2.4 Momentum & Impulse

Mark Schemes

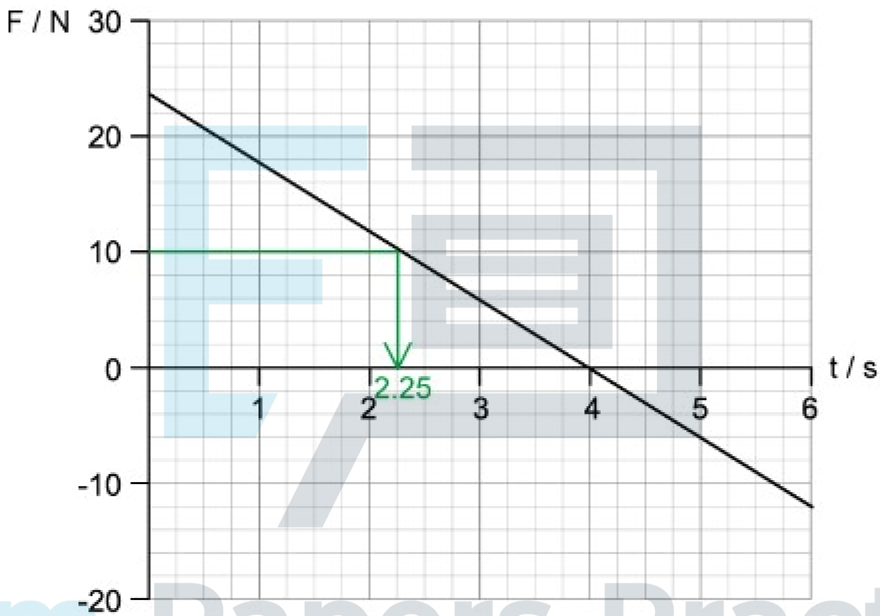
Course	DP IB Physics
Section	2. Mechanics
Topic	2.4 Momentum & Impulse
Difficulty	Medium

To be used by all students preparing for DP IB Physics HL
Students of other boards may also find this useful

1

The correct answer is **C** because:

- The equation relating force, *F* and acceleration *a* is from Newton's second law:
  - $F = ma$
- At an acceleration of 2 m s^{-2} the force is therefore:
  - $F = 5.0 \times 2 = 10$ N
- From the graph, this gives a time of:



- $t = 2.25$ s

Always use the graph in a question to help you answer it. You might start with a = $\frac{v - u}{t}$ but then wonder how to find *v* and *t*. Use the graph to find the time for the correct force.

Take a close look at the scales on both graphs. Although the vertical scale goes up in units of 2 N per square, the horizontal scale is 0.25 s per square (each square is $\frac{1}{4}$ = 0.25). This, as well as the units, should always be double checked from the graph. Remember to use a ruler, or straight edge, to make sure you're reading the most accurate value.

2

The correct answer is **A** because:

- In this explosion, as with any, momentum must be conserved
- The conservation of momentum states that:
  - The total momentum before the explosion = The total momentum after the explosion (in a closed system)
- Momentum, p is defined by:
  - $p = mv$ where m is the mass and v is the velocity
- Before the explosion:
  - $p_{before} = 0$ (since the mass $3M$ has a $v = 0$ m s^{-1} at rest)
- After the explosion:
  - $p_{after} = (2M \times v_{2m}) - (M \times v_m)$
  - They will both be travelling at different speeds because they have a different mass
- Therefore, from the conservation of momentum:
  - $0 = (2M \times v_{2m}) - (M \times v_m)$
  - $M v_m = 2M v_{2m}$
  - $v_m = 2 v_{2m}$
- Therefore, the ratio of momentums is:
  - $\frac{momentum\ of\ 2M}{momentum\ of\ M} = \frac{2Mv_{2m}}{-M2v_{2m}} = -1$
- The ratio of kinetic energy is:
- $\frac{kinetic\ energy\ of\ 2M}{kinetic\ energy\ of\ M} = \frac{\frac{1}{2}2M(v_{2m})^2}{\frac{1}{2}2M(v_{2m})^2}$
- $\frac{2(v_{2m})^2}{4(v_{2m})^2} = \frac{1}{2}$

You do not know the final velocity of the particles after the explosion, so must use conservation of momentum first to calculate this. The ratio of the momentums should be the easiest to notice because the momentum before the explosion is 0 since the $3M$ mass is at rest. Therefore, the momentum of the $2M$ and M mass must be equal in magnitude but opposite in direction, this would always give a ratio of -1.

