Oxford Cambridge and RSA

Friday 24 May 2019 – Morning

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Time allowed: 2 hours 15 minutes

You must have:
- the Insert (inserted)
- the Data, Formulae and Relationships booklet (sent with general stationery)

You may use:
- a scientific or graphical calculator
- a ruler (cm/mm)

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number | | | | | | Candidate number | | | | |

First name(s) ____________________

Last name ____________________

INSTRUCTIONS
- The Insert will be found inside this document.
- Use black ink. You may use an HB pencil for graphs and diagrams.
- Answer **all** the questions.
- Where appropriate, your answers should be supported with working. Marks may be given for a correct method even if the answer is incorrect.
- Write your answer to each question in the space provided. If additional space is required, use the lined page(s) at the end of this booklet. The question number(s) must be clearly shown.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended responses will be assessed in questions marked with an asterisk (*).
- This document consists of **28** pages.

SECTION A

Answer **all** the questions.

1 This question is about momentum and force.

(a) A block of mass 0.20 kg has velocity +1.8 m s^{-1}. It collides with a stationary block of mass 0.30 kg. The two blocks stick together after the impact.

(i) Calculate the velocity of the two blocks after impact. Ignore the effects of friction.

velocity = ... m s^{-1} **[2]**

(ii) Show that kinetic energy is **not** conserved in this collision.

[2]

(iii) The collision took place over time, Δt. By calculating the change of momentum of both blocks, show that the force on one block is equal and opposite to the force on the other block, an example of Newton's third law of motion.

[3]

(b) In a crash test, a driverless car strikes a wall and stops. The graph in Fig. 1.1 shows the variation of the force on the car over the time of the collision.

