Exam Papers Practice

Forces & Momentum

Mark Schemes

Course	HL IB Physics
Section	Space, Time & Motion
Topic	Forces & Momentum
Difficulty	Medium

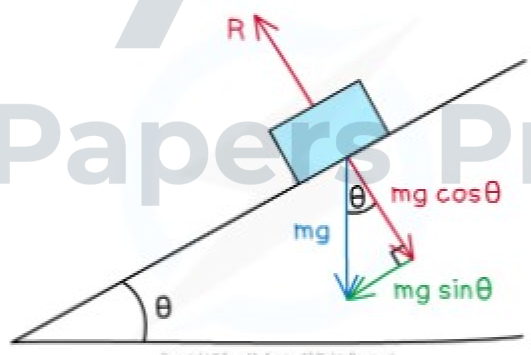
To be used by all students preparing for HL IB Physics
Students of other boards may also find this useful

1

The correct answer is **A** because:

- Newton's first law states that an object remains at rest, or moves with constant velocity, unless acted on by a resultant force
- This means that since the block has a constant velocity, it has **no** resultant force
  - This eliminates options **B** and **D**
- The force sliding the block down the plane is its weight component $W \sin \theta$
- The force resisting its motion up the plane is the friction force F
- For the resultant force to be 0, these two must be equal
  - Therefore, $F = W \sin \theta$

Sin θ and cos θ are mixed up a lot for the components of the weight. The weight (W or mg) can be split into a component perpendicular to the slope ($W \cos \theta$) and parallel to the slope ($W \sin \theta$). To remember the one that is 'cos', think of 'the cos sandwich' i.e. the 'cos' component that 'sandwiches' the angle θ between the vector and the original W vector.



2

The correct answer is **B** because:

- Newton's third law states that whenever two bodies interact, the forces they exert on each other are equal and opposite and of the same type
  - In other words, if object A exerts a force on object B, then object B exerts an **equal** but **opposite** force on object A

- Therefore, the forces must:
  - The same **type**
  - **Opposite** in direction
  - **Equal** in magnitude
- The only force pair that satisfies all three conditions in option **B**

A is incorrect as the weight of the book is the gravitational force from the earth on the book, and the force of the book on the table is a contact force. They are in the same direction, and have the same magnitude, so they are not a Newton's third law pair.

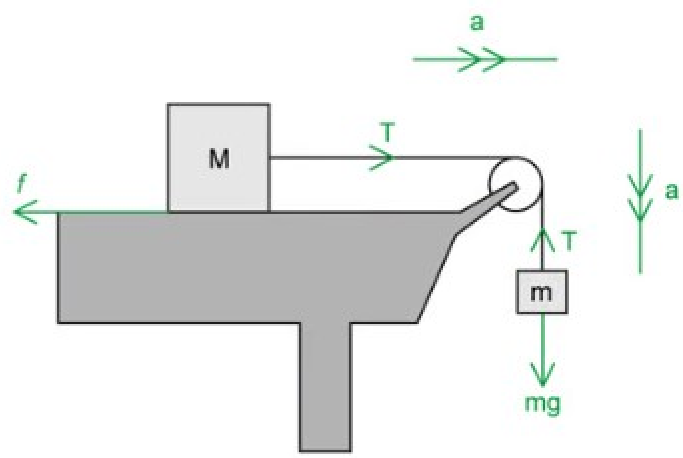
C is incorrect as weight and normal reaction are two different types of forces (weight is gravitational and reaction force is a contact force), and they also act on the same body (the book). Therefore, they cannot be a Newton's third law force pair. This is the most common misconception of this law.

D is incorrect as these are three objects in this scenario (book, Earth and table), instead of two which is required for the Newton's third law force pair.

3

The correct answer is **C** because:

- Consider Newton's second law for both masses separately
  - Resultant force = mass × acceleration ($F = ma$)
  - Both masses have the **same** acceleration, a and tension T



- For mass m:
  - $mg - T = ma$ (Equation 1)
- For mass M:
  - $T - f = Ma$ (Equation 2) where f is the frictional force from the surface
- Rearranging for tension T in equation 2 gives:
  - $T = Ma + f$
- Substituting this equation for T into equation 1:
  - $mg - (Ma + f) = ma$
  - $mg - Ma - f = ma$
- Rearranging for acceleration, a:
  - $mg - f = ma + Ma = a(m + M)$
  - $a = \frac{mg - f}{(m + M)}$

Once you have learnt this technique for solving simultaneous equations by substitution masses on a pulley, you will notice exam questions require a similar approach each time. This is a **very** common exam question. Take great care with your algebra, watch out for minus signs outside brackets – remember to multiply **all** variables in the brackets by the minus sign, otherwise, you will get an answer that looks like distractor option **B**!

