INTERNATIONAL BACCALAUREATE
BACCALAURÉAT INTERNATIONAL
BACHILLERATO INTERNACIONAL

N00/430/H(2)

PHYSICS
HIGHER LEVEL
PAPER 2

Friday 10 November 2000 (afternoon)

2 hours 15 minutes

Name

Number

INSTRUCTIONS TO CANDIDATES

- Write your candidate name and number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: Answer all of Section A in the spaces provided.
- Section B: Answer two questions from Section B in the spaces provided.
- At the end of the examination, indicate the numbers of the Section B questions answered in the boxes below.

QUESTIONS ANSWERED		EXAMINER	TEAM LEADER	IBCA
SECTION A	ALL	/35	/35	/35
SECTION B QUESTION QUESTION		 /30 /30	 /30 /30	 /30 /30
		TOTAL /95	TOTAL /95	TOTAL /95

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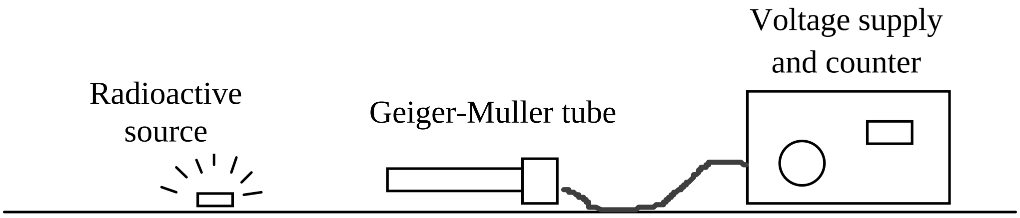
SECTION A

*Candidates must answer **all** questions in the spaces provided.*

A1. Radioactive decay measurement

A medical physicist wishes to investigate the decay of a radioactive isotope and determine its decay constant and half-life. A Geiger-Muller counter is used to detect radiation from a sample of the isotope, as shown.



(a) Define the activity of a radioactive sample. *[1]*

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Theory predicts that the activity A of the isotope in the sample should decrease exponentially with time t according to the equation $A = A_0 e^{-\lambda t}$, where A_0 is the activity at $t = 0$ and λ is the decay constant for the isotope.

(b) Manipulate this equation into a form which will give a straight line if a semi-log graph is plotted with appropriate variables on the axes. State what variables should be plotted. *[2]*

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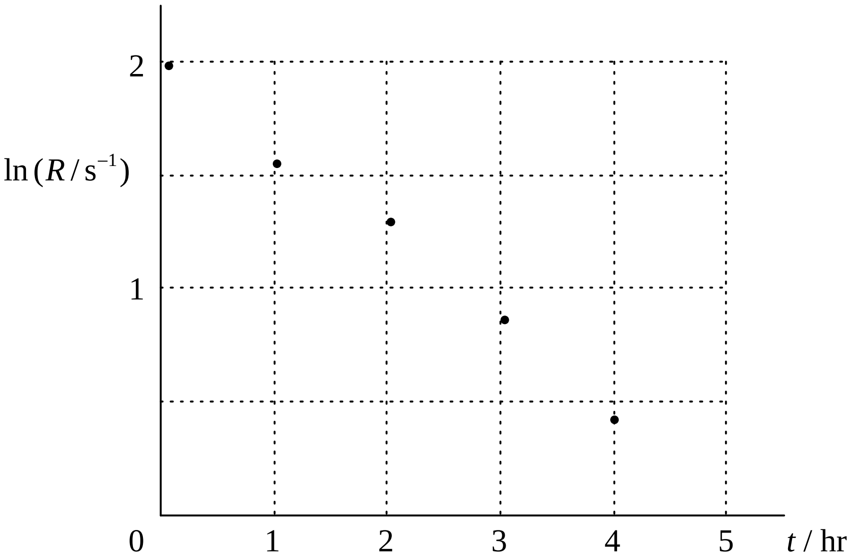
(Question A1 continued)

The Geiger-counter detects a proportion of the particles emitted by the source. The physicist records the count-rate R of particles detected as a function of time t and plots the data as a graph of $\ln R$ versus t, as shown below.



(c) Does the plot show that the experimental data are consistent with an *exponential* law? Explain. *[1]*

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(d) The Geiger-counter does not measure the total activity A of the sample, but rather the count-rate R of those particles that enter the Geiger tube. Explain why this will not matter in determining the decay constant of the sample. *[1]*

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(e) From the graph, determine a value for the decay constant λ. *[2]*

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(Question A1 continued)

The physicist now wishes to calculate the half-life.

(f) Define the half-life of a radioactive substance. *[1]*

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(g) Derive a relationship between the decay constant λ and the half-life τ. *[2]*

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(h) Hence calculate the half-life of this radioactive isotope. *[1]*

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A2. Dynamics of connected bodies

This question is about the application of dynamics to a system of two connected bodies.

Figure 1 below shows two blocks of masses *M* and *m*, connected by a long cord over a pulley. Mass *M* is greater than mass *m*, *i.e.* $M > m$. Assume the cord and the pulley have negligible mass and that friction is negligible.