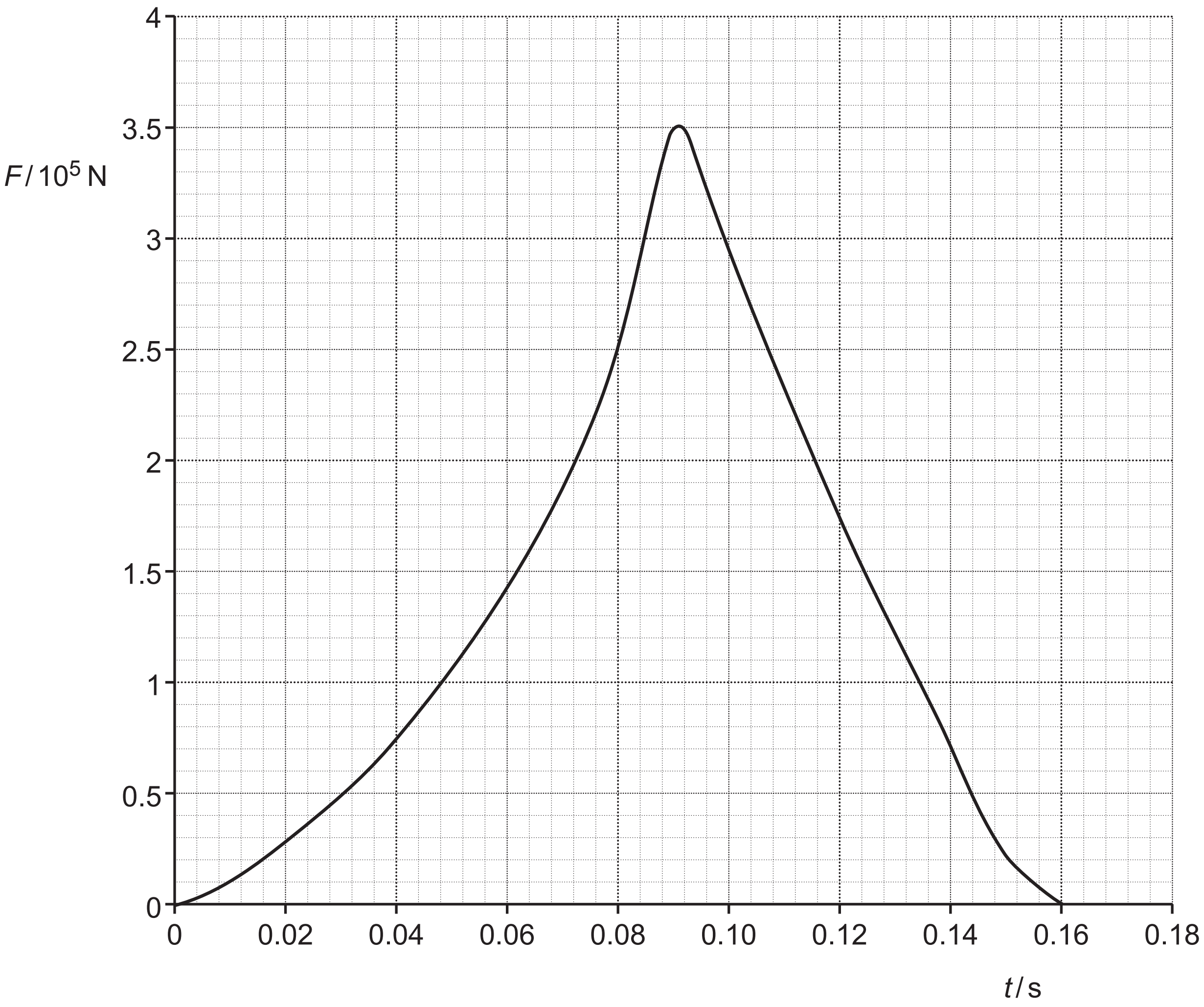

Fig. 1.1

The impulse on the car is given by the area under the curve. Use data from the graph to calculate the initial velocity of the car. Explain your method and reasoning.

mass of car = 1400 kg

initial velocity of car = ... m s^{-1} **[3]**

2 Fig. 2.1 shows a potential divider circuit using cells with very low internal resistance.

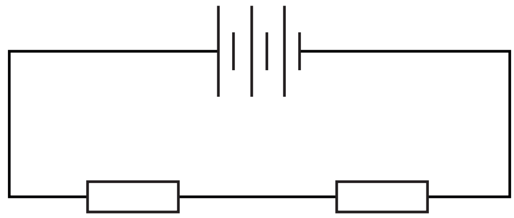

Fig. 2.1

(a) Show that the potential difference across the 4.7 kΩ resistor is 4.2 V to 2 significant figures.

[1]

(b) An analogue voltmeter connected across the 4.7 kΩ resistor reads 3.2 V.

Show that the resistance of the voltmeter is about 5 kΩ.

[3]

(c) A cell is made by inserting a zinc strip and a copper strip into a potato. When the same analogue voltmeter is connected to the cell as shown in Fig. 2.2, it registers a potential difference of 0.50 V.

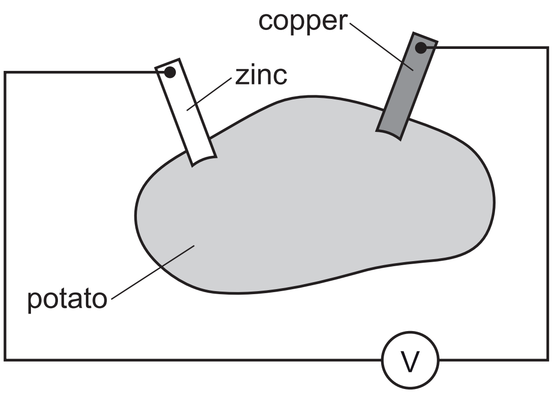

Fig. 2.2

(i) Using your answer to **(b)**, calculate the current in the circuit.

current = ... A **[1]**

(ii) When a digital voltmeter of resistance 1.0 MΩ replaces the analogue voltmeter in Fig. 2.2, it registers a potential difference of 0.93 V. Use the readings from the two meters to calculate an estimate for the internal resistance of the potato, stating any assumptions you make.

internal resistance = ... Ω **[3]**

3 This question is about electromagnetic induction and eddy currents.

(a) A bar magnet is dropped through a vertically mounted coil connected to a data-logger, as shown in Fig. 3.1.

