IB · DP · Physics

3 hours 15 questions

Structured Questions

2.4 Momentum & Impulse

2.4.1 Force & Momentum / 2.4.2 Impulse / 2.4.3 Conservation of Linear Momentum / 2.4.4 Collisions & Explosions

Easy (5 questions)	/64
Medium (5 questions)	/58
Hard (5 questions)	/63
Total Marks	**/185**

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Easy Questions

1 (a) (i) Write an equation for the momentum of an object in words

[1]

(ii) State the fundamental SI units of momentum

[1]

(2 marks)

(b) A railway carriage, C_1, of mass 1100 kg is rolling along a horizontal track at a speed of 6 m s^{-1} towards a stationary carriage, C_2, as shown below. Carriage C_2 has a mass of 3300 kg.

Calculate:

(i) The initial momentum of carriage C_1 before the collision

[2]

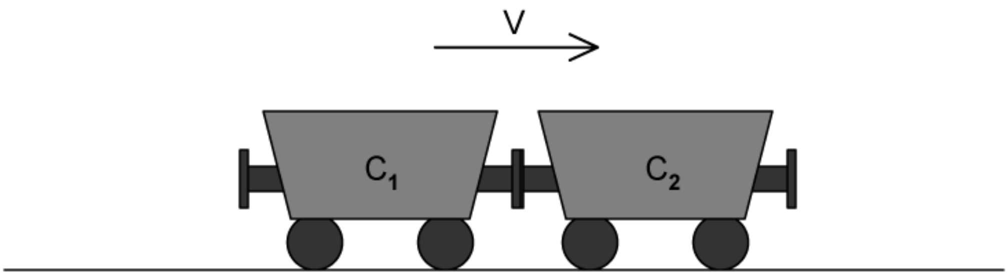
(ii) The initial momentum of carriage C_2 before the collision.

[1]

(3 marks)

(c) At the moment of collision, both carriages C_1 and C_2, become joined.

The joined carriages move off with a velocity, *v*, as shown below.



Calculate the total momentum of C_1 and C_2 after they have joined.

Use your answers from part (b) and the conservation of momentum.

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(3 marks)

(d) Calculate the velocity, *v*, at which the carriages C_1 and C_2 move after becoming joined.

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(3 marks)

2 (a) A film stuntman, of mass 85.0 kg, is being trained to jump off high objects.

In one scene he steps off a roof and falls vertically to the ground below. Just before he hits the ground he has a velocity of 9.08 m s^{-1}. After he has landed on the ground he remains at rest.

Calculate the momentum of the stuntman:

(i) Just before he hits the ground.

[2]

(ii) After he has landed.

[1]

(3 marks)

(b) Using your answers to part (a), calculate the change of momentum of the stuntman during the landing.

(2 marks)

(c) State the impulse experienced by the stuntman during landing.

Give an appropriate unit with your answer.

(2 marks)

(d) When the stuntman keeps his legs fully rigid, the time for the impact is 4.20 ms.

Calculate the magnitude of the average resultant force acting on the stuntman's legs during this time.

(4 marks)

3 (a) A bullet, of mass 20 g, leaves the barrel of a rifle, of mass 1.9 kg, with a momentum 4.0 kg m s^{-1}.

(i) State the total momentum of the rifle and the bullet before the rifle is fired

[1]

(ii) Give a reason for your answer to part (i)

[1]

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(2 marks)

(b) Calculate the velocity of the bullet just after the rifle is fired.

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(3 marks)

(c) Use the principle of conservation of momentum and your answer to part (a) to:

(i) State the total momentum of the rifle and the bullet immediately after the rifle has been fired.

[2]

(ii) Calculate the recoil momentum of the rifle.

[2]

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(4 marks)

(d) The bullet has a momentum of 3 kg m s^{-1} just before it hits a target. It takes 0.0025 s for the bullet to be stopped by the target.

$$F = \frac{\Delta p}{\Delta t}$$

Calculate the average force needed to stop the bullet.

