GRADE
12

Physical Sciences

SELF STUDY GUIDE

MOMENTUM AND IMPULSE

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

Second Chance
Matric Support Programme

2030 NDP

NATIONAL
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WOZA MATRICS
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TOGETHER WE CAN BEAT THE CORONAVIRUS

1. Introduction

The declaration of COVID-19 as a global pandemic by the World Health Organisation led to the disruption of effective teaching and learning in many schools in South Africa. The majority of learners in various grades spent less time in class due to the phased-in approach and rotational/ alternate attendance system that was implemented by various provinces. Consequently, the majority of schools were not able to complete all the relevant content designed for specific grades in accordance with the Curriculum and Assessment Policy Statements in most subjects.

As part of mitigating against the impact of COVID-19 on the current Grade 12, the Department of Basic Education (DBE) worked in collaboration with subject specialists from various Provincial Education Departments (PEDs) developed this Self-Study Guide. The Study Guide covers those topics, skills and concepts that are located in Grade 12, that are critical to lay the foundation for Grade 12. The main aim is to close the pre-existing content gaps in order to strengthen the mastery of subject knowledge in Grade 12. More importantly, the Study Guide will engender the attitudes in the learners to learning independently while mastering the core cross-cutting concepts

2. How to use this Self Study Guide?

The intention of this booklet is to guide you through the topic of momentum and impulse.

It should be used in conjunction with the CAPS document as well as the examination guidelines.

Other resources should be used to reinforce content knowledge and understanding, e.g. textbooks, previous question papers and other study materials.

The intent of this booklet is to make sure you understand the basics and fundamentals of the topic momentum and impulse.

Read through the glossary of terms, make sure you understand these terms.

Know your definitions.

Work through the worked examples to get comfortable with same type of questions.

Work through the exercises given on your own, before looking at the answers. Only when you are done, then compare your answer to the memorandum.

If your answer is incorrect study the memorandum to see where you made a mistake.

Be in possession of the formula sheet, there is no need to study the formulae off by heart. – Formulae for momentum and impulse will be provided in this guide.

Extracts from the examination guidelines will be included before exercises are given, use these guidelines to make sure you know what is expected of you to study for the examination.

Definition: The product of an object's mass and its velocity.

Formula: $p = m\,v$

$p = momentum\ (kg.m.s^{-1})$

$m = mass\ (kg)$

$v = velocity\ (m.s^{-1})$

Units for momentum:

$kg.m.s^{-1}$

Momentum is directly proportional to both the mass and velocity of an object.
If the mass is constant, then the greater the velocity the greater the **momentum**.

EXAMPLES:

1. A dog with mass 30 kg runs at a velocity of $45\ m.s^{-1}$. Calculate the momentum of the dog.

   $p = m\,v$

   $p = 30\ \times 45$

   $\underbrace{\underbrace{p = 1350}_{\textbf{Magnitude}}\ \underbrace{kg.m.s^{-1}}_{\textbf{units}}}\ \underbrace{\text{in the direction of motion.}}_{\textbf{Direction}}$

2. A car is travelling at 60 $km.h^{-1}$, if the mass of the car is 250 kg, calculate the momentum of the car.

   $p = m\,v$

   $p = 250\ \times 16{,}66666..$

   $p = 4166.67\ kg.m.s^{-1}$ in the direction of motion.

Hint: to convert $km.h^{-1}$ to $m.s^{-1}$; $\frac{60}{3.6}$

CALCULATIONS:

- Always convert mass to **kg** and velocity to $\boldsymbol{m.s^{-1}}$.
- Remember to indicate direction using **"+"** and **"-" signs**.
- Provide your answer with a unit and direction.
- If you obtain a negative answer for a vector it only means the direction is opposite to what you chose as positive.

MOMENTUM

Formula: $p = mv$

Units: $kg.m.s^{-1}$

Momentum is a vector

Vector: A vector is a physical quantity with **magnitude** and **direction.**

$\boldsymbol{p = mv}$, in the momentum formula velocity is a vector.

- We have to consider direction when substituting velocity or momentum.
- Linear momentum is a vector with the same direction as the velocity of the object.
- Always choose a direction as positive in your questions.
- All movements in the opposite direction may then be substituted as negative (–) for vectors!
- Remember momentum will always have magnitude and direction because it is a vector.
- Vector diagrams can be used to represent the magnitude and direction of a vector, e.g.

$p = 3kg.m.s^{-1}$ East

CHANGE IN MOMENTUM:

Formula: $\Delta p = p_f - p_i = mv_f - mv_i$

Units: $kg.m.s^{-1}$

Remember the initial momentum, final momentum and change in momentum are vector quantities. Direction is very important and should be included in your substitutions. Hence choose a direction as "+" e.g. take to the right as "+", the opposite direction will then be "-".

Can momentum be zero?

Yes, the object will have zero momentum when the velocity of the object is zero. The velocity of an object will be zero when the object is at rest.

An object that is not moving is said to be: at rest or stationery.

Formula: $\boldsymbol{\Delta p = p_f - p_i}$

$\boldsymbol{\Delta p = change\ in\ momentum\ (kg.m.s^{-1})}$

$\boldsymbol{p_f = final\ momentum\ (kg.m.s^{-1})}$

$\boldsymbol{p_i = initial\ momentum\ (kg.m.s^{-1})}$

Take note of the following notations:

- Momentum changes **<u>by</u>** $x\ kg.m.s^{-1}$ relates to $\boldsymbol{\Delta p}$
- Momentum changes **<u>to</u>** $x\ kg.m.s^{-1}$ relates to $\boldsymbol{p_f}$

Newton's second law states that when a net / resultant force acts on an object, the object will accelerate in the direction of the net / resultant force, at an acceleration directly proportional to the force and inversely proportional to the mass of the object.

So whenever a net / resultant force acts on an object the object will move faster or slower.

- This means the velocity will change.
- When the velocity changes the momentum will also change since it is dependent on velocity.

$$\Delta p = m\Delta v$$

$$\Delta p = mv_f - mv_i$$

$$\Delta p = m(v_f - v_i)$$

$\boldsymbol{\Delta p = change\ in\ momentum\ (kg.m.s^{-1})}$

$\boldsymbol{m = mass\ (kg)}$

$\boldsymbol{v_f = final\ velocity\ (m.s^{-1})}$

$\boldsymbol{v_i = initial\ velocity\ (m.s^{-1})}$

<u>EXAMPLE:</u>

1. A tennis player serves a tennis ball towards his opponent, the ball moves through the air with momentum of $11\ kg.m.s^{-1}$ east. The opponent hits the ball back in the opposite direction and the momentum of the ball changes to $8\ kg.m.s^{-1}$ west.
   a) Calculate the change in momentum of the tennis ball.

Take east as "+"

$\Delta p = p_f - p_i$

$\Delta p = (-8) - (11)$

$\Delta p = -19\ kg.m.s^{-1}\ \therefore 19\ kg.m.s^{-1}\ \boldsymbol{West}$

<u>EXAMPLE:</u>

2. An arrow is shot with an initial momentum of $20\ kg.m.s^{-1}$ towards a target. It penetrates the target and its momentum changes by $4\ kg.m.s^{-1}$ in the opposite direction. Calculate the final momentum of the arrow.

Take towards the target as "+"

a) $\Delta p = p_f - p_i$

$-4 = p_f - 20$

$p_f = 16\ kg.m.s^{-1}$ **towards the target.**

Law of Conservation of Momentum: The total linear momentum in an isolated system remains constant (in magnitude and direction.)

Formula: $\sum_{pi} = \sum_{pf}$

$$m_1v_{1\,i} + m_2v_{2\,i} = m_1v_{1\,f} + m_2v_{2\,f}$$

$m_1 = mass\ of\ object\ 1\ (kg)$

$m_2 = mass\ of\ object\ 2\ (kg)$

$v_{1\,i} = initial\ velocity\ of\ object\ 1\ (m.s^{-1})$

$v_{2\,i} = initial\ velocity\ of\ object\ 2\ (m.s^{-1})$

$v_{1\,f} = final\ velocity\ of\ object\ 1\ (m.s^{-1})$

$v_{2\,f} = final\ velocity\ of\ object\ 2\ (m.s^{-1})$

A girl with mass 30 kg runs at 5 $m.s^{-1}$ and jumps on a 2 kg skateboard that is at **rest.**

Calculate the velocity of the skateboard and the girl after she jumps on it.

Solution: Take direction of motion as (+)

$$\sum_{pi} = \sum_{pf}$$

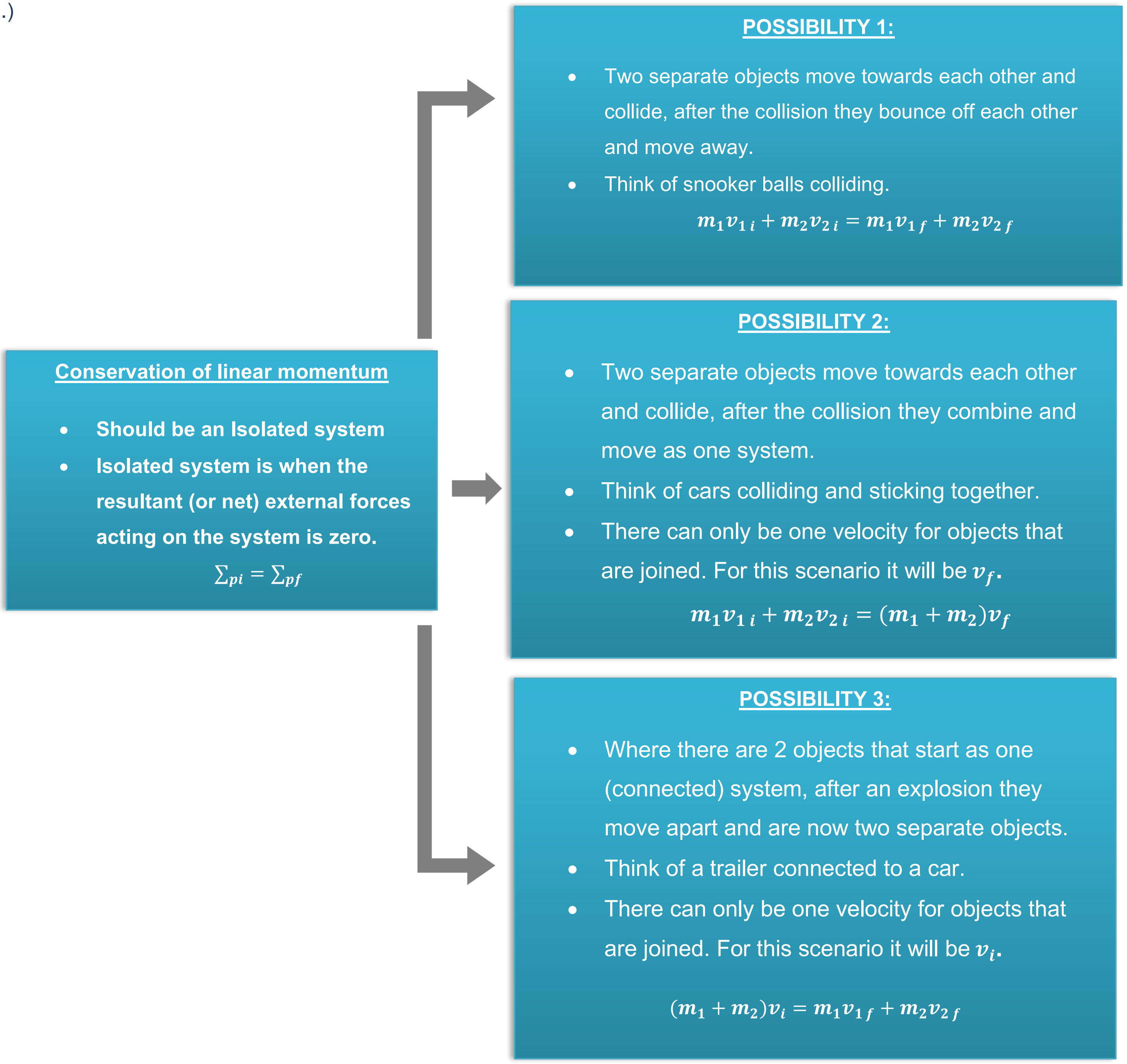
$$m_1v_{1\,i} + m_2v_{2\,i} = (m_1 + m_2)v_f$$

(30)(5) + (2)(0) = (30 + 2) v_f

150 + 0 = (32) v_f

$$v_f = \frac{150}{32}$$

v_f = 4,69 $m.s^{-1}$ in the direction of motion.



Conservation of linear momentum

- **Should be an Isolated system**
- **Isolated system is when the resultant (or net) external forces acting on the system is zero.**

$$\sum_{pi} = \sum_{pf}$$

POSSIBILITY 1:

- Two separate objects move towards each other and collide, after the collision they bounce off each other and move away.
- Think of snooker balls colliding.

$$m_1v_{1\,i} + m_2v_{2\,i} = m_1v_{1\,f} + m_2v_{2\,f}$$

POSSIBILITY 2:

- Two separate objects move towards each other and collide, after the collision they combine and move as one system.
- Think of cars colliding and sticking together.
- There can only be one velocity for objects that are joined. For this scenario it will be v_f.

$$m_1v_{1\,i} + m_2v_{2\,i} = (m_1 + m_2)v_f$$

POSSIBILITY 3:

- Where there are 2 objects that start as one (connected) system, after an explosion they move apart and are now two separate objects.
- Think of a trailer connected to a car.
- There can only be one velocity for objects that are joined. For this scenario it will be v_i.

$$(m_1 + m_2)v_i = m_1v_{1\,f} + m_2v_{2\,f}$$

Impulse: The product of the resultant / net force acting on an object and the time the resultant / net force acts on the object.

Formula: $F_{NET}\Delta t = \Delta p$

$F_{NET} = \boldsymbol{Resultant\ force}\ (N)$

$\Delta t = \boldsymbol{time}\ (s)$ (Contact time)

$\Delta p = \boldsymbol{change\ in\ momentum}\ (kg.m.s^{-1})$

Units for impulse:

$N.s\ or\ kg.m.s^{-1}$

EXAMPLES:

1. A 300 g soccer ball is kicked against the goal post. It hits the post with a velocity of 15 $m.s^{-1}$, and bounces off the post after 0.2 seconds with a velocity of 10 $m.s^{-1}$.

a) Calculate the impulse that the post exerts on the ball.