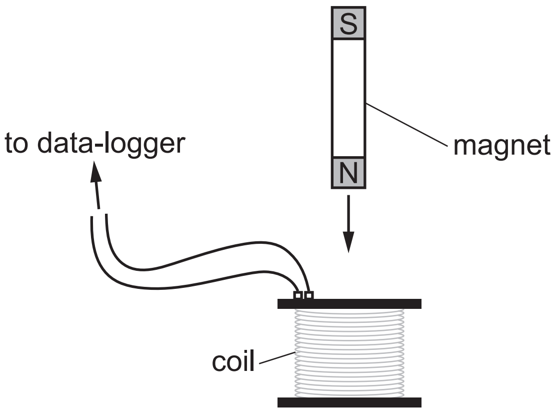

Fig. 3.1

The e.m.f. recorded by the data-logger varies as shown in Fig. 3.2.

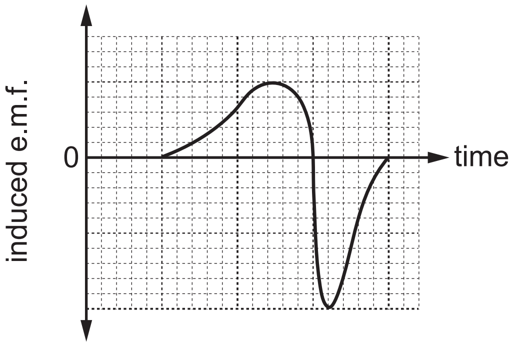

Fig. 3.2

Use the ideas of electromagnetic induction to explain the variation in e.m.f. in Fig. 3.2. **[4]**

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(b) An aluminium disk, mounted horizontally on a low-friction pivot, is placed between the poles of a strong magnet, as shown in Fig. 3.3. There is a uniform magnetic field between the poles of the magnet.

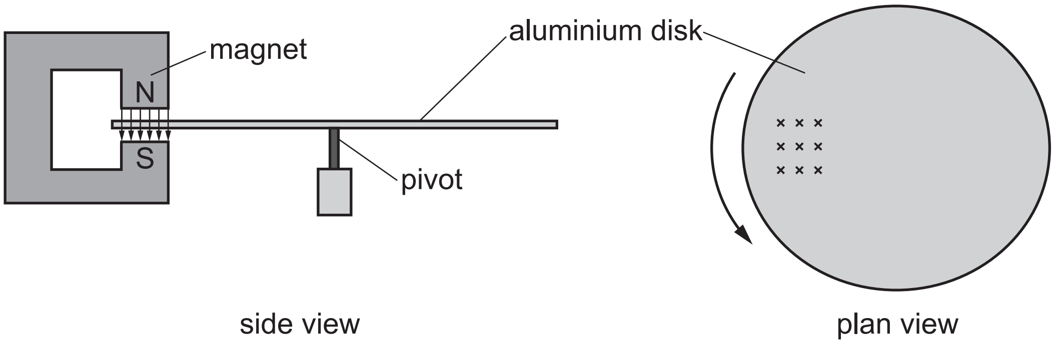

Fig. 3.3

A student sets the disk spinning in the direction shown by the arrow in the plan view above.

Explain how eddy currents are produced in the spinning disk and why these eddy currents make the disk slow down.

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(c) The student monitors the slowing of the aluminium disk using light gates to measure the speed of a card fastened to the edge of the disk, as shown in Fig. 3.4.

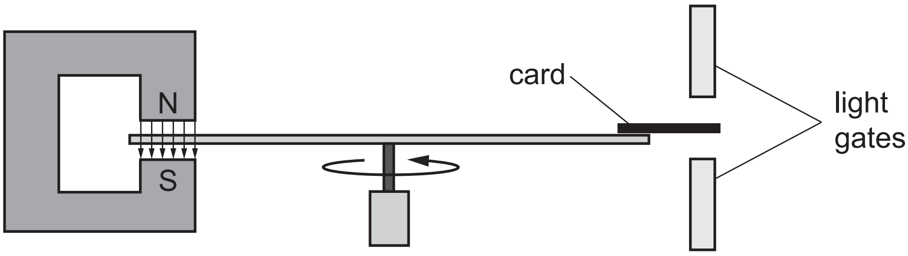

Fig. 3.4

Fig. 3.5 shows how the speed falls over time.

