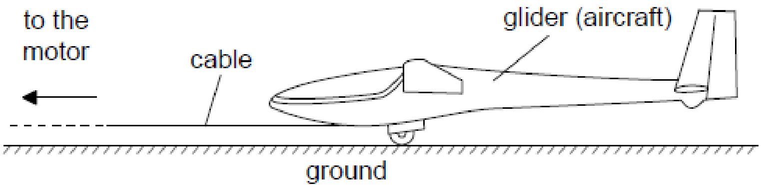
Motion-practice-1-extended

[226 marks]

A glider is an aircraft with no engine. To be launched, a glider is uniformly accelerated from rest by a cable pulled by a motor that exerts a horizontal force on the glider throughout the launch.



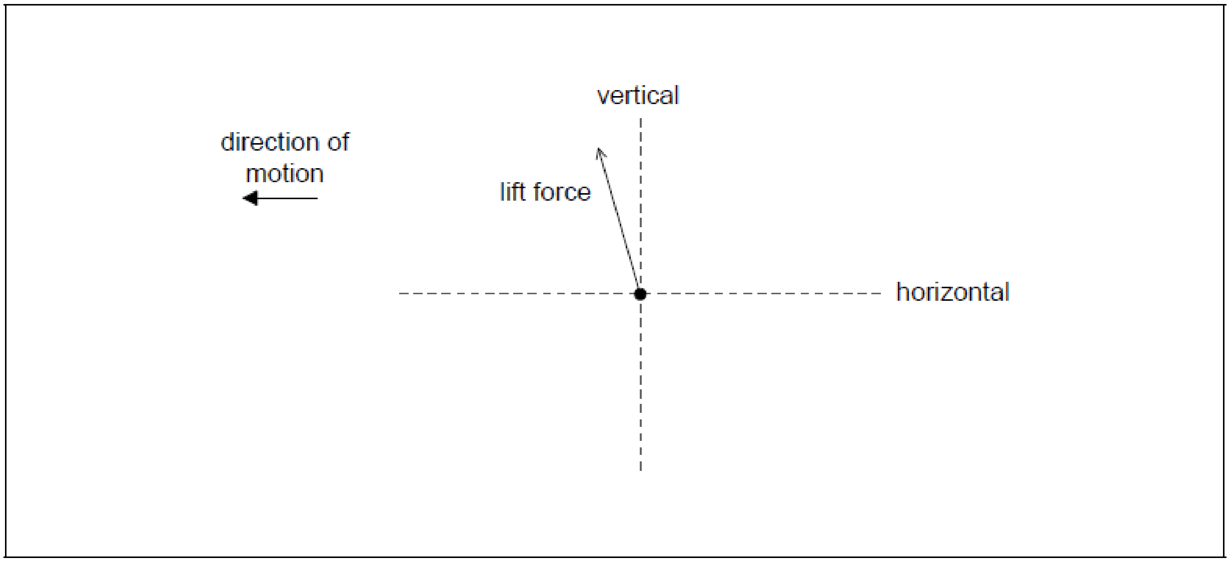
1a. The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s. Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. *[2 marks]*

1b. The glider and pilot have a total mass of 492 kg. During the acceleration the glider is subject to an average resistive force of 160 N. Determine the average tension in the cable as the glider accelerates. *[3 marks]*

1c. The cable is pulled by an electric motor. The motor has an overall efficiency of 23 %. Determine the average power input to the motor. *[3 marks]*

1d. The cable is wound onto a cylinder of diameter 1.2 m. Calculate the angular velocity of the cylinder at the instant when the glider has a speed of 27 m s^{-1}. Include an appropriate unit for your answer. *[2 marks]*

1e. After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. The diagram shows the lift force acting on the glider and the direction of motion of the glider. *[2 marks]*

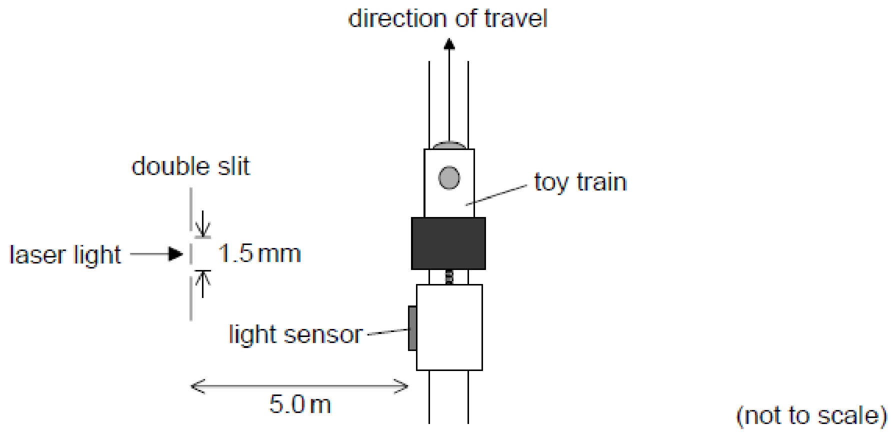


Draw the forces acting on the glider to complete the free-body diagram. The dotted lines show the horizontal and vertical directions.

1f. Explain, using appropriate laws of motion, how the forces acting on the glider maintain it in level flight. *[2 marks]*

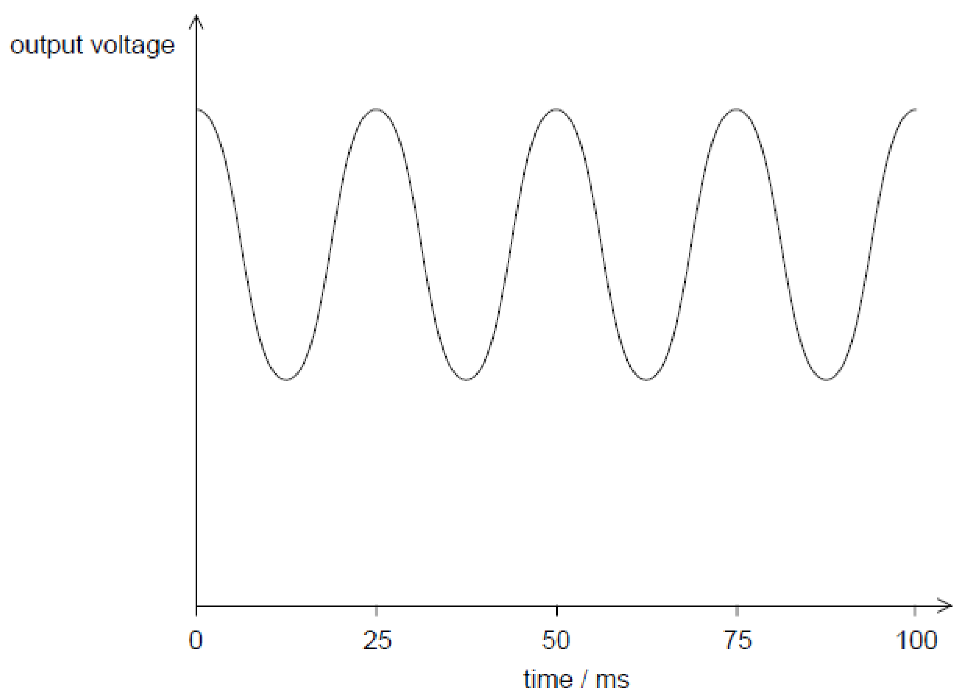
1g. At a particular instant in the flight the glider is losing 1.00 m of vertical height for every 6.00 m that it goes forward horizontally. At this instant, the horizontal speed of the glider is 12.5 m s^{-1}. Calculate the **velocity** of the glider. Give your answer to an appropriate number of significant figures. *[3 marks]*

A student investigates how light can be used to measure the speed of a toy train.



Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.

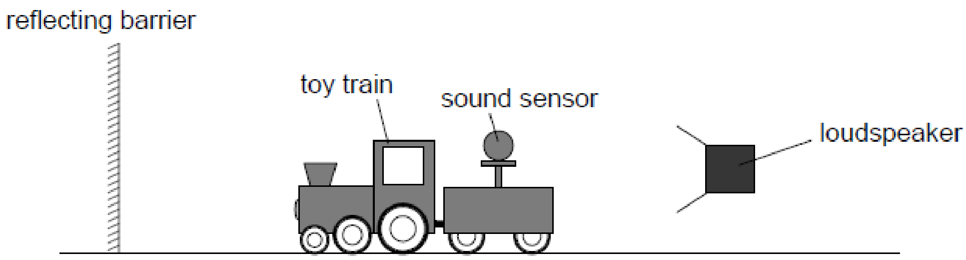


2a. Explain, with reference to the light passing through the slits, why a series of voltage peaks occurs. *[3 marks]*

2b. The slits are separated by 1.5 mm and the laser light has a wavelength of 6.3×10^{-7} m. The slits are 5.0 m from the train track. Calculate the separation between two adjacent positions of the train when the output voltage is at a maximum. *[1 mark]*

2c. Estimate the speed of the train. *[2 marks]*

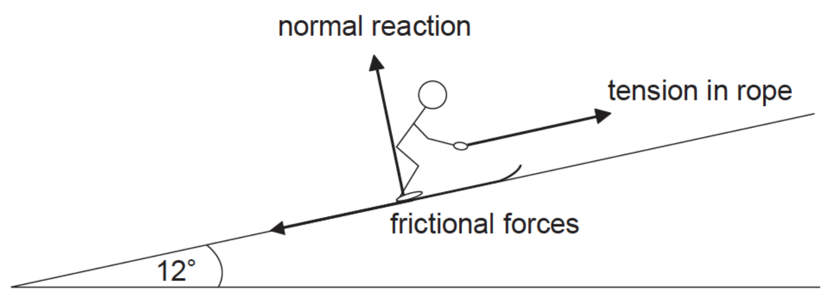
2d. In another experiment the student replaces the light sensor with a sound sensor. The train travels away from a loudspeaker that is emitting sound waves of constant amplitude and frequency towards a reflecting barrier. *[2 marks]*



The sound sensor gives a graph of the variation of output voltage with time along the track that is similar in shape to the graph shown in the resource. Explain how this effect arises.

This question is about the forces on a skier.

A skier is pulled up a hill by a rope at a steady velocity. The hill makes an angle of 12° with the horizontal. The mass of the skier and skis is 73 kg. The diagram below shows three of the forces acting on the skier.



3a. On the diagram, draw and label **one** other force acting on the skier. *[1 mark]*

3b. Calculate the magnitude of the normal reaction acting on the skier. *[2 marks]*

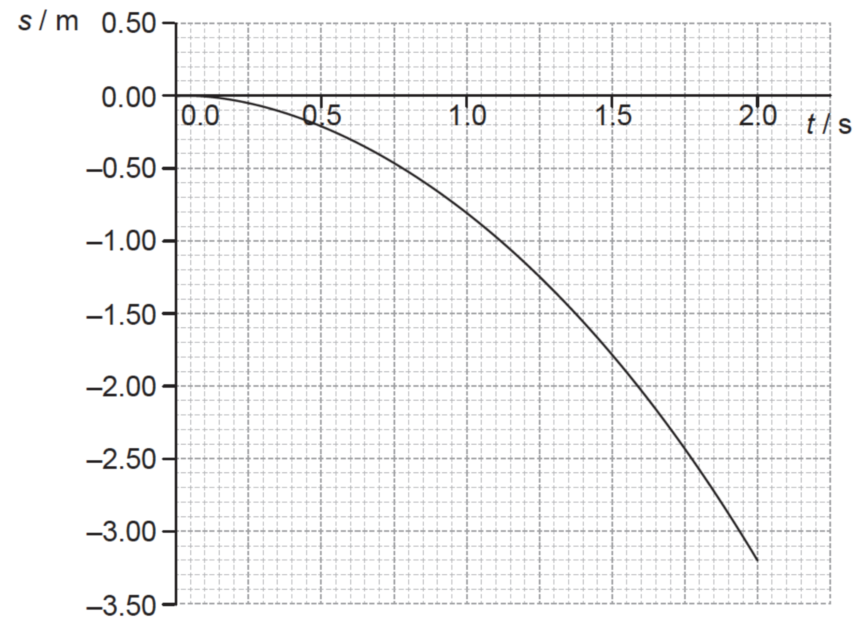
3c. The total frictional force acting is 65 N. Determine the tension in the rope. *[2 marks]*

3d. Explain, using Newton's first law of motion, why the resultant force on the skier must be zero. *[2 marks]*

This question is in **two** parts. **Part 1** is about kinematics and gravitation. **Part 2** is about radioactivity.

Part 1 Kinematics and gravitation

A ball is released near the surface of the Moon at time $t=0$. The point of release is on a straight line between the centre of Earth and the centre of the Moon. The graph below shows the variation with time t of the displacement s of the ball from the point of release.



4a. State the significance of the negative values of s. *[1 mark]*

4b. Use the graph to *[6 marks]*

(i) estimate the velocity of the ball at $t = 0.80$ s.

(ii) calculate a value for the acceleration of free fall close to the surface of the Moon.

4c. The following data are available. *[4 marks]*

Mass of the ball = 0.20 kg

Mean radius of the Moon = 1.74×10^6 m

Mean orbital radius of the Moon about the centre of Earth = 3.84×10^8 m

Mass of Earth = 5.97×10^{24} kg

Show that Earth has no significant effect on the acceleration of the ball.

4d. Calculate the speed of an identical ball when it falls 3.0 m from rest close to the surface of Earth. Ignore air resistance. *[1 mark]*

4e. Sketch, on the graph, the variation with time *t* of the displacement *s* from the point of release of the ball when the ball is dropped close to the surface of Earth. (For this sketch take the direction towards the Earth as being negative.) *[3 marks]*

Part 2 Radioactivity

Two isotopes of calcium are calcium-40 $\left(\frac{40}{20}\mathrm{Ca}\right)$ and calcium-47 $\left(\frac{47}{20}\mathrm{Ca}\right)$. Calcium-40 is stable and calcium-47 is radioactive with a half-life of 4.5 days.

4f. Calculate the percentage of a sample of calcium-47 that decays in 27 days. *[3 marks]*

4g. The nuclear equation for the decay of calcium-47 into scandium-47 $\left({}^{47}_{21}\mathrm{Sc}\right)$ is given by *[4 marks]*

$${}^{47}_{20}\mathrm{Ca} \rightarrow {}^{47}_{21}\mathrm{Sc} + {}^{0}_{-1}\mathrm{e} + \mathrm{X}$$

(i) Identify X.

(ii) The following data are available.