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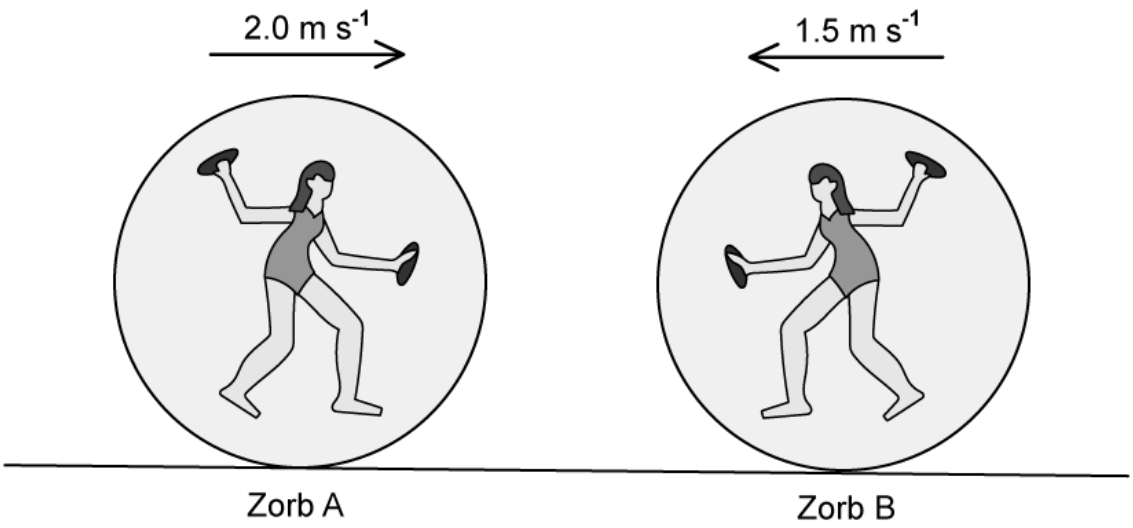
(4 marks)

4 (a) Zorbing is an activity which involves a person running inside an inflatable ball, called a 'zorb'. Two zorbs, A and B, collide head on with each other, as shown. The total mass of zorb A and its occupant is 75 kg and the total mass of zorb B and its occupant is 60 kg. Before the collision, zorb A is travelling at 2.0 m s^{-1} and zorb B is travelling at 1.5 m s^{-1}.



Calculate:

(i) The momentum of zorb A before the collision

[2]

(ii) The momentum of zorb B before the collision

[2]

(iii) The total momentum of both zorbs before the collision

[2]

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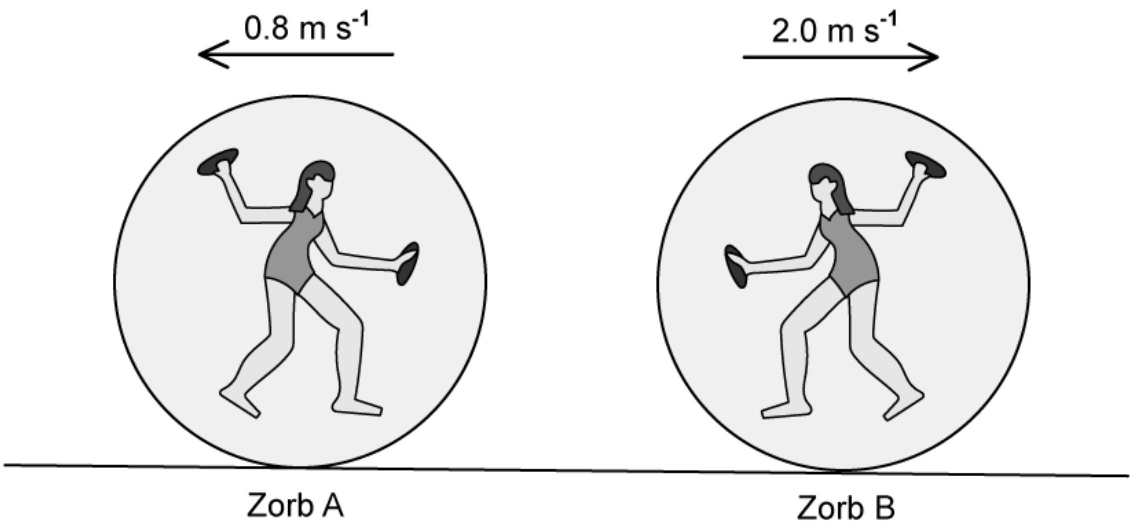
(6 marks)

(b) After the collision, both zorbs bounce off each other and move in opposite directions, as shown below. Zorb A travels at 0.8 m s^{-1} and zorb B travels at 2.0 m s^{-1}.



Calculate:

(i) The momentum of zorb A after the collision

[2]

(ii) The momentum of zorb B after the collision

[2]

(iii) The total momentum of both zorbs after the collision

[2]

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(6 marks)

(c) Calculate:

(i) The total kinetic energy of the zorbs before the collision.

[2]

(ii) The total kinetic energy of the zorbs after the collision.

[2]

(4 marks)

(d) State whether:

(i) Momentum is or is not conserved during the collision of the zorbs.

[1]

(ii) Kinetic energy is or is not conserved during the collision of the zorbs.

[1]

(iii) The collision of the zorbs is elastic or inelastic.

[1]

(3 marks)

5 (a) A collision can be described as being elastic or inelastic. When there are no external forces acting on the collision.

Place a tick (✓) next to the quantities that are conserved in each type of collision,

Quantity	**Elastic Collision**	**Inelastic Collision**
Momentum		
Total Energy		
Kinetic Energy		

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(3 marks)

(b) During a safety test, a car of mass 1250 kg travels at 0.5 m s^{-1} towards a wall.