Physical System

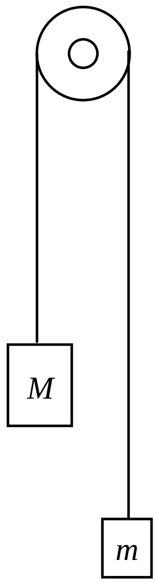

Figure 1

Free-body Diagrams

Figure 2

We wish to analyse the forces in this system and derive an expression for the acceleration *a* of the blocks and the tension *T* in the cord, in terms of the variables *M*, *m* and the gravitational field strength *g*.

(a) In **Figure 2** above, draw free-body force diagrams for each block, showing and labelling all the forces acting on each. The lengths of force vectors should reflect their comparative magnitudes. *[3]*

(This question continues on the following page)

(Question A2 continued)

(b) (i) Apply Newton's second law to each block *separately*, and hence obtain **two** equations for the two unknowns *a* and *T*. *[2]*

Block *M*	Block *m*

(ii) By solving these equations simultaneously, show that the acceleration of the system is given by $a = \frac{(M-m)g}{(M+m)}$, and the tension in the cord by $T = \frac{2Mmg}{(M+m)}$. *[4]*

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(c) Consider the special case where mass *M* is **much greater** than mass *m*, *i.e.* $M \gg m$.

(i) Without referring to the equations, predict the acceleration and the tension in this case, by giving physical reasoning about the system. *[3]*

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(ii) Show whether the equations above for acceleration and tension support your predictions. *[2]*

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A3. Electric circuit

This question involves physical reasoning and calculations for electric circuits.

Light bulbs are marked with the rating 10 V; 3 W. Suppose you connect three of the bulbs in series with a switch and a 30 V battery as shown in **Figure 1** below. Switch **S** is initially open.

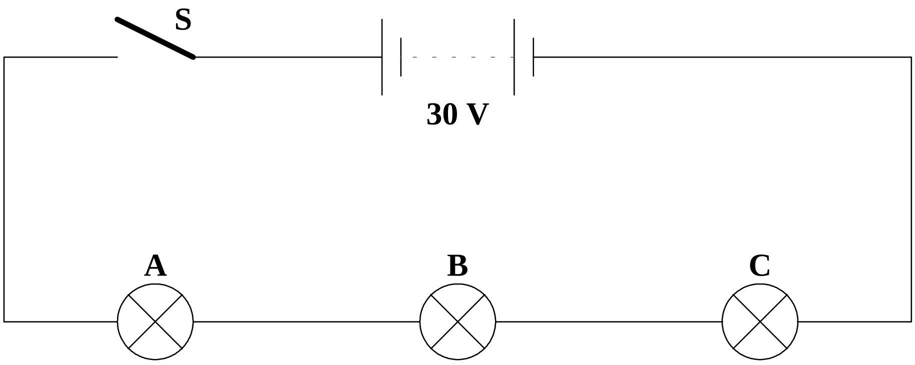

Figure 1

(a) A student tells you that after switch **S** is closed, bulb **C** will light up first, because electrons from the negative terminal of the battery will reach it first, and then go on to light bulbs **B** and **A** in succession. Is this prediction and reasoning correct? How would you reply? *[2]*

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(b) State how the brightnesses of the three bulbs in the circuit will compare with each other. *[1]*

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(Question A3 continued)

(c) The student now connects a fourth bulb **D** across bulb **B** as shown in **Figure 2** below.

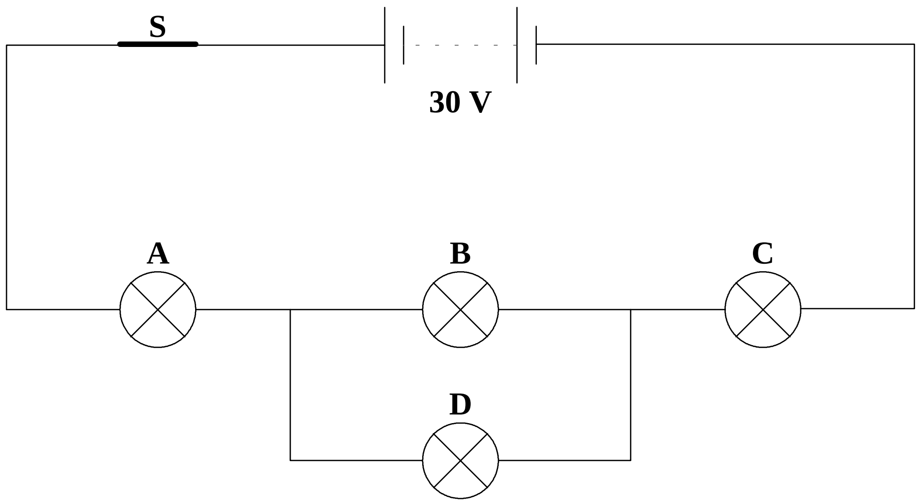

Figure 2

When she connects **D**, what will happen to the brightnesses of bulbs **A**, **B** and **C**? Explain your reasoning. *[3]*

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(d) Assuming that the resistance of the bulbs remains constant, calculate the power output of bulb **B**:

(i) in the original circuit in **Figure 1**; *[1]*

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(ii) in the modified circuit in **Figure 2**. *[3]*