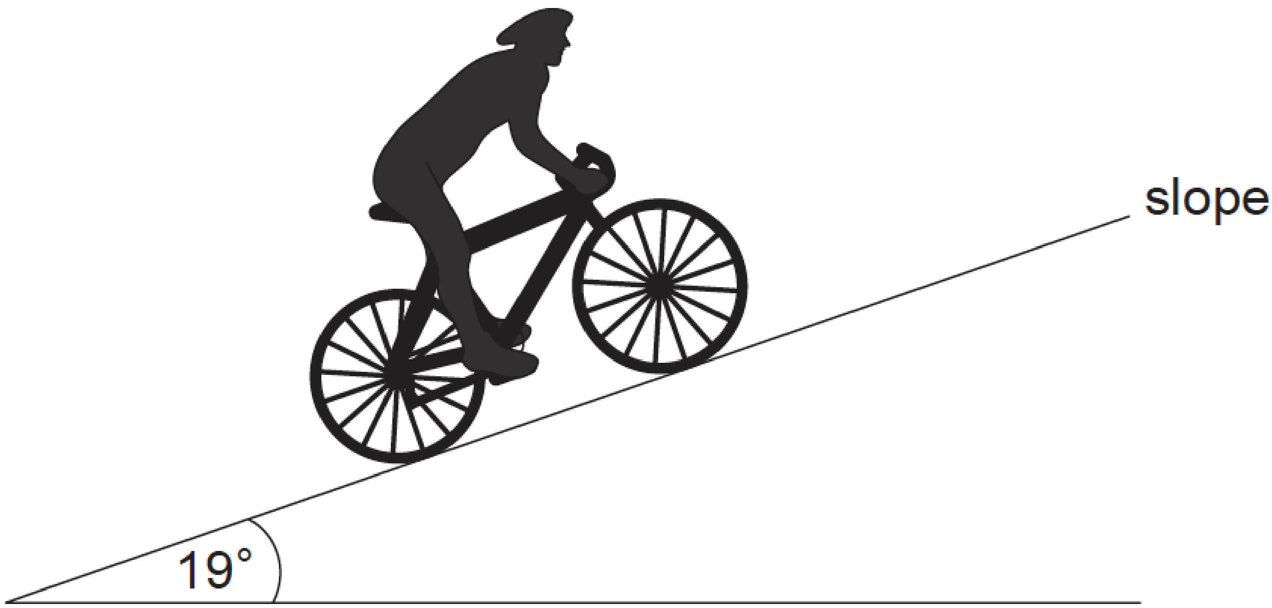
Mass of calcium-47 nucleus = 46.95455 u
Mass of scandium-47 nucleus = 46.95241 u

Using the data, determine the maximum kinetic energy, in MeV, of the products in the decay of calcium-47.

(iii) State why the kinetic energy will be less than your value in (h)(ii).

This question is about the motion of a bicycle.

A cyclist is moving up a slope that is at an angle of 19° to the horizontal. The mass of the cyclist and the bicycle is 85 kg.



5a. Calculate the *[3 marks]*

(i) component of the weight of the cyclist and bicycle parallel to the slope.

(ii) normal reaction force on the bicycle from the slope.

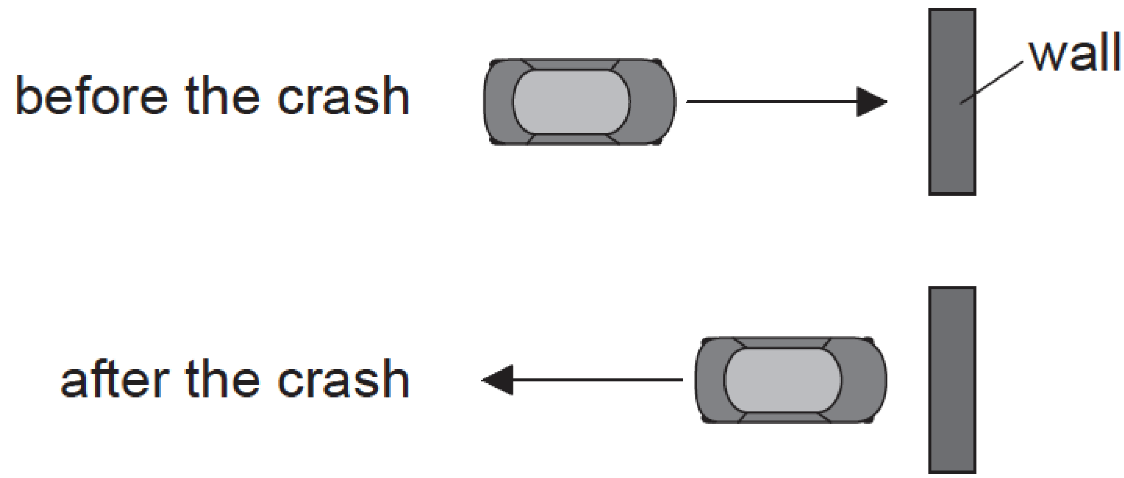
5b. At the bottom of the slope the cyclist has a speed of $5.5 ms^{-1}$. The cyclist stops pedalling and applies the brakes which provide an additional decelerating force of 250 N. Determine the distance taken for the cyclist to stop. Assume air resistance is negligible and that there are no other frictional forces. *[4 marks]*

This question is in two parts. **Part 1** is about momentum. **Part 2** is about electric point charges.

