(iii) A beam containing singly ionised U-235$^+$ and U-238$^+$ ions, all travelling at the same speed, enters a region of uniform magnetic field. Sketch the paths of these ions in the region of the magnetic field in Fig. 2. Label the diagram clearly. No calculation is required.

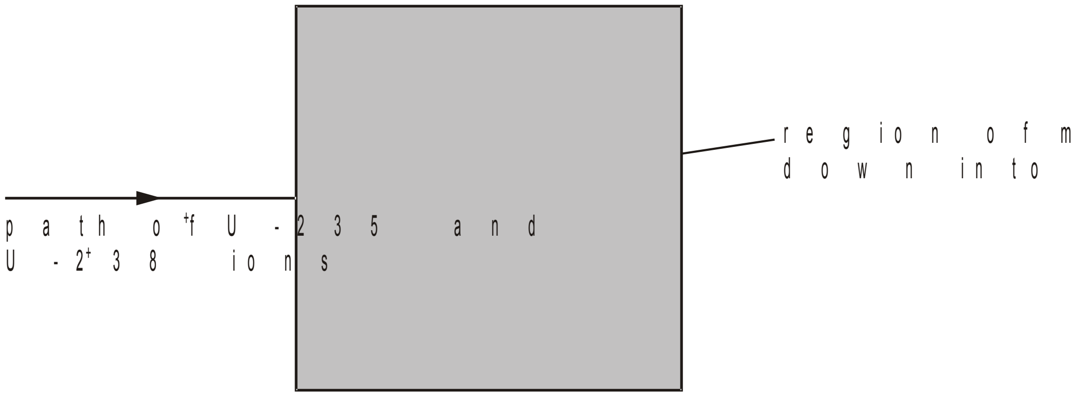


Fig. 2

[3]

[Total 16 marks]

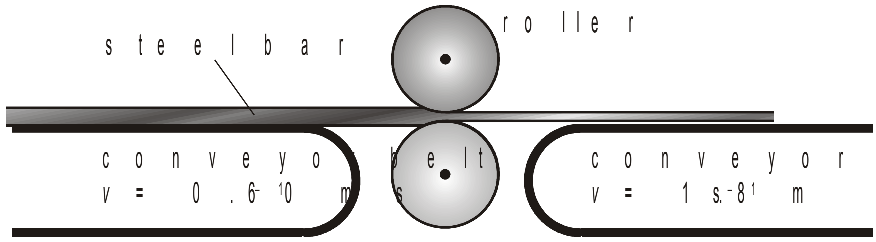
71. This question is about pressing a red hot bar of steel into a sheet in a rolling mill.

(a) A bar of steel of mass 500 kg is moved on a conveyor belt at 0.60 m s^{-1}. Calculate the momentum of the bar giving a suitable unit for your answer.

momentum = ... unit ....

[2]

(b) From the conveyor belt, the bar is passed between two rollers, shown in the figure below. The bar enters the rollers at 0.60 m s^{-1}. The rollers flatten the bar into a sheet with the result that the sheet leaves the rollers at 1.8 m s^{-1}.



(i) Explain why there is a resultant horizontal force on the bar at the point immediately between the rollers.

....

....

....

....

[2]

(ii) Draw an arrow on the figure at this point to show the direction of the force.

[1]

(iii) The original length of the bar is 3.0 m. Calculate the time it takes for the bar to pass between the rollers.

time = ... s

[1]

(iv) Calculate the magnitude of the resultant force on the bar during the pressing process.

force = ... N

[3]

(c) To monitor the thickness of the sheet leaving the rollers, a radioactive source is placed below the sheet and a detector is placed above the sheet facing the source. State, with a reason, which radioactive emission would be suitable for this task. Assume that the thickness of the sheet is about 20 mm.

....

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[2]

[Total 11 marks]

72. This question is about the discharge of combinations of capacitors.

In Figs. 1 and 2, the capacitors are charged through a 10 kΩ resistor from a 10 V d.c. supply when the switch **S** is connected to **X**. They discharge when the switch is moved to **Y**. The ammeters A_1, A_2, A_3 and A_4 monitor the currents in the circuits. Initially, the switch is connected to **X** and the capacitors are fully charged.