Direction towards goal post is +

$\underbrace{\mathrm{F_{NET}\Delta t}} = \Delta \mathrm{p}$

$\mathrm{Impulse} = 0.3(-10) - 0.3(15)$

$\mathrm{Impulse} = -7.5\ \mathrm{N.s}$ (Remember $\mathrm{F_{NET}\Delta t = Impulse}$)

$\therefore 7.5\ \mathrm{N.s}\ \underbrace{\textbf{away from the goal post.}}_{\text{Direction}}$

b) Calculate the average force acting on the ball during the collision with the post.

$\mathrm{F_{NET}\Delta t} = \Delta \mathrm{p} = mv_f - mv_i$

$\mathrm{F_{NET}}(0{,}2) = 0{,}3(-10 - 15)$

$\mathrm{F_{NET}} = \dfrac{0{,}3(-10-15)}{(0{,}2)} = -37{,}5\ N$

$\therefore F_{NET} = 37{,}5\ N$ **away from the goal post.**

Impulse: $F_{NET}\Delta t = \Delta p$

Like momentum, impulse is a vector quantity, and the direction of the impulse is the same as the direction of the net force that causes it.

IMPULSE:

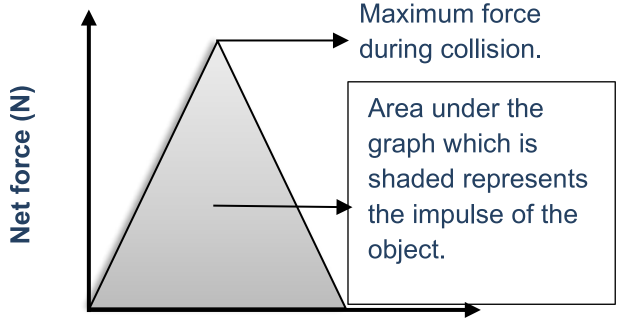
Formula: $Impulse = net\ force\ \times time$

$$F_{NET}\Delta t = \Delta p$$

Units: $N.s$ **or** $kg.m.s^{-1}$

GRAPH: Net force vs time

Any collision that takes place between two objects will cause the net force to change from 0 N to a maximum value and then return back to 0 N after the collision. The contact time between the two objects is referred to as Δt.



Newton's second law expressed in terms of momentum.

Definition: The resultant / net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant / net force.

- Newton's second law states that when a net force acts on an object, it will cause the object to accelerate in the direction of the net force at an acceleration directly proportional to the net force and inversely proportional to the mass of the object.
- We can now conclude that the net force acting on an object is changing the velocity of the object and hence the momentum will change.

$F_{NET} = ma\ ;\quad a = \dfrac{v_f - v_i}{\Delta t} = \dfrac{\Delta v}{\Delta t}$

$F_{NET} = m\dfrac{\Delta v}{\Delta t}$

$F_{NET} = \dfrac{mv_f - mv_i}{\Delta t}\ ;\ \Delta p = mv_f - mv_i$

$F_{NET} = \dfrac{\Delta p}{\Delta t}$

$\therefore F_{NET}\Delta t = \Delta p$

ELASTIC AND INELASTIC COLLISIONS:

Elastic collision: A collision in which the total linear momentum and **kinetic energy** is **conserved.**

Total kinetic energy **before** the **collision** is **EQUAL** to the total kinetic energy **after** the collision.

Inelastic collision: A collision during which the total linear momentum is conserved, but **kinetic energy** is **NOT conserved**.

Total kinetic energy **before** the **collision** is **NOT EQUAL** to the total kinetic energy **after** the collision.

Elastic collisions:

- Objects cannot combine together after collisions.
- We accept no energy is lost to the environment or transferred to other forms of energy e.g. energy transferred to heat or sound during a collision.
- Kinetic energy (E_k) of an isolated system is conserved:

$$\left.\begin{aligned}\sum E_{k\ initial} &= \frac{1}{2}m_1{v_{i\ 1}}^2 + \frac{1}{2}m_2{v_{i\ 2}}^2 \\ \sum E_{k\ final} &= \frac{1}{2}m_1{v_{f\ 1}}^2 + \frac{1}{2}m_2{v_{f\ 2}}^2\end{aligned}\right]$$

The answers for these 2 calculations will be equal!!

- A ball that bounces to the same height from which it was dropped has an almost elastic collision with the ground.

It does not matter whether it is an elastic or inelastic collision, the total linear momentum remains conserved in an **isolated** system.

EXAMPLE:

A truck travelling at 40 $km.h^{-1}$ east, with a mass of 950 kg crashes into a car with a mass of 300 kg that is travelling at 60 $km.h^{-1}$ west. Immediately after the collision, the truck travels at 10 $km.h^{-1}$ in its original direction of motion, and the car travels at 35 $km.h^{-1}$ in the direction east. (Ignore all effects of friction)

Was this an elastic or inelastic collision?

Kinetic energy $(E_k)/K$:

Kinetic energy is the energy that an object possess because it is in motion.

Formula: $E_k = \frac{1}{2}mv^2$; **Units:** J (Joules)

$\boldsymbol{m = mass\ (kg)}$

$\boldsymbol{v = velocity\ (m.s^{-1})}$

Inelastic collisions:

- Objects can combine after collisions, and be considered as one system.
- Kinetic Energy is not conserved and may be lost to other forms e.g. heat or sound.

$$\left.\begin{aligned}\sum E_{k\ initial} &= \frac{1}{2}m_1{v_{i\ 1}}^2 + \frac{1}{2}m_2{v_{i\ 2}}^2 \\ \sum E_{k\ final} &= \frac{1}{2}m_1{v_{f\ 1}}^2 + \frac{1}{2}m_2{v_{f\ 2}}^2\end{aligned}\right]$$

The answers for these 2 calculations will NOT be equal!!

$$\sum E_{k\ initial} \neq \sum E_{k\ final}$$

- Think of two cars that are part of a collision and they combine after they collided.
- NOTE: Always do the calculation for E_{ki} separate from the one for E_{kf}.

ANSWER:

$$\sum E_{k\ initial} = \tfrac{1}{2}m_1{v_{i\ 1}}^2 + \tfrac{1}{2}m_2{v_{i\ 2}}^2 = \tfrac{1}{2}(950)(11{,}11..)^2 + \tfrac{1}{2}(300)(16{,}66..)^2 =$$

$$\boldsymbol{100308{,}64\ J}$$

$$\sum E_{k\ final} = \tfrac{1}{2}m_1{v_{f\ 1}}^2 + \tfrac{1}{2}m_2{v_{f\ 2}}^2 = \tfrac{1}{2}(950)(2{,}77..)^2 + \tfrac{1}{2}(300)(9{,}72..)^2 =$$

$$\boldsymbol{17843{,}36\ J}$$

$$\sum E_{k\ initial} \neq \sum E_{k\ final}$$

$$\therefore collision\ is\ inelastic.$$

3.2. Study and examination tips.

3.2.1. Format of the question paper:

- Momentum and impulse are part of paper 1.
- It falls under the topic mechanics.
- It can be examined in the multiple choice questions, as well as the structured questions.
- Remember momentum can be integrated with topics such as vertical projectile motion and work, energy and power.

3.2.2. Resources in the examination:

- Every question paper will be accompanied by a formula and data sheet at the end of the paper.
- It is of utmost importance that you are comfortable with the formula sheet, and that you know which formulae are applicable to momentum and impulse.
- Formulae labeled under **FORCE** in the formula sheet bears reference to momentum and impulse.
- The kinetic energy formula can be found under **work, energy and power.**

3.2.3. Table 2: Formulae

FORCE

$p = mv$
$F_{NET}\Delta t = \Delta p$
$\Delta p = mv_f - mv_i$

Momentum and Impulse

WORK, ENERGY AND POWER

$K = \frac{1}{2}mv^2$ **OR** $E_k = \frac{1}{2}mv^2$

Kinetic energy, used in calculations for elastic and inelastic collisions.

3.2.4. Laws, definitions and principals.

- Study the definitions from the examination guidelines.
- Pay careful attention to **keywords**. – Definitions used in this booklet are taken from the examination guidelines.
- Try to memorise the definitions with understanding.
- Most of the times the definition can be remembered by looking at the formula. e.g. $p = m \times v$; Linear momentum is the product of an object's mass and its velocity.

3.2.5. Glossary of terms:

Momentum	**The product of an object's mass and its velocity.**
Linear momentum	Linear momentum is the product of an object's mass and its velocity. A vector quantity with the same direction as the velocity of the object.
Contact forces	Contact forces arise from the physical contact between two objects (e.g. a soccer player kicking a ball.) or e.g. Tension.
Non-contact forces	Non-contact forces arise even if two objects do not touch each other (e.g. the force of attraction of the earth on a parachutist even when the earth is not in direct contact with the parachutist.) e.g. F_g
Newton's second law of motion in terms of momentum	The resultant/net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant/net force.
Principle of conservation of linear momentum	The TOTAL linear momentum of an isolated system remains constant (is conserved).
Closed system / Isolated system (in Physics)	A system in which the resultant/net external force acting on the system is zero.
Impulse	The product of the resultant/net force acting on an object and the time the resultant/net force acts on the object.
Elastic collision	A collision in which both total linear momentum and total kinetic energy are conserved.
Inelastic collision	A collision during which total linear momentum is conserved but total kinetic energy is not conserved.
System	A system is a part of space that has been chosen for studying the changes that takes place within it.
Environment	Everything outside the system is called the environment.
Internal forces	Forces that objects exert on each other within a system, e.g. contact forces.
External forces	Forces that are outside the system, but acts on the objects within the system, e.g. frictional force.

3.2.6. Extract from examination guidelines:

(Examiners will follow these guidelines when the NSC exam is set).

Momentum and Impulse

(This section must be read in conjunction with the CAPS, p. 99–101.)

Momentum

- Define *momentum* as the product of an object's mass and its velocity.
- Describe the *linear momentum* of an object as a vector quantity with the same direction as the velocity of the object.
- Calculate the momentum of a moving object using p = mv.
- Describe the *vector nature of momentum* and illustrate it with some simple examples.
- Draw vector diagrams to illustrate the relationship between the initial momentum, the final momentum and the change in momentum for each of the above examples.

Newton's second law of motion in terms of momentum

- State Newton's second law of motion in terms of momentum: The resultant/net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant/net force.
- Express Newton's second law of motion in symbols: $F_{NET} = \frac{\Delta p}{\Delta t}$
- Calculate the change in momentum when a resultant/net force acts on an object and its velocity:

o Increases in the direction of motion, e.g. 2^{nd} stage rocket engine fires.

o Decreases, e.g. brakes are applied.

o Reverses its direction of motion, e.g. a soccer ball kicked back in the direction it came from.

Impulse

- Define *impulse* as the product of the resultant/net force acting on an object and the time the resultant/net force acts on the object.
- Deduce the impulse-momentum theorem: $F_{net}\Delta t = m\Delta v$.
- Use the impulse-momentum theorem to calculate the force exerted, the time for which the force is applied and the change in momentum for a variety of situations involving the motion of an object in one dimension.
- Explain how the concept of impulse applies to safety considerations in everyday life, e.g. airbags, seatbelts and arrestor beds.

Conservation of momentum and elastic and inelastic collisions

- Explain what is meant by *a closed/an isolated system* (in Physics), i.e. a system on which the resultant/net external force is zero.

  A closed/an isolated system excludes external forces that originate outside the colliding bodies, e.g. friction. Only internal forces, e.g. contact forces between the colliding objects, are considered.
- State the principle of conservation of linear momentum: The total linear momentum of a closed system remains constant (is conserved).
- Apply the conservation of momentum to the collision of two objects moving in one dimension (along a straight line) with the aid of an appropriate sign convention.
- Distinguish between *elastic collisions* and *inelastic collisions* by calculation.

3.3. Answering questions in the examination.

3.3.1. Momentum:

- Remember momentum is a **vector** quantity.
- Make use of **sign conventions,** preferably choose one direction of motion to be positive.
- Indicate this direction at the top, next to your solution so that you will remember.
- All motions for vectors that occur in the opposite direction to what you chose as positive will be substituted as negative.
- Make use of this sign convention throughout the question, do not change it at sub-questions, i.e., the sign convention chosen at 2.1 should be used in 2.2 etc.
- Make sure you copy formulae from the formula sheet, **do not write it from memory.**
- Write down the formula as it is from the formula sheet. **Do NOT manipulate the formula.**
- Always attempt substitution, you will not be awarded a mark for the formula if substitution is not attempted.
- **Substitute into the original formula**, then solve or calculate the unknown value.
- Remember **direction** is very **important** when **vectors** are being substituted.
- We use **"+"** and **"-"** sign conventions to indicate **direction.**
- SI-units for **mass** and **velocity** are **kg** and $\boldsymbol{m.s^{-1}}$ respectively.
- SI-units should **always** be used when substituting, meaning when substituting mass it must be measured in kg, and when substituting velocity it must be measured in $m.s^{-1}$.
- If the SI-units in the question differs, make use of conversions to obtain the correct SI-unit.
- To convert grams to kg: $\frac{g}{1000}$.
- To convert $km.h^{-1}$ to $m.s^{-1}$: $\frac{km.h^{-1}}{3.6}$
- Your **final answers** should consist of **magnitude**, **units** and **direction**. Remember momentum is a vector, however if the magnitude of a vector is only required then you don't have to give direction.
- **Try to use un-rounded off values in your question** – it will assist in the final answer being more accurate, e.g. if given 0,1768 do not substitute 0,18. Use it as it is.

- Round off your final answer to a **minimum** of two decimal places.

Worked examples:

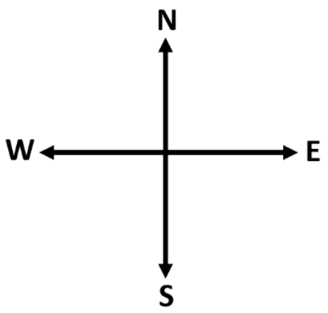
a) What will the momentum of an object moving at 15 $m.s^{-1}$ to the east be, if the object has a mass of 2 kg?