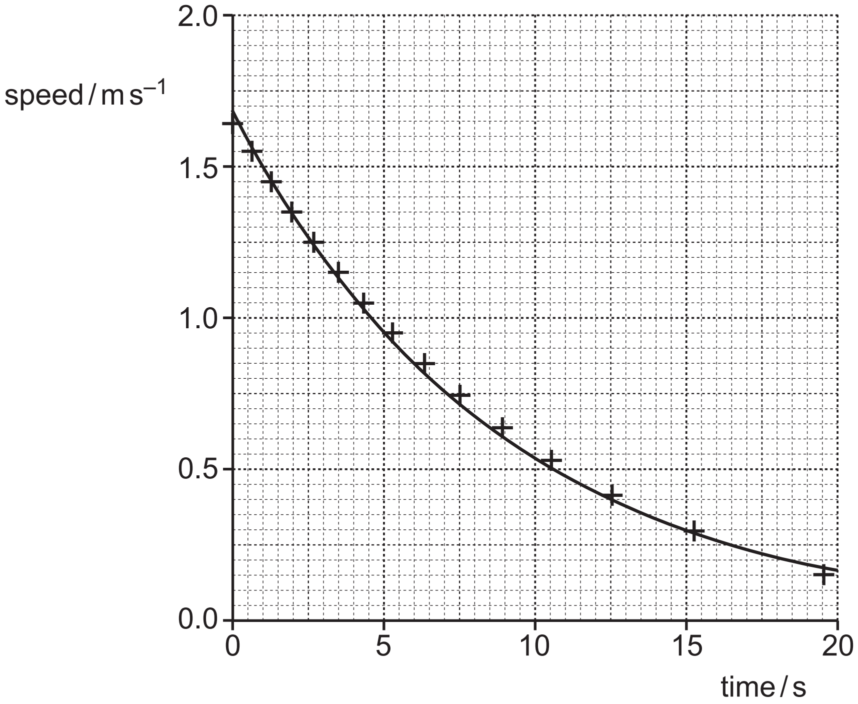

Fig. 3.5

The student suggests that the speed decreases exponentially.

(i) Explain what the student means by 'decreases exponentially' and, using ideas from part **(b)**, explain whether you would expect the speed of the disk to decrease in this way.

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.... **[4]**

(ii) Use data from the graph to test whether there is an exponential decrease in speed over time. Make your conclusion clear.

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.... **[3]**

SECTION B

Answer **all** the questions.

4 This question is about electrons showing wave-like properties.

(a) (i) An electron is accelerated through a p.d. of 4.3 kV. Calculate the velocity of the accelerated electron. Ignore relativistic effects.

velocity = ... $m\,s^{-1}$ **[2]**

(ii) Explain whether it is reasonable to ignore relativistic effects in the calculation in **(a)(i)**. Include a calculation in your explanation.

[3]

(iii) Calculate the de Broglie wavelength of the accelerated electron.

wavelength = ... m **[1]**

(b) Accelerated electrons can be diffracted by layers of graphite in a very similar way to light diffracted through a grating. When electrons are accelerated in a glass vessel and pass through graphite, they diffract and form circular rings on a fluorescent screen. Each electron striking the screen emits a tiny flash of light.