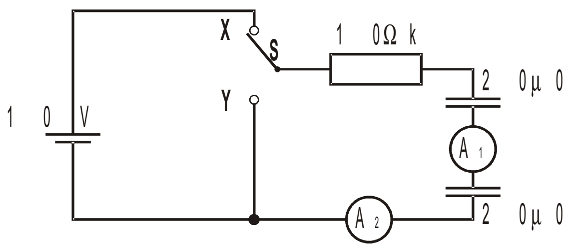

Fig. 1

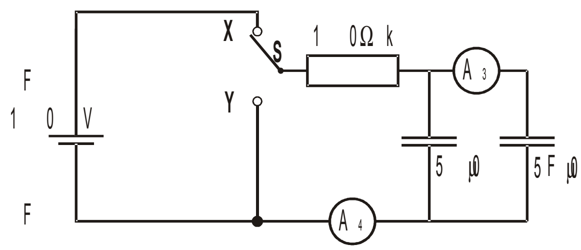

Fig. 2

(a) State

(i) the voltage across each capacitor in Fig. 1 V

[1]

(ii) the voltage across each capacitor in Fig. 2 V

[1]

(b) (i) Calculate the total charge stored in the circuit of Fig. 2.

charge = ... C

[2]

(ii) Explain why the total charge stored in the circuit of Fig. 1 is the same as in the circuit of Fig. 2.

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[2]

(c) Fig. 3 shows how the reading *I* on ammeter A2 in the circuit of Fig. 1 varies with time *t* as the capacitors discharge, after the switch is moved from **X** to **Y** at *t* = 0.

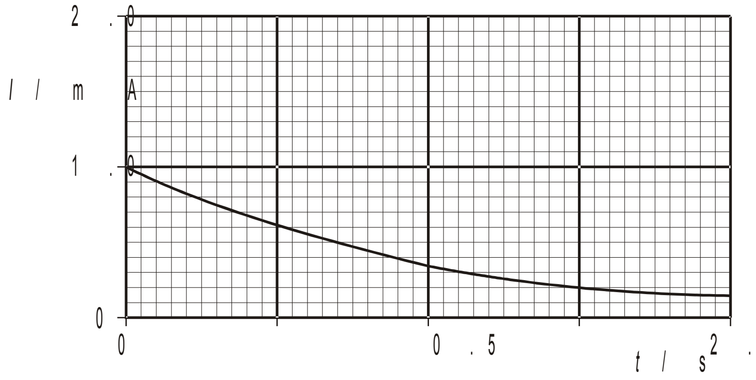

Fig. 3

(i) Describe how and explain why the reading on ammeter A_1 varies, if at all, over the same time interval.

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[2]

(ii) Sketch curves on Fig. 3 to show how you expect the readings on ammeters A_3 and A_4 to vary with time from *t* = 0, when the switch is moved from **X** to **Y** in Fig. 2. Label your curves $\mathbf{A_3}$ and $\mathbf{A_4}$ respectively.

[3]

[Total 11 marks]

73. A nitrogen atom is initially stationary at point **P** in Fig. 1, midway between two large horizontal parallel plates in an evacuated chamber. The nitrogen atom becomes charged.
There is an electric field between the plates. Ignore any effects of gravity.

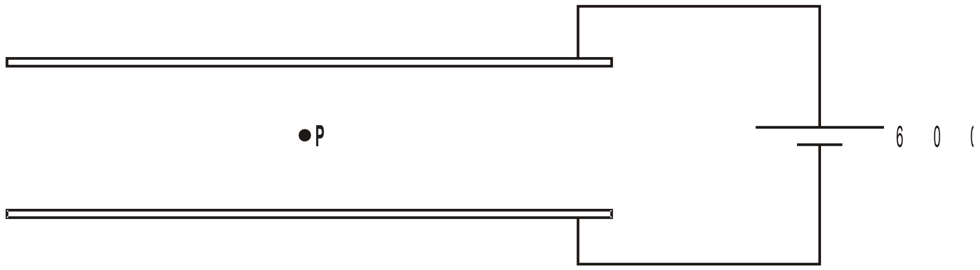

Fig. 1

(a) The direction of the electric force on the nitrogen ion is vertically downwards. State with a reason the sign of the charge on the ion.