Solution:

Step 1: With the use of sign conventions, choose a positive direction.

East = →

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.



$p = ?$

$v = 15\ m.s^{-1}$

$m = 2\ kg$

Step 3: Choose a suitable formula from the formula sheet.

$p = mv$

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the **units and direction** for the answer.

$p = mv$

$p = (2)(15)$

$p = 30\ kg.m.s^{-1}\ East$

b) The momentum of a truck with mass 1.5 ton is 19 590 $kg.m.s^{-1}$. At what velocity is the truck travelling?

Step 1: With the use of sign conventions, choose a positive direction.

Motion of truck = →

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$p = 19\,590\ kg.m.s^{-1}.$

$v = ?\ m.s^{-1}$

$m = 1.5\ ton$ **Convert to kg:** $\mathbf{1.5 \times 1000 = 1500\ kg}$

Step 3: Choose a suitable formula from the formula sheet.

$$p = mv$$

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction for the answer.

$p = mv$

$19\,590 = (1\,500)(\mathrm{v})$

$v = 13{,}06\, m.s^{-1}\ \textit{in the direction of motion.}$

c) In a cricket match the bowler bowls a 150 g cricket ball towards the batsman. The velocity of the ball is 135 $km.h^{-1}$. Calculate the momentum of the ball.

Step 1: With the use of sign conventions, choose a positive direction.

Towards the batsman is taken as "+" →

(Siyavula textbook)

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$p = ?$

$v = 135\ km.h^{-1}$ **Convert to $m.s^{-1}$:** $\boldsymbol{\frac{135}{3.6} = 37,5\ m.s^{-1}}$

$m = 150\ g$ **Convert to kg:** $\boldsymbol{\frac{150}{1000} = 0,15\ kg}$

Step 3: Choose a suitable formula from the formula sheet.

$$p = mv$$

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction for the answer.

$p = mv$

$p = (0.15)(37{,}5)$

$p = 5{,}63\ kg.m.s^{-1}\ \textit{Towards the batsman.}$

3.3.2. Change in momentum.

- **Momentum** and **velocity** are **vectors**.
- Make use of **sign conventions,** meaning always choose one direction of motion to be positive.
- All motions for vectors that occur in the **opposite direction** to what you chose as positive will be substituted as **negative.**
- **SI-units** should **always** be used when **substituting**, meaning when substituting **mass** it must be measured in **kg**, and when substituting **velocity** it must be measured in $\boldsymbol{m.s^{-1}}$.
- Change in momentum: $\boldsymbol{\Delta p = p_f - p_i}$

$$\boldsymbol{\Delta p = mv_f - mv_i}$$
$$\boldsymbol{\Delta p = m(v_f - v_i)}$$

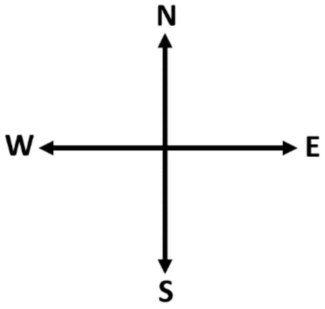
Worked examples:

a) At the US open a tennis player serves a tennis ball with mass of 100 g towards his opponent with a velocity of $220\ km.h^{-1}$ east. The serve is returned by the opponent at $154{,}8\ km.h^{-1}$ in the opposite direction.

Calculate the change in momentum of the ball.

Step 1: With the use of sign conventions, choose a positive direction.

East =



Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$\Delta p = ?$

$v_i = 220\ km.h^{-1}$ **Convert to** $\boldsymbol{m.s^{-1}}$: $\boldsymbol{\frac{220}{3.6} = 61,1111..\,m.s^{-1}}$

$v_f = -154{,}8\ km.h^{-1}$ **Convert to** $\boldsymbol{m.s^{-1}}$: $\boldsymbol{\frac{-154{,}8}{3.6} = -43\ m.s^{-1}}$

$m = 100\ g$ **Convert to kg:** $\boldsymbol{\frac{100}{1000} = 0,1\ kg}$

Negative sign only indicates that the direction of the ball is now **West**.

Step 3: Choose a suitable formula from the formula sheet.

$$\Delta p = mv_f - mv_i$$

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction for the answer.

Note: $p_i = mv_i$

$p_i = (0{,}1)(61{,}1111)$

$p_i = 6{,}11\ kg.m.s^{-1}$ **East.**

Velocity is substituted as a **positive** value because it is in **the same** direction of motion chosen as **"+" (East)**

$p_f = mv_f$

$p_f = (0{,}1)(-43)$

$p_f = -4.3\ kg.m.s^{-1}$

Velocity is substituted as a **negative** value because it is in the **opposite** direction of motion chosen as "+", **(West)**

$p_f = 4.3\ kg.m.s^{-1}$ **West.**

$$\Delta p = p_f - p_i$$

$$\Delta p = -4{,}3 - 6{,}11$$

$$\Delta p = -10{,}41\ kg.m.s^{-1}$$

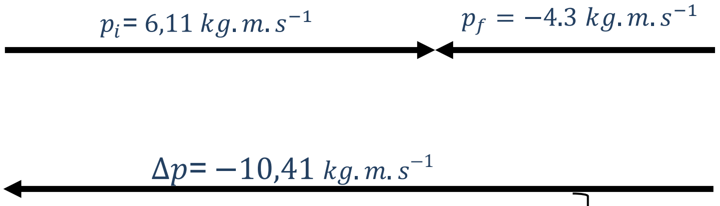
$\Delta p = 10{,}41\ kg.m.s^{-1}$ **West.**

NOTE:

You don't have to use separate calculations in the examination like we did in this example. You can do it as one calculation as shown in option 2.

We only wanted to **emphasize** the importance of **direction** and how it will influence the **initial momentum** (p_i), **final momentum** (p_f) and **change in momentum** (Δp).

Graphical representation: Graphical representation for an object where the momentum changes to the opposite direction.



Negative values only indicates that the direction of motion is in the opposite direction.

Option 2:

$$\Delta p = mv_f - mv_i$$

$$\Delta p = 0{,}1(-43 - 61{,}1111)$$

$$\Delta p = -10{,}41\ kg.m.s^{-1}$$

$\Delta p = 10{,}41\ kg.m.s^{-1}$ **West.**

This is the preferred method to use in the examination.

b) Graphical representation for an object where the momentum decrease in the same direction.

At the US open a tennis player serves a tennis ball with mass 100 g towards his opponent with a velocity of $220\ km.h^{-1}$ east. The tennis ball hits the net and continues to move towards the opponent with a velocity of 120 $km.h^{-1}$

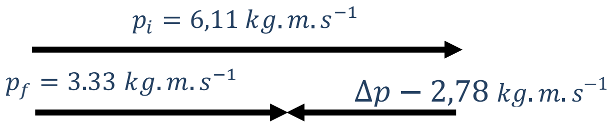
$$\Delta p = mv_f - mv_i$$

v_f *and* v_i must be converted to $m.s^{-1}$

$$\Delta p = 0{,}1(33{,}3333 - 61{,}1111)$$

$$\Delta p = -2{,}78\ kg.m.s^{-1}$$

$$\Delta p = 2{,}78\ kg.m.s^{-1}\ \boldsymbol{West}.$$



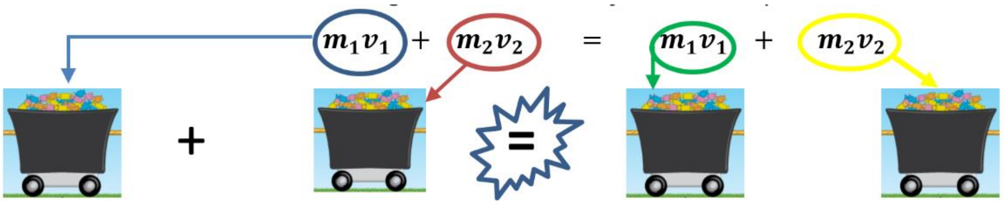
You will notice that even though the **initial momentum** and **final momentum** of the tennis ball remains in **the same direction**, the **change in momentum** is in the **opposite direction** because the **magnitude** of the **final momentum** is **less** than the **magnitude** of the **initial momentum**.

3.3.3. Conservation of linear momentum.

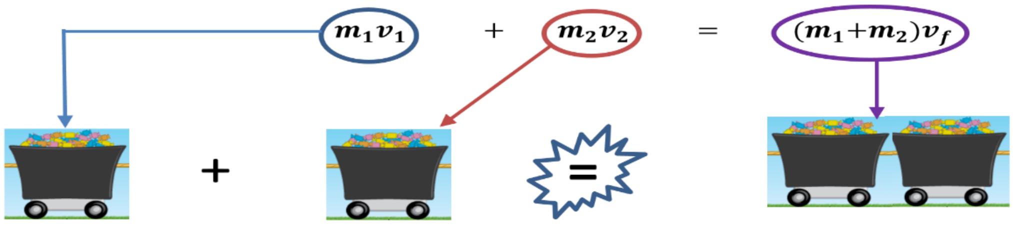
- Linear Momentum will always be **conserved** when the collision occurs in a **closed** or **isolated** system.
- Linear Momentum is **conserved** when the **resultant** or **net external forces** acting on the system is **zero.**
- Always start the questions with the following equation. $\sum_{\boldsymbol{pi}} = \sum_{\boldsymbol{pf}}$
- Remember the above formula is not given on the formula sheet.
- All the information substituted *before* the "=" sign refers to '***before** the collision'* ***(initial),*** all the information substituted *after* the "=" sign refers to '***after** the collision'* ***(final).***

The following three scenarios are most frequently asked. Remember conservation of momentum only occurs in closed or isolated systems.

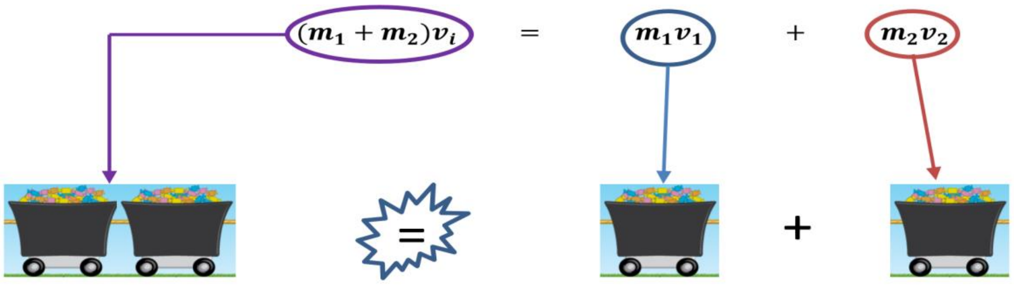
1. Two **separate** objects which are initially not in contact, collide and bounce of each other remain two **separate** objects, each with its **own velocity.**



2. Two **separate** objects which are initially not in contact, collide and are now joined **together** moving with only **one final velocity.**



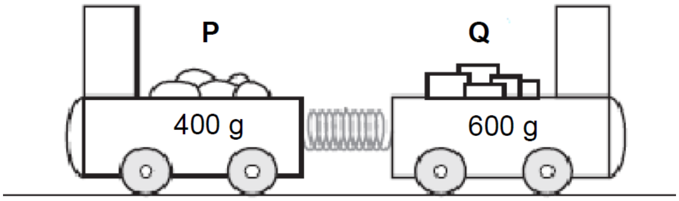
3. Two objects that are **joined,** with **one initial velocity** experience a collision and **separate** into two **different** objects, each with its **own velocity.**



- Remember **direction** is important when substituting **velocity** in the above equations. – make use of **sign conventions.**
- You must be able to manipulate the equations to solve any of the variables in that equation when a final answer is calculated. **Do not** manipulate the formula before substitution.

Worked examples:

a) The diagram below shows two trolleys, **P** and **Q**, held together by means of a compressed spring on a flat, frictionless horizontal track. The masses of **P** and **Q** are 400 g and 600 g respectively. Ignore the effects of friction.



When the spring unwinds Trolley **Q** moves to the right at 4 $m.s^{-1}$.

Calculate the Velocity of trolley **P** after the trolleys are released.

Step 1: With the use of sign conventions, choose a positive direction.

Motion towards the right = →

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$m_P = 400\ g$ Convert to kg: $\frac{400}{1000} = 0{,}4\ kg$

$m_Q = 600\ g$ Convert to kg: $\frac{600}{1000} = 0{,}6\ kg$

$v_{pi} = 0\ m.s^{-1}$

$v_{qi} = 0\ m.s^{-1}$

$v_{Q\ f} = 4\ m.s^{-1}$

$v_{P\ f} = ?\ m.s^{-1}$

Because P and Q are initially combined they will have the same initial velocity!

Step 3: Choose a suitable formula. Conservation of momentum should **always** be started with the following formula: $\sum_{p\ i} = \sum_{p\ f}$, it can then be expanded to 1 of the 3 scenarios.

$\sum_{\mathrm{p\ i}} = \sum_{\mathrm{p\ f}}$

$(\mathrm{m_P} + \mathrm{m_Q})\mathrm{v_i} = \mathrm{m_P v_{P\ f}} + \mathrm{m_Q v_{Q\ f}}$ (Scenario 3 will work best- 2 objects that starts of as one system, and after the spring is released are now two separate objects.)

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction of the answer.

$$\sum_{\mathrm{p\,i}} = \sum_{\mathrm{p\,f}}$$

$$(\mathrm{m_P} + \mathrm{m_Q})\mathrm{v_i} = \mathrm{m_P}\mathrm{v_{P\,f}} + \mathrm{m_Q}\mathrm{v_{Q\,f}}$$

$$(0{,}4 + 0{,}6)0 = (0{,}4)\mathrm{v_{P\,f}} + (0{,}6)(4)$$

$$0 = (0{,}4)\mathrm{v_{P\,f}} + 2{,}4$$

$$\frac{-2{,}4}{0{,}4} = \mathrm{v_{P\,f}}$$

$$-6\ \mathrm{m.s^{-1}} = \mathrm{v_{P\,f}}$$

$$\therefore \mathrm{v_{P\,f}} = 6\ m.s^{-1}\ Towards\ the\ left.$$

We have changed the subscript to suit our scenario. Using P and Q as stated in the question. This will help us to easily relate to our information.