4

The correct answer is **C** because:

- The two strings have a tension force that acts up towards where the strings are fixed
- In a free-body diagram, all the vectors are represented by arrows, with the arrow head in the direction of that vector
- Since the tension T is equal in both strings, the tension vector arrows must be the same length
- The diagram that satisfies all three conditions is option **C**

A is incorrect as the arrows for the tension forces are the wrong way around.

B is incorrect as the arrow is missing for the W force.

D is incorrect as the strings have equal tension *T*, so both arrows for tension need to be the same size. The second one here is shorter than the first, indicating it has a smaller tension.

5

The correct answer is **B** because:

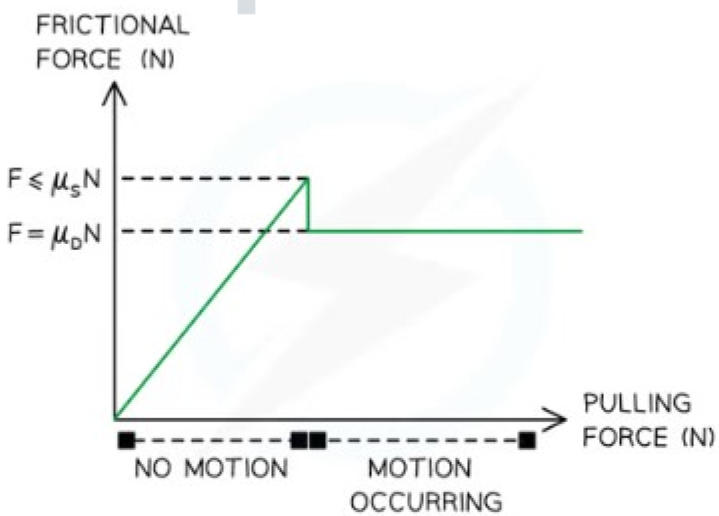
- The maximum coefficient value of static friction μ_s is **higher** than the coefficient of dynamic friction μ_d
  - Dynamic friction acts when the object is moving
- The coefficient of friction has to be a value between 0 and 1
- The pair of values that satisfies these conditions is option **B**

A is incorrect as $\mu_d > \mu_s$ which is never the case

B is incorrect as $\mu_s > 1$ which cannot be the case, it can only be between 0 and 1

C is incorrect as $\mu_d > 1$ which cannot be the case, it can only be between 0 and 1

These values can be seen on a coefficient of friction graph:



6

The correct answer is **C** because:

- Since the top of the ladder is in contact with the wall, there is a normal reaction force from the wall on the ladder
  - The normal reaction force is always perpendicular to the surface
  - Therefore, this is an arrow horizontally to the left at the point of contact between the ladder and wall
- Since the ladder is uniform, its weight acts vertically downward from its centre of mass
- Since the bottom of the ladder is in contact with the ground, there is a normal reaction force from the ground to the ladder
- Since the ground is rough, this means there is a frictional force on the bottom of the ladder
  - If the ladder slipped, the bottom of it would move to the left as it falls into the wall
  - This means the frictional force is in the opposite direction i.e. to the right
- The diagram that satisfies all these conditions is option **C**

A is incorrect as there should only be the arrow to the right on the bottom of the ladder showing the frictional force, there is no arrow to the left

B is incorrect as the normal force from the wall on the ladder is perpendicular to the wall, there is no force going down the wall

D is incorrect as the normal force from the wall on the ladder is perpendicular to the wall, there is no force going along the ladder **AND** there should only be the arrow to the right on the bottom of the ladder showing the frictional force, there is no arrow to the left

Always check that the friction force is in the opposite direction to which the object will move in.