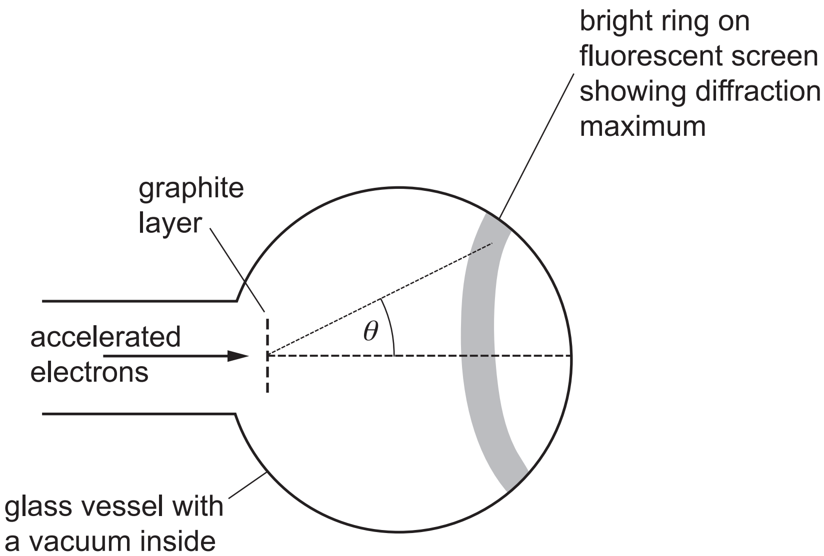

Fig. 4.1

Explain why the rings on the screen become smaller and brighter when the accelerating p.d. the electrons pass through is increased.

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(c)* Explain how this demonstration shows that electrons can be considered as 'quantum particles' showing both wave-like and particle-like behaviour. Your answer should describe which aspects of the demonstration show each type of behaviour and explain how diffraction effects can be explained using ideas about phasors. **[6]**

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Additional answer space if required

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5 A radioisotope that decays forming another isotope is known as a **parent** isotope and the newly formed isotope is known as the **daughter** product. For a sample initially made up of pure parent isotope, with a daughter product which does not decay, Fig. 5.1 shows how the number of parent and daughter nuclei change with time. The daughter product in this case is described as ‘stable’.