Remember velocity is a vector, the negative answer for $\mathrm{v_{P\,f}}$ indicates that the motion of direction will be opposite to what we chose as positive. Hence the direction of P is towards the left because we chose towards the right to be positive.

We always write our final answer as a positive value.

If the answer is negative like in the example above, we re-write it as positive with the correct indication of direction represented by the negative sign.

a) In the illustration below, ball **A** and ball **B** both with the **SAME** mass are moving towards each other at 15 $m.s^{-1}$ and 8 $m.s^{-1}$ respectively. They collide and after the collision ball **A** is moving at 5 $m.s^{-1}$ towards the right. Calculate the velocity of ball **B** after the collision. Ignore the effects of friction.

Step 1: With the use of sign conventions, choose a positive direction.

Motion towards the right = →

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$m_A = m_B$

$v_{A\,i} = 15\,m.s^{-1}$

$v_{B\,i} = -\,8\,m.s^{-1}$ *(The negative sign indicates that ball B is travelling towards the left)*

$v_{A\,f} = 5\,m.s^{-1}$

$v_{B\,f} = ?\,m.s^{-1}$

Step 3: Choose a suitable formula. Conservation of momentum can always be started with the following formula: $\sum_{p\,i} = \sum_{p\,f}$, it can then be expanded to 1 of the 3 scenarios.

Exam tip:

1 mark is awarded for the formula, but only if substitution is attempted.

Marks are awarded for correct substitutions.

A mark is awarded for the answer, but only if it has units.

If the answer is a vector quantity direction should be included in the answer to obtain the mark, unless magnitude only is required.

$\sum_{p\,i} = \sum_{p\,f}$

$\boldsymbol{m_1 v_{1\,i} + m_2 v_{2\,i} = m_1 v_{1\,f} + m_2 v_{2\,f}}$ (Scenario 1 will work best- 2 separate objects colliding and remain two separate objects after the collision)

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction of the answer.

$m_A v_{A\,i} + m_B v_{B\,i} = m_A v_{A\,f} + m_B v_{B\,f}$

$m_A(15) + m_B(-8) = m_A(5) + m_B v_{B\,f}$

$m(15-8) = m(5 + v_{B\,f})$

$(15-8) = (5 + v_{B\,f})$

$7 - 5 = v_{B\,f}$

$v_{B\,f} = 2\,m.s^{-1}$

$\therefore v_{B\,f} = 2\,m.s^{-1}$ $\textit{towards the right}$

Our direction is towards the right because our **answer** is **positive.** And we **chose** in step 1, that motion towards the right is **positive**.

We have changed the subscript to suit our scenario. Using **A** and **B** as stated in the question. This will help us to easily relate to our information.

Always remember to make use of your sign conventions. The velocity of **B** is substituted as a negative "-" value because it is moving towards the left.

A and B have the same mass as stated in the question, we can use a maths technique and factorise mass on both sides.

This will allow us to **eliminate mass**, hence we did not need a value for mass to solve the question.

3.3.4. Impulse and momentum theorem.

- Formula: $\boldsymbol{F_{NET}\Delta t = \Delta p}$
- The SI-unit for impulse is $\boldsymbol{N.s}$ or $\boldsymbol{kg.m.s^{-1}}$
- **Impulse = change in momentum.**
- **Impulse** is a **vector** quantity, hence **direction** is important.
- When writing the **answer** always include the **units** and **direction.**
- If the question only asks for the magnitude of the impulse, you don't have to include direction in the answer.
- $\boldsymbol{\Delta t}$, is the time interval that the net force is acting on the object. The focus will be **during** the **collision.**
- We can accept that the net force will remain constant for this time interval.
- The change in momentum will always be in the direction of the net force.
- When using the formula for impulse, only **apply** it to **one object** because both objects will experience **equal forces (magnitude)** but in opposite directions. (Newton's 3rd law). The contact time for both objects will always be the same. Therefore the impulse experienced by both objects will be the same, but in opposite directions.

$$\boldsymbol{(F_{NET}\Delta t)_{A\ on\ B} = -(F_{NET}\Delta t)_{B\ on\ A}}$$

- **Impulse** can be used to explain why **safety belts, airbags, arrestor beds, crumple zones** etc. are so vital in ensuring our **safety.**
- The **net force** is **directly proportional** to **the change in momentum**, and **inversely proportional** to the **contact time**. $\boldsymbol{F_{NET} = \frac{\Delta p}{\Delta t}}$, hence when the **change** in **momentum remains constant** and the **contact time increases** the **net force** experienced will **decrease**.

Worked examples:

b) At the US open a tennis player serves a tennis ball with mass 100 g towards his opponent with a velocity of 220 km.h^{-1} west. The serve is returned by the opponent at 154,8 km.h^{-1}.

Calculate the impulse of the ball.

Step 1: With the use of sign conventions, choose a positive direction.

West = "+"

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$m_{Ball} = 100\ g$ **Convert to kg:** $\mathbf{\frac{100}{1000} = 0,1\ kg}$

$v_{Ball\ i} = 220\ km.h^{-1}$ **Convert to** $\mathbf{m.s^{-1}}$**:** $\mathbf{\frac{220}{3,6} = 61,11111\ldots\ m.s^{-1}}$

$v_{Ball\ f} = 154{,}8\ km.h^{-1}$ **Convert to** $\mathbf{m.s^{-1}}$**:** $\mathbf{\frac{154,8}{3,6} = 43\ m.s^{-1}}$

Step 3: Choose a suitable formula from the formula sheet.

$$F_{NET}\Delta t = \Delta p$$

HINT: If asked to calculate impulse, substitute "$F_{NET}\Delta t$" with the word impulse. This will prevent you from using time and thus calculating the net force instead of the impulse.

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction of the answer.

$F_{NET}\Delta t = \Delta p$ We also know that: $\Delta p = mv_f - mv_i$

$\underbrace{F_{NET}\Delta t} = mv_f - mv_i$

$Impulse = (0{,}1)(-43) - (0{,}1)(61{,}1111..)$

$Impulse = -4{,}3 - 6{,}1111$

$Impulse = -10{,}41$

$Impulse = 10{,}41\ N.s\ \ East$

The **final velocity** of the ball is substituted as a **negative** value because it is travelling in the **opposite direction.**

Always make sure to substitute SI-units. **Mass** should be in **kg** and **velocity** in $\mathbf{m.s^{-1}}$

Re-write your **answer** as a **positive value**, the negative value indicates direction.

We chose west = "+", therefore a negative value will indicate that the motion is in the direction east.

c) A cricket ball of mass 156 g is thrown horizontally towards a player at 37 $m.s^{-1}$. It is hit back in the opposite direction with a velocity of 45 $m.s^{-1}$. The ball is in contact with the bat for a period of $0{,}04\ s$.

Calculate the average force exerted on the ball by the bat.

Step 1: With the use of sign conventions, choose a positive direction.

Initial motion of ball = "+"

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$m_{Ball} = 156\ g$ **Convert to kg:** $\boldsymbol{\frac{156}{1000} = 0,156\ kg}$

$v_{Ball\ i} = 37\ m.s^{-1}$

$v_{Ball\ f} = -45\ m.s^{-1}$ (The negative sign indicates that the ball is travelling in the opposite direction)

$\Delta t = 0{,}04\ s$ (Contact time)

Step 3: Choose a suitable formula from the formula sheet.

$F_{NET}\Delta t = \Delta p$

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction of the answer.

$F_{NET}\Delta t = \Delta p$

$F_{NET}\Delta t = mv_f - mv_i$

$F_{NET}(0{,}04) = (0{,}156)(-45) - (0{,}156)(37)$

$F_{NET} = \dfrac{-7{,}02 - 5{,}772}{0{,}04}$

$F_{NET} = -319{,}80\ N$

$F_{NET} = 319{,}80\ N$ in the opposite direction.

The **final velocity** of the ball is substituted as a **negative** value because it is travelling in the **opposite direction.**

Always make sure to substitute SI-units. **Mass** should be in **kg** and **velocity** in $\boldsymbol{m.s^{-1}}$

Re-write your **answer** as a **positive value**, the negative value indicates direction.

We chose initial direction of motion = "+", therefore a negative value will indicate that the motion is in the opposite direction.

What will the average force exerted by the ball on the bat be?

$F_{NET} = 319{,}80\ N$ in the direction of motion.   Newton's 3rd law

Only one object should be used when calculating the impulse, do not mix the information of both objects for Δp.

When calculating impulse always use the information for the object **ON** which you want the impulse.

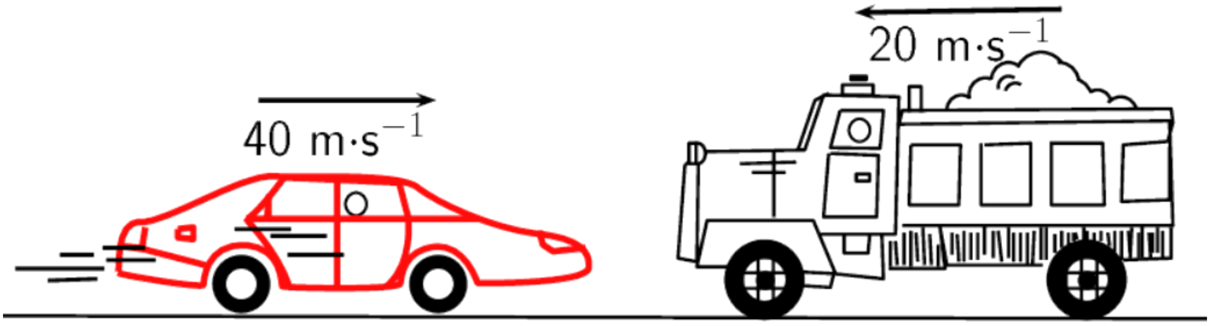
The impulse will be the same for both objects, only in opposite directions.

$$(\boldsymbol{F_{NET}\Delta t})_{\boldsymbol{A\ on\ B}} = -(\boldsymbol{F_{NET}\Delta t})_{\boldsymbol{B\ on\ A}}$$

3.3.5. Elastic and inelastic collisions:

- Remember to calculate the **kinetic energy** of every object **before** the **collision** and **add** the energies **together.**
- Remember to calculate the **kinetic energy** of every object **after** the **collision** and **add** the energies **together**.
- Remember to do these **calculations separately !**
- If the **answers** are **equal** for the above bullets it indicates an **elastic collision**.
- If there is a **difference** in the **answers** for the above bullets it indicates an **inelastic collision**.

a) In the illustration below, a car of mass 1000 kg travelling at $40\ m.s^{-1}$, collides head-on with a truck of mass 5000 kg moving at $20\ m.s^{-1}$. After the collision, the car and truck move together at $10\ m.s^{-1}$ towards the left. Ignore the effects of friction.



The car experiences a force of 100 000 N towards the left. Calculate the contact time of the collision.

Step 1: With the use of sign conventions, choose a positive direction.

Motion towards the right =

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$m_C = 1000\ kg$

$m_T = 5000\ kg$

$v_{C\,i} = 40\ m.s^{-1}$

$v_{T\,i} = -20\ m.s^{-1}$ (The **negative** sign indicates that the truck is travelling towards the **left**)

$v_f = -10\ m.s^{-1}$ (The **negative** sign indicates that the truck and the car are travelling as one system towards the **left** after the collision)

$F_{NET\ car} = -100\ 000\ N$ (Remember **force** is a **vector.** The **negative** sign indicates that the force experienced by the car is towards the **left**)

Step 3: Choose a suitable formula from the formula sheet.

$F_{NET}\Delta t = \Delta p$

Step 4: Substitute the values from step 2 into the formula and do the calculations. Remember to write down the units and direction of your answer.

Remember when working with impulse you should only use the data of one object. In this example we are using the data given for the CAR.	**Remember when working with impulse you should only use the data of one object. In this example we are using the data given for the TRUCK.**
$F_{NET}\Delta t = \Delta p$ $F_{NET}\Delta t = mv_{C\,f} - mv_{C\,i}$ $F_{NET}\Delta t = m(v_{C\,f} - v_{C\,i})$ $(-100000)\Delta t = 1000(-10 - 40)$ $\Delta t = \frac{-50000}{-100000}$ $\Delta t = 0,5\ s$ - **Note that the average force experienced by the car is to the left, hence a negative "-" value for F_{NET}.**	$F_{NET}\Delta t = \Delta p$ $F_{NET}\Delta t = mv_{T\,f} - mv_{T\,i}$ $F_{NET}\Delta t = m(v_{T\,f} - v_{T\,i})$ $(100000)\Delta t = 5000(-10 - (-20))$ $\Delta t = \frac{50000}{100000}$ $\Delta t = 0,5\ s$ - Note that the average force experienced by the truck is to the right, hence a positive "+" value for F_{NET}.
$F_{NET\ car\ on\ truck} = -F_{NET\ truck\ on\ car}$ $\Delta t\ (car) = \Delta t\ (truck)$	

Is the above collision elastic or inelastic? Show all your calculations.

Step 1: Remember energy is a scalar quantity, hence direction is not needed.

Step 2: Determine what information is given, and write it down. Always make sure you are working with the correct SI-units.

$m_C = 1000\ kg$

$m_T = 5000\ kg$

$v_{C\ i} = 40\ m.s^{-1}$

$v_{T\ i} = 20\ m.s^{-1}$

$v_f = 10\ m.s^{-1}$

This will be the **final velocity** for both the **car** and **truck**, because they are **combined after** the collision and moving as **one system**.

Step 3: Choose a suitable formula from the formula sheet.

To determine if the collision was elastic or inelastic we have to calculate the kinetic energy of all objects before the collision, and the kinetic energy of all objects after the collision. That is why we use the phrase "**the sum of"** kinetic energy. It means we **add** all the kinetic energy of the objects **before** the **collision**, and we **add** all the kinetic energy of the objects **after** the **collision**. If these **answers** are **equal** it indicates an **elastic collision**, if the **answers differ** it will indicate an **inelastic collision**.

$$\sum E_{k\ initial} = \frac{1}{2} m_C {v_C}^2 + \frac{1}{2} m_T {v_T}^2$$

Sum of the initial kinetic energy of the car and the truck before the collision.

Initial kinetic energy of the car before the collision.