....

....

....

[1]

(b) The voltage between the plates is 600 V. At the instant that the ion, charge 1.6×10^{-19} C and mass 2.3×10^{-26} kg, reaches the lower plate, show that

(i) the kinetic energy of the ion is 4.8×10^{-17} J

[2]

(ii) the speed of the ion is 6.5×10^{4} m s^{-1}.

[2]

(c) The electric field strength between the plates is 4.0×10^4 N C^{-1}. Calculate the separation of the plates.

separation = ... m

[2]

(d) The ion passes through a hole in the lower plate at a speed of 6.5×10^4 m s^{-1}. It enters a region of uniform magnetic field of flux density 0.17 T perpendicularly into the plane of Fig. 2.

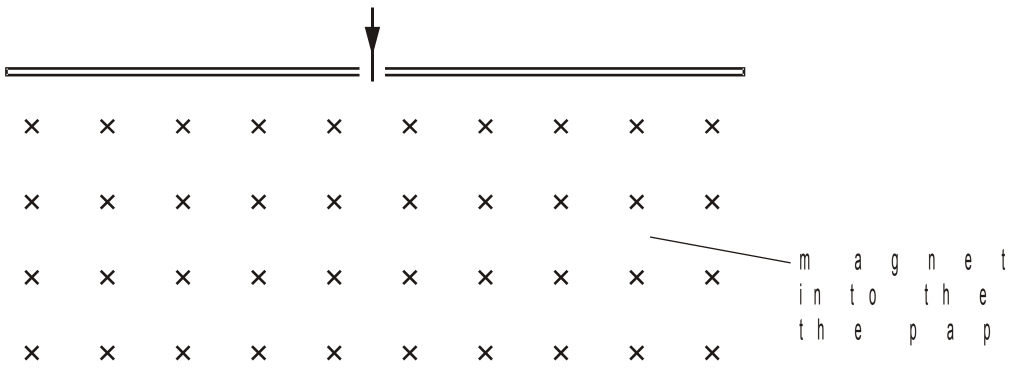

Fig. 2

(i) Sketch on Fig. 2 the semicircular path taken by the ion.

[1]

(ii) Calculate how far from the hole the ion will collide with the plate. Use data from **(b)**.

distance = ... m

[5]

[Total 13 marks]

74. The radioactive radium nuclide $^{226}_{88}Ra$ decays by alpha-particle emission to an isotope of radon Rn with a half-life of 1600 years.

(a) State the number of

(i) neutrons in a radium nucleus ....

[1]

(ii) protons in the radon nucleus resulting from the decay ....

[1]

(b) The historic unit of radioactivity is called the curie and is defined as the number of disintegrations per second from 1.0 g of $^{226}_{88}Ra$. Show that

(i) the decay constant of the radium nuclide is 1.4×10^{-11} s^{-1}

1 year = 3.16×10^{7} s

[1]

(ii) 1 curie equals 3.7×10^{10} Bq.

[3]

(c) Use the data below to show that the energy release in the decay of a single nucleus of $^{226}_{88}Ra$ by alpha-particle emission is 7.9×10^{-13} J.

nuclear mass of Ra-226 = 226.0254 u
nuclear mass of Rn-222 = 222.0175 u
nuclear mass of He = 4.0026 u

[3]

(d) Estimate the time it would take a freshly made sample of radium of mass 1.0 g to increase its temperature by 1.0 °C. Assume that 80% of the energy of the alpha-particles is absorbed within the sample so that this is the energy which is heating the sample. Use data from (b) and (c).

specific heat capacity of radium = 110 J kg^{-1} K^{-1}

time = ... s

[4]

[Total 13 marks]

75. In this question, two marks are available for the quality of written communication.

This question is about electromagnetic induction.

State Faraday's law of electromagnetic induction. Explain the terms *magnetic flux* and *magnetic flux linkage* which you may have used in your statement of the law.