7

The correct answer is **D** because:

- The equation for dynamic friction, f is:
  - $f = \mu R$
- Since the friction force acts between the block and the trolley, the reaction force R upwards on m is equal to the weight of m
  - $R = mg$
- Therefore the frictional force is:
  - $f = \mu mg$
- The question asks for the acceleration of the **trolley**. Newton's second law states:
  - $F = ma$, where F is the resultant force on an object, m is the mass of the object and a is its acceleration
- The only force that is on the trolley is the frictional force, therefore, this is the resultant force on the trolley
- The acceleration, a on the trolley is:
  - $a = \frac{f}{M} = \frac{\mu mg}{M}$

A is incorrect as the force F is not a force that is on the trolley. It is only on mass m so does not affect its acceleration

B is incorrect as the question asks about the acceleration of the trolley, so it is mass M of the trolley that should be in Newton's second law equation

C is incorrect as the force F does is not a force that is on the trolley, only on mass m so does not affect its acceleration and the m and M are the wrong way around in the fraction

The force F here is a big red herring. The important part of this question is to check which object it asks the acceleration for. This would be a very different question had it asked about the acceleration of the block of mass m instead, so remember to read the question carefully!

8

The correct answer is **A** because:

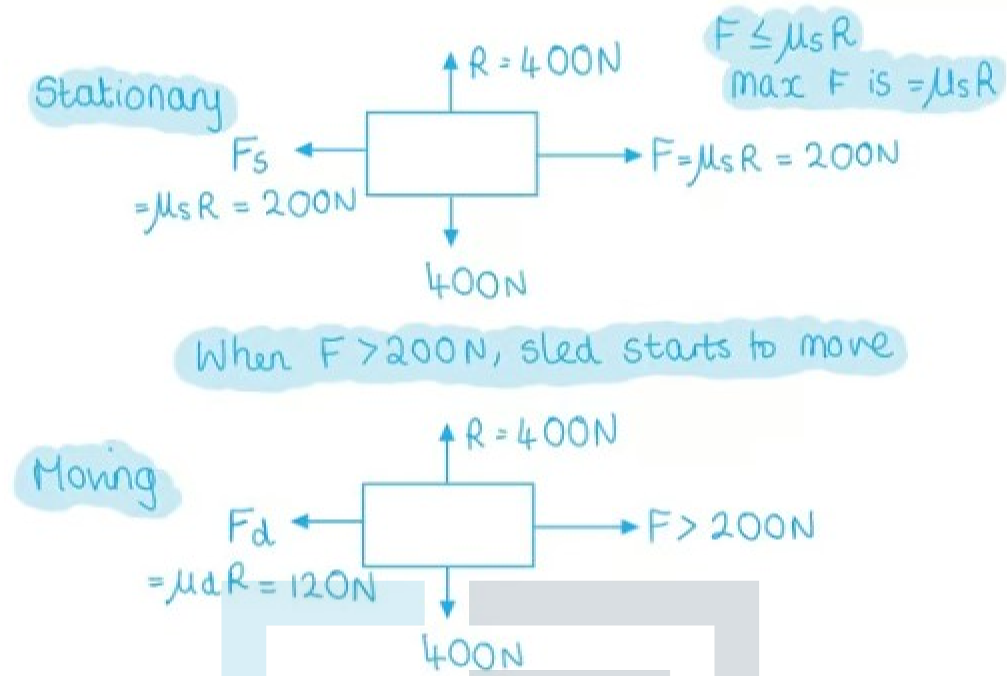
- The maximum static frictional force between the sled and surface just before it moves is:
  - $F_{static} = \mu_s R$ where R is the normal reaction force and μ_s is the coefficient of static friction
- Since the sled is not moving vertically up or down, R is equal to the combined weight of the child and sled
  - $R = W = 400$ N
- Therefore, the maximum static frictional force is:
  - $F_{static} = 0.50 \times 400 = 200$ N
- Once the sled is in motion, the dynamic frictional force between the sled and surface whilst its moving is:
  - $F_{dynamic} = \mu_d R$
- Substituting in the values gives:
  - $F_{dynamic} = 0.30 \times 400 = 120$ N
- Therefore, the minimum resultant force on the sled and child is:
  - 200 – 120 = 80 N

B is incorrect as the calculation is incorrectly 120 – 200 and ignored the minus sign

C is incorrect as the net force has been calculated as the sum of the forces instead of the force when stationary minus the force when moving

D is incorrect as since the sled moves from rest it must have accelerated to do so, since the question does not mention it travelling at constant speed there is therefore a resultant force on the sled (and it is not 0)

This scenario should be treated as whilst the sled is stationary, then when the sled is moving separately. This is because the dynamic and static friction are different values.