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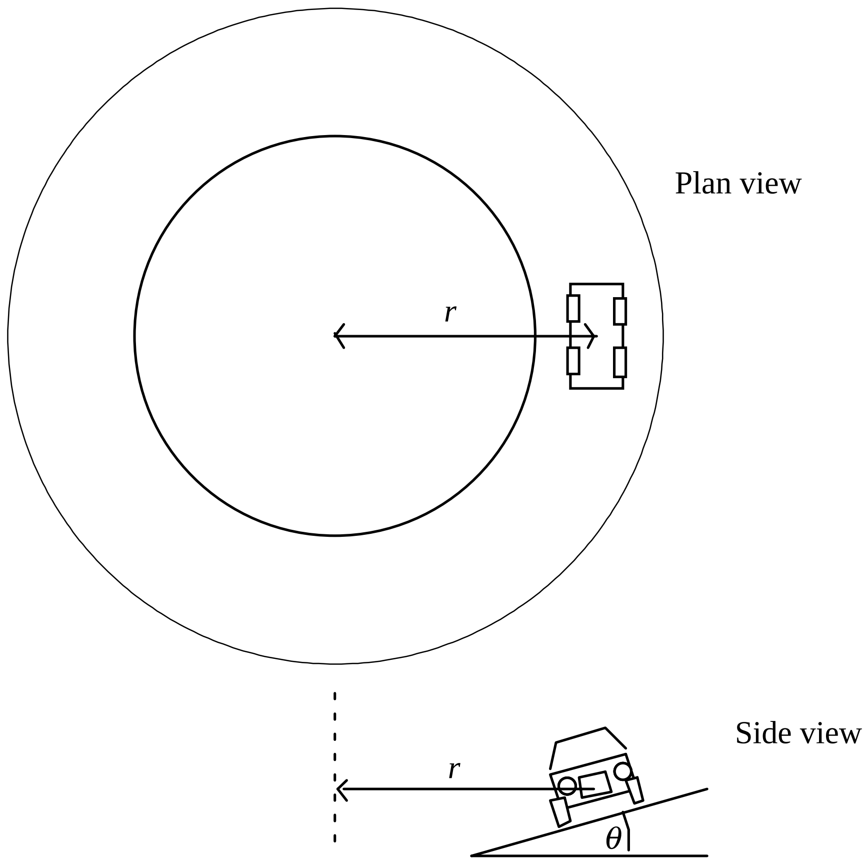
SECTION B

This section consists of four questions: B1, B2, B3 and B4. Answer any ***two*** *questions in this section.*

B1. This question is in **three** parts. **Part 1** is about circular motion dynamics, **Part 2** is about mixing ice and water and **Part 3** is about beats. Answer **all three** parts if you choose **B1**.

Part 1. Banked track

A car travels at a steady speed v in a circular path of radius r on a circular track banked at an angle θ, as shown in the plan and side views in the diagram.



The car's speed is such that there is no sideways frictional force between the tyres and the track.

(a) Does the car have an acceleration? Explain why or why not. If you say yes, state its direction. *[2]*

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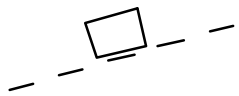
(Question B1 Part 1 continued)

(b) The car on the track is represented by a block in the figure below, moving perpendicular to the page. Draw a force diagram, showing and labelling all the forces acting on the moving car. *[2]*



(c) Is there a resultant force on the moving car? If you say yes, explain why and state its direction. If you say no, explain why not. In either case, refer to your force diagram to support your answer. *[2]*

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(d) The track is banked at an angle of 17° and the circular path of the car has radius 30 m. Calculate the speed at which the car must travel in order that there be no sideways frictional force between the tyres and the track. Show all working. *[4]*

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(Question B1 continued)

Part 2. Mixing ice and water

2 kg of ice from a freezer at $-15\ ^\circ\mathrm{C}$ is mixed with 10 kg of water at $30\ ^\circ\mathrm{C}$.

(a) Determine the final temperature of the mixture after equilibrium is reached. Energy losses to the environment are negligible. *[4]*

Data:

Specific heat capacity of ice: $2.1\times10^{3}\ \mathrm{J\,kg^{-1}\,^\circ C^{-1}}$
Specific heat capacity of water: $4.2\times10^{3}\ \mathrm{J\,kg^{-1}\,^\circ C^{-1}}$
Specific latent heat of melting of ice: $3.4\times10^{5}\ \mathrm{J\,kg^{-1}}$

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(b) In the stage of the process while the ice is melting, it absorbs energy but its temperature does not increase. Explain, from the molecular point of view, how this can be consistent with the principle of conservation of energy. State what becomes of the energy absorbed. *[3]*

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(Question B1 continued)

Part 3. Beats

This question is about the formation of beats in sound waves.