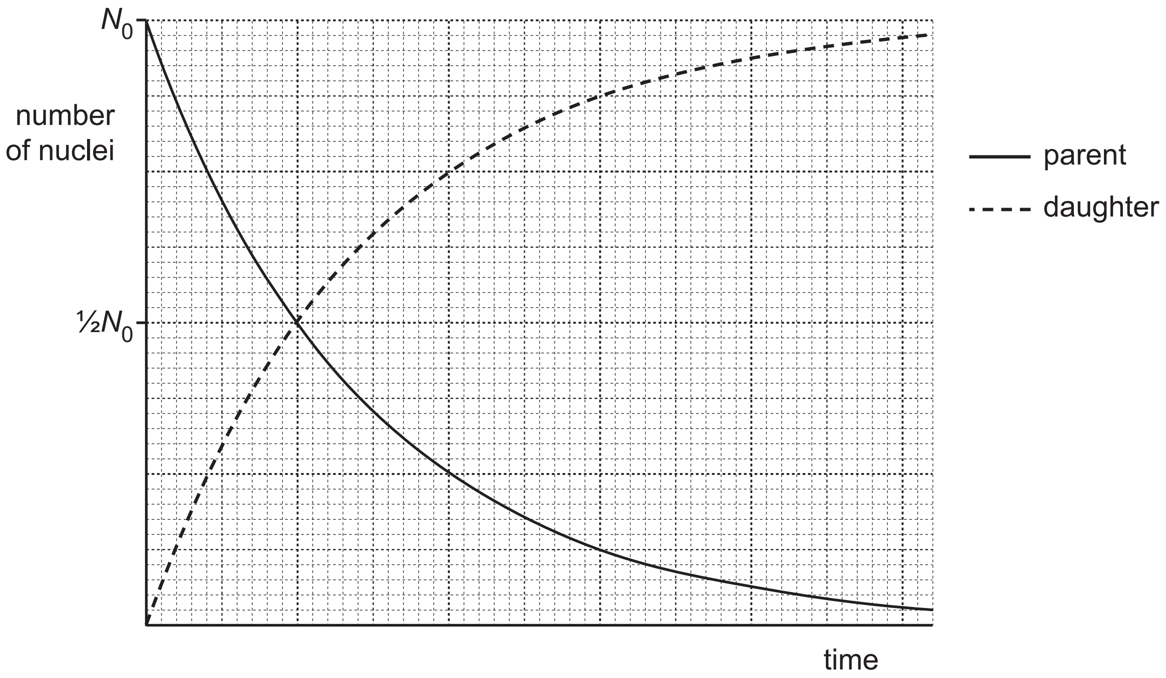

Fig. 5.1

(a) For a stable product, the number of daughter nuclei D at time t is given by the equation

$D = N_0 - N$

where N_0 is the original number of parent nuclei and N is the number of parent nuclei at time t.

Show that the number of daughter nuclei after time t is given by

$D = N_0(1 - e^{-\lambda t})$

[1]

(b) The ratio of the number of parent nuclei to number of daughter nuclei can be used to calculate the age of rocks.

The uranium isotope $^{238}_{92}U$ is the beginning of a 'radioactive series' that ends with the stable isotope of lead, $^{206}_{82}Pb$.

(i) Show that a total of eight alpha decays and six beta decays will produce $^{206}_{82}Pb$ from $^{238}_{92}U$.

[2]

(ii) The half-life of the series is 4.47×10^{9} years. This means that it will take about 4.5 billion years before half the uranium-238 (^{238}U) has decayed into lead-206 (^{206}Pb).

Show that the decay constant for this process is about 1.6×10^{-10} year^{-1}.

[1]

(iii) A rock is assumed to have contained no lead-206 when it was formed.

In a sample of the rock, the ratio

$$\frac{\text{number of lead-206 atoms present in rock sample}}{\textbf{original}\text{ number of uranium-238 atoms present in rock sample}}$$

is measured to be 0.39.

Calculate how long ago the rock formed, assuming that all the lead-206 formed has remained in the rock.

time since formation of rock = ... years **[3]**

(c) The same rock sample also contains uranium-235, which undergoes a series of decays to form the stable isotope lead-207.

The half-life of this series is 7.0×10^8 years. The ratio

$$\frac{\text{number of lead-207 atoms present in rock sample}}{\text{number of } \textbf{remaining} \text{ uranium-235 atoms present in rock sample}}$$

is measured to be 22.8.

(i) Use the relationship $N = N_0 \, e^{-\lambda t}$ to show that the number of daughter nuclei after time t is given by

$$D = N\left(\frac{1}{e^{-\lambda t}} - 1\right)$$

where N is the number of parent nuclei remaining at time t.

[1]

(ii) Use the equation for D given in **(c)(i)** and the data given to calculate the value for the age of the rock based on the uranium-235 decay series.

age of rock = ... years **[3]**

(iii) Rocks are often dated using three separate decay series. Suggest and explain an advantage of three decay series to date rocks rather than just one.

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.... **[2]**

6 Fig. 6.1 shows the basic components of a mass spectrometer. This is an instrument which separates ions according to the ratio of their charge to mass.

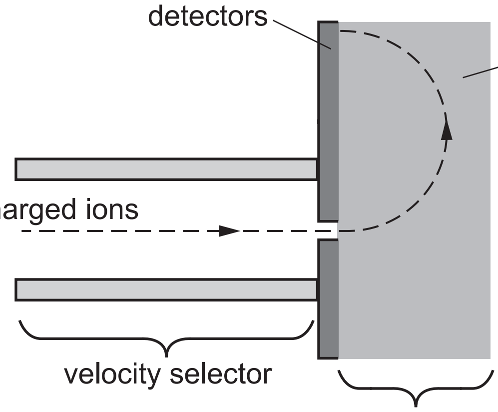

Fig. 6.1

Ions from an ion source (not shown in Fig. 6.1) pass into a region of uniform electric and magnetic fields called a velocity selector. Ions of different mass but with the same velocity will pass through to the deflection region. The ions are then deflected by a separate magnetic field in the deflection region and are detected by a bank of detectors. The position at which the ion is detected depends on the charge-to-mass ratio of the ion.