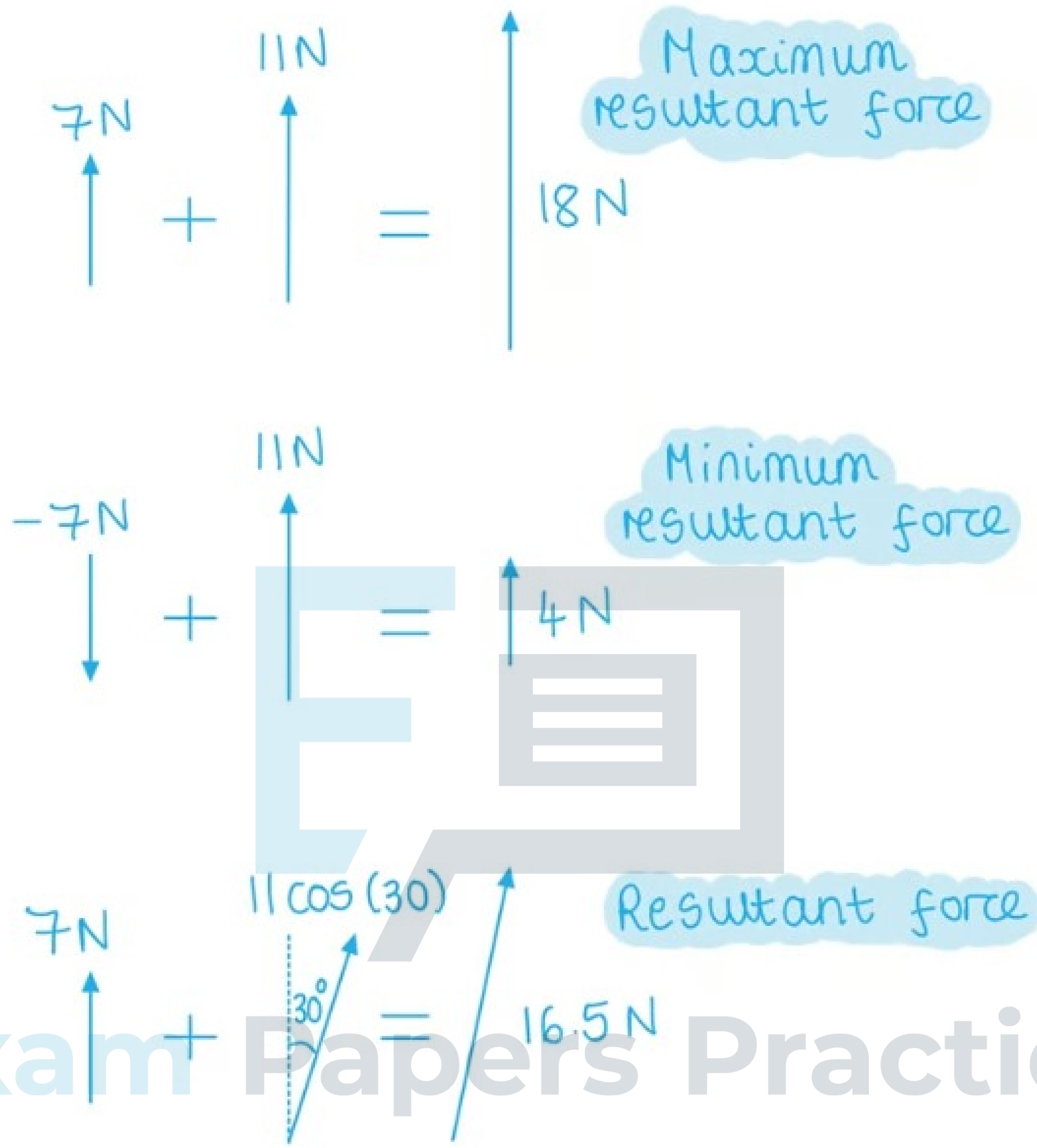


9

The correct answer is **B** because:

- Force is a **vector**, so this is treated like vector addition
- Given two coplanar forces:
  - The maximum resultant force is the **sum** of the forces
  - The minimum resultant force is the **difference** between the forces
- For the two forces 11 N and 7 N therefore:
  - Max resultant force: 11 + 7 = 18 N
  - Min resultant force: 11 – 7 = 4 N
- Therefore:
  - 4 N ≤ Resultant force ≤ 18 N
- Since option **B** of 1 N is < 4 N, it is therefore not a possible resultant of these two vectors

The values in between the maximum and minimum resultant force come from the fact that the forces could be at an angle to each other.