(a) State the principle of linear superposition as applied to waves. *[2]*

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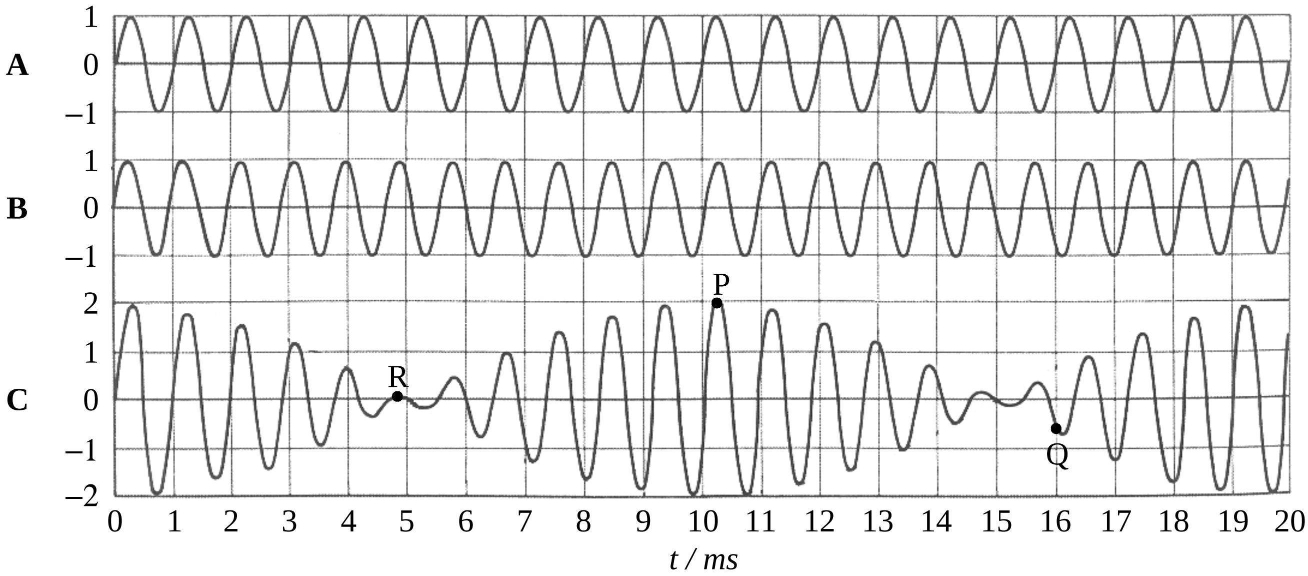
Two tuning forks **A** and **B** of slightly different frequencies are sounded simultaneously, producing two sound waves of the same amplitude. The figure below shows the disturbance at a particular point in the air as a function of time for each of the tuning forks separately, and the resultant disturbance **C**.



(b) Three points on the resultant waveform are labelled **P**, **Q** and **R**. For **each** of these points, check whether the resultant waveform **C** as drawn is correct, by referring to the two component waves. Explain in each case. *[3]*

Point **P**: . . . .

Point **Q**: . . . .

Point **R**: . . . .

(This question continues on the following page)

(Question B1 Part 3 continued)

(c) Use the diagram to determine

(i) the frequencies of **A** and **B**; *[2]*

A: . . . .

B: . . . .

(ii) the beat frequency. *[2]*

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(d) (i) Beats at this frequency could not actually be perceived as beats by human hearing. Explain why. *[1]*

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(ii) In order that the beats become perceived as such by the ear, would the difference in frequency between **A** and **B** have to be greater or smaller than in the case above? *[1]*

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(e) Explain how use could be made of beats to tune a guitar string against a tuning fork. *[2]*

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B2. This question is in **three** parts. **Part 1** is about a collision, **Part 2** is about molecular motion and evaporation and **Part 3** is about Huygen's principle. Answer **all three** parts if you choose **B2**.

Part 1. Collision between car and truck

A car and a truck are both travelling at the speed limit of 60 km h^{-1} but in opposite directions as shown. The truck has **twice** the mass of the car.

The vehicles collide head-on and become entangled together.

(a) During the collision, how does the force exerted by the car on the truck compare with the force exerted by the truck on the car? Explain. *[2]*

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(b) In what direction will the entangled vehicles move after collision or will they be stationary? Support your answer, referring to a physics principle. *[2]*

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(c) Determine the speed (in km h^{-1}) of the combined wreck immediately after the collision. *[3]*

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(d) How does the acceleration of the car compare with the acceleration of the truck during the collision? Explain. *[2]*

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(Question B2 continued)

(e) Both the car and truck drivers are wearing seat belts. Which driver is likely to be the more severely jolted in the collision? Explain. *[2]*

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(f) The total kinetic energy of the system decreases as a result of the collision. Is the principle of conservation of energy violated? Explain. *[1]*

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(Question B2 continued)

Part 2. Molecules and evaporation

(a) Molecules in a liquid are in continuous motion. What aspect of the molecular motion is most directly related to the *temperature* of the liquid? *[1]*

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(b) At a given temperature, the molecules have a distribution of speeds from small to large. Why do the molecules not all have the same speed? Hint: supposing the molecules did all have the same speed at a particular instant of time, what would happen next? *[2]*

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(c) Molecules will gradually evaporate from the open surface of an exposed liquid. Explain why a liquid *cools* when evaporation takes place. *[2]*