Fig. 6.2 indicates the uniform electric and magnetic fields in the velocity selector. The magnetic field is acting into the paper. A positive charge q is entering the selector at velocity v.

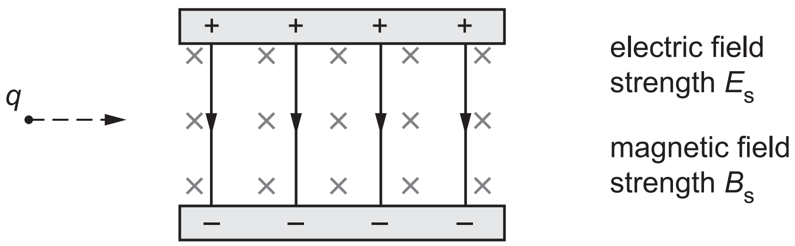

Fig. 6.2

(a) State how Fig. 6.2 shows that the electric field is uniform within the selector.

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.... **[1]**

(b) A positive charge q moving horizontally through the selector at velocity v as shown in Fig. 6.2 will experience a downwards electric force and an upwards magnetic force.

(i) By considering the forces on the charge, explain why the charge will **not** be deflected when

$v = \frac{E_s}{B_s}$.

[2]

(ii) Show that the units of $\frac{\text{electric field strength}}{\text{magnetic field strength}}$ are equivalent to the unit of velocity.

[2]

(iii) Describe and explain the motion of charges moving through the region if their velocities are not equal to $\frac{E_s}{B_s}$.

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.... **[3]**

(c) When charges enter the deflection region shown in Fig. 6.3, they experience a force due to the magnetic field.

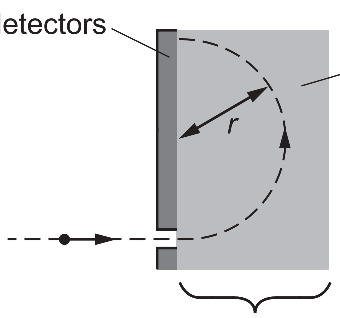

Fig. 6.3

(i) Show that the force on a proton moving at a velocity of $5.2 \times 10^6\,\mathrm{m\,s^{-1}}$ at right angles to a field of strength 0.64 T is about 5.3×10^{-13} N.

[1]

(ii) Calculate the radius *r* of the path the proton will follow.

radius = ... m **[2]**

(iii) A beam of $^{12}_{6}C$ and $^{14}_{6}C$ singly charged positive ions with equal velocities enters a deflection region, travelling at right angles to a uniform magnetic field of unknown strength.

Showing your working, calculate the ratio:

$$\frac{\text{radius of path of } ^{14}_{6}C}{\text{radius of path of } ^{12}_{6}C}$$

[3]

SECTION C

Answer **all** the questions.

This section is based on the Advance Notice Article, which is an insert.

