(v - 5) = 6$.

Answer .....

A4 From chapter 2 [2 marks]

Find the kinetic energy of a car of mass $1200\ \text{kg}$ moving at $15\ \text{m s}^{-1}$.

Answer .....

B Examples and practice

A-Level Further

Your teacher works each example with you (I do). You try the one beside it together (We do). Then practise that part on your own (You do).

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PART 1 Momentum and impulse

EXAMPLE 1 · I DO

A ball of mass $0.15\ \text{kg}$ moves in a straight line at $12\ \text{m s}^{-1}$. Find its momentum. Its speed then rises to $20\ \text{m s}^{-1}$ in the same direction. Find the change in its momentum.

Hint Momentum is mass × velocity. Its unit is N s (the same as kg m s^{-1}).

YOUR TURN · WE DO

B1 A car of mass $1200\ \text{kg}$ slows from $25\ \text{m s}^{-1}$ to $15\ \text{m s}^{-1}$ along a straight road. Find its momentum at the start and at the end, and the change in its momentum. State the direction of the change. [3 marks]

Answer .....

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EXAMPLE 2 · I DO

A ball of mass $0.2\ \text{kg}$ moving horizontally at $15\ \text{m s}^{-1}$ is hit by a bat. It moves back along the same line at $25\ \text{m s}^{-1}$. Find the magnitude and direction of the impulse on the ball.

Hint Choose a positive direction first. The ball moves the other way afterwards, so its velocity after is negative.

YOUR TURN · WE DO

B2 A puck of mass $0.12\ \text{kg}$ slides at $9\ \text{m s}^{-1}$ on smooth ice. It is struck by a stick and moves back along the same line at $6\ \text{m s}^{-1}$. Find the magnitude and direction of the impulse on the puck. [4 marks]

Answer .....

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C1 A ball of mass $0.6\ \text{kg}$ is dropped onto a horizontal floor. It hits the floor at $8\ \text{m s}^{-1}$ and rebounds vertically upwards at $6\ \text{m s}^{-1}$. Find the magnitude and direction of the impulse that the floor gives the ball. [4 marks]

Answer .....

C2 A tennis ball of mass $0.25\ \text{kg}$ moves horizontally at $18\ \text{m s}^{-1}$. It is hit by a racket and moves back along the same line at $26\ \text{m s}^{-1}$. Sam works out the impulse like this: [4 marks]

$$0.25 \times 26 - 0.25 \times 18 = 2\ \text{N s}.$$

Explain Sam's mistake, and find the magnitude of the impulse on the ball.

Answer .....

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PART 2 Impulse as force times time

EXAMPLE 3 · I DO

A particle of mass $2\ \text{kg}$ moves at $3\ \text{m s}^{-1}$ on a smooth horizontal surface. A constant force of $30\ \text{N}$ acts on it for $0.4\ \text{s}$, opposite to its motion. Find its velocity afterwards.

Hint For a constant force, impulse $=$ force $\times$ time. Then use $I = mv - mu$.

YOUR TURN · WE DO

B3 A particle of mass $0.5\ \text{kg}$ moves at $8\ \text{m s}^{-1}$ on a smooth horizontal surface. A constant force of $15\ \text{N}$ acts on it for $0.6\ \text{s}$, opposite to its motion. Find its velocity afterwards. [4 marks]

Answer .....

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C3 A football of mass $0.45\ \text{kg}$ moves horizontally at $20\ \text{m s}^{-1}$. A goalkeeper catches it and brings it to rest in $0.15\ \text{s}$. Find the magnitude of the impulse on the ball and the magnitude of the average force the goalkeeper exerts. [4 marks]

Answer .....

C4 A particle of mass $0.8\ \text{kg}$ moves at $3\ \text{m s}^{-1}$. It receives an impulse of magnitude $J\ \text{N s}$ in the direction opposite to its motion. Afterwards its speed is $2\ \text{m s}^{-1}$. Find the two possible values of J. [4 marks]

Answer .....

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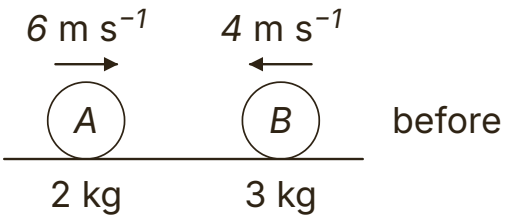
PART 3 Conservation of momentum in a collision

EXAMPLE 4 · I DO

Smooth spheres A and B of equal radius move towards each other along a straight line on a smooth horizontal surface. A has mass $2\ \text{kg}$ and speed $6\ \text{m s}^{-1}$. B has mass $3\ \text{kg}$ and speed $4\ \text{m s}^{-1}$. After they collide, A moves back at $3\ \text{m s}^{-1}$. Find the velocity of B after the collision.



Hint Draw a before and an after picture. Total momentum before = total momentum after. B's velocity before is negative.

YOUR TURN · WE DO

B4 Smooth spheres A and B of equal radius move towards each other along a straight line on a smooth horizontal surface. A has mass $4\ \text{kg}$ and speed $6\ \text{m s}^{-1}$. B has mass $3\ \text{kg}$ and speed $2\ \text{m s}^{-1}$. After they collide, A moves at $1.5\ \text{m s}^{-1}$ in its original direction. Find the velocity of B after the collision. [4 marks]

Answer .....