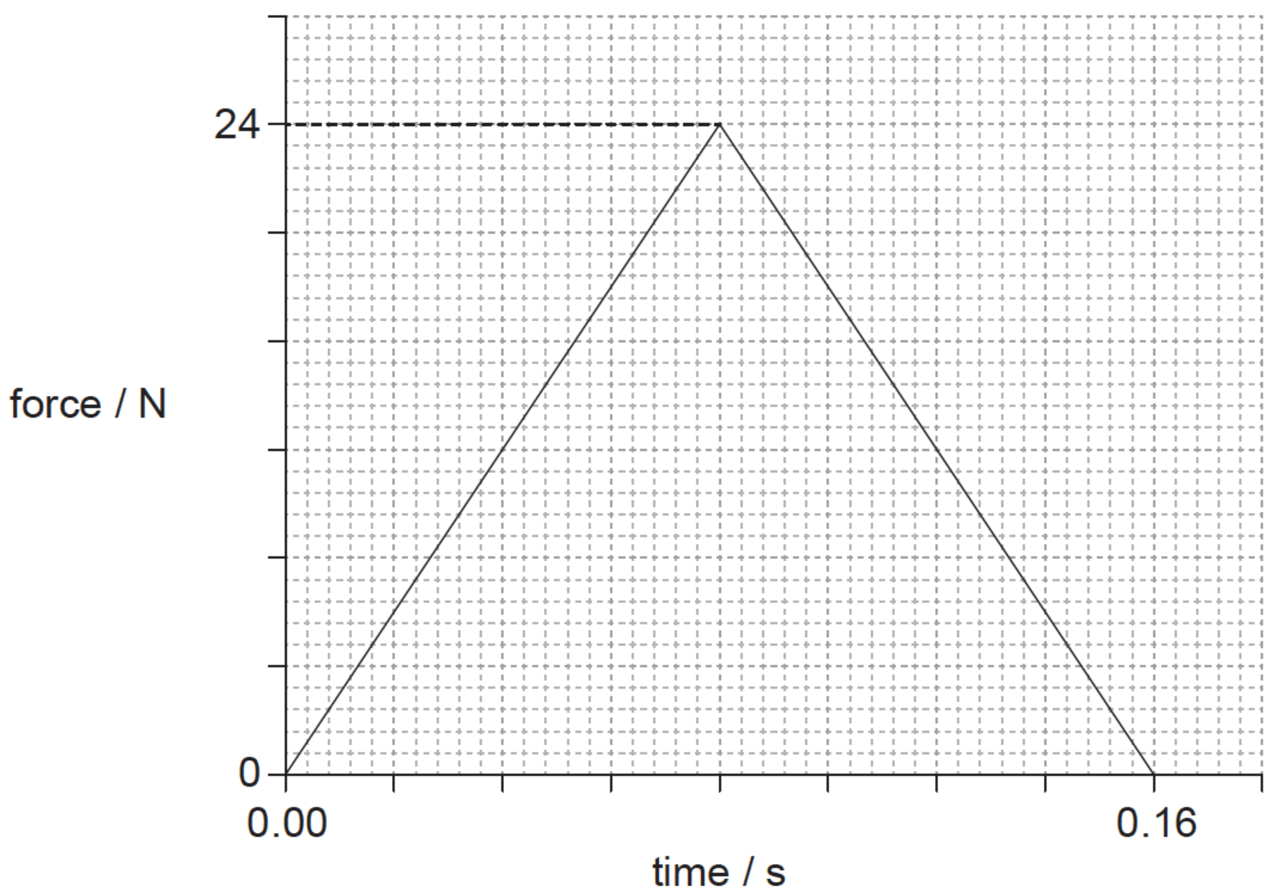
Part 1 Momentum

6a. State the law of conservation of linear momentum. *[2 marks]*

6b. A toy car crashes into a wall and rebounds at right angles to the wall, as shown in the plan view. *[9 marks]*



The graph shows the variation with time of the force acting on the car due to the wall during the collision.

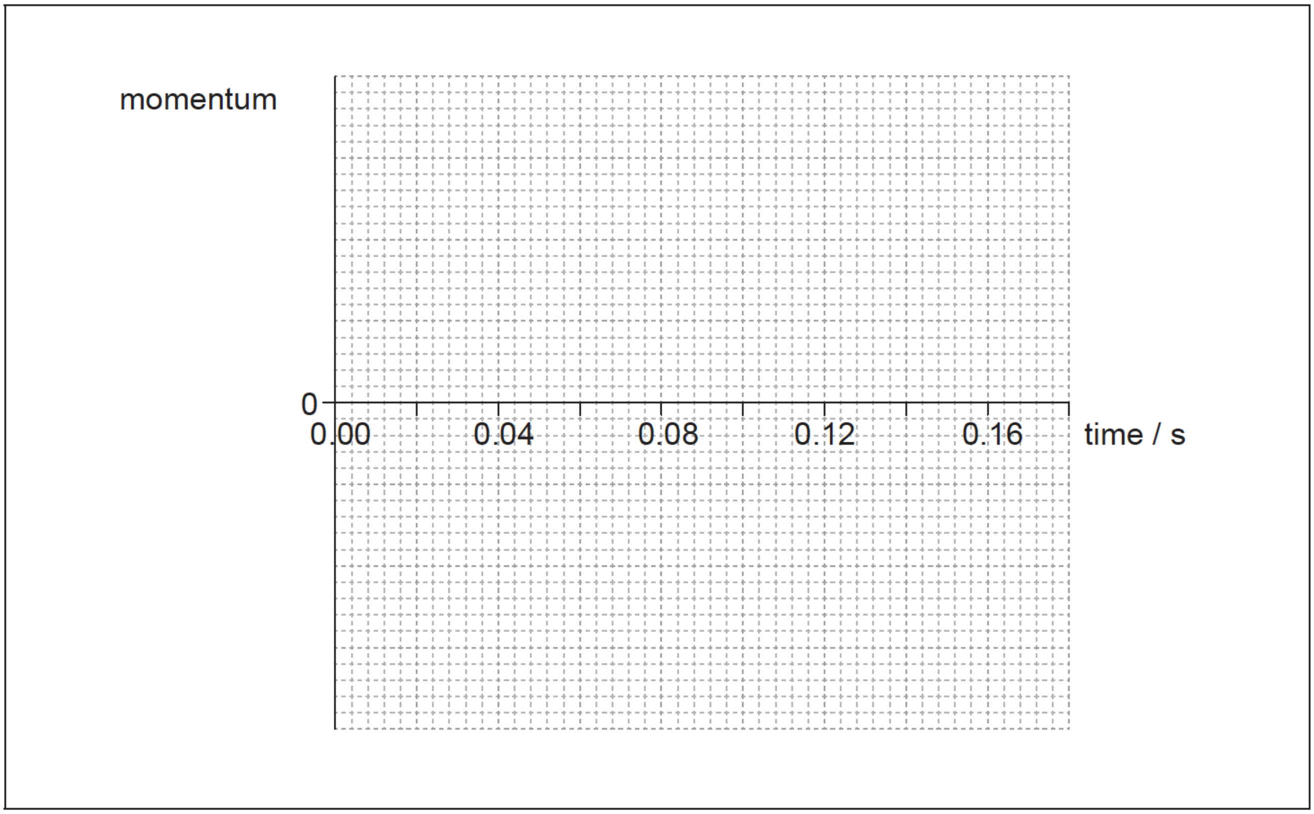


The kinetic energy of the car is unchanged after the collision. The mass of the car is 0.80 kg.

(i) Determine the initial momentum of the car.

(ii) Estimate the average acceleration of the car before it rebounds.

(iii) On the axes, draw a graph to show how the momentum of the car varies during the impact. You are not required to give values on the y-axis.

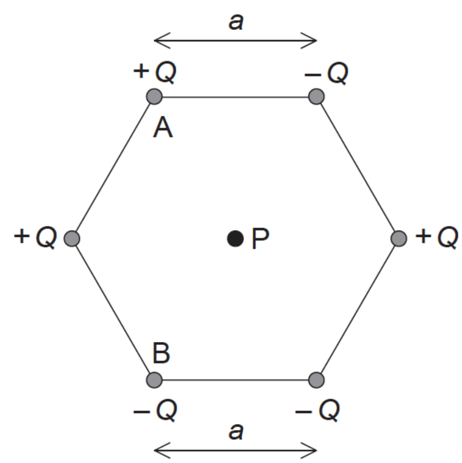


6c. Two identical toy cars, A and B are dropped from the same height onto a solid floor without rebounding. Car A is unprotected whilst car B is in a box with protective packaging around the toy. Explain why car B is less likely to be damaged when dropped. *[4 marks]*

Part 2 Electric point charges

6d. Define *electric field strength* at a point in an electric field. *[2 marks]*

6e. Six point charges of equal magnitude *Q* are held at the corners of a hexagon with the signs of the charges as shown. Each side of the hexagon has a length *a*. *[8 marks]*



P is at the centre of the hexagon.