Calculate the momentum of the car before it collides with the wall.

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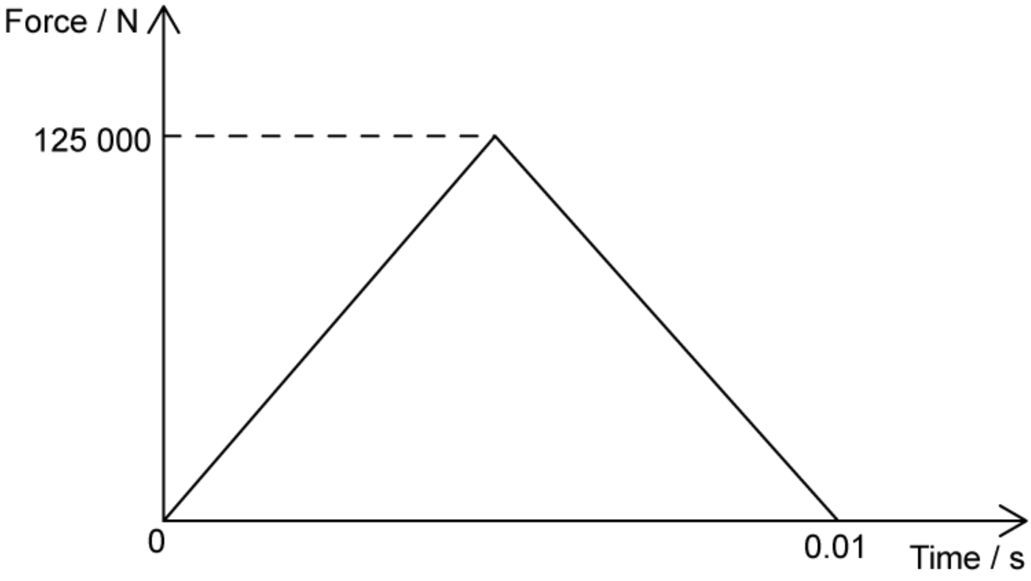
(2 marks)

(c) The car has a force sensor attached to the bumper which detects the force exerted on the front of the car. The graph below shows the variation of force with time for the duration of the collision.



Use the graph to show that the impulse of the collision is 625 N s.

(3 marks)

(d) All cars are designed with a crumple zone to protect passengers if they are involved in a collision.

State how a crumple zone:

(i) Affects the impact time of a collision.

[1]

(ii) Affects the force exerted on the car during a collision.

[1]

(2 marks)

Medium Questions

1 (a) Show, using the equation $F = ma$, how the impulse of a force F is related to the change in momentum Δp that it produces for a mass m with acceleration a.

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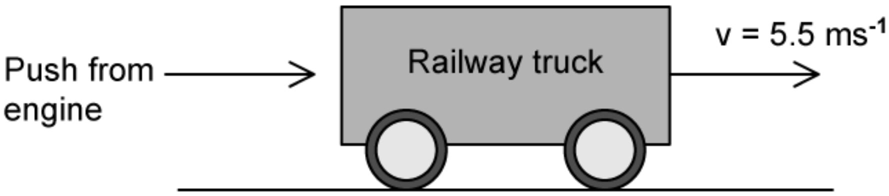
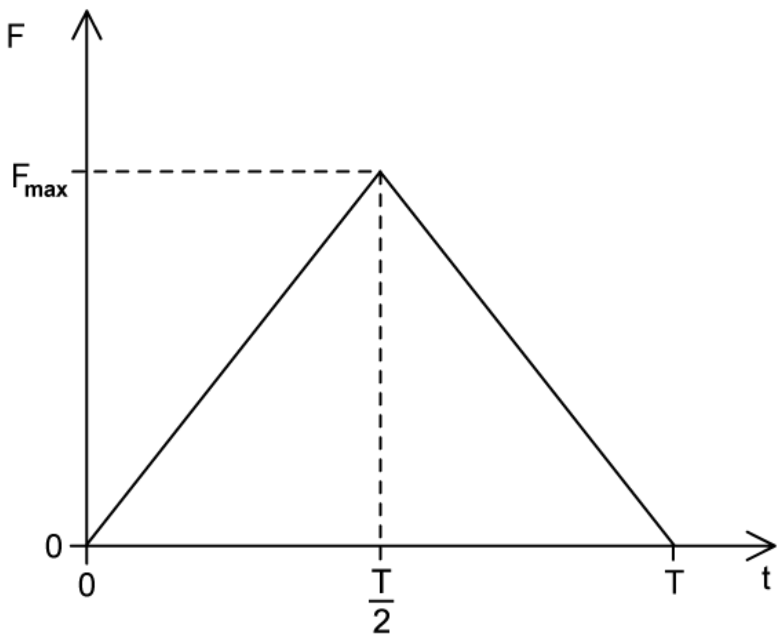
(2 marks)

(b) A railway truck on a level, straight track is initially at rest. The truck is given a quick, horizontal push by an engine so that it now rolls along the track.