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[5]

Quality of Written Communication [2]

[Total 7 marks]

76. In this question, two marks are available for the quality of written communication.

This question is about electromagnetic induction.

Fig. 1 shows a simple a.c. generator used for demonstrations in the laboratory. It consists of a magnet being rotated inside a cavity in a soft iron core. The output from the coil, wound on the iron core, is connected to an oscilloscope.

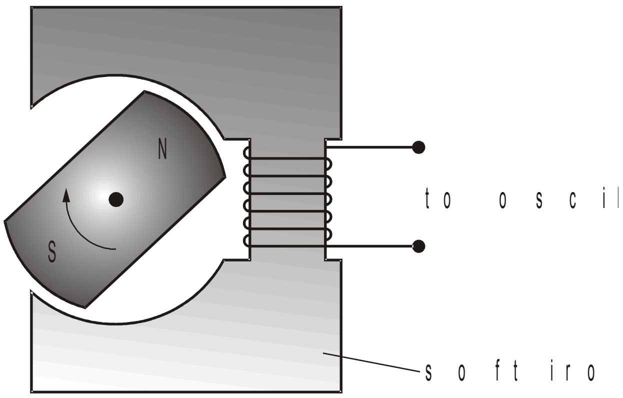

Fig. 1

Sketch on Fig. 2 a typical output voltage which would be seen on the oscilloscope screen. State and explain, using Faraday's law and/or the terms *magnetic flux* and *magnetic flux linkage*, how doubling each of the following factors will alter this output voltage:

- the speed of rotation of the magnet
- the number of turns on the coil

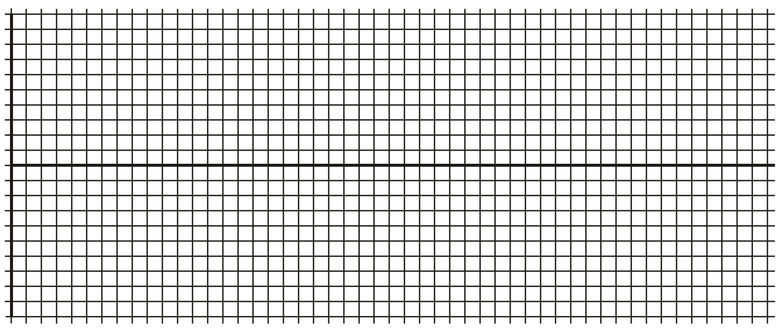

Fig. 2

Finally, explain how the output voltage would be different if the soft iron core were removed, leaving the magnet and coil in the same positions.

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[7]

Quality of Written Communication [2]

[Total 9 marks]

77. When a star ceases to be Main Sequence, it may evolve in several different ways. Explain the circumstances which will lead to the formation of a neutron star.

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[Total 4 marks]

78. (i) A star of mass 7×10^{30} kg becomes a neutron star of radius 10 km. Calculate the average density of the neutron star, assuming that 50% of the original star's mass has been lost.

density = ……………….. kg m^{-3}

[3]

(ii) State how the density of a neutron star compares to that of materials commonly found on Earth.

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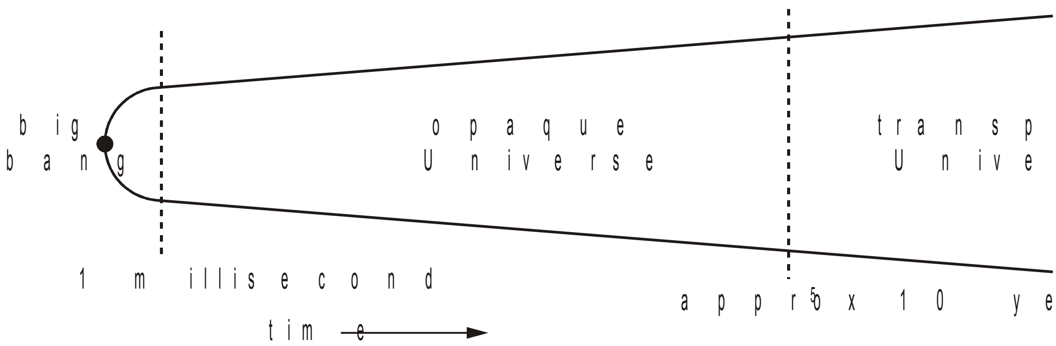
[2]

[Total 5 marks]

79. Some stages in the early evolution of the Universe are represented in the figure below.



(i) What limits our understanding of events in the first millisecond?