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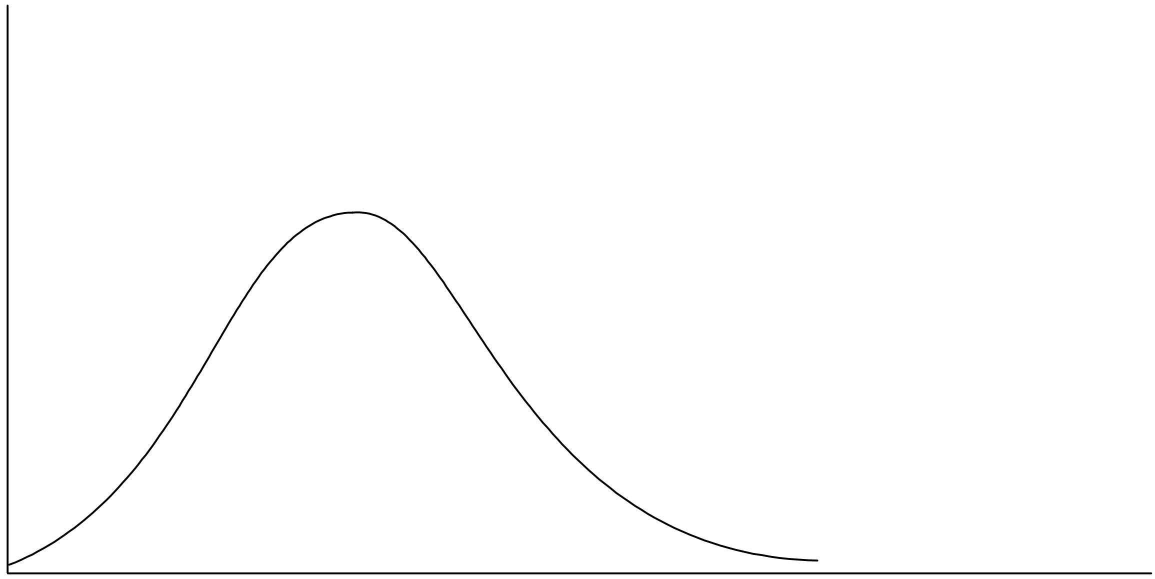
(Question B2 Part 2 continued)

(d) The graph below shows the Maxwell-Boltzmann distribution of molecular speeds in a sample of liquid at a certain temperature.



(i) Label the axes on the graph. *[2]*

(ii) The liquid is now heated to a *higher* temperature. On the figure above, sketch in the new molecular speed distribution. Explain how and why it differs from the original. *[3]*

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(iii) The rate of evaporation from a liquid is very strongly dependent on temperature (if the temperature of the liquid is increased just a few degrees K the evaporation rate can easily double). Explain, with reference to the two distribution curves above, why this should be so. *[3]*

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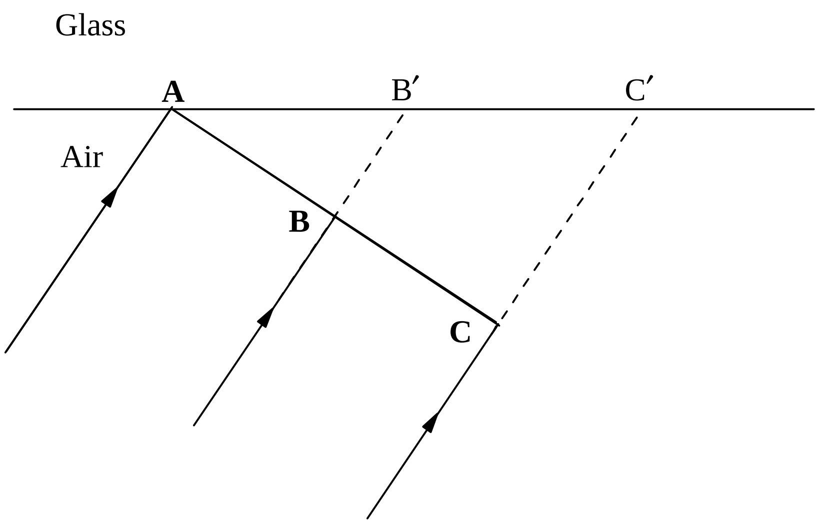
(Question B2 continued)

Part 3. Huygen’s principle and refraction

In this question you use Huygen’s principle to determine how light refracts at an interface.

A beam of plane light waves in air approaches a glass surface obliquely as shown in the figure below. A section of one particular wavefront (**ABC**) has been drawn at the time when point **A** has just reached the glass surface.



Point **B**, at the midpoint of the wavefront section, will reach the glass slightly later than point **A**, and point **B** is followed by point **C**.