The engine is in contact with the truck for a time T = 0.60 s and the initial speed of the truck after the push is 5.5 m s^{-1}. The mass of the truck is 3.1×10^3 kg.

Due to the push, a force of magnitude F is exerted by the engine on the truck. The sketch shows how F varies with contact time t.



Determine the magnitude of the maximum force exerted by the engine on the truck.

(4 marks)

(c) When the speed of the truck is 2.3 m s^{-1}, it collides with a stationary truck of mass 4.7 × 10^3 kg. The two trucks move off together with a speed *V*.

Show that the speed V = 0.9 m s^{-1}

(4 marks)

(d) State and explain whether the collision of the two trucks is elastic or inelastic.

(2 marks)

2 (a) Two identical blocks A and B of mass 200 g are travelling towards each other along a straight line through their centre. Assume that the surface is frictionless.

Both blocks are moving at a speed of 0.21 m s^{-1} relative to the surface.

As a result of the collision, the blocks reverse their direction of motion and travel at the same speed as each other. During the collision, 30% of the kinetic energy of the blocks is given off as thermal energy to the surroundings.

Deduce whether the collision is elastic or inelastic and state your reasoning.

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(2 marks)

(b) Calculate the final speed of the blocks relative to the surface.

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(4 marks)

(c) The duration of the collision between the blocks is 650 ms.

Determine the average force one block exerted on the other.

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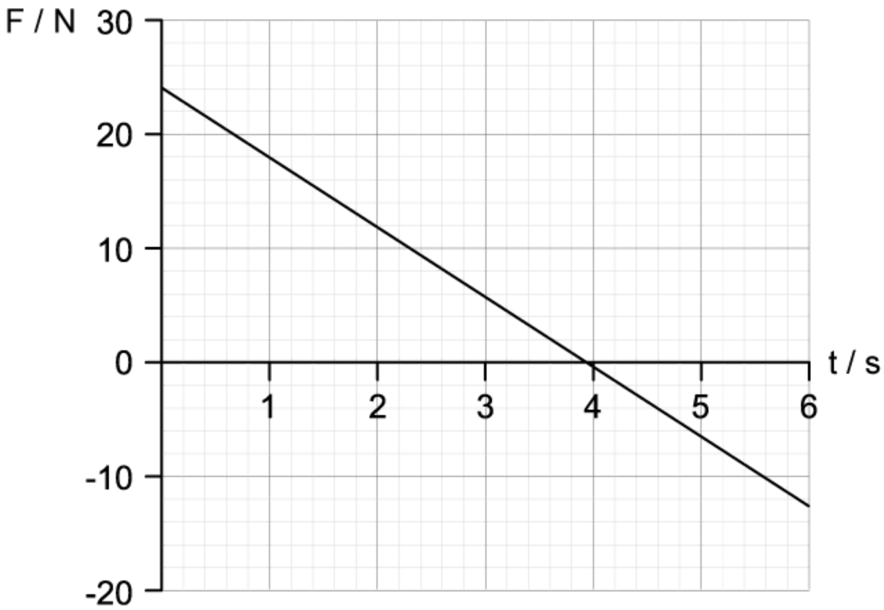
(3 marks)

3 (a) The force acts on a mass of 5.0 kg initially at rest.



Show that the speed of the mass at t = 3 s is 9.0 m s^{-1}.

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(4 marks)

(b) Calculate the deceleration of the mass up to time t = 4 s.

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(3 marks)

(c) Calculate the total impulse experienced by the mass.

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(3 marks)

(d) Outline the motion of the mass as indicated by the graph.

(2 marks)

4 (a) A space rocket is moving with constant velocity. The engines of the space rocket are turned on and it accelerates by burning fuel and ejecting gases.

Discuss how the law of conservation of momentum allows the space rocket to accelerate forward, although it ejects gases in the opposite direction.

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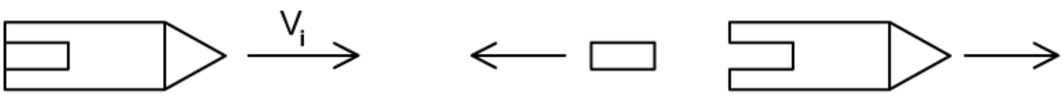
(3 marks)

(b) A rocket is travelling at constant velocity in space after exiting the Earth's atmosphere. The engines are turned off, and a module separates from the rocket.



The module has a mass of 6 000 kg and is ejected at 10 km s^{-1}. The combined mass of the rocket and the module is 81 000 kg and the remaining part of the rocket after the explosion travels at 4500 m s^{-1} after the module has been ejected.