(i) Show, using Coulomb's law, that the magnitude of the electric field strength at point P due to **one** of the point charges is

$$\frac{kQ}{a^2}$$

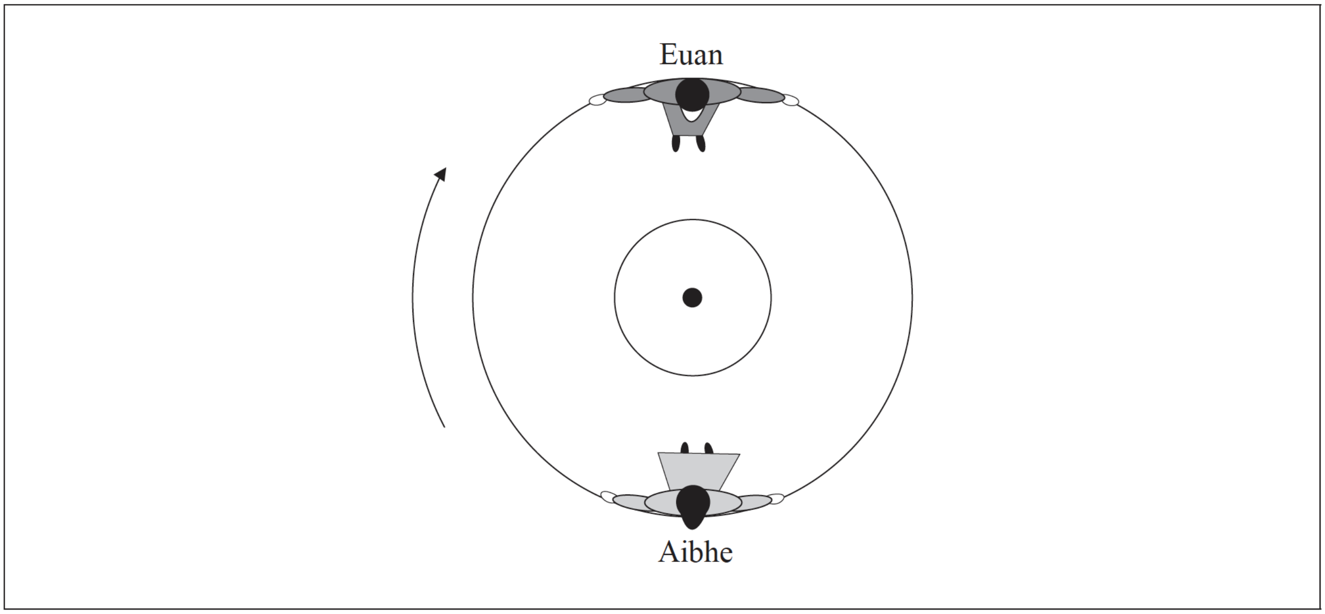
(ii) On the diagram, draw arrows to represent the direction of the field at P due to point charge A (label this direction A) and point charge B (label this direction B).

(iii) The magnitude of *Q* is 3.2 μC and length *a* is 0.15 m. Determine the magnitude and the direction of the electric field strength at point P due to all six charges.

This question is in **two** parts. **Part 1** is about two children on a merry-go-round. **Part 2** is about electric circuits.

Part 1 Two children on a merry-go-round

Aibhe and Euan are sitting on opposite sides of a merry-go-round, which is rotating at constant speed around a fixed centre. The diagram below shows the view from above.



Aibhe is moving at speed 1.0ms^{-1} relative to the ground.

7a. Determine the magnitude of the velocity of Aibhe relative to *[2 marks]*

(i) Euan.

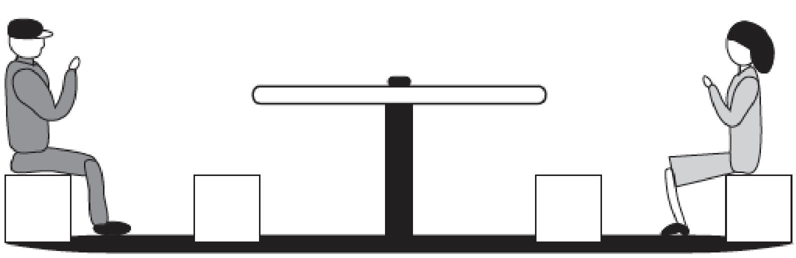
(ii) the centre of the merry-go-round.

7b. (i) Outline why Aibhe is accelerating even though she is moving at constant speed. *[6 marks]*

(ii) Draw an arrow on the diagram on page 22 to show the direction in which Aibhe is accelerating.

(iii) Identify the force that is causing Aibhe to move in a circle.

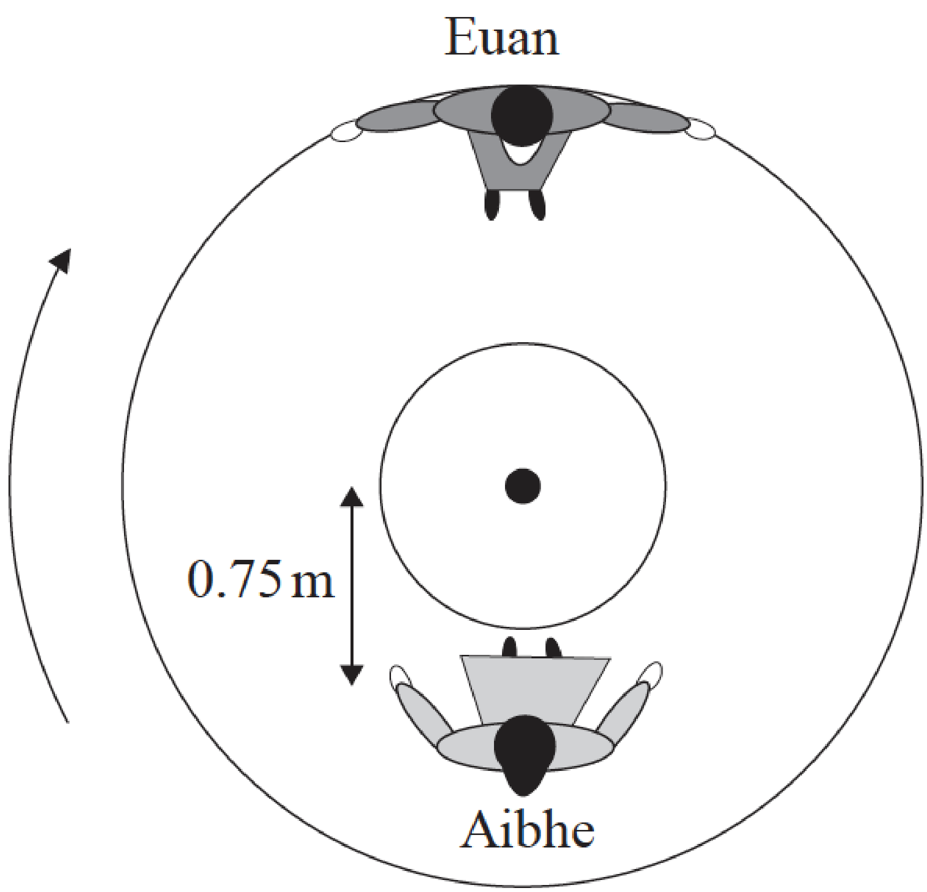
(iv) The diagram below shows a side view of Aibhe and Euan on the merry-go-round.



Explain why Aibhe feels as if her upper body is being “thrown outwards”, away from the centre of the merry-go-round.

7c. Euan is rotating on a merry-go-round and drags his foot along the ground to act as a brake. The merry-go-round comes to a stop after 4.0 rotations. The radius of the merry-go-round is 1.5 m. The average frictional force between his foot and the ground is 45 N. Calculate the work done. *[2 marks]*

7d. Aibhe moves so that she is sitting at a distance of 0.75 m from the centre of the merry-go-round, as shown below. *[5 marks]*



Euan pushes the merry-go-round so that he is again moving at 1.0 ms^{-1} relative to the ground.

(i) Determine Aibhe's speed relative to the ground.

(ii) Calculate the magnitude of Aibhe's acceleration.

This question is about the use of energy resources.

8a. State the difference between renewable and non-renewable energy sources. *[1 mark]*

Electrical energy is obtained from tidal energy at La Rance in France.