For the resultant force at angle, the vector addition is done from addition a **component** of the vector instead that is in the same direction as the other vector it is being added too. The last example gives a magnitude of: 7 + 11 cos (30) = 16.5 N. The vertical component has been taken because this is the same direction as the 7 N force. The direction of the resultant force will be somewhere in the middle of both of the individual vectors.

10

The correct answer is **D** because:

- The boxes are moving at a constant speed
- Since acceleration is the rate of change of velocity, at constant speed this means they have 0 acceleration
- Newton's first law says that a body will move at a constant velocity unless a resultant force acts on it
    - Therefore, since the box is moving at a constant speed in a straight line, the resultant force on it must be zero

At first glance, the answer to this question looks like it will be **C**. This is why it's very important to make sure to read the question properly. Often, seemingly complicated questions are simplified by a very straightforward application of Newton's laws!

11

The correct answer is **C** because:

- The kinetic energy is given by the equation
    - $\frac{1}{2}mv^2$
- The linear velocity, v is given by the equation
    - $v = \omega r = 2\pi fr$
- Substituting the equation for v into the kinetic energy equation gives
    - $\frac{1}{2}m(2\pi fr)^2 = \frac{1}{2}m4\pi^2 f^2 r^2$
- The 4 and the 2 cancel out to give
    - $2mr^2\pi^2 f^2$ which is option **C**

When variables are multiplied together in algebraic equations, your final answer might appear in a slightly different order. So although it may look like your answer is not one of the options, always double check whether the variables are just given in a different order. For example $r^2 m\pi^2 2f^2$ would still be option **C**.

12

The correct answer is **D** because:

- The centripetal force, F is calculated using the equation:
  - $F = \frac{mv^2}{r}$
- The radius of the circular orbit of the ball is the length of the string, r = 0.1 m
- The velocity, v is defined by:
  - $v = r\omega = \frac{2\pi r}{r}$
- Substituting in the values gives:
  - $v = \frac{2\pi \times 0.1}{\frac{\pi}{10}} = 0.2 \times 10 = 2\ \text{m s}^{-1}$
- Substituting in the values gives us
  - $F = \frac{0.05 \times (2)^2}{0.1} = \frac{0.05 \times 4}{0.1} = 2.0\ \text{N}$

A is incorrect as the velocity v has not been squared. The formula says v^2 and not just v

B is incorrect as both the mass and velocity have been squared. The formula says v^2 and not $(mv)^2$

C is incorrect as $(mv)^2$ has not been divided by radius r. The formula states: $F = \frac{mv^2}{r}$

To make the fraction easier to calculate with decimals $\frac{0.05 \times 4}{0.1}$, try and remove the decimals by multiplying the numerator and denominator 100. This would give $\frac{5 \times 4}{10} = \frac{20}{10} = 2$. Only to multiply the 0.05 **or** the 4 by 100, and not both, since they are multiplied together anyway.

13

The correct answer is **C** because:

- Linear velocity is defined by the equation:
  - $v = r\omega$

- Comparing *v* for both X and Y:
  - X: $v_X = r\omega = 3L\omega$
  - Y: $v_Y = r\omega = L\omega$
- So, $v_X = 3v_Y$
- Centripetal acceleration is defined by the equation:
  - $a = \frac{mv^2}{r}$
- Comparing *a* for both X and Y:
  - X: $a_X = \frac{mv^2}{r} = \frac{m(3L\omega)^2}{3L} = \frac{9mL^2\omega^2}{3L} = 3mL\omega^2$
  - Y: $a_Y = \frac{mv^2}{r} = \frac{m(L\omega)^2}{L} = \frac{mL^2\omega}{L} = mL\omega^2$
- So, $a_X = 3a_Y$

A is incorrect as the linear velocity of 3*v* has not been squared the formula for acceleration is $a = \frac{mv^2}{r}$ and not $a = \frac{mv}{r}$

B is incorrect as linear velocity and acceleration are not the same for both X and Y because points X and Y sit at different distances from the centre of the circle

D is incorrect as the radius of X is 3 times the radius of Y and not 2 times

There are quite a few formulas in this topic, but make sure to check your data booklet for the ones that are given for you!