Calculate the initial speed of the rocket.

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(4 marks)

(c) Calculate the force exerted on the module in 0.2 s during the explosion.

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(3 marks)

(d) Inside the rocket, some walls are padded to reduce damage to its interior when it is accelerated into space.

Explain, with reference to change in momentum, why padded walls are less likely to cause damage to the interior of the rocket compared to a rigid wall.

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(2 marks)

5 (a) Joanna and Lindsay are two roller skaters initially at rest on a horizontal surface. They are facing each other and Joanna is holding a ball. Joanna throws the ball to Lindsay who catches it. The speed at which the ball leaves Joanna, measured relative to the ground, is 6.2 m s^{-1}.

The following data are available.

Mass of Joanna = 59 kg

Mass of Lindsay = 64 kg

Mass of ball = 3.3 kg

(i) Calculate the velocity *v* of Joanna relative to the ground immediately after she throws the ball

[3]

(ii) State the direction that Joanna travels in after she throws the ball

[1]

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(4 marks)

(b) Calculate the speed *V* of Lindsay relative to the ground immediately after she catches the ball. Assume the speed of the ball stays constant throughout its motion.

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(4 marks)

(c) Determine whether Lindsay catching the ball is an elastic or inelastic collision.

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(3 marks)

(d) Lindsay has a previous injury to her hand, so decides to wear padded gloves whilst playing this game with Joanna. This is similar to what players would wear in cricket if they need to catch a ball at high speed.

Explain why the padded gloves would protect Lindsay's hands when she catches the ball.

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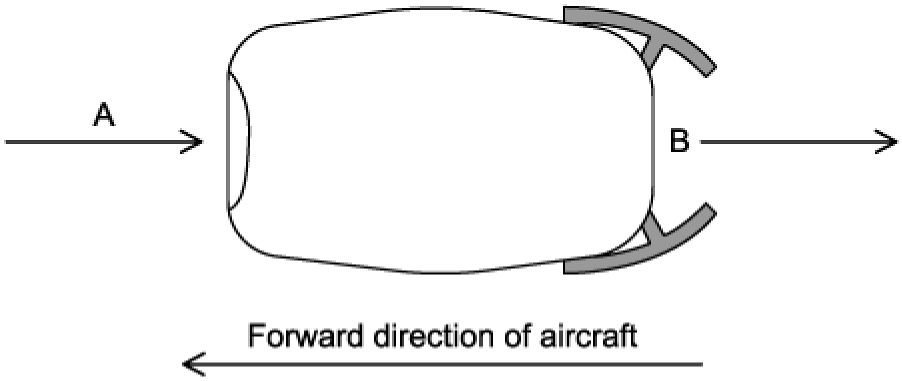
(2 marks)

Hard Questions

1 (a) Air enters a cargo plane's engine at A and is heated before leaving at B, at a much higher speed.

The rotating blades draw air in and while in the engine, the air is compressed and mixed with fuel, combusted and shot out the back of the engine.



In one second a mass of 3.75×10^5 g of air enters A and the speed of this mass of air increases by 587 m s^{-1} as it passes through the engine.

Calculate the force exerted by the air on the engine.

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(1 mark)

(b) Hot air flows out of the exhaust engine at B through a cross-sectional area of 5.9×10^6 mm^2. The density of the hot air is 457.9 g m^{-3}.

Calculate the volume of air leaving the engine every second.

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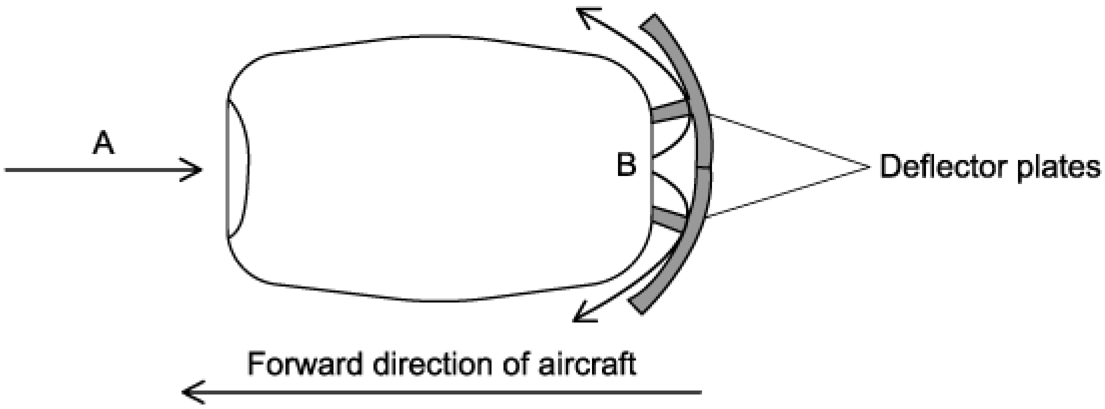
(2 marks)

(c) Explain, referring to the momentum of the air as it passes through the engine and using appropriate laws of motion, why it exerts a force on the engine in a forward direction.