Water flows into a river basin from the sea for six hours and then flows from the basin back to the sea for another six hours. The water flows through turbines and generates energy during both flows.

The following data are available.

Area of river basin $= 22\ \mathrm{km}^2$

Change in water level of basin over six hours $= 6.0\ \mathrm{m}$

Density of water $= 1000\ \mathrm{kg\,m}^{-3}$

8b. (i) The basin empties over a six hour period. Show that about $6000\ \mathrm{m}^3$ of water flows through the turbines every second. *[10 marks]*

(ii) Show that the average power that the water can supply over the six hour period is about 0.2 GW.

(iii) La Rance tidal power station has an energy output of $5.4 \times 10^8\ \mathrm{kW\,h}$ per year. Calculate the overall efficiency of the power station. Assume that the water can supply 0.2 GW at all times.

Energy resources such as La Rance tidal power station could replace the use of

fossil fuels. This may result in an increase in the average albedo of Earth.

(iv) State **two** reasons why the albedo of Earth must be given as an average value.

Nuclear reactors are used to generate energy. In a particular nuclear reactor, neutrons collide elastically with carbon-12 nuclei $\left({}^{12}_{6}\mathrm{C}\right)$ that act as the moderator of the reactor. A neutron with an initial speed of $9.8 \times 10^6\ \mathrm{m\,s}^{-1}$ collides head-on with a stationary carbon-12 nucleus. Immediately after the collision the carbon-12 nucleus has a speed of $1.5 \times 10^6\ \mathrm{m\,s}^{-1}$.

8c. (i) State the principle of conservation of momentum. *[10 marks]*

(ii) Show that the speed of the neutron immediately after the collision is about $8.0 \times 10^6\ \mathrm{m\,s}^{-1}$.

(iii) Show that the fractional change in energy of the neutron as a result of the collision

is about 0.3.

(iv) Estimate the minimum number of collisions required for the neutron to reduce its initial energy by a factor of 10^6.

(v) Outline why the reduction in energy is necessary for this type of reactor to function.

This question is in **two** parts. **Part 1** is about the motion of a car. **Part 2** is about electricity.

Part 1 Motion of a car

9a. A car accelerates uniformly along a straight horizontal road from an initial speed of $12\ \mathrm{m\,s^{-1}}$ to a final speed of $28\ \mathrm{m\,s^{-1}}$ in a distance of 250 m. The mass of the car is 1200 kg. Determine the rate at which the engine is supplying kinetic energy to the car as it accelerates. *[4 marks]*

A car is travelling along the straight horizontal road at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. The power output required at the wheels is 0.13 MW.

9b. A car is travelling along a straight horizontal road at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. The power output required at the wheels is 0.13 MW. *[5 marks]*

(i) Calculate the total resistive force acting on the car when it is travelling at a constant speed of $56\ \mathrm{m\,s^{-1}}$.

(ii) The mass of the car is 1200 kg. The resistive force F is related to the speed v by $F \propto v^2$. Using your answer to (b)(i), determine the maximum theoretical acceleration of the car at a speed of $28\ \mathrm{m\,s^{-1}}$.

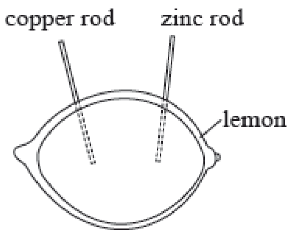
A driver moves the car in a horizontal circular path of radius 200 m. Each of the four tyres will not grip the road if the frictional force between a tyre and the road becomes less than 1500 N.

9c. (i) Calculate the maximum speed of the car at which it can continue to move in the circular path. Assume that the radius of the path is the same for each tyre. *[6 marks]*

(ii) While the car is travelling around the circle, the people in the car have the sensation that they are being thrown outwards. Outline how Newton’s first law of motion accounts for this sensation.

Part 2 Electricity

A lemon can be used to make an electric cell by pushing a copper rod and a zinc rod into the lemon.



A student constructs a lemon cell and connects it in an electrical circuit with a variable resistor. The student measures the potential difference *V* across the lemon and the current *I* in the lemon.

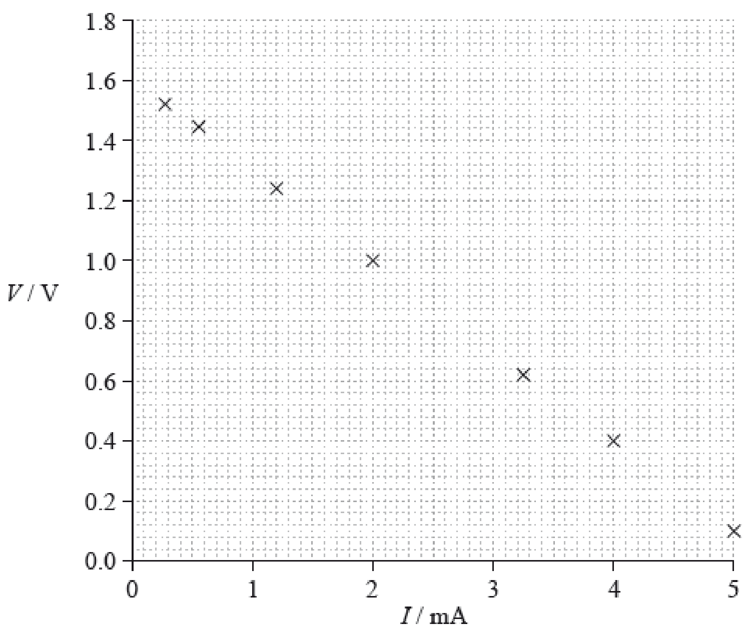
9d. (i) Draw a circuit diagram of the experimental arrangement that will enable the student to collect the data for the graph. *[10 marks]*

(ii) Show that the potential difference V across the lemon is given by

$$V = E - Ir$$

where E is the emf of the lemon cell and r is the internal resistance of the lemon cell.

(iii) The graph shows how V varies with I.



Using the graph, estimate the emf of the lemon cell.

(iv) Determine the internal resistance of the lemon cell.

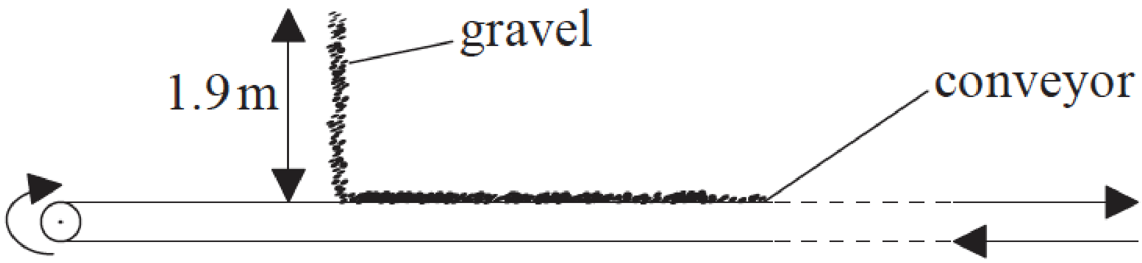
(v) The lemon cell is used to supply energy to a digital clock that requires a current of $6.0\ \mu\text{A}$. The clock runs for 16 hours. Calculate the charge that flows through the clock in this time.

This question is in **two** parts. **Part 1** is about momentum change. **Part 2** is about an oscillating water column (OWC) energy converter.