Initial kinetic energy of the truck before the collision.

$$\sum E_{k\ initial} = \frac{1}{2} m_C {v_C}^2 + \frac{1}{2} m_T {v_T}^2$$

$$\sum E_{k\ initial} = \frac{1}{2}(1000)(40)^2 + \frac{1}{2}(5000)(20)^2$$

$$\sum E_{k\ initial} = 800\ 000 + 1\ 000\ 000$$

$\sum E_{k\ initial} = 1{,}8 \times 10^6\ J$ - This is the **total kinetic energy** of the **car** and **truck before** the **collision**.

$$\sum E_{k\ final} = \frac{1}{2}(m_C + m_T)\ {v_f}^2$$

Sum of the final kinetic energy of the car and the truck after the collision.

Final kinetic energy of the car and truck after the collision.

We wrote it as one term because they are moving together as one system. – They are having the same final velocity.

$$\sum E_{k\,final} = \frac{1}{2}m_{C\ and\ T}v^2$$

$$\sum E_{k\,final} = \frac{1}{2}(1000 + 5000)10^2$$

$\sum E_{k\,final} = 3{,}0 \times 10^5\ J$ – This is the **total kinetic energy** of the **car** and **truck after** the **collision**.

$$1{,}8 \times 10^6\ J > 3{,}0 \times 10^5\ J$$

$$\therefore \sum E_{k\,initial} \neq \sum E_{k\,final}$$

$$\therefore \boldsymbol{collision\ is\ inelastic.}$$

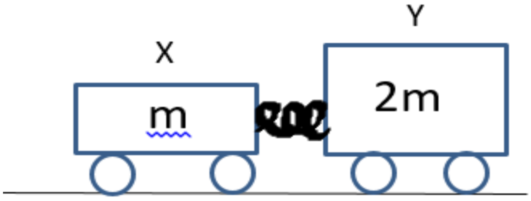
4. Exercises

4.1. Multiple-choice questions.

- These questions will have 4 possible answers.
- Only **one** answer will be **correct**, the other three answers are only **distractors**.
- It is advisable to answer these questions at the end. If the distractors confuse you, it will show in the content questions as well.
- Read the question and cover the answers, decide for yourself what you think the correct answer is.
- Now uncover the options and see if one corresponds to your answer.
- Choose the option that corresponds best to your answer.
- Read all the options to make sure there is not a better answer than the one you have selected.
- Elimination can also be used as a method – out of the four answers, eliminate those that you know cannot be correct. Then by using laws and principles of the relevant topic reason out which one is the correct answer.

Multiple-choice questions: Various options are provided as possible answers to the following questions. Each question has only **ONE** correct answer.

1. Two trolleys, **X** and **Y**, of masses **m** and **2m** respectively, are held together by a compressed spring between them. Initially they are stationary on a horizontal floor, as shown below. Ignore the effects of friction



The spring is now released and falls to the floor while the trolleys move apart.

The magnitude of the MOMENTUM of trolley **X** while it moves away is…

A zero.

B half the magnitude of the momentum of trolley **Y**.

C twice the magnitude of the momentum of trolley **Y**.

D the same as the magnitude of the momentum of trolley **Y**. (2)

2. An object is dropped from rest and after falling a distance ***x***, its momentum is ***p****.* Ignore the effects of air friction.
The momentum of the object, after it has fallen a distance ***2x****,* is…

A *p.*

B $\sqrt{2p}$

C $\frac{p}{2}$

D *2p* (2)

3. When the velocity of a moving object is *doubled*, and mass is kept constant, the

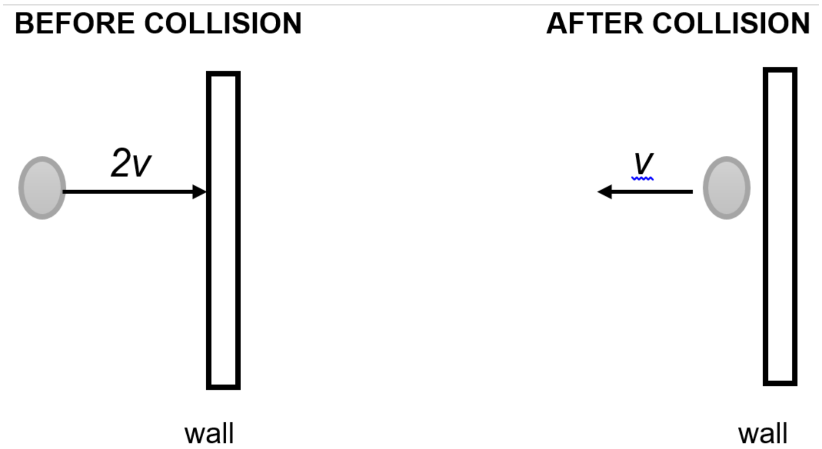
A Net work done by the object is doubled.

B Kinetic energy of the object is doubled.

C Potential energy of the object is doubled.

D Linear momentum of the object is doubled. (2)

4. A ball, moving horizontally, hits a wall with speed ***2v.*** The ball then bounces back horizontally with a speed ***v,*** as shown in the diagram below. Ignore all forms of friction.



Which ONE of the following combinations regarding the linear momentum and the total kinetic energy of the ball for the collision above is CORRECT?

	LINEAR MOMENTUM	TOTAL KINETIC ENERGY
A	Conserved	Not conserved
B	Conserved	Conserved
C	Not conserved	Not conserved
D	Not conserved	Conserved

(2)

5 A person drops a glass bottle onto a concrete floor from a certain height and the bottle breaks. The person then drops a second, identical glass bottle from the same height onto a thick, woolen carpet, but the bottle does not break.

Which ONE of the following is CORRECT for the second bottle compared to the first bottle for the same momentum change?

	AVERAGE FORCE ON SECOND BOTTLE	TIME OF CONTACT WITH CARPET
A	Larger	Smaller
B	Smaller	Smaller
C	Larger	Larger
D	Smaller	Larger

(2)

6 Which of the following physical quantities is equal to the product of net force and change in time?

A Power

B Impulse

C Energy

D Work (2)

7 Two bodies undergo an **INELASTIC** collision in the absence of friction. Which ONE of the following combinations of **momentum** and **kinetic energy** of the system is **CORRECT**?

	MOMENTUM	KINETIC ENERGY
A	Not conserved	Conserved
B	Conserved	Not conserved
C	Not conserved	Not conserved
D	Conserved	Conserved

(2)

8 Airbags in modern cars provide more safety during an accident.

The statements below are made by a learner to explain how airbags can ensure better safety in a collision.

(i) The time of impact increases

(ii) The impact force decreases

(iii) The impulse increases

Which of the statements above are CORRECT?

A (i) only

B (ii) only

C (ii) and (iii) only

D (i) and (ii) only (2)

9 The net (resultant) force acting on an object is equal to the… of the object in the direction of the net force.

A change in momentum

B change in kinetic energy

C rate of change of momentum

D rate of change of kinetic energy (2)

10 If the total momentum of a system is changing...

A particles of the system must be exerting forces on each other.

B the system must be under the influence of gravity.

C the system must move at constant velocity.

D a net external force must be acting on the system. (2)

11 The linear momentum of an object is a….

A vector quantity with the same direction as the velocity of the object.

B scalar quantity with the same direction as the velocity of the object.

C vector quantity with direction opposite to that of the velocity of the object.

D scalar quantity with direction opposite to that of the velocity of the object.

(2)

12 Ball **M**, moving at speed **v** to the right, collides with a stationary ball **N** on a smooth horizontal surface. Immediately after the collision, ball **M** comes to rest and ball **N** moves to the right with speed **v**.

Which ONE of the following statements about the collision of the balls is CORRECT?

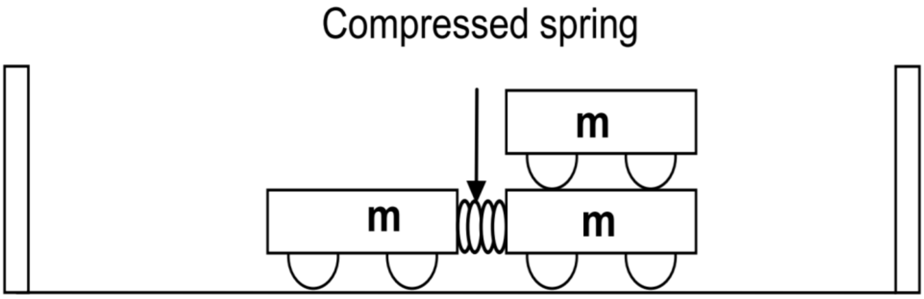
A Total momentum is conserved and the masses of the balls are unequal.

B Total kinetic energy is conserved and the masses of the balls are unequal.

C Total momentum and total kinetic energy are conserved and the masses of the balls are equal.

D Total momentum is conserved but total kinetic energy is not conserved and the masses of the balls are equal. (2)

13 Learners perform an experiment using identical trolleys, each of mass **m**. The trolleys are arranged, as shown in the diagram below. They are initially at rest on a frictionless surface and are connected with a compressed, massless spring.



When the spring is released it falls vertically down and the single trolley moves with momentum **p** to the left.

The magnitude of the momentum of the two trolleys moving to the right will be:

A $2p$

B p

C $\frac{1}{2}p$

D $\frac{1}{4}p$

(2)

14 An object **X**, mass **m**, is moving at constant velocity **v** along a smooth, horizontal surface. An identical object **Y** is dropped onto object **X** and stays there. Which one of the following represents the velocity of the combination **X + Y?**

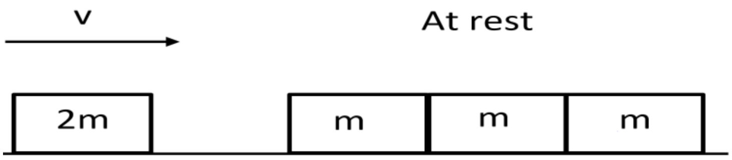
A Zero

B $\frac{1}{2}v$

C v

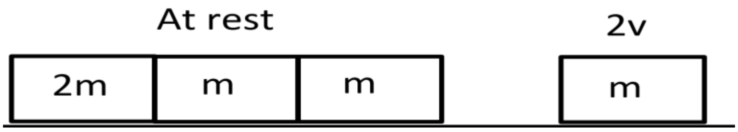
D $2v$ (2)

15 Three separate, identical blocks are in contact with each other in a straight line. They are at rest on a smooth, horizontal surface. Each of these blocks has a mass **m**. Another block with the same dimensions, but with mass **2m**, moving at a velocity **v**, collides ELASTICALLY and in the same straight line with the three stationary blocks.

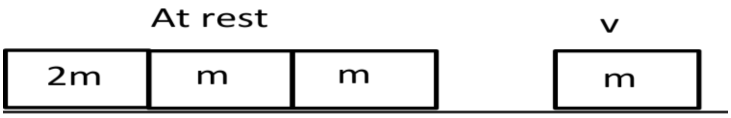


Which one of the following diagrams represents the situation immediately after the collision?

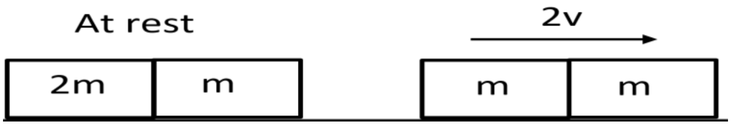
A


At rest
2v
2m
m
m
m

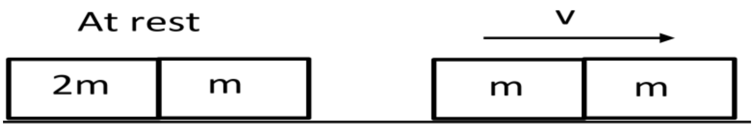
B


At rest
v
2m
m
m
m

C


At rest
2v
2m
m
m
m

D

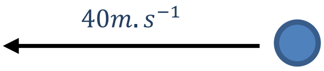

At rest
v
2m
m
m
m

(2)

4.2. Structured questions.

Question 1

A 400 g ball is moving horizontally towards a cricketer at a velocity of $40\ m.s^{-1}$. Then it is hit away by the cricketer in the opposite direction it had come from with a net force of 400 N. The bat makes contact with the ball for $0{,}1\ s$. Ignore the vertical motion of the ball.

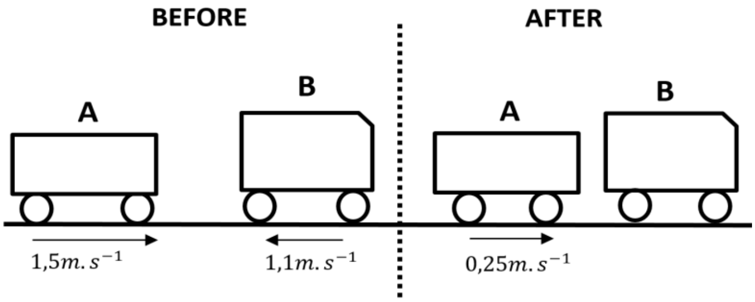


1.1 Define impulse. (2)

1.2 Calculate the initial momentum of the ball before it hits the bat. (3)

1.3 Calculate the magnitude of the final velocity of the cricket ball. (4)

1.4 When cars are equipped with flexible bumpers, they will bounce off each other during low-speed collisions, thus causing less damage. In one such accident, car **A** with mass 1 750 kg, traveling to the right at $1{,}5\ m.s^{-1}$, collides with car **B** of mass 1 450 kg going to the left at $1{,}1\ m.s^{-1}$. Measurements show that the speed of car **A** just after the collision has been $0{,}25\ m.s^{-1}$ in its original direction. Ignore the effects of friction during the collision.



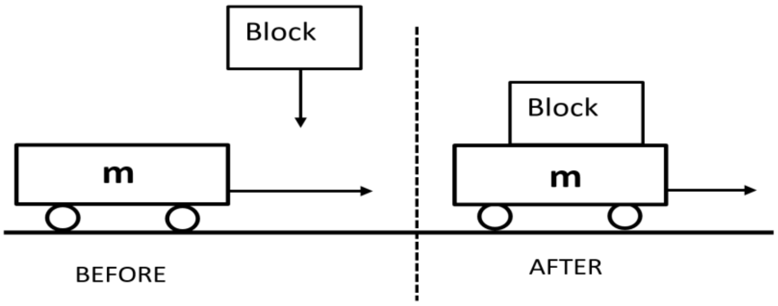
1.4.1 Calculate the velocity of car **B** immediately after the collision. (5)

1.4.2 "When cars are equipped with flexible bumpers, they will bounce off each other during low-speed collisions, thus causing less damage." Explain how flexible bumpers reduce damages during low speed collisions. (3)

[17]

Question 2

In a Physics laboratory, a trolley of unknown mass, **m**, moves along a track at a constant velocity of $0{,}4\ m.s^{-1}$. A wooden block, mass 500 g, is released directly above and it lands on top of the trolley. The trolley, along with the block, continues moving at $0{,}15\ m.s^{-1}$ in the same direction, as the diagram below illustrates.