(3 marks)

(d) When a cargo plane lands its engines exert a decelerating force on the aircraft by making use of deflector plates. These cause the air leaving the engines to be deflected at an angle to the direction the aircraft is travelling.



The speed of the deflected air is the same as the speed of the air leaving B.

(i) Explain why the momentum of the air changes.

[2]

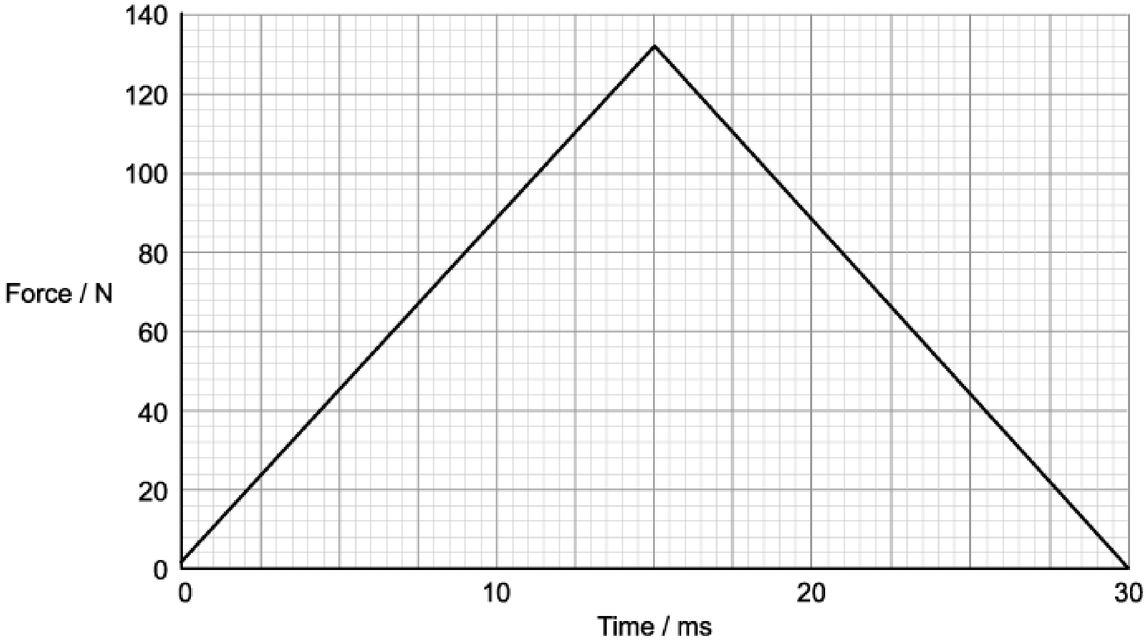
(ii) Suggest why the decelerating force provided by the deflector plates may not remain constant.

[2]

(4 marks)

2 (a) A squash ball is raised from the ground and dropped onto a hard plate to test its properties. A sensor measured the force exerted by the plate on the ball during its collision with the plate.

The variation of force exerted on the squash ball with time is shown on the graph.



The ball strikes the plate with a speed of 19.16 m s^{-1} and has a mass of 60 g. It leaves the plate with a speed of 13.83 m s^{-1}.

Show that this is consistent with the impulse obtained from the graph.

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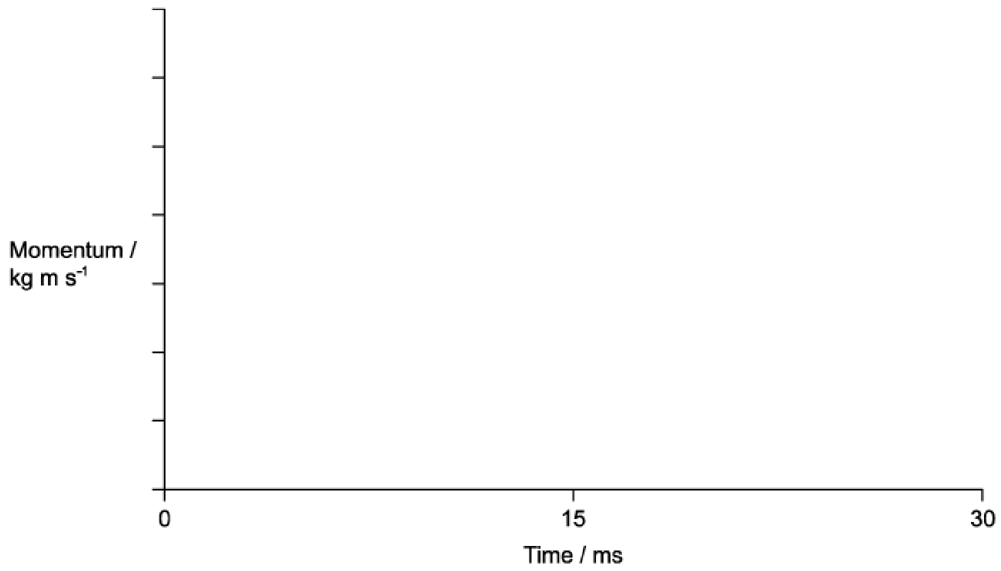
(3 marks)

(b) Considering the first 30 ms of the ball's motion:

(i) Sketch a graph to show how the momentum of the ball varies.