(a) The speed of light in the glass is **two-thirds** that in air. At the instant that **C** on the wavefront has reached the glass at C′, construct the semicircular Huygen’s wavelets which have meanwhile spread out **in the glass** from point **A** and point **B**. Take any measurements you need from the diagram. (If you do not have a ruler or compass, a neat freehand construction is acceptable.) *[3]*

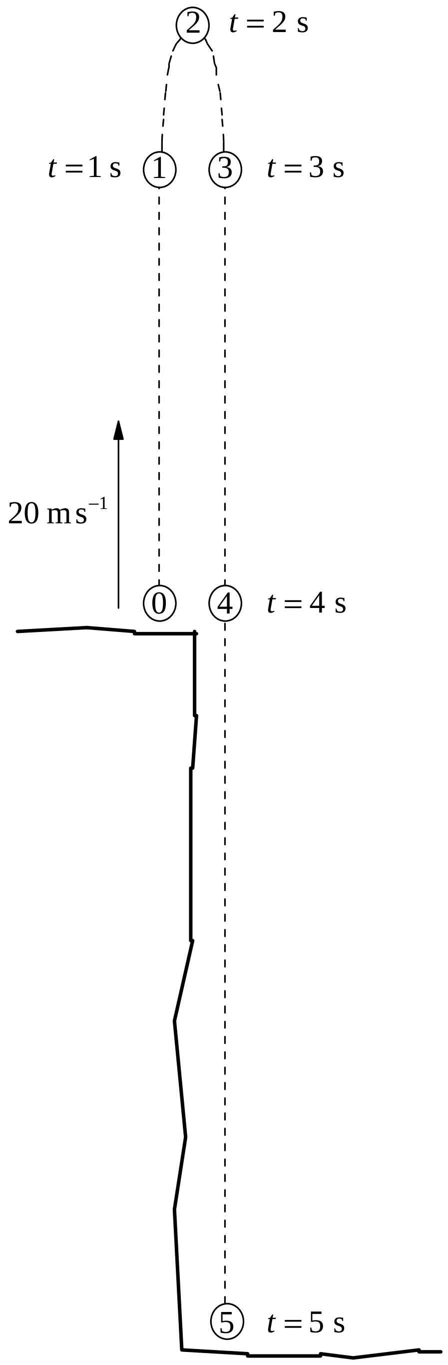
(b) From the envelope of these wavelets construct the wavefront which has arisen in the glass. *[1]*

(c) Hence draw in the path that the refracted beam of light will follow in the glass (by drawing three rays). *[1]*

B3. This question is in **two** parts. **Part 1** is about a stone projected upwards and **Part 2** is about electromagnetic induction. Answer **both** parts if you choose **B3**.

Part 1. Stone projected upwards from a cliff

A stone is projected almost vertically upwards at 20 $m s^{-1}$ from the edge of a cliff as shown. It finally lands on the ground at the base of the cliff. The sequence diagram below shows the position of the stone at one-second intervals. Image 0 is just after projection, and Image 5 is just before landing. Gravitational acceleration is taken as 10 $m s^{-2}$ and air resistance is ignored.



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(Question B3 Part 1 continued)

(a) State whether the stone's acceleration is upward, downward or zero in each of the following cases:

(i) when the stone is on its way **up** . . . .

(ii) when the stone is on its way **down** . . . .

(iii) when the stone is at the **top** of its path . . . . *[3]*

(b) Next to each of the six images draw in a vector to represent the **instantaneous velocity** at that stage of the motion. The vector at image 0 has been drawn in for you. Pay attention to the direction and relative lengths of the vectors, and label them with their magnitudes in $m\,s^{-1}$. *[3]*

(c) At each image of the stone, draw in vectors to represent the **force**(**s**) acting on the stone at that instant. Pay attention to both magnitude and direction. State the cause of any force. *[2]*

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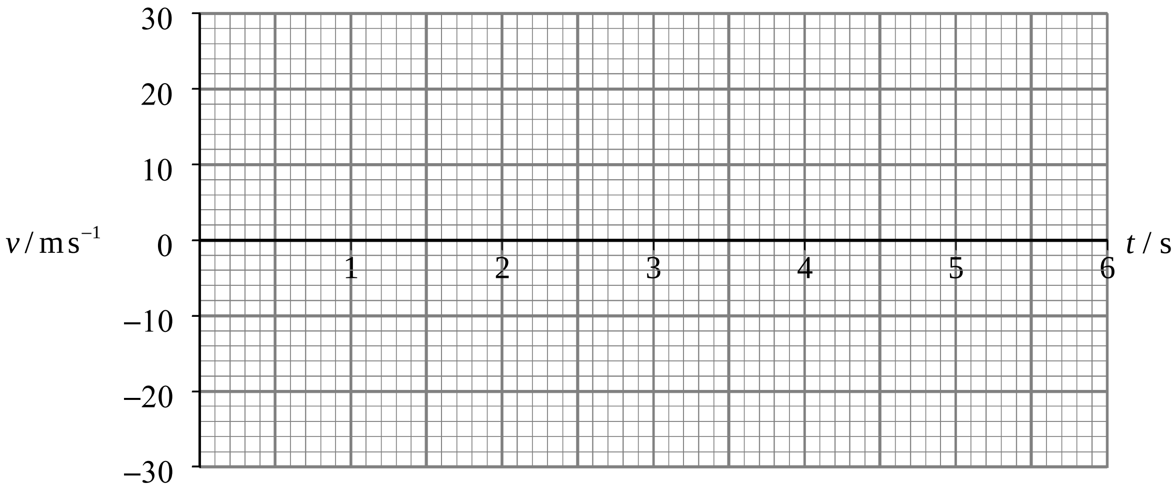
(d) Draw a velocity–time graph to represent the motion of the stone. On the graph label the stages representing **upwards motion** and **downwards motion**, and label the **topmost point** of the motion. *[3]*