14

The correct answer is **A** because:

- First calculate the frequency of the spinning top:
  - Frequency is defined as the number of revolutions in 1 second
- Convert five minutes into seconds:
  - $5 \times 60 = 300$ s
- Calculate the frequency:
  - Frequency = $\frac{20}{300} = \frac{1}{15}$ Hz
- The angular speed, ω is defined as:
  - $\omega = 2\pi f$
- Substitute in the values into the angular speed equation:
  - $\omega = 2\pi \times \frac{1}{15} = \frac{2\pi}{15}$ rad s^{-1}

B is incorrect as the frequency is not just $\frac{1}{300}$, it is $\frac{20}{300}$ because there are 20 revolutions in five minutes

C is incorrect as the time must be measured in seconds and not minutes. There should be 5 × 60 seconds in five minutes and not just 5. This means the frequency has been calculated incorrectly

D is incorrect as this is the frequency of the spinning top and not the angular velocity

Understanding the definition of frequency is important – it is the number of revolutions per **second**. This question can also be done by:

Finding the time period, *T* (time taken for 1 revolution)

$\frac{300}{20} = 15$

Substitute this into the equation $\omega = \frac{2\pi}{T}$

$\omega = \frac{2\pi}{15} = \frac{2\pi}{15}$

Remember back in GCSE how to simplify fractions. This is really important when working with a non-calculator paper, since it makes the numbers a lot easier to calculate with.

E.g. To simplify $\frac{20}{300}$

1. Determine the highest common factor for both 20 and 300. This is 20 (i.e. 20 is the largest number that goes into 20 and 300)
2. Divided the numerator and denominator by this factor

This gives $\frac{1}{15}$

15

The correct answer is **A** because:

- Angular acceleration, a is defined by the equation:
  - $a = \frac{\Delta\omega}{\Delta t}$
- From $t = 5.0$ s to $t = 15$ s
  - $a = \frac{\omega_f - \omega_i}{t_f - t_i} = \frac{2.4 - 0.4}{15 - 5.0} = 0.2$ rad s^{-2}
- From $t = 15$ s to $t = 25$ s
  - $a = \frac{\omega_f - \omega_i}{t_f - t_i} = \frac{4.4 - 2.4}{25 - 15} = 0.2$ rad s^{-2}
- From $t = 25$ s to $t = 35$ s
  - $a = \frac{\omega_f - \omega_i}{t_f - t_i} = \frac{6.4 - 4.4}{35 - 25} = 0.2$ rad s^{-2}
- Therefore, the angular acceleration a is constant at = 0.2 rad s^{-2}

B is incorrect as $a = \frac{\Delta\omega}{\Delta t}$ so, $a = \frac{\text{change in angular velocity}}{\text{change in time}}$ and not just the angular velocity at one point.

C is incorrect as $a = \frac{\Delta\omega}{\Delta t}$ so, $a = \frac{\text{change in angular velocity}}{\text{change in time}}$ and is not equal to the initial angular velocity ω.

D is incorrect as a is constant during the whole motion it does not increase during the motion but remains at 0.2 rad s^{-2}.

The key to this question is recognising that a = change in angular velocity ÷ by the change in time. This is the angular version to the equation a = change in linear velocity / change in time.

16

The correct answer is **C** because:

- When the mass is released it travels off at a **tangent** to the circle
- Gravity will affect the vertical velocity of the mass and accelerate it downwards
- However, it still continues at a constant velocity in the horizontal direction
- Therefore, it still follows a parabolic path when viewed in the vertical plane

17

The correct answer is **B** because:

- The centripetal force on the object is the tension in the steel rod
  - This is the force that keeps the object moving in a circle
- The tension in the rod will be greatest when it is directly opposing the weight of the object
- This occurs when the rod is hanging vertically below the centre of the circle.
  - It is the rod that is keeping the object in circular motion

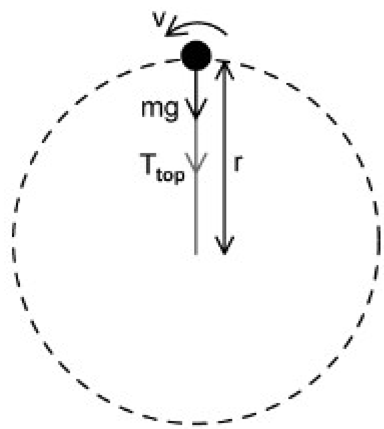
A is incorrect as the tension in the rod will be greatest when opposing the total weight of the object and not just a component of the weight downwards at that point. The maximum values of the weight are when the object is directly at the bottom of the circle

C is incorrect as the tension in the rod changes continually as the centripetal force in the circle. This is because of the changing components of weight acting on the object at different angles to the vertical