2.1 Define, in words, the term *momentum* as used in Physics. (2)

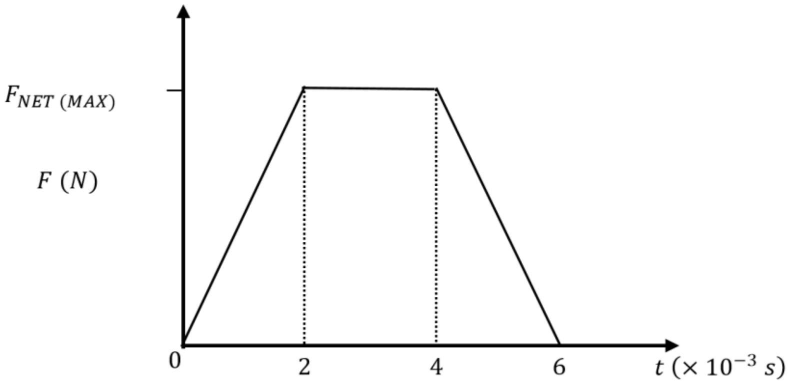
2.2 Is the collision between the wooden block and the trolley ELASTIC or INELASTIC? Use a suitable calculation to justify the answer. (7)

2.3 Draw a velocity versus time sketch graph to illustrate the motion of the trolley BEFORE and AFTER the block lands on it. (No values required). (2)

[11]

Question 3

The graph below represents the NET FORCE F (versus time) on a 58 g ball that collides with a wall. The initial speed of the ball is $34\ m.s^{-1}$, perpendicular to the wall. The ball re-bounds at the same speed, perpendicular to the wall. Disregard the effect of friction.

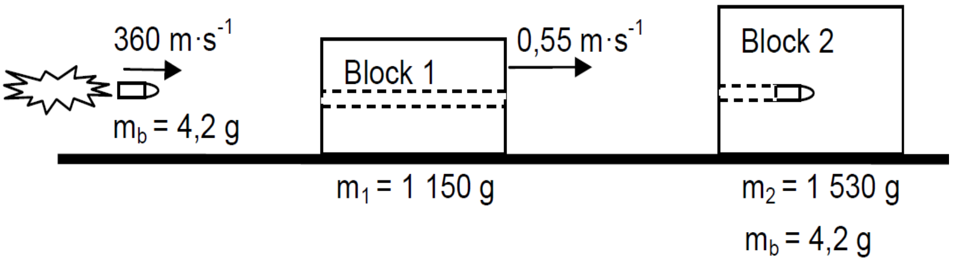


3.1 Define the term *impulse* in words. (2)

3.2 For how long was the ball in contact with the wall? (1)

3.3 Calculate the magnitude of the maximum net force, $F_{NET\ (MAX)}$, on the ball during the collision. (4)

3.4 A $4,2\ g$ bullet, moving horizontally to the right at a velocity of $360\ m.s^{-1}$, strikes a stationary block with mass m_1 of 1150 g. The velocity of the block immediately after the bullet has passed through it is $0,55\ m.s^{-1}$ to the right. The bullet proceeds and strikes another stationary block with mass m_2 of 1 530 g. THE BULLET REMAINS EMBEDDED IN THE SECOND BLOCK. Ignore the effects of friction.



3.4.1 State the principal of the conservation of linear momentum in words. (2)

3.4.2 Calculate the magnitude of the velocity of the second block after the bullet has been embedded in the block. (6)

[15]

Question 4

A bullet is fired from a stationary gun. Assume that the bullet moves horizontally. Immediately after firing, the gun recoils (moves back) with a velocity of $1,4\ m.s^{-1}$. The momentum of the gun after firing the bullet is observed to be $4,2\ kg.m.s^{-1}$. It is calculated that the gun is 150 times heavier than the bullet. Ignore all effects of friction.

4.1 Would you consider this to be a closed or isolated system? Give a reason for your answer. (2)

4.2 State *Newton's second law expressed in terms of momentum* in words. (2)

4.3 How does the force that the bullet experience compares to the force that the gun experience? Choose from: GREATER; SMALLER OR THE SAME AS. (1)

4.4 A learner observes that the speed of the bullet is much greater than the speed at which the gun recoils. Give a reason to explain this observation. (2)

4.5 Calculate the velocity of the bullet just after it has been fired. (7)

[14]

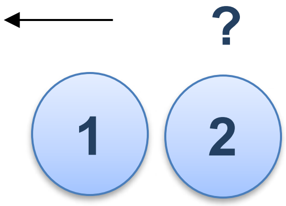
Question 5

A sample of xenon gas (Xe) is sealed in a closed container. The xenon atoms are all moving at high velocities and constantly colliding with each other as well as the container walls. A single xenon atom has a mass of $2{,}2 \times 10^{-25} kg$.

Consider a single collision between two of the atoms. Just before the collision, Atom 1 is moving with a velocity of $208\ m.s^{-1}$ to the left and Atom 2 is moving with a velocity of $272\ m.s^{-1}$ to the left.

BEFORE

Immediately after the two atoms collide, Atom 1 has a velocity of $272\ m.s^{-1}$ to the left.



IMMEDIATELY AFTER

5.1 State the *principle of conservation of linear momentum* in words. (2)

5.2 Determine the momentum of Atom 2 immediately after the collision. (5)

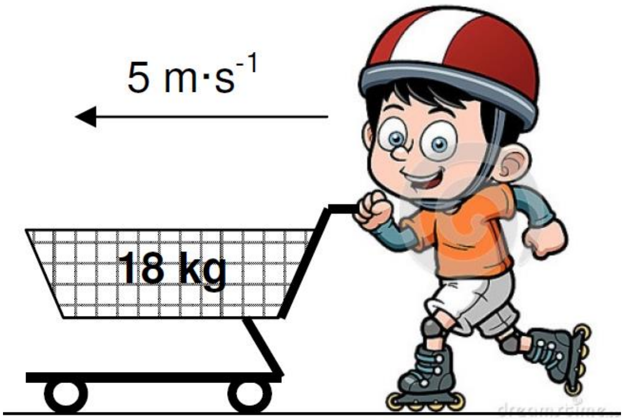
5.3 According to kinetic molecular theory, this collision should be elastic. Perform a suitable calculation to show that the collision between the two atoms is perfectly elastic. (4)

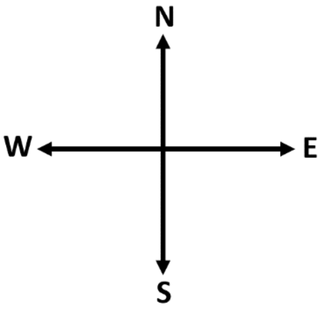
5.4 Determine the magnitude of the impulse experienced by Atom 1 during the collision. (3)

[13]

Question 6

A boy on roller blades with his hands on a fully loaded trolley, mass 18 kg, moves west at $5\ m.s^{-1}$ over a frictionless surface as shown in the sketch. The boy now pushes the trolley so that he moves at $1\ m.s^{-1}$ east after this push. The mass of the boy and his roller blades is 45 kg.





6.1 State the conservation principle that is applicable during the interaction between the boy and the trolley. (2)

6.2 Calculate the velocity of the trolley directly after the boy pushed it. (4)

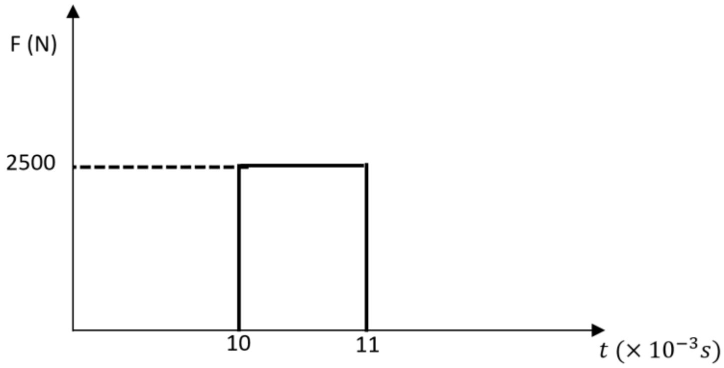
6.3 During the pushing motion of the boy on the trolley, the trolley experiences an impulse. How does the magnitude of the impulse that the boy experiences compare to that of the trolley? Write down INCREASES, DECREASES or REMAINS THE SAME and explain your answer. (3)

6.4 If the force exerted on the trolley lasts $0{,}4\ s$, calculate the force that the boy exerts on the trolley. (4)

[13]

Question 7

A 2 kg block is sliding to the right on a frictionless horizontal surface at $4\ m.s^{-1}$. A force of 2 500 N is now exerted on the block for a short period of time as indicated in the graph below.



7.1 Define the term impulse. (2)

7.2 Calculate the magnitude of the impulse on the block. (3)

7.3 Calculate the velocity of the block immediately after the force stops acting on the block if the force was exerted to:

- 7.3.1 The right (4)
- 7.3.2 The left (3)

[12]

Question 8

Percy, mass 75 kg, rides at $20\ m.s^{-1}$ on a quad bike (motorcycle with four wheels) with a mass of 100 kg. He suddenly applies the brakes when he approaches a red traffic light on a wet and slippery road. The wheels of the quad bike lock and the bike slides forward in a straight line. The force of friction causes the bike to stop in 8 s.

8.1 Define the concept *momentum* in words. (2)

8.2 Calculate the change in momentum of Percy and the bike, from the moment the brakes lock until the bike comes to a stop. (4)

8.3 Calculate the average frictional force exerted by the road on the wheels to stop the bike. (4)

[10]

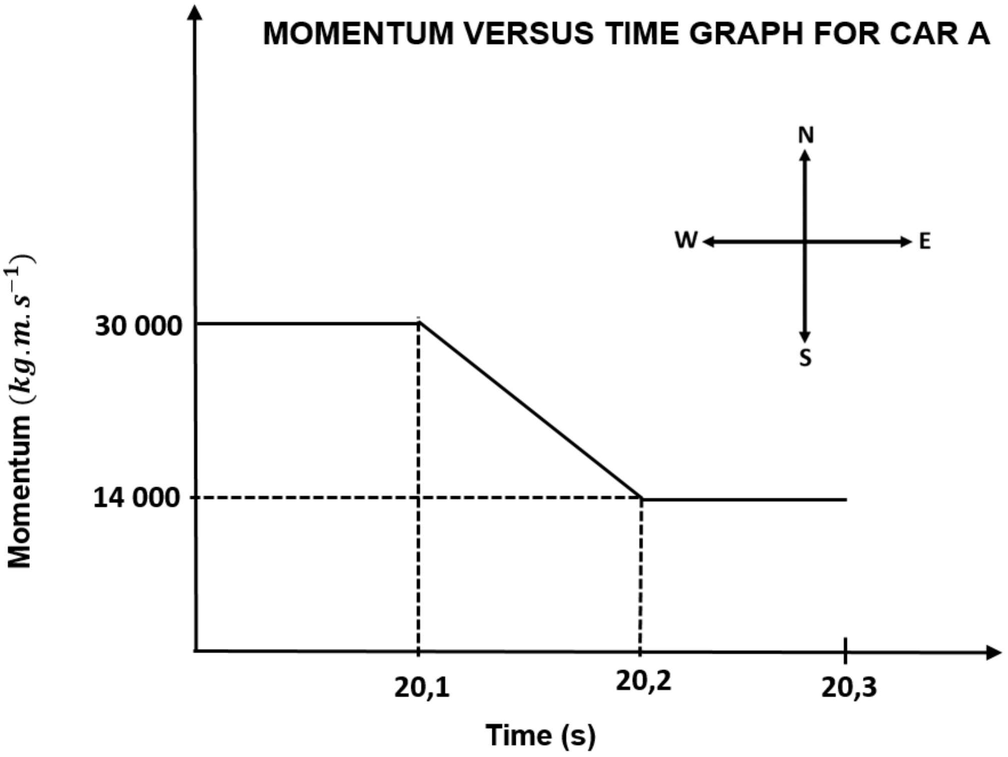
Question 9

The graph below shows how the momentum of car **A** changes with time *just before* and *just after* a head-on collision with car **B.**

Car **A** has a mass of 1 500 kg, while the mass of car **B** is 900 kg.

Car **B** was travelling at a constant velocity of $15\ m.s^{-1}$ west before the collision.

Take east as positive and consider the system as isolated.



9.1 What do you understand by the term *isolated system* as used in physics? (1)

Use the information in the graph to answer the following questions.

9.2 Calculate the:

- 9.2.1 Magnitude of the velocity of car **A** just before the collision. (3)
- 9.2.2 Velocity of car **B** just after the collision. (5)
- 9.2.3 Magnitude of the net average force acting on car **A** during the collision. (4)

[13]

5. Answers

5.1. Answers to multiple-choice questions.

1	D	**6**	B	**11**	A
2	B	**7**	B	**12**	C
3	D	**8**	D	**13**	B
4	A	**9**	C	**14**	B
5	D	**10**	D	**15**	D

5.2. Answers to structured questions.

Question 1

1.1 The product of the resultant/net force ✓acting on an object and the time the resultant/net force acts on the object.✓ (2)

	Option 1	**Option 2**	
	Towards the cricketer = "+"	**Away from cricketer = "+"**	
1.2	$p = mv$ ✓	$p = mv$ ✓	
	$p = (0,4)(40)$ ✓	$p = (0,4)(-40)$ ✓	
	$p = 16\ kg.m.s^{-1}$ Towards the cricketer ✓	$p = -16\ kg.m.s^{-1}$	
		$\therefore p = 16\ kg.m.s^{-1}$ Towards the cricketer ✓	(3)

	Option 1	**Option 2**	
1.3	**Towards the cricketer = "+"**	**Away from cricketer = "+"**	
	$F_{NET}\Delta t = \Delta p$ ✓	$F_{NET}\Delta t = \Delta p$ ✓	
	$F_{NET}\Delta t = m(v_f - v_i)$	$F_{NET}\Delta t = m(v_f - v_i)$	
	$(-400)(0,1)$✓ $= 0,4(v_f - 40)$ ✓	$(400)(0,1)$✓ $= 0,4(v_f - (-40))$ ✓	
	$-100 = v_f - 40$	$100 = v_f + 40$	
	$v_f = -60\ m.s^{-1}$	$v_f = 60\ m.s^{-1}$	
	$\therefore v_f = 60\ m.s^{-1}$ ✓	$\therefore v_f = 60\ m.s^{-1}$ ✓	(4)

We don't have to indicate direction in the answer for 1.3 because the question only asked for **MAGNITUDE**.