[1]

(ii) Explain how the ball's momentum varies in the first 30 ms of the motion.

[5]

(6 marks)

(c) The ball continues to bounce, each time losing the same fraction of its energy when it strikes the plate. Air resistance is negligible.

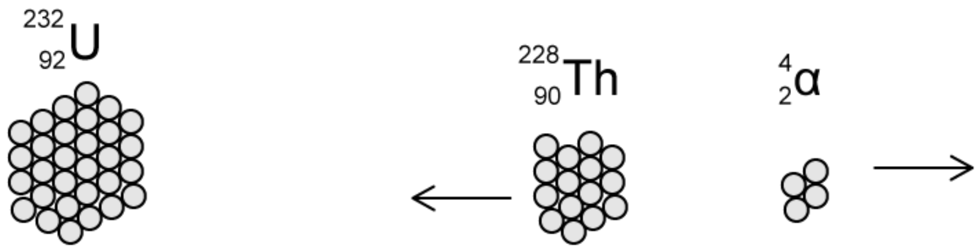
Determine the percentage of the original gravitational potential energy of the ball that remains when it reaches its maximum height after bouncing five times.

(3 marks)

(d) Explain, with reference to the conservation of momentum, the effect that the motion of the squash ball has on the motion of the Earth from the instant it is released until it bounces off the plate.

(3 marks)

3 (a) A stationary uranium nucleus decays by emitting an α particle and thorium nucleus.



Discuss how the principle of conservation of momentum applies in this explosion.

(3 marks)

(b) Assume that all of the energy released in the emission process is transferred as kinetic energy to the α particle and the recoiling nucleus and is equal to 6.46 MeV.

Calculate the kinetic energy of the Thorium nucleus and α particle in MeV.

(4 marks)

(c) Show that momentum is conserved in this decay.

(3 marks)

(d) Collisions can occur between neutrons and stationary Uranium nuclei, for example, during nuclear fission.

Discuss how this collision would be if this was inelastic as opposed to elastic.

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(4 marks)

4 (a) Hemp ropes were the first to be used for ships' rigging to adjust the position of the sails and support the masts. Hemp is one of the strongest natural fibres available, has a very high tensile strength and is extremely rigid.

Today rock climbers use nylon ropes which are attached to their harness to break their fall. Nylon stretches considerably under tension.

Discuss in terms of impulse and momentum, why nylon ropes are favoured by rock climbers compared to hemp ropes.

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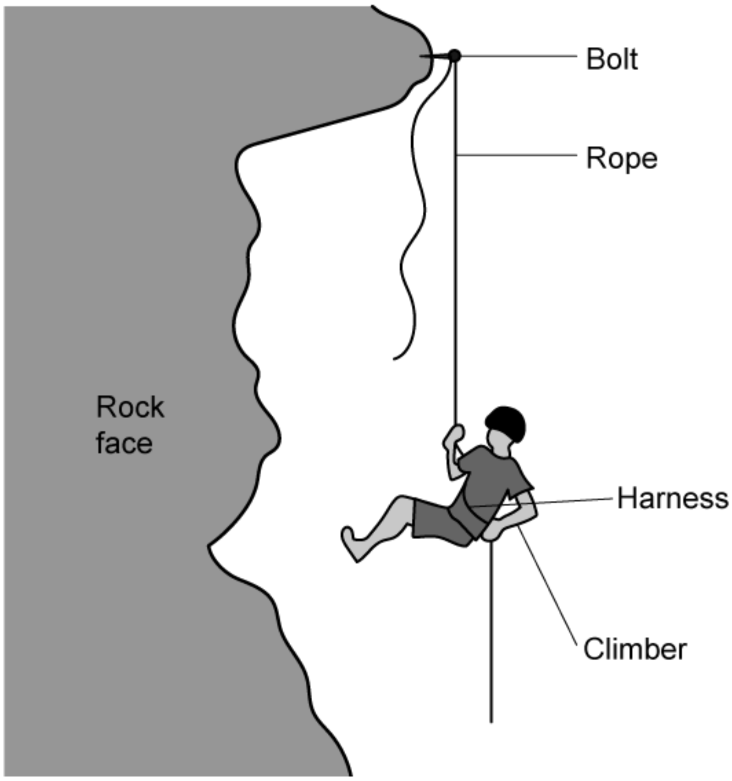
(4 marks)

(b) A rock climber of mass *m* slips just after they attach a bolt to a piece of rock as they are climbing.