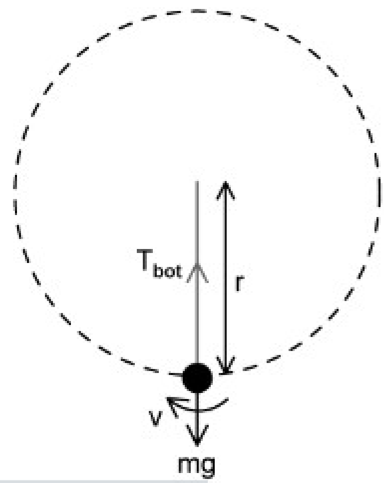
D is incorrect as the tension in the rod is least at the top of the circle because it is acting in the same direction as the weight of the object. At this point, it is the weight that keeps the object moving in a circle, so the tension can be at a minimum.

This diagram explains the principles behind the maximum and minimum values of tension, T in vertical circular motion:

Object at the top



Object at the bottom



For object at the top

$\downarrow$ Centripetal force $= \frac{mv^2}{r} = mg + T_{top}$

$\Rightarrow T_{top} = m\left(\frac{v^2}{r} - g\right)$

For object at the botom

$\uparrow$ Centripetal force $= \frac{mv^2}{r} = T_{bot} - mg$

$\Rightarrow T_{bot} = m\left(\frac{v^2}{r} + g\right)$

18

The correct answer is **C** because:

- Momentum, p is defined by the equation:
  - $p = mv$
- Since velocity is a vector, so is momentum
- Velocity is defined as the **rate of change of displacement**
  - Since the direction of an object moving in a circle is always changing, therefore its velocity is also constantly changing
- If the velocity is constant changing, then so much its momentum and therefore its momentum is not constant
- Therefore **C** is incorrect

19

The correct answer is **D** because:

- The time period is defined as:
  - The time taken for an object to complete one full orbit
- The equation for the time period for X in circular motion is given by:
  - $T_X = \frac{2\pi}{\omega} = \frac{1}{f} = \frac{2\pi r}{v}$
- Therefore, the time period for Y is:
  - $T_Y = \frac{\frac{2\pi r}{2}}{2v} = \frac{\pi r}{2v}$
- T_Y is therefore 4 times less than T_X
  - This is $\frac{T}{4}$
- Objects X and Y follow the same orbital path, so the time period of their orbits will be the same

This question requires you to consider the formulae for time period and radius and identify the variables involved. The time period equations come from:

- $v = \omega r$ where $\omega = 2\pi f = \frac{2\pi}{T}$
- Therefore, $\omega = \frac{v}{r} = \frac{2\pi}{T}$
- Rearranging for T gives $T = \frac{2\pi r}{v}$

This can also be seen from the

$$speed = \frac{distance}{time}$$

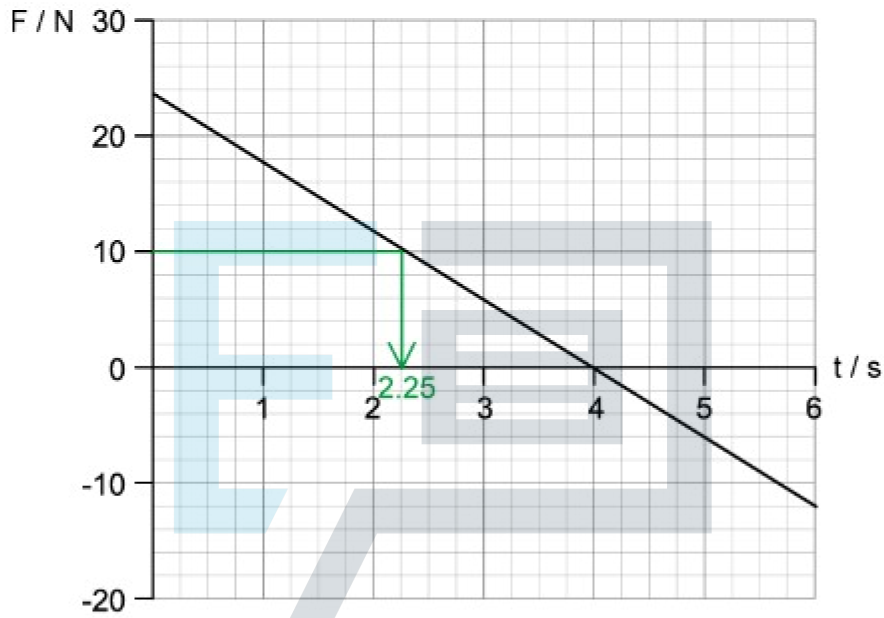
Rearranging, we could see here

$$time = \frac{distance}{speed}$$

20

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.