1.4.1 **Option 1: Towards the right as positive**

$$\left.\begin{aligned}&\sum \mathrm{p\ i} = \sum \mathrm{p\ f}\\ &m_A v_{A\,i} + m_B v_{B\,i} = m_A v_{A\,f} + m_B v_{B\,f}\end{aligned}\right\} \checkmark$$

$(1750)(1{,}5) + (1450)(-1{,}1)\checkmark = (1750)(0{,}25) + (1450)v_{B\,f}\checkmark$

$592.5 = (1450)v_{B\,f}$

$v_{B\,f} = 0{,}41\ m.s^{-1}\checkmark$ to the right. ✓ (5)

Option 2: Towards the left as positive

$$\left.\begin{aligned}&\sum \mathrm{p\ i} = \sum \mathrm{p\ f}\\ &m_A v_{A\,i} + m_B v_{B\,i} = m_A v_{A\,f} + m_B v_{B\,f}\end{aligned}\right\}$$

$(1750)(-1{,}5) + (1450)(1{,}1)\checkmark = (1750)(-0{,}25) + (1450)v_{B\,f}\checkmark$

$-592.5 = (1450)v_{B\,f}$

$v_{B\,f} = -0{,}41\ m.s^{-1}$ (5)

$\therefore v_{B\,f} = 0{,}41\ m.s^{-1}$ ✓ to the right. ✓

1.4.2 Flexible bumpers reduce the net force ✓by increasing the time ✓required to bring about the same change in momentum. ✓

OR

According to $F_{NET} = \frac{\Delta p}{\Delta t}$ ✓; For the same change in momentum✓ increasing Δt decreases the net force. ✓ (3)

[17]

Question 2

2.1 The product of an object's mass and its velocity. ✓✓ (2)

2.2 We have to calculate the mass of the trolley first. – We need this value to calculate the kinetic energy, which will tell us if the collision was elastic or inelastic.

$\sum p_{\text{i}} = \sum p_{\text{f}}$

$m_T v_{T\,i} + m_B v_{B\,i} = (m_T + m_B)v_f$

$m_T(0{,}4) + (0{,}5)(0) = (m_T + 0{,}5)(0{,}15)$ ✓

$0{,}4m_T = 0{,}15m_T + 0{,}075$

$m_T = 0{,}3\ kg.$ ✓

Hints:

The motion of the trolley is taken as the positive direction.

The mass of the block must be converted to kg.

The block has a velocity of 0 $m.s^{-1}$ before it is dropped.

$\sum E_{k\ initial} = \frac{1}{2}m_T {v_T}^2 + \frac{1}{2}m_B {v_B}^2$ ✓ (Before the block is dropped.)

$\sum E_{k\ initial} = \frac{1}{2}(0{,}3)(0{,}4)^2 + \frac{1}{2}(0{,}5)(0)^2$

$\sum E_{k\ initial} = 0{,}024\ J$ ✓

$\sum E_{k\ final} = \frac{1}{2}(m_T + m_B){v_f}^2$ (After the block is dropped on the trolley)

$\sum E_{k\ final} = \frac{1}{2}(0{,}3 + 0{,}5)(0{,}15)^2$

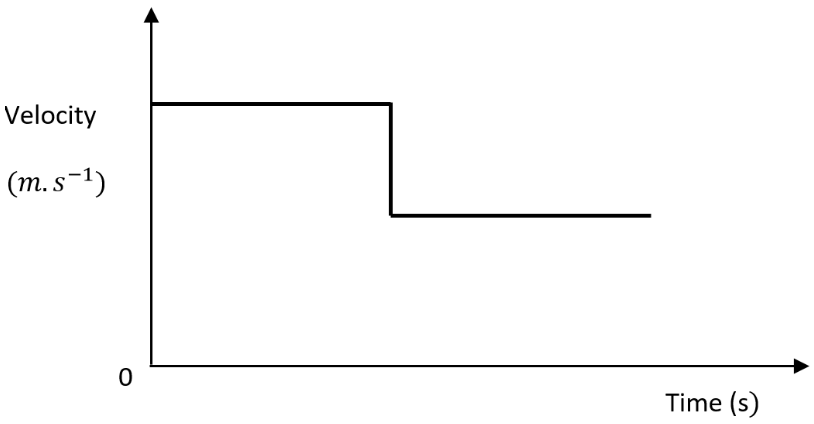
$\sum E_{k\ initial} = 0{,}009\ J$ ✓

$\therefore \sum E_{k\ initial} \neq \sum E_{k\ final}$ ✓ OR $\sum E_{k\ initial}$ is greater than $\sum E_{k\ final}$

$\therefore$ *collision is inelastic* ✓, *kinetic energy is not conserved.* (7)

2.3

GRAPH OF VELOCITY VS TIME



(2)

[11]

Question 3

3.1 The product of the resultant/net force ✓acting on an object and the time the resultant/net force acts on the object.✓ (2)

3.2 $6 \times 10^{-3}\ s$ ✓ **OR** $0{,}006\ s$ (1)

3.3 **Hint:** Remember the question asks to calculate the maximum force. If you only calculate F_{NET} it will represent the average force between the ball and the wall during the contact time.

Option 1:

$$\left.\begin{aligned} F_{NET\ (MAX)}\Delta t &= \Delta p \\ F_{NET\ (MAX)}\Delta t &= m(v_f - v_i) \end{aligned}\right\} \checkmark$$

$$\underbrace{\tfrac{1}{2}(2 \times 10^{-3} + 6 \times 10^{-3})F_{NET\ (MAX)} = 0{,}\checkmark}_{\text{Area of Trapezium}}058(34 - (-34))\checkmark\ \checkmark$$

Area of Trapezium

$$A = \frac{1}{2}(a+b)h$$

$$F_{NET\ (MAX)} = 986\ N \quad \checkmark$$

Option 2:

Impulse = area under the graph

Impulse = Δp

$\therefore \Delta p = area\ under\ the\ graph$

$\Delta p = \frac{1}{2}(a+b)h$ ✓

$$m(v_f - v_i) = \frac{1}{2}(a+b)h$$

$(0{,}058)(34) - (0{,}058)(-34)\checkmark = \frac{1}{2}(2 \times 10^{-3} + 6 \times 10^{-3})\ F_{NET\ (MAX)}\checkmark$

$F_{NET\ (MAX)} = 986\ N$ ✓

Option 3: If you don't feel comfortable working with the area of a trapezium, divide the graph up into easier shapes. For this graph we will use 2 triangles and 1 rectangle.

Impulse = area under the graph

Impulse = Δp

$\therefore \Delta p = area\ under\ the\ graph$

$\Delta p = \frac{1}{2}bh + (l \times b) + \frac{1}{2}bh$ ✓

$$m(v_f - v_i) = \frac{1}{2}bh + (l \times b) + \frac{1}{2}bh$$

$$(0{,}058)(34)-(0{,}058)(-34)\ \checkmark=\frac{1}{2}(2\times10^{-3})F_{NET\ (MAX)}+(2\times10^{-3})(F_{NET\ (MAX)})+\frac{1}{2}(2\times10^{-3})F_{NET\ (MAX)}\ \checkmark$$

$$F_{NET\ (MAX)} = 986\ N\ \checkmark$$

(4)

3.4.1 The TOTAL linear momentum in an isolated system remains constant (is conserved). ✓ ✓ (2)

3.4.2 **Option 1: (Right positive)** $\xrightarrow{+}$

$$\left.\begin{array}{l}\sum p_i = \sum p_f \\ m_{Bullet}v_{Bullet\ i} + m_{Block\ 1}v_{Block\ 1\ i} = m_{Bullet}v_{Bullet\ f} + m_{Block\ 1}\,v_{Block\ 1\ f}\end{array}\right\}\checkmark$$

$$(0{,}0042)(360) + (1{,}15)(0)\checkmark = (0{,}0042)v_{Bullet\ f} + (1{,}15)(0{,}55)\ \checkmark$$

$$1{,}512 - 0{,}6325 = 0{,}0042v_{Bullet\ f}$$

$v_{Bullet\ f} = 209{,}40\ m.s^{-1}$ (This will be the velocity of the bullet after it passes through block 1).

Hint: The question states we should ignore friction, hence we can accept that the velocity with which the bullet leaves block 1 will be the same velocity with which the bullet strikes block 2.

$$\sum p_i = \sum p_f$$

$$m_{Bullet}v_{Bullet\ i} + m_{Block\ 2}v_{Block\ 2\ i} = (m_{Bullet} + m_{Block\ 2})\ v_f$$

$$(0{,}0042)(209{,}40) + (1{,}53)(0)\checkmark = (0{,}0042 + 1{,}53)v_f\checkmark$$

$$0{,}87948 = (1{,}5342)v_f$$

$$v_f = 0{,}57\ m.s^{-1}\ \checkmark$$

No direction is needed with the answer since the question only asked for magnitude.

Option 2: Left positive $\xleftarrow{\quad + \quad}$

$\sum_{\text{p i}} = \sum_{\text{p f}}$ ✓

$m_{Bullet}v_{Bullet\ i} + m_{Block\ 1}v_{Block\ 1\ i} = m_{Bullet}v_{Bullet\ f} + m_{Block\ 1}\ v_{Block\ 1\ f}$

$(0{,}0042)(-360) + (1{,}15)(0)$✓ $= (0{,}0042)v_{Bullet\ f} + (1{,}15)(-0{,}55)$ ✓

$-1{,}512 + 0{,}6325 = 0{,}0042v_{Bullet\ f}$

$v_{Bullet\ f} = -209{,}40\ m.s^{-1}$ (This will be the velocity of the bullet after it passes through block 1).

$\sum_{\text{p i}} = \sum_{\text{p f}}$

$m_{Bullet}v_{Bullet\ i} + m_{Block\ 2}v_{Block\ 2\ i} = (m_{Bullet} + m_{Block\ 2})\ v_f$

$(0{,}0042)(-209{,}40) + (1{,}53)(0)$✓ $= (0{,}0042 + 1{,}53)v_f$✓

$-0{,}87948 = (1{,}5342)v_f$

$v_f = -0{,}57\ m.s^{-1}$

$\therefore v_f = 0{,}57\ m.s^{-1}$ ✓ (6)

No direction is needed with the answer since the question only asked for magnitude.

[15]

Question 4

4.1 Yes✓, all effects of friction can be ignored. ✓ (No external forces acting on the system) (2)

OR

The net external force acting on the system is equal to zero.

4.2 The resultant/net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant/net force. ✓✓ (2)

4.3 THE SAME AS ✓ (1)

4.4 The mass of the bullet is much smaller✓ than the mass of the gun, both the gun and bullet will experience the same change in momentum✓, hence the velocity of the bullet should be greater than the recoil speed of the gun. (2)

4.5 Consider the motion towards the right as "+"

$p_{G\,f} = m\,v$

$-4{,}2 = m(-1{,}4)$

$m = 3\ kg$✓ (This is the mass of the Gun)

We know the ratio of bullet mass to gun mass: 1 : 150 ✓

$\therefore\ IF\ the\ mass\ of\ the\ gun\ is\ 3\ kg\ the\ mass\ of\ the\ bullet\ will\ be:$

$\frac{3}{150} = 0{,}02\ kg$ (using the ratio)

$$\left.\begin{array}{l}\sum \mathrm{p\ i} = \sum \mathrm{p\ f} \\ (m_G + m_B)v_i = m_G v_{G\,f} + m_B\,v_{B\,f}\end{array}\right\} \checkmark$$

$(m_G + m_B)0$✓ $= -4{,}2 + (0{,}02)\ v_{B\,f}$✓ (7)

$$v_{B\,f} = \frac{4{,}2}{0{,}02}$$

$v_{B\,f} = 210\ m.s^{-1}$. ✓ Towards the right. ✓

[14]

Question 5

5.1 The TOTAL linear momentum in an isolated system remains constant (is conserved). ✓✓ (2)

5.2 **Take right as positive.**

$$\xrightarrow{\qquad + \qquad}$$

$$\left.\begin{array}{l}\sum \mathrm{p\ i} = \sum \mathrm{p\ f} \\ m_1 v_{1\,i} + m_2 v_{2\,i} = m_1 v_{1\,f} + m_2\,v_{2\,f}\end{array}\right\} \checkmark \qquad \checkmark$$

$(2{,}2 \times 10^{-25})(-208\,) + (2{,}2 \times 10^{-25})(-272) = (2{,}2 \times 10^{-25})(-272) + p_f$

$-1{,}056 \times 10^{-22} = -5{,}984 \times 10^{-23} + p_f$

$p_f = -4{,}58 \times 10^{-23}\ kg.m.s^{-1}$

$p_f = 4{,}58 \times 10^{-23}\ kg.m.s^{-1}$ ✓ $towards\ the\ left.$ ✓

OR

Take left as positive. $\xleftarrow{\quad + \quad}$

$$\left.\begin{array}{l}\sum_{p\,i} = \sum_{p\,f} \\ m_1 v_{1\,i} + m_2 v_{2\,i} = m_1 v_{1\,f} + m_2\, v_{2\,f}\end{array}\right\} \checkmark\checkmark$$

$(2{,}2 \times 10^{-25})(208\,) + (2{,}2 \times 10^{-25})(272) = (2{,}2 \times 10^{-25})(272) + p_f$

$1{,}056 \times 10^{-22} = 5{,}984 \times 10^{-23} + p_f$

$p_f\ = 4{,}58 \times 10^{-23}\ kg.m.s^{-1}$ ✓ *towards the left.* ✓ (5)

5.3 $\sum E_{k\ initial} = \frac{1}{2} m_1 {v_1}^2 + \frac{1}{2} m_2 {v_2}^2$ ✓ (Before the collision.)