The length of the rope between their harness and the bolt on the rock face is *h.* Once the rope is fully extended their speed just before they come to a stop is *v.*



Show that the magnitude of the average decelerating force *F* on the climber when they are brought to rest is equal to their weight.

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(3 marks)

(c) Deduce, without calculation, whether the average decelerating force *F* would still be equal to the climber's weight if they fell from higher up.

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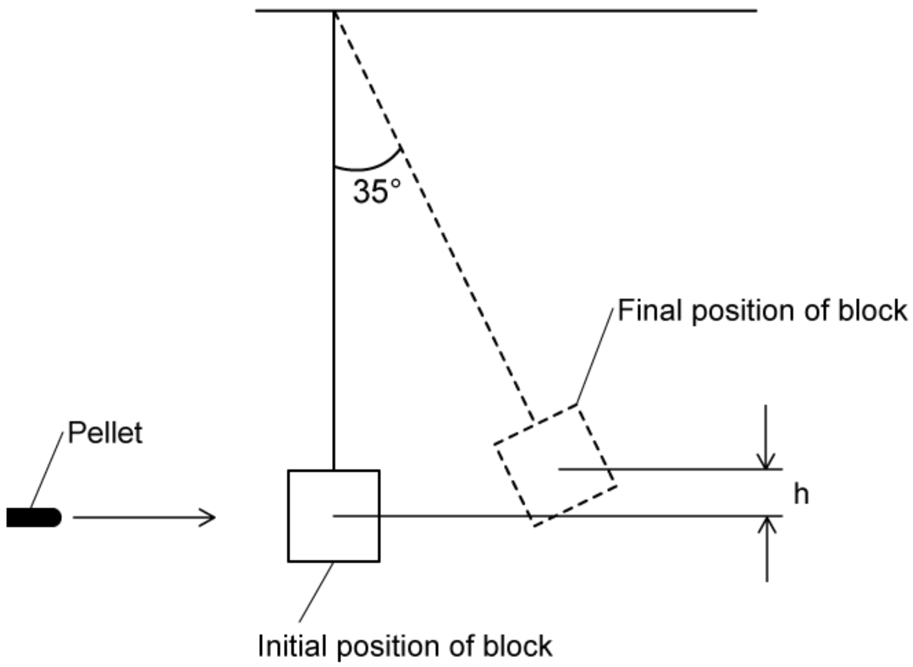
(2 marks)

5 (a) The speed of a dart pellet of mass 2.73 g is measured by firing it into a polystyrene block of mass 543 g suspended from a rigid support. The pellet becomes completely embedded in the polystyrene block. The block can swing freely at the end of a light inextensible string of length 1.5 m measured from the pivot to the centre of the block.



The centre of mass of the block rises by *h* at an angle of 35° to the vertical.

Determine the speed of the pellet when it strikes the polystyrene block.

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(5 marks)

(b) The polystyrene block is replaced by a wooden block of the same mass. The experiment is repeated with the wooden block and an identical pellet. The pellet rebounds after striking the block.

A student makes an assumption that the angle that the wooden block makes with the vertical will be greater than 35° because the block doesn't have the additional mass of the pellet embedded within it.

Discuss the validity of the student's assumptions.

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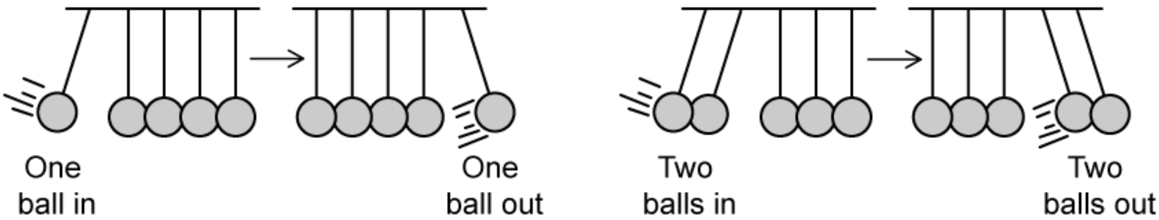
(5 marks)

(c) A popular demonstration of the conservation of momentum and conservation of energy is Newton's cradle. It features several identical polished steel balls hung in a straight line in contact with each other.

If one ball is pulled back and allowed to strike the line, one ball is released from the other end whilst the rest are stationary. If two are pulled out, two are released on the other end and so forth.



Assuming that Newton's Cradle is in a vacuum and considering energy and momentum conservation, explain why swinging one ball from the left will not release two balls on the right.

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(5 marks)