21

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:
  - $0 = (2M \times v_{2m}) - (M \times v_m)$
  - $M v_m = 2Mv_{2m}$
  - $v_m = 2v_{2m}$
- 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:
- $\frac{kinetic\ \ energy\ \ of\ \ 2M}{kinetic\ \ energy\ \ of\ \ M} = \frac{\frac{1}{2}2M\left(v_{2m}\right)^2}{\frac{1}{2}2M\left(v_{2m}\right)^2}$
- $\frac{2\left(v_{2m}\right)^2}{4\left(v_{2m}\right)^2} = \frac{1}{2}$

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.

22

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

23

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.

24

The correct answer is **A** because:

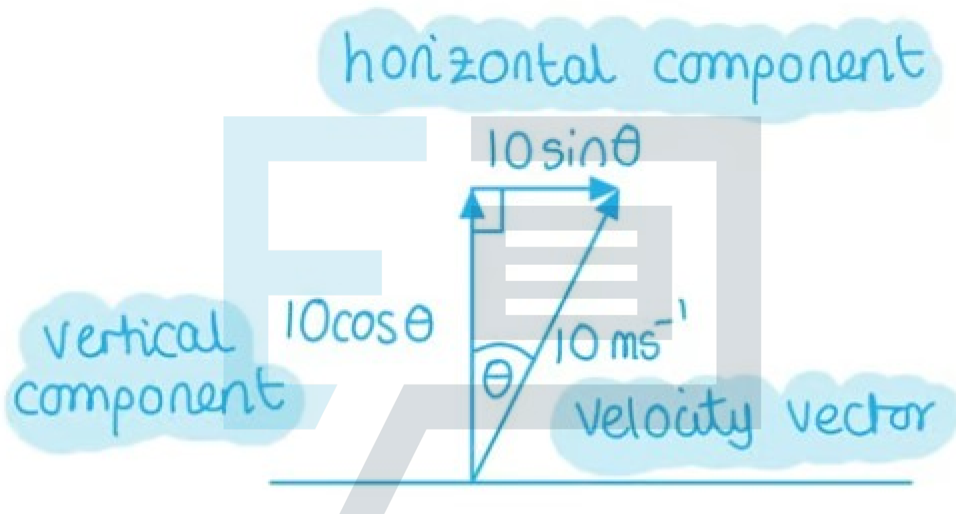
- Momentum, p is defined by:
  - $p = mv$
- In projectile motion, the velocity is split into its vertical and horizontal components
  - The vertical component of the velocity at P = 0 (this is the very top of the parabola)
  - The horizontal component of the velocity = 10 m s^{-1}
- Therefore, the momentum 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.

25

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).

26

The correct answer is **D** because:

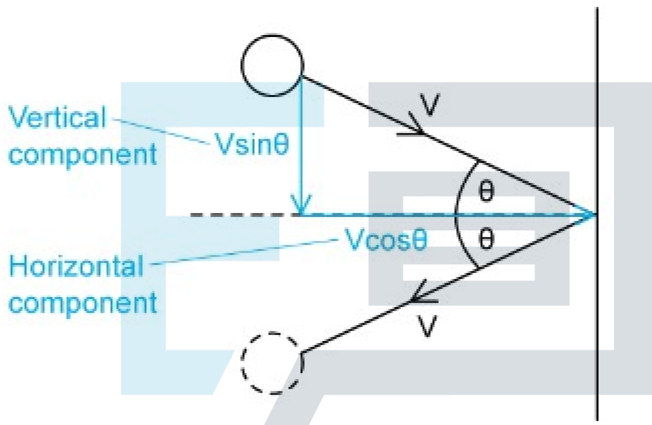
- Momentum, p is defined by:
  - $p = mv$ where m is the mass and v is the velocity of the ball
- The impulse is defined as:
  - $I = \Delta p = m(v_{final} - v_{initial})$
- The horizontal component of the velocity of the ball is given by:
  - $v\cos\theta$
- Therefore, if the right is considered the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

27

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:
  - $v = \frac{5.6}{4.0} = 14 \text{ m s}^{-1}$

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 × 8) + (7 × 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.

28

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.

29

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 $2m$ 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.