(e) What does the gradient of the graph represent? *[1]*

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(Question B3 Part 1 continued)

(f) Determine the height of the cliff. *[3]*

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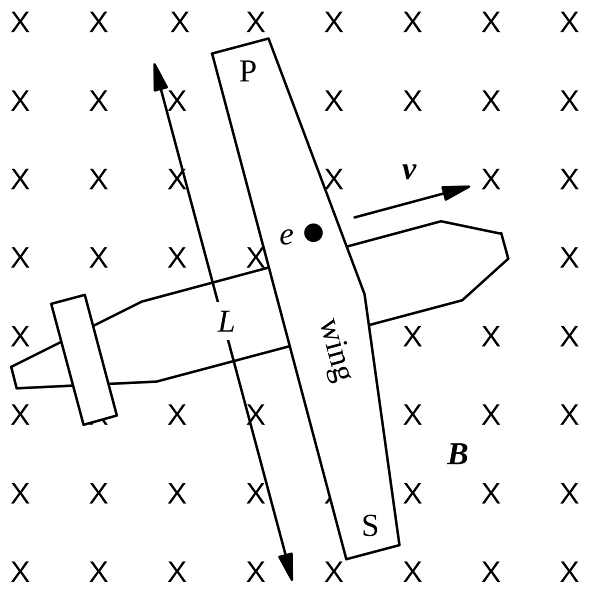
(Question B3 continued)

Part 2. Electromagnetic induction

A jet aeroplane is flying with velocity ***v*** at right angles to the Earth's magnetic field ***B*** near the North pole of the Earth, as shown in the plan view below. The plane's wingspan (distance between wingtips) is *L*. The wingtips are labelled P (port) and S (starboard).



(a) Consider an electron of charge magnitude *e* in the metal wing of the plane at the point shown by a dot in the figure.

(i) In what direction will this electron experience a magnetic force due to its motion in the magnetic field? Draw a vector on the diagram to represent the force. *[1]*

(ii) State an expression for the magnitude of the force on the electron in this situation. *[1]*

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(This question continues on the following page)

(Question B3 Part 2 continued)

(b) While the plane is flying steadily in the magnetic field, the electrons in the wing experience this magnetic force but do not move along the wing; such motion is opposed by an *electric* field arising in the wing.

(i) Explain how this electric field originates, and draw a vector in the diagram to show its direction. *[2]*

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(ii) Explain why the electric force on the electron is **exactly** equal to the magnetic force, in this situation. (Hint: imagine this were not the case and consider what would happen next.) *[2]*

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(c) Show that the magnitude of the electric field produced in the wing is given by $E = \boldsymbol{vB}$. *[1]*

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(d) Derive an expression for the induced potential difference which arises between the tips of the moving wing. (In terms of the length L, speed $\boldsymbol{v}$ and magnetic field strength $\boldsymbol{B}$.) *[3]*

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(e) Calculate the potential difference developed between the wingtips if the plane flies at $200\ \text{m s}^{-1}$ ($720\ \text{km hr}^{-1}$) in the Earth's field of 8×10^{-5} T near the pole and the wingspan is 30 m. *[1]*

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(Question B3 Part 2 continued)

(f) Would the potential difference between the wingtips still arise if the plane were flying near the Equator? Explain. *[1]*

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(g) Suppose one wanted to check if there really was a potential difference between wingtips. If one connected a moving-coil voltmeter between the wingtips, would it give a reading? Explain. *[2]*

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(h) Will there also be a potential difference between the *nose* and the *tail* of the plane? Explain why or why not. *[1]*

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B4. This question is in **two** parts. **Part 1** is about electrostatic charging and **Part 2** is about Rutherford scattering and a nuclear reaction. Answer **both** parts if you choose **B4**.

Part 1. Charging processes

This question is about three electrostatic charging processes.

(a) A rubber rod R is originally uncharged. When rubbed with fur, the rod becomes positively charged. Explain **briefly** how the net positive charge arises on the rod. *[1]*

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Suppose we now wish to use the positively charged rubber rod to charge a metal rod. Two different ways to do this are by **contact** or by **induction**.

(b) **By contact.** The charged rubber rod is touched against the metal rod and then removed. Describe the process by which the metal rod becomes charged and state whether it becomes positive or negative. Explain also whether the rubber rod remains charged or not. *[2]*

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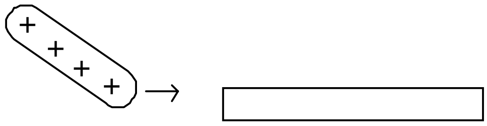
(Question B4 Part 1 continued)

(c) **By induction.** The diagrams below show the steps in the process. For each step, state what happens and draw the charge distribution in the metal rod. *[4]*

(i) The charged rubber rod is brought close to the metal rod.



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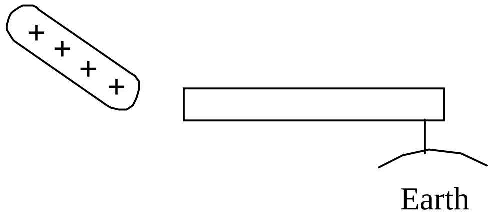
(ii) The metal rod is connected to earth.