Part 1 Momentum change

10a. State the law of conservation of linear momentum. *[2 marks]*

10b. Gravel falls vertically onto a moving horizontal conveyor belt. *[7 marks]*



(i) The gravel falls at a constant rate of 13 kg s^{-1} through a height of 1.9 m. Show that the vertical speed of the gravel as it lands on the conveyor belt is about 6 m s^{-1}.

(ii) The gravel lands on the conveyor belt without rebounding. Calculate the rate of change of the vertical momentum of the gravel.

(iii) Gravel first reaches the belt at t = 0.0 s and continues to fall. Determine the total vertical force that the gravel exerts on the conveyor belt at t = 5.0 s.

10c. The conveyor belt moves with a constant horizontal speed of 1.5 m s^{-1}. As the gravel lands on the belt, it has no horizontal speed. *[4 marks]*

(i) Calculate the rate of change of the kinetic energy of the gravel due to its change in horizontal speed.

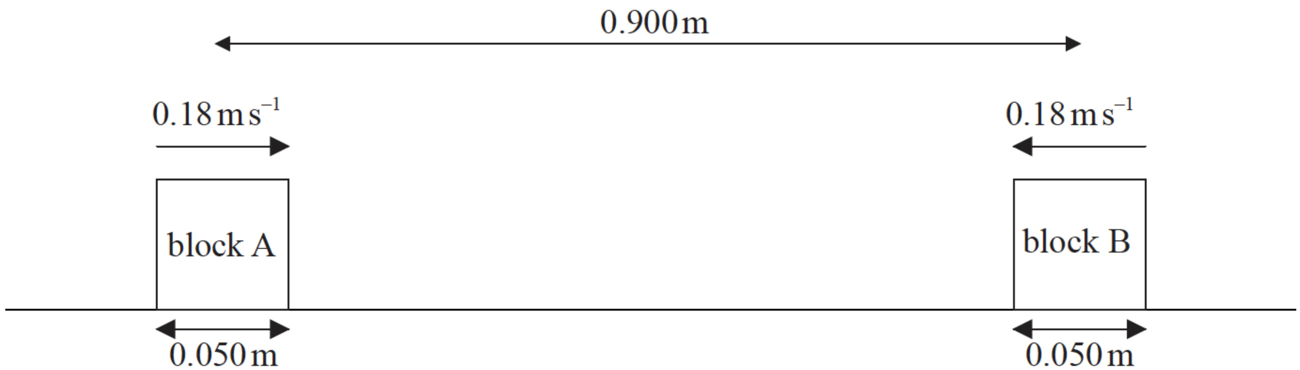
(ii) Determine the power required to move the conveyor belt at constant speed.

(iii) Outline why the answers to (c)(i) and (ii) are different.

This question is in **two** parts. **Part 1** is about a collision. **Part 2** is about electric current and resistance.

Part 1 A collision

Two identical blocks of mass 0.17kg and length 0.050m are travelling towards each other along a straight line through their centres as shown below. Assume that the surface is frictionless.



The initial distance between the centres of the blocks is 0.900m and both blocks are moving at a speed of 0.18ms^{-1} relative to the surface.

11a. Determine the time taken for the blocks to come into contact with each other. *[3 marks]*

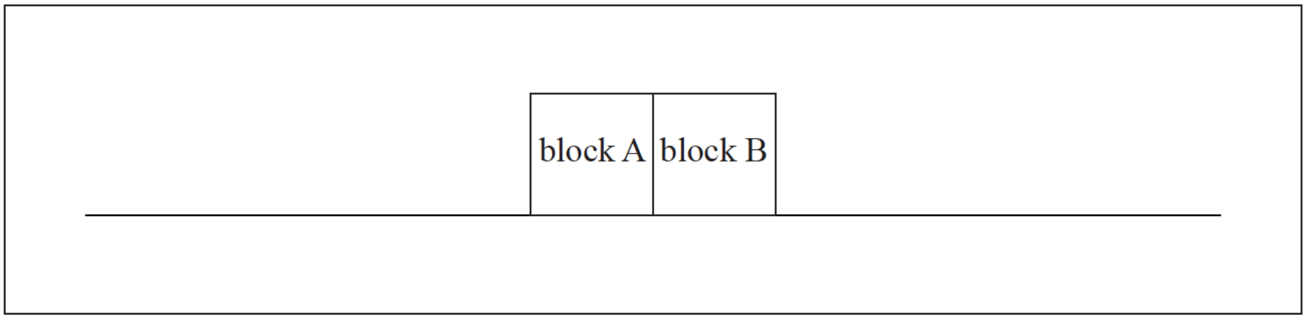
11b. As a result of the collision, the blocks reverse their direction of motion and travel at the same speed as each other. During the collision, 20% of the kinetic energy of the blocks is given off as thermal energy to the surroundings. *[5 marks]*

(i) State and explain whether the collision is elastic or inelastic.

(ii) Show that the final speed of the blocks relative to the surface is 0.16 m s^{-1}.

11c. (i) State Newton’s third law of motion. *[7 marks]*

(ii) During the collision of the blocks, the magnitude of the force that block A exerts on block B is F_{AB} and the magnitude of the force that block B exerts on block A is F_{BA}. On the diagram below, draw labelled arrows to represent the magnitude and direction of the forces F_{AB} and F_{BA}.

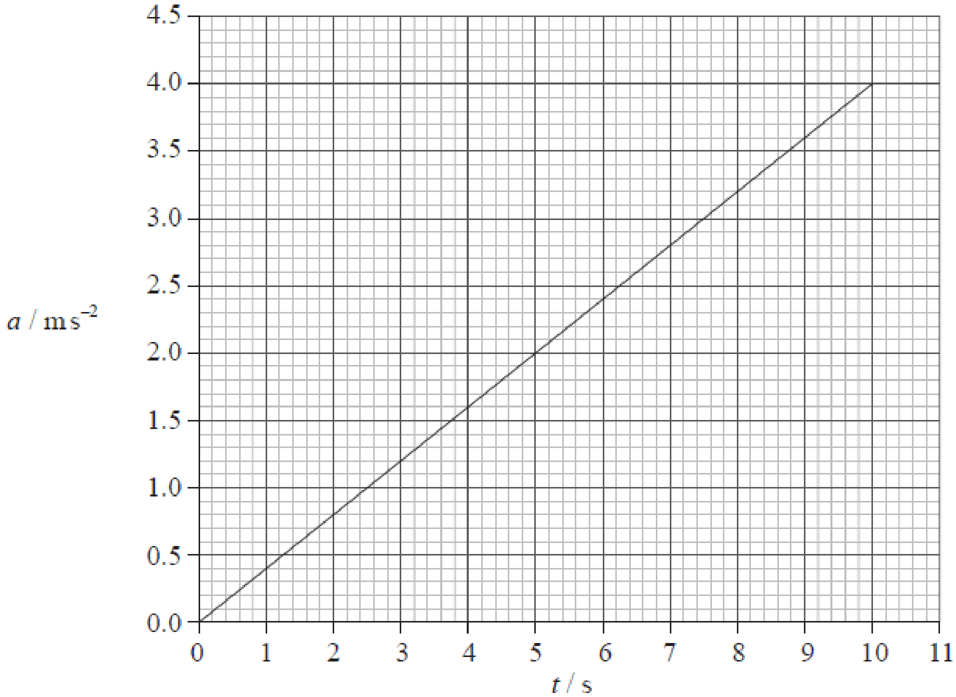


(iii) The duration of the collision between the blocks is 0.070 s. Determine the average force one block exerted on the other.

This question is about kinematics.

12a. State the difference between average speed and instantaneous speed. *[2 marks]*

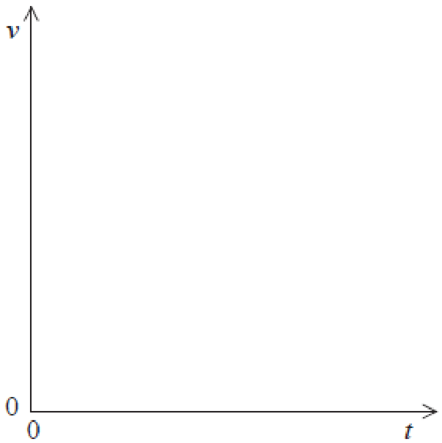
12b. The graph shows how the acceleration *a* of a particle varies with time *t*. *[3 marks]*



At time $t = 0$ the instantaneous speed of the particle is zero.

(i) Calculate the instantaneous speed of the particle at $t = 7.5$ s.

(ii) Using the axes below, sketch a graph to show how the instantaneous speed v of the particle varies with t.



This question is in **two** parts. **Part 1** is about kinematics and mechanics. **Part 2** is about electric potential difference and electric circuits.

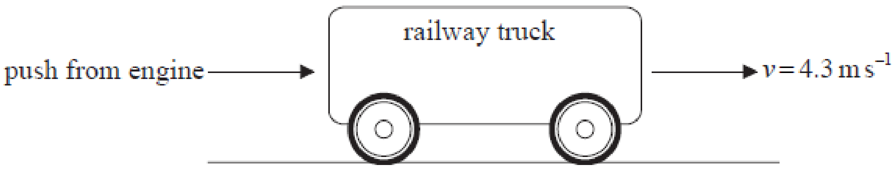
Part 1 Kinematics and mechanics

13a. State, in terms of momentum, Newton's second law of motion. *[1 mark]*

13b. Show, using your answer to (b), how the impulse of a force *F* is related to the change in momentum Δp that it produces. *[1 mark]*

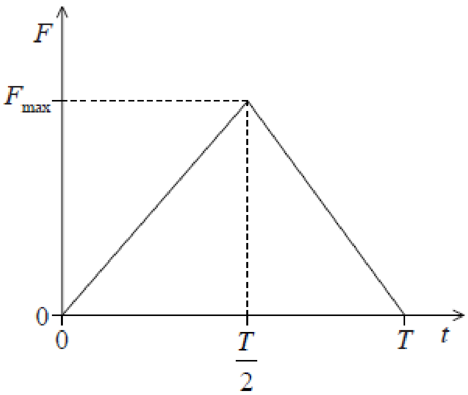
13c. Show, using your answer to (b), how the impulse of a force *F* is related to the change in momentum Δp that it produces. *[1 mark]*

13d. 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. *[12 marks]*



The engine is in contact with the truck for a time T = 0.54 s and the initial speed of the truck after the push is 4.3 ms^{-1}. The mass of the truck is 2.2×10^3 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.



(i) Determine the magnitude of the maximum force F_{max} exerted by the engine on the truck.

(ii) After contact with the engine (t = 0.54 s) the truck moves a distance 15 m along the track. After travelling this distance the speed of the truck is 2.8 ms^{-1}. Assuming a uniform acceleration, calculate the time it takes the truck to travel 15 m.

(iii) Calculate the average rate at which the kinetic energy of the truck is dissipated as it moves along the track.

(iv) When the speed of the truck is 2.8ms^{-1} it collides with a stationary truck of mass 3.0×10^3kg. The two trucks move off together with a speed V. Show that the speed V=1.2ms^{-1}.

(v) Outline the energy transformations that take place during the collision of the two trucks.

In 1997 a high-speed car of mass 1.1×10^4 kg achieved the world land speed record. The car accelerated uniformly in two stages as shown in the table. The car started from rest.

	Time / s	Speed attained at end of stage / m s^{-1}
Stage 1	0.0 – 4.0	44
Stage 2	4.0 – 12	280

Use the data to calculate the

14a. average acceleration of the car in stage 1. *[1 mark]*

14b. average net force required to accelerate the car in stage 2. *[3 marks]*

14c. total distance travelled by the car in 12 s. *[2 marks]*

This question is in **two** parts. **Part 1** is about the production of energy in nuclear fission. **Part 2** is about collisions.

Part 1 Production of energy in nuclear fission

A possible fission reaction is

$$^{235}_{92}U +^{1}_{0} n \rightarrow^{92}_{36} Kr +^{141}_{56} Ba + x^{1}_{0}n.$$

15a. (i) State the value of x. *[6 marks]*

(ii) Show that the energy released when one uranium nucleus undergoes fission in the reaction in (a) is about 2.8×10^{-11} J.

$$\begin{aligned} &\text{Mass of neutron} && = 1.00867\ \text{u} \\ &\text{Mass of U - 235 nucleus} && = 234.99333\ \text{u} \\ &\text{Mass of Kr - 92 nucleus} && = 91.90645\ \text{u} \\ &\text{Mass of Ba - 141 nucleus} && = 140.88354\ \text{u} \end{aligned}$$

(iii) State how the energy of the neutrons produced in the reaction in (a) is likely to compare with the energy of the neutron that initiated the reaction.

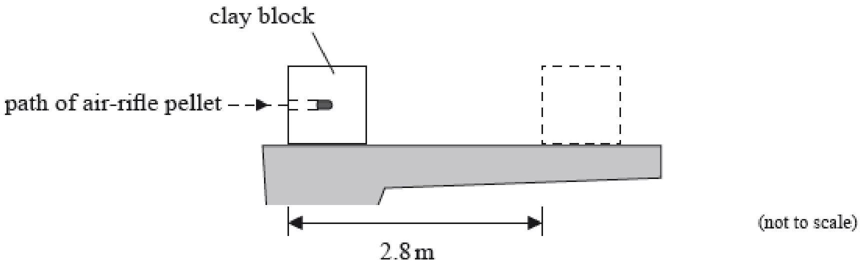
15b. Outline the role of the moderator. *[2 marks]*

15c. A nuclear power plant that uses U-235 as fuel has a useful power output of 16 MW and an efficiency of 40%. Assuming that each fission of U-235 gives rise to 2.8×10^{-11} J of energy, determine the mass of U-235 fuel used per day. *[4 marks]*

Part 2 Collisions

15d. State the principle of conservation of momentum. *[2 marks]*

In an experiment, an air-rifle pellet is fired into a block of modelling clay that rests on a table.



The air-rifle pellet remains inside the clay block after the impact.

As a result of the collision, the clay block slides along the table in a straight line and comes to rest. Further data relating to the experiment are given below.

$$\text{Mass of air - rifle pellet} = 2.0\text{ g}$$
$$\text{Mass of clay block} = 56\text{ g}$$
$$\text{Velocity of impact of air - rifle pellet} = 140\text{ m s}^{-1}$$
$$\text{Stopping distance of clay block} = 2.8\text{ m}$$

15e. (i) Show that the initial speed of the clay block after the air-rifle pellet strikes it is 4.8 m s^{-1}. *[6 marks]*

(ii) Calculate the average frictional force that the surface of the table exerts on the clay block whilst the clay block is moving.

15f. Discuss the energy transformations that occur in the clay block and the air-rifle pellet from the moment the air-rifle pellet strikes the block until the clay block comes to rest. *[3 marks]*

15g. The clay block is dropped from rest from the edge of the table and falls vertically to the ground. The table is 0.85 m above the ground. Calculate the speed with which the clay block strikes the ground. *[2 marks]*