3

The correct answer is **D** because:

- An elastic collision is where kinetic energy is conserved
- The direction in which the objects move after the collision is not important
- This is because kinetic energy is defined by:
  - $KE = \frac{1}{2}mv^2$
- Where v is the speed of the objects
- Speed is a scalar quantity and is the **magnitude** of the velocity
  - This means that whatever direction the objects go in, their speed will not change
- Therefore, option **D** is correct

A is incorrect as	the ball has an initial kinetic energy with speed v but since the mass m of the ball doesn't change, and its reaches a lower height afterwards, this means there is less KE to convert to GPE after the ball has bounced. This means the KE after bouncing is smaller than its initial KE
B & **C** are incorrect as	when the objects link together, their speed will be the same afterwards and the total mass will be the combined mass of both trucks/particles. When they first combine, there is energy lost to internal energy to do this, leaving less kinetic energy for the combined objects after the collision

4

The correct answer is **B** because:

- The force, F exerted on the wall is given by:
  - $F = \frac{\Delta p}{\Delta t} = \frac{m\Delta v}{\Delta t} = \frac{m(v_{final} - v_{initial})}{\Delta t}$
- Rearranging for v_{final} gives:
  - $F\Delta t = m(v_{final} - v_{initial}) = mv_{final} - mv_{initial}$
  - $v_{final} = \frac{F\Delta t + mv_{initial}}{m}$
- Impulse is equal to:
  - Impulse = $\Delta p = F\Delta t$
- Therefore, the equation can be written in terms of impulse with:
  - $v_{final} = \frac{I + mv_{initial}}{m}$

A is incorrect as	the mass m has not been multiplied by the $v_{initial}$
C is incorrect as	the $mv_{initial}$ has been subtracted on both sides when rearranging for v_{final}, instead of adding
D is incorrect as	the mass m has not been multiplied by the $v_{initial}$ and the $mv_{initial}$ has been subtracted on both sides when rearranging for v_{final}, instead of adding

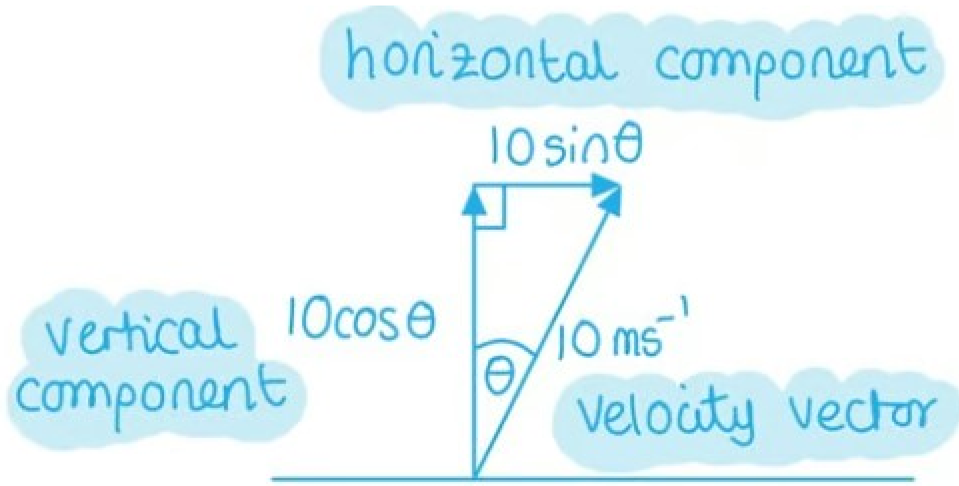
5

The correct answer is **A** because:

- Momentum, p is defined by:
  - $p = mv$
- In projectile motion, the velocity is split into its vertical and horizontal components
  - The vertical component of the velocity at P = 0 (this is the very top of the parabola)
  - The horizontal component of the velocity = 10 m s^{-1}
- Therefore, the momentum will only be due to the horizontal component of the velocity
- Since the stone is launched at an angle:
  - Horizontal component of velocity, $u = 10 \sin \theta$
- Therefore, the momentum of the stone at P is:
  - $p = mu \sin \theta = (0.5 \times 10) \sin \theta$
  - $p = 5 \sin \theta$

B is incorrect as	the horizontal component of the initial velocity has not been taken into account
C is incorrect as	cos θ will be the initial vertical component of the velocity, not horizontal. The vertical velocity will be 0 at point P and constantly changes throughout the projectile motion
D is incorrect as	although the vertical component of the velocity is 0, there is still a horizontal component of the velocity which means the stone will still have some momentum

This question links resolving vectors, projectile motion and momentum. Make sure you're comfortable with resolving vectors into their components in order to tackle the medium to hard questions.



In projectile motion, the horizontal component always stays the same throughout the motion. The vertical velocity will change from maximum to 0 at the top, and back to a maximum again as the object moves under the influence of gravity (and is therefore accelerating and decelerating). This acceleration doesn't affect the horizontal velocity.

6

The correct answer is **B** because:

- The principle of momentum states that:
  - The total momentum before a collision = The total momentum after a collision (in a closed system)
- The momentum, p is given by:
  - $p = mv$ where m is the mass and v is the velocity
- Therefore, since the trucks are identical, they both have mass m
- The momentum before the collision is:
  - $p_{before} = m \times 2v = 2mv$
- Option **B** is the only scenario where the momentum after the collision is also equal to $2mv$
- Taking the left direction as positive gives:
  - $2mv = 2mv$

A is incorrect as	$p_{after} = mv - mv = 0$, therefore, p is not conserved
C is incorrect as	$p_{after} = 2mv + 2\ mv = 4\ mv$, therefore, p is not conserved
D is incorrect as	$p_{after} = -2mv$, therefore, p is not conserved

The important part of this question is that momentum is a **vector** therefore the **direction** in which the trucks move in must be taken into account.

It doesn't matter which direction is taken as positive (the mark scheme assumes the left, because that is the initial direction of the truck).

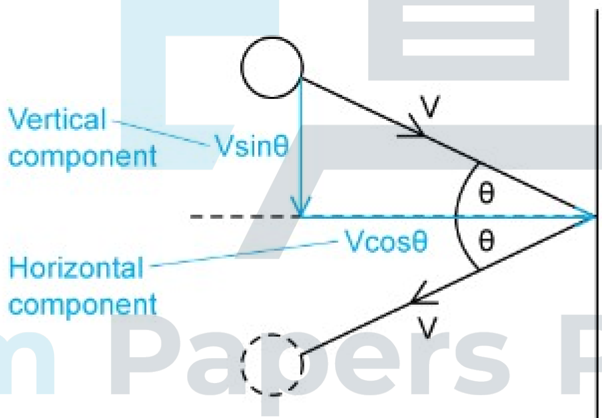
7

The correct answer is **D** because:

- Momentum, p is defined by:
  - $p = mv$ where m is the mass and v is the velocity of the ball
- The impulse is defined as:
  - $I = \Delta p = m(v_{final} - v_{initial})$
- The horizontal component of the velocity of the ball is given by:
  - $v\cos\theta$
- Therefore, if the right is considered the positive direction, the impulse is:
  - $I = m(-v\cos\theta - v\cos\theta)$
  - $I = -2mv\cos\theta$
- The magnitude of the impulse is:
  - $I = 2mv\cos\theta$