7 Fig. 7.1 is an image from Mariner 9. It shows most of the crater at the top of Olympus Mons.

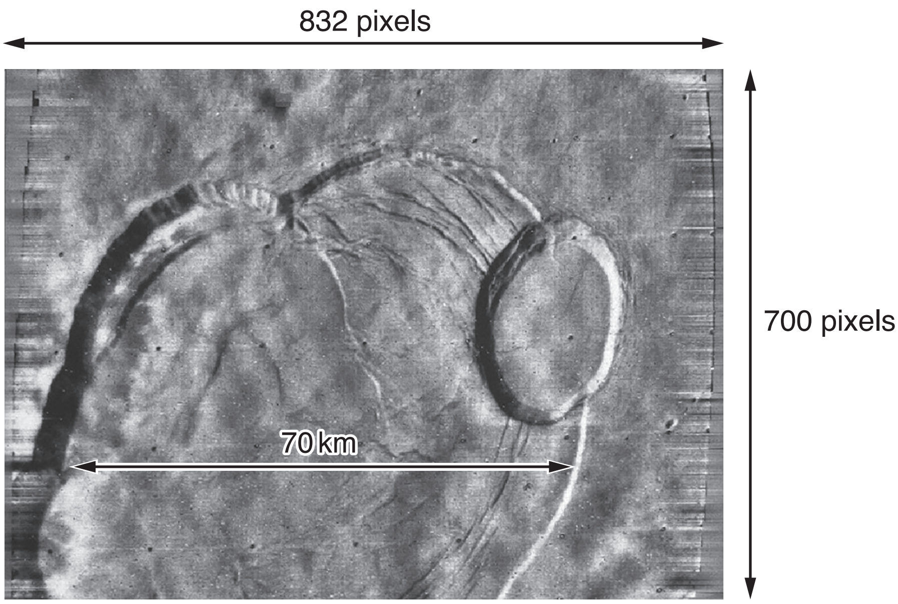

Fig. 7.1

Use data from Fig. 7.1 to calculate the resolution of the image.

resolution = ... km pixel^{-1} **[2]**

8 This question is about Martian meteorites (lines 43–47).

(a) Use the value of *G* and data from the article (lines 56–62) to show that the radius of Mars is about 3.4×10^6 m.

[2]

(b)* Calculate the gravitational potential at the surface of Mars and use this value to estimate the energy needed to eject a 0.2 kg rock from the surface to a great distance from the planet. Explain your reasoning.

Use ideas about the gravitational potential of the Sun and the Earth to explain why your calculated value is higher than the energy required for the rock to reach Earth but lower than the value required for the rock to escape from the Solar System. **[6]**

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Additional answer space if required

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9 An estimate of the atmospheric pressure p at height h above the surface of Mars can be found from the equation

$$\ln p = \ln p_s - \frac{mgh}{kT}$$

where p_s is the pressure at the average surface level, g is the gravitational field strength at the surface, k the Boltzmann constant and T the temperature of the atmosphere.

The pressure at the top of Olympus Mons is 0.03 kPa. Assuming that the Martian atmosphere is carbon dioxide (mass of one molecule = 7.3×10^{-26} kg), use the equation given and data from the article (lines 56–62) to calculate an estimate for the height of Olympus Mons above average surface level.

Suggest **one** reason why this method of estimating the height may be unreliable and explain how this would affect the value of the pressure at the top of Olympus Mons.

Calculation:

height = ... m

Suggestion and explanation:

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.... **[4]**

10 A large proportion of the radiation absorbed by astronauts comes from high-energy protons in cosmic rays. The American space agency, NASA, estimates that the dose equivalent received by an astronaut on a three-year return trip to Mars is about 1200 mSv. The calculation assumes that the astronaut spends 18 months on the surface of the planet.

(a) The risk of contracting cancer due to radiation exposure is 5% per Sievert. The percentage risk of contracting cancer for an astronaut on a three-year mission to Mars is about 6%. Compare this with the risk for someone on Earth over the same period. Give reasons for the difference in risk on the two planets.

Annual dose equivalent on Earth from cosmic rays = 0.4 mSv.

risk on Earth = ... %

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.... **[3]**

(b) Explain why exposure to radiation increases the risk of contracting cancer and how the high level of radiation on the surface of Mars may affect the design of the buildings for a human colony on the planet.

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.... **[2]**

11 This question is about placing a 'magnetic shield' at the L1 point between Mars and the Sun (lines 86–95). Fig. 11.1 shows the position of the L1 point.

Fig. 11.1 (not to scale)

(a) Calculate the centripetal force required to keep a 1000 kg 'shield' in orbit around the Sun at the L1 point with an orbital period the same as the orbital period of Mars.

Show that the combined gravitational force from the Sun and Mars acting on the 'shield' is approximately equal to the centripetal force required.

orbital period of Mars = 5.94×10^{7} s
mass of Sun = 2.00×10^{30} kg

[5]

(b) Suggest why the shield may not remain at the L1 point even though the net force from Mars and the Sun is equal to the centripetal force required.

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.... **[1]**

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).