$\sum E_{k\ initial} = \frac{1}{2}(2{,}2 \times 10^{-25})(208)^2 + \frac{1}{2}(2{,}2 \times 10^{-25})(272)^2$ ✓

$\sum E_{k\ initial} = 1{,}29 \times 10^{-20}\ J$

$\sum E_{k\ final} = \frac{1}{2} m_1 {v_1}^2 + \frac{1}{2} m_2 {v_2}^2$ (After the collision.)

$\sum E_{k\ final} = \frac{1}{2}(2{,}2 \times 10^{-25})(272)^2 + \frac{1}{2}(2{,}2 \times 10^{-25})(208)^2$ ✓

$\sum E_{k\ final} = 1{,}29 \times 10^{-20}\ J$

$\therefore \sum E_{k\ initial} = \sum E_{k\ final}$ ✓

$\therefore$ ***The collision is elastic.*** (4)

5.4 $F_{NET}\,\Delta t = \Delta p$ ✓

$F_{NET}\,\Delta t = m(v_f - v_i)$

$Impulse = m(v_f - v_i)$

$Impulse = (2{,}2 \times 10^{-25})(-272 - (-208))$ ✓

$Impulse = -1{,}41\ \times 10^{-23}\ N.s$

$Impulse = 1{,}41 \times 10^{-23}\ N.s$ ✓ (3)

Remember atoms are moving towards the **left**, because we chose right as positive in this option, we should substitute the velocities as **negative.**

It is allowed to use the unit $kg.m.s^{-1}$

We do not need to include direction, the question only asked for magnitude.

We can determine the velocity of Atom 2 after the collision in the following manner.

$p_f = mv_f$

$4{,}58 \times 10^{-23} = (2{,}2 \times 10^{-25})v_f$

$v_f = 208\ m.s^{-1}$

[13]

Question 6

6.1 The TOTAL linear momentum in an isolated system remains constant (is conserved). ✓✓ (2)

You may note how many times in questions this definition is asked, just an indication of its importance – make sure to study it for the exam.

6.2 **Option 1: West taken as "+"**

$$\left.\begin{array}{l}\sum_{\mathrm{p\ i}} = \sum_{\mathrm{p\ f}} \\ m_1 v_{1\,i} + m_2 v_{2\,i} = m_1 v_{1\,f} + m_2\, v_{2\,f}\end{array}\right\} \checkmark$$

$(18 + 45)(5)$✓ $= 45(-1) + (18)v_f$✓

$v_f = 20\,m.s^{-1}\ West.$ ✓

Option 2: East taken as "+"

$$\left.\begin{array}{l}\sum_{\mathrm{p\ i}} = \sum_{\mathrm{p\ f}} \\ m_1 v_{1\,i} + m_2 v_{2\,i} = m_1 v_{1\,f} + m_2\, v_{2\,f}\end{array}\right\} \checkmark$$

$(18 + 45)(-5)$✓ $= 45(1) + (18)v_f$✓ (4)

$v_f = -20\,m.s^{-1}$

$\therefore v_f = 20\,m.s^{-1}\ West.$ ✓

6.3 **Remains the same,** ✓ The force experienced by both the boy and the trolley is the same ✓– Newton's 3rd law. The change in momentum (Δp) remains constant. ✓

OR $\Delta p_{trolley} = -\Delta p_{Boy}$ ✓; $Impulse = \Delta p$✓ (3)

(NOTE: Always answer the question first!)

6.4 **Option 1: Information of trolley is used. Take West as "+"**

$F_{NET}\,\Delta t = \Delta p$ ✓

$F_{NET}\,\Delta t = mv_f - mv_i$

$F_{Trolley}\,(0{,}4)$✓ $= 18(20 - 5)$ ✓ **OR** $F_{Trolley}\,(0{,}4)$✓ $= 18(20) - 18(5)$ ✓

$F_{Trolley} = 675\ N\ West.$ ✓

Option 2: Information of trolley is used. Take East as "+"

$F_{NET}\,\Delta t = \Delta p$ ✓

$F_{NET}\,\Delta t = mv_f - mv_i$

$F_{Trolley}\,(0{,}4)$✓ $= 18(-20 - (-5))$ ✓***OR*** $F_{Trolley}\,(0{,}4) = 18(-20) - 18(-5)$

$F_{Trolley} = -675\ N$

$F_{Trolley} = 675\ N\ West.$ ✓

Option 3: Information of boy is used. Take West as "+"

$F_{NET}\,\Delta t = \Delta p \checkmark$

$F_{NET}\,\Delta t = mv_f - mv_i$

$F_{Boy}\,(0{,}4)\checkmark = 45(-1-5) \checkmark$

$F_{Boy} \;= -675\ N$

$F_{Boy} \;= 675\ N\ East.$

$\therefore\ F_{Trolley} \;= 675\ N\ West. \checkmark$

Remember the question asked the force exerted on the **trolley.** Because of Newton's 3rd law we know that the force experienced by the boy will be the same as the force experienced by the trolley but in the **opposite direction.** For this option we will have to write a conclusion answer stating the force of the trolley.

(4)

[13]

Question 7

7.1 The product of the resultant/net force ✓acting on an object and the time the resultant/net force acts on the object.✓ (2)

7.2 **Option 1:**

$Impulse = F_{NET}\Delta t \checkmark$

$Impulse = (2500)(1 \times 10^{-3}) \checkmark$

$Impulse = 2{,}5\ N.s \checkmark$

Option 2:

$Impulse = area\ under\ the\ graph$

$Impulse = l\ \times b\checkmark$

$Impulse = (2500)(1 \times 10^{-3}) \checkmark$

$Impulse = 2{,}5\ N.s \checkmark$

Hint: The difference in time from 10 to 11 is $\mathbf{1 \times 10^{-3}}$**s.** (x-axis of graph)

We don't need to indicate the direction, the question only asks for the magnitude.

(3)

7.3.1 **Option 1: Right as positive**

$F_{NET}\,\Delta t = m(v_f - v_i) \checkmark$

$Impulse = \ m(v_f - v_i)$

$(2{,}5)\checkmark\ = 2(v_f - 4) \checkmark$

$v_f = 5{,}25\ m.s^{-1}\ right. \checkmark$

Remember!!

$Impulse = F_{NET}\Delta t$

You calculated the impulse in 7.2

Option 2: Left as positive

$F_{NET}\,\Delta t = m(v_f - v_i) \checkmark$

$(-2{,}5)\checkmark = 2(v_f - (-4)) \checkmark$

$v_f = -5{,}25\ m.s^{-1}$

$v_f = 5{,}25\ m.s^{-1}\ \ right. \checkmark$

(4)

7.3.2 **Option 1: Right as positive**

$F_{NET}\,\Delta t = m(v_f - v_i)$

$(-2{,}5)\checkmark = 2(v_f - 4) \checkmark$

$v_f = 2{,}75\ m.s^{-1}\ right. \checkmark$

Option 2: Left as positive

$F_{NET}\,\Delta t = m(v_f - v_i)$

$(-2{,}5)$✓ $= 2(v_f - (-4))$ ✓

$v_f = -2{,}75\ m.s^{-1}$

$v_f = 2{,}75\ m.s^{-1}\ right.$ ✓ (3)

[12]

Question 8

8.1 Momentum is the product of an object's mass and its velocity. ✓✓ (2)

8.2 **Option 1: Direction of motion is taken as positive.**

$\Delta p = m(v_f - v_i)$ ✓

$\Delta p = (175)(0 - 20)$ ✓

$\Delta p = -3\,500\ kg.m.s^{-1}$

$\Delta p = 3\,500\ kg.m.s^{-1}$✓ opposite the direction of motion. ✓

Always write your final answer as a positive value, the negative sign only indicates that the motion was in the opposite direction.

Option 2: Direction of motion is taken as negative.

$\Delta p = m(v_f - v_i)$ ✓

$\Delta p = (175)(0 - (-20))$ ✓

$\Delta p = 3\,500\ kg.m.s^{-1}$✓ opposite the direction of motion. ✓ (4)

8.3 **Option 1: Direction of motion is taken as positive.**

$F_{NET}\,\Delta t = \Delta p$✓

$f(8) = -3\,500$✓

$f = -437{,}5\ N$

$f = 437{,}5\ N$ ✓ *opposite to direction of motion.* ✓

Option 2: Direction of motion is taken as negative.

$F_{NET}\,\Delta t = \Delta p$✓

$f(8) = 3\,500$✓

$f = 437{,}5\ N$ ✓ *opposite to direction of motion.* ✓ (4)

[10]

Question 9

9.1 A system on which the resultant/net external force is zero ✓ (1)

9.2.1

Option 1:	**Option 2:**	
$p = mv$✓	$\Delta p = mv_f - mv_i$✓	
$30\,000 = (1\,500)v$✓	$0 = (1\,500)v_f - 30\,000$✓	
$v = 20\ m.s^{-1}$✓	$v = 20\ m.s^{-1}$✓	(3)

9.2.2 **Option 1:** **Remember the instruction was that east must be taken as positive.**

$$\left.\begin{array}{l}\sum p_i = \sum p_f \\ m_A v_{A\,i} + m_B v_{B\,i} = m_A v_{A\,f} + m_B\, v_{B\,f}\end{array}\right] \quad \checkmark$$

$$30\ 000 + (900)(-15)\checkmark = 14\ 000 + 900v_B\checkmark$$

$v_B = 2{,}78\ m.s^{-1}$ East. ✓

Option 2: **Remember the instruction was that east must be taken as positive.**

$$\left.\begin{array}{l}\Delta p_A = -\Delta p_B \\ p_{A\,f} - p_{A\,i} = -(m_B v_{B\,f} - m_B v_{B\,i})\end{array}\right] \quad \checkmark$$

$$14\ 000 - 30\ 000\checkmark = 900v_{B\,f} - 900(-15)\checkmark$$

$v_{B\,f} = 2{,}78\ m.s^{-1}$ East. ✓ (4)

9.2.3 **Option 1:**

$$Slope = \frac{\Delta p}{\Delta t} = F_{NET}\checkmark$$

$$Slope = \frac{(14\ 000 - 30\ 000)\checkmark}{(20{,}2 - 20{,}1)\checkmark}$$

$$Slope = -160\ 000\ N$$

$$\therefore F_{NET} = 160\ 000\ N\checkmark$$

Option 2:

$$F_{NET}\Delta t = \Delta p\checkmark$$

$$F_{NET}(0{,}1)\checkmark = 14\ 000 - 30\ 000\checkmark$$

$$F_{NET} = -160\ 000\ N$$

$$\therefore F_{NET} = 160\ 000\ N\checkmark$$

Option 3:

$$F_{NET}\Delta t = \Delta p\checkmark$$

$$F_{NET}(0{,}1)\checkmark = 900[(2{,}78) - (-15)]$$

$$F_{NET} = -160\ 020\ N$$

$$F_A = -F_B$$

$$F_{NET} = 160\ 020\ N$$

Remember: There is no need to show direction because the question only asked for the magnitude.

6. MESSAGE TO GRADE 12 LEARNERS

Allow me this opportunity to wish you the best of luck during the upcoming exams. There will be times where you are stressed and confused, it may feel like a hopeless situation and that you will not be able to get the job done – we understand that, but keep going. Nothing in life that is worth having will come easy. We are behind you, cheering you on to the finish line. Remember the following quotes from two brilliant scientists.

Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less. — Marie Curie

Life is like riding a bicycle. To keep your balance you must keep moving. – Albert Einstein

We know you can do this, good luck!

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8. Reference

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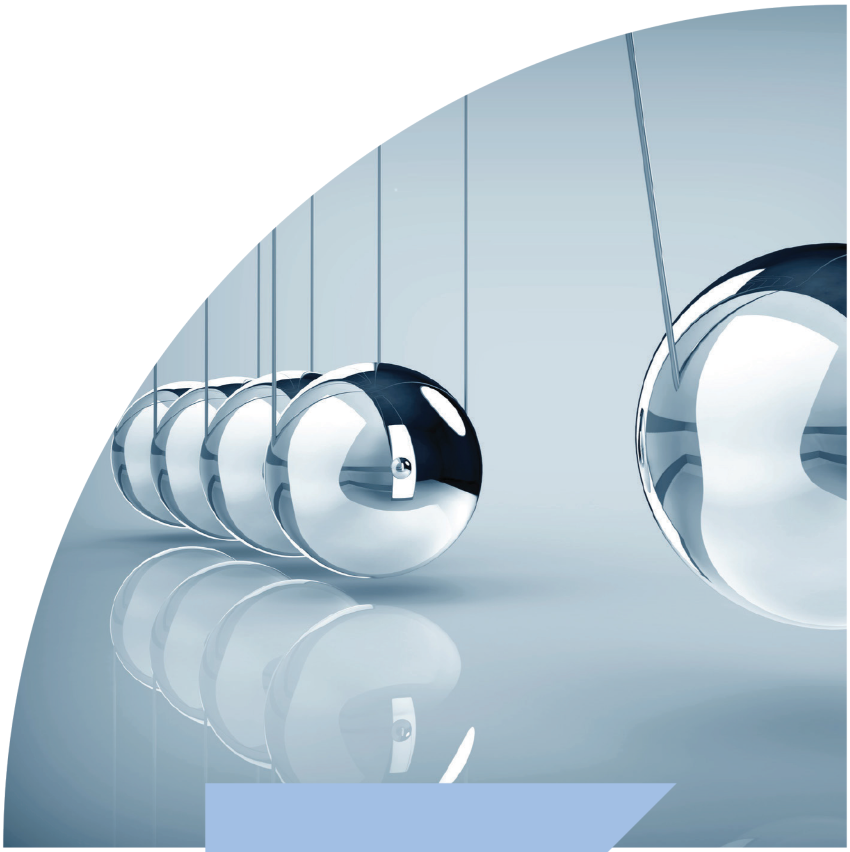

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