A is incorrect as	the sign change has not been taken into account in the ($v_{final} - v_{initial}$) part of the impulse formula
B is incorrect as	the velocity has not been split into its components
C is incorrect as	this is the vertical component of the velocity, and not the horizontal

The horizontal component of the velocity is considered for the impulse because that is the component which hits the walls. The velocity vector is resolved into its vertical and horizontal components as shown below:



It is good practice to label the diagram or draw your own sketch if you are unsure whether the components should be sin θ or cos θ. Don't let the – sign confuse you in your answer. The question says magnitude and its magnitude would be without the minus

8

The correct answer is **C** because:

- Impulse is defined by:
  - Impulse = Δp = area under a force-time graph
- Momentum is given by:
  - $p = mv$ where m is the mass of the object and v is its velocity
- The impulse from the area under the graph is:
  - $(\frac{1}{2} \times 7 \times 8) + (\frac{1}{2} \times 7 \times 8) = 7 \times 8 = 56$ N s
- Therefore:
  - $\Delta p = 56 = mv$
- Rearranging for velocity v gives:
  - $v = \frac{5.6}{4.0} = 14$ m s^{-1}

A is incorrect as	only the area under half the graph has been considered $(\frac{1}{2} \times 7 \times 8)$ instead of $(\frac{1}{2} \times 7 \times 8) + (\frac{1}{2} \times 7 \times 8)$. This gives an impulse of 28 N s instead of 56 N s
B is incorrect as	the impulse hasn't been divided by the mass of 4.0 kg
D is incorrect as	the area under the graph has been calculated as $(7 \times 8) + (7 \times 8)$ giving an impulse of 112 N s instead of 56 N s

Although impulse is Δp (**change in** momentum) instead of just p as calculated in this mark scheme, since the object is initially at rest, the initial velocity $u = 0$ and therefore its initial momentum is also 0. This means Δp just considers the final velocity v.

9

The correct answer is **A** because:

- An elastic collision is one where kinetic energy is **not** conserved
- However, momentum is always conserved in a closed system, whether or not kinetic energy is
    - Therefore, momentum is conserved in an inelastic collision

B is incorrect as	impulse is the **change** in momentum
C is incorrect as	the direction of an object changes its velocity, which changes its momentum and therefore its change in momentum (impulse)
D is incorrect as	impulse depends on the speed / velocity of an object as well. A heavy object moving slowly can have the same impulse as a light object moving very fast

10

The correct answer is **A** because:

- Since the collision is elastic, this means that kinetic energy is conserved
- Therefore:
    - Total kinetic energy before the collision = Total kinetic energy after the collision
- The kinetic energy before the collision is:
    - $\frac{1}{2}mv^2 + \frac{1}{2}(2m)(2v)^2 = \frac{1}{2}mv^2 + 4mv^2 = \frac{9}{2}mv^2$
- The kinetic energy after the collision is:
    - $\frac{1}{2}m(2v)^2 + \frac{1}{2}(2m)V^2 = 2mv^2 + mV^2$
- Equating the kinetic energy before and after gives:
    - $\frac{9}{2}mv^2 = 2mv^2 + mV^2$
    - $\frac{9}{2}v^2 = 2v^2 + V^2$
- Rearranging for the final speed of the $2m$ ball gives:
    - $\frac{5}{2}v^2 = V^2$
    - $\sqrt{\frac{5}{2}}\,v = V$

B is incorrect as	the square root hasn't been taken in the final part of the calculation
C is incorrect as	when calculating the initial kinetic energy of the $2m$ mass, the velocity has not been squared i.e has been calculated as $2v^2$ instead of $(2v)^2 = 4v^2$

D is incorrect as	the square root hasn't been taken in the final part of the calculation and when calculating the initial kinetic energy of the 2*m* mass, the velocity has not been squared i.e has been calculated as $2v^2$ instead of $(2v)^2 = 4v^2$

Remember to substitute carefully into the kinetic energy equation, especially with the velocity being **squared**! It is a very common mistake to substitute incorrectly and not square the velocity.