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EXAMPLE 5 · I DO

Particle A of mass $0.6\ \text{kg}$ moves at $5\ \text{m s}^{-1}$ towards particle B, which has mass $0.4\ \text{kg}$ and is at rest. They collide and coalesce. Find their common speed, and the impulse that each particle exerts on the other.

Hint Coalesce means they move off together, as one particle of mass $0.6 + 0.4$. Then find the change in momentum of each one.

YOUR TURN · WE DO

B5 Particle A of mass $1.5\ \text{kg}$ moves at $4\ \text{m s}^{-1}$. Particle B of mass $0.5\ \text{kg}$ moves at $2\ \text{m s}^{-1}$ towards A along the same line. They collide and coalesce. Find the velocity of the combined particle, and the magnitude and direction of the impulse on B and on A. [5 marks]

Answer .....

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C5 Particles A of mass $2\ \text{kg}$ and B of mass $5\ \text{kg}$ are at rest on a smooth horizontal surface with a compressed spring between them. The spring is released and A moves off at $7.5\ \text{m s}^{-1}$. Find the velocity of B, and the impulse that the spring gives each particle. [4 marks]

Answer .....

C6 Smooth spheres A and B of equal radius move towards each other along a straight line. A has mass $5\ \text{kg}$ and speed $4\ \text{m s}^{-1}$. B has mass $3\ \text{kg}$ and speed $6\ \text{m s}^{-1}$. In the collision B's direction is reversed and it moves at $2\ \text{m s}^{-1}$. Find the speed of A after the collision and state its direction of motion. [4 marks]

Answer .....

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C7 Particle P of mass $3\ \text{kg}$ moves at $u\ \text{m s}^{-1}$. Particle Q of mass $2\ \text{kg}$ moves towards P along the same line at $4\ \text{m s}^{-1}$. After they collide, P is at rest and Q moves back at $5\ \text{m s}^{-1}$. Find u, and the magnitude of the impulse on P. [5 marks]

Answer .....

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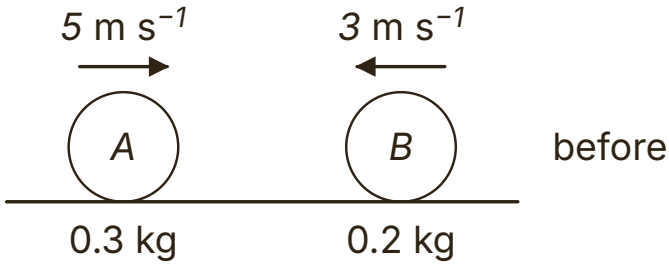
D1 Two particles A and B, of masses $0.3\ \text{kg}$ and $0.2\ \text{kg}$, move towards each other along a straight line on a smooth horizontal surface. A has speed $5\ \text{m s}^{-1}$ and B has speed $3\ \text{m s}^{-1}$. After the collision B moves at $3.6\ \text{m s}^{-1}$ and its direction has reversed.

(a) Find the velocity of A after the collision. [3 marks]



Answer .....

(b) Find the magnitude and direction of the impulse that A exerts on B. [3 marks]

Answer .....

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(c) State the magnitude and direction of the impulse that B exerts on A. Give a reason. [2 marks]

(d) The particles are in contact for $0.025\ \text{s}$. Find the magnitude of the average force between them. [2 marks]

Answer .....

Total for D1: 10 marks

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D2

> Alex says: “The van had no momentum before the crash, so the van exerts no impulse on the car.”

A car of mass $1200\ \text{kg}$ moving at $15\ \text{m s}^{-1}$ runs into the back of a van of mass $1800\ \text{kg}$, which is at rest. After the collision the car and the van move together.

(a) Find the speed of the car and the van just after the collision. [3 marks]

Answer .....

(b) Find the magnitude of the impulse on the car. Explain why Alex is wrong. [3 marks]

Answer .....

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(c) The collision lasts 0.12 s. Find the magnitude of the average force on the van. [2 marks]

Answer .....

(d) State one modelling assumption you have made in part (a). Explain how it affects your answer. [2 marks]

Total for D2: 10 marks

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E Extension

Stretch

No route is given. The hints are at the end of the sheet. Use one at a time.

E1 Particle P of mass m moves with speed u and collides with particle Q of mass km, which is at rest. After the collision P moves with speed $\frac{1}{4}u$ and Q moves with speed $\frac{1}{2}u$. Find the possible values of k. For each value, find the magnitude of the impulse on P. [8 marks]

Answer .....

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Extension hints

Cover these with paper. Uncover one at a time.

E1

Hint 1 The question gives P's speed afterwards, not its velocity. Which ways could P be moving?

Hint 2 Write a momentum equation for each case, with Q's velocity $+\frac{1}{2}u$.

Hint 3 The impulse on P is $m(v-u)$. Use the signed velocity of P in each case.

How did it go?

Colour one circle on each line: not yet, nearly, yes.

I can find the momentum of a particle and its change, with a direction.	○ ○ ○
I can use impulse $= mv - mu$ and impulse $=$ force $\times$ time, taking care with signs.	○ ○ ○
I can use conservation of momentum to find an unknown velocity, mass or speed.	○ ○ ○
I can state the impulse that each particle in a collision gives the other.	○ ○ ○

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