....

....

[1]

(ii) State and explain how the temperature of the Universe has changed after the first millisecond.

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[2]

(iii) Explain how the Universe became *transparent*.

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[3]

[Total 6 marks]

80. Describe and explain **two** pieces of evidence which suggest that the Universe did in fact begin with a big bang.

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[Total 5 marks]

81. What is meant by the *cosmological principle*?

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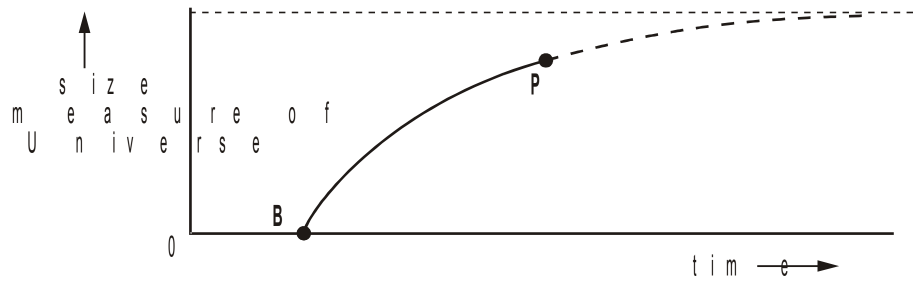
[Total 2 marks]

82. The ultimate fate of the Universe is not yet clear. The figure below shows a graph where the size of the Universe is represented from the big bang B to the present day P. The graph has been extended into the future by the dotted line (– – – – –).



(i) Calculate a value for the age of the Universe in years. Assume the Hubble constant to be 75 km s^{-1} Mpc^{-1}.

age = …..………………… years

[3]

(ii) Describe and explain what final fate for the Universe is represented in the figure above.

....

....

....

[2]

(iii) The mass of the Universe may be significantly greater than that assumed in the first paragraph of this question.
Taking this to be case, sketch a second graph on the figure above using the same scales to show the future evolution of the Universe.

[2]

(iv) Comment upon the implications of your graph for the future of the Universe.

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[1]

[Total 8 marks]

83. For a spacecraft launched into the outer regions of the solar system, it is not practical to have its battery recharged by solar panels. Such spacecraft use a Radioisotope Thermoelectric Generator (RTG). This generator has no moving parts and contains two different metals joined to form a closed electric circuit. When the two junctions between these metals are kept at different temperatures, an electric current is produced. One junction is cooled by space while the other is heated by the decay from a radioactive isotope. RTGs are very reliable sources of power.

Nowadays, RTGs use plutonium-238 which is an alpha emitter with a half-life of 88 years.
Each alpha particle is emitted with a kinetic energy of 5.0MeV.

(a) State **one** reason why solar panels are not practical in deep space.

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....

[1]

(b) Suppose such a spacecraft transmits for 120 minutes each day from a 12 V circuit which draws a current of 5.0 A while transmitting back to Earth. During the rest of the day, the transmitting circuit is shut down. The battery charging, however, carries on continuously.

(i) Show that the energy required per day for transmission is about 0.4 MJ.

[2]

(ii) The overall efficiency in the RTG battery charging system is 25%. Show that the steady power output required from the RTG is about 20 W.

[2]

(iii) Calculate the minimum activity of the source (i.e. the number of 5 MeV alpha particles emitted per second) required to generate this power.

activity = ... Bq

[2]

(c) (i) Show that the decay constant λ of Pu-238 is $2.5 \times 10^{-10}\ s^{-1}$.

[2]

(ii) Calculate the number N of nuclei of Pu-238 required to generate the activity calculated in (b)(iii).

N = ...

[2]

(iii) Calculate the mass of Pu-238 corresponding to this number of nuclei.

mass = ... kg

[2]

(d) Plutonium is one of the most dangerous chemical poisons known, as well as being a radioactive hazard. It has been estimated