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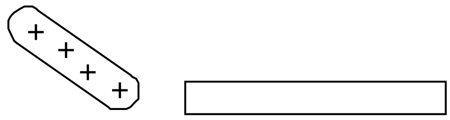
(iii) The earth connection is removed.



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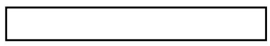
(iv) The rubber rod is removed.



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(d) Would the method still work if steps (i) and (ii) were interchanged, *i.e.* the metal rod was connected to earth *before* the charged rubber rod was brought near it? Explain. *[1]*

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(e) Would the method still work if steps (iii) and (iv) were interchanged, *i.e.* the rubber rod was removed before the earth connection was removed? Explain. *[1]*

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(Question B4 Part 1 continued)

(f) The charged rubber rod can continue to be used to charge additional metal rods by induction. How is this consistent with the principle of charge conservation? Explain, accounting for all charge before and after the process. *[2]*

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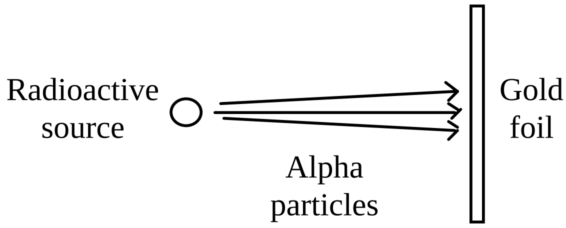
(Question B4 continued)

Part 2. Rutherford scattering and a nuclear reaction

In 1911 Geiger and Marsden bombarded a thin gold foil with alpha particles from a radioactive source.



(a) Based on ideas about atoms at the time, physicists had expected that the alpha particles would go through the atoms in the foil with very little deflection. They were astonished that some alpha particles were scattered almost completely backward. What did Rutherford conclude from this about the structure of the atom? Explain. *[2]*

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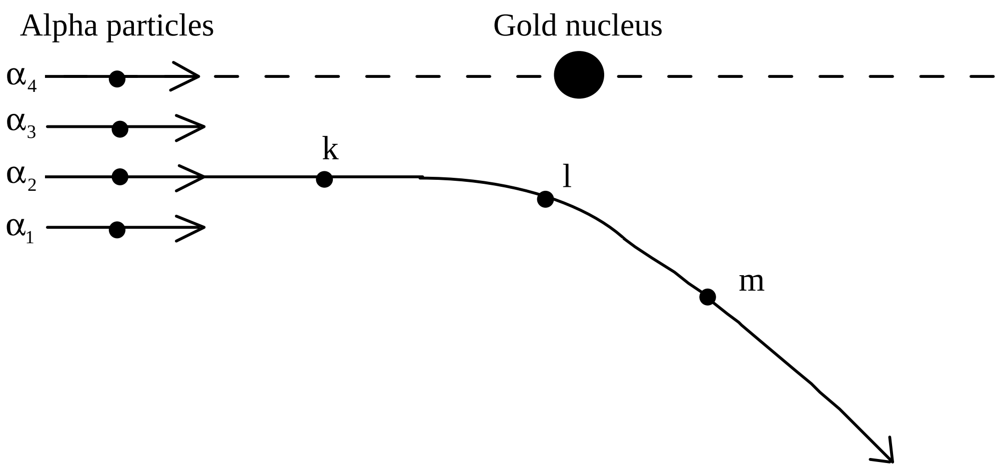
The diagram below shows four alpha particles approaching a gold nucleus. The deflected path of one of them (α_2) is shown. Assume that any recoil of the gold nucleus can be neglected.



(b) Draw in the force(s) acting on alpha particle α_2 when it is at the positions labelled k, l and m. Your force vectors should be of the right relative lengths, given that points k and m are **twice** as far from the nucleus as l is. State the source of any forces you show. *[2]*

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(This question continues on the following page)

(Question B4 Part 2 continued)

(c) As α_2 travels the path shown, describe what happens to its electric potential energy, kinetic energy and total energy. The recoil energy of the gold nucleus is negligible. *[2]*

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(d) On the diagram, sketch the approximate paths of the three other alpha particles labelled α_1, α_3 and α_4. Explain the paths you have drawn. *[4]*

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(e) The alpha particles have energy 5.0 MeV and the gold nucleus has atomic number 79. Calculate the distance of closest approach to the nucleus for α_4, which is incident 'head-on'. Compare this with the radius of the gold nucleus, which is 7×10^{-15} m, and state whether alpha particles can reach the nucleus. *[6]*

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(f) For heavy targets like gold, which have large atomic number, the 5 MeV alpha particles do not actually reach the nucleus, and are simply scattered by the Coulomb force. However for nuclei of low atomic number, alpha particles *are* able to reach the nucleus. Explain this difference. *[1]*

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(g) If alpha particles do reach the nucleus, a nuclear reaction may occur. Thus when alpha particles bombard the light element beryllium, neutrons are produced.
Complete the equation for the reaction of beryllium with an alpha particle. Include all the atomic and mass numbers. *[2]*

$${}^{9}_{4}\mathrm{Be} \quad + \quad \mathrm{He} = \quad \mathrm{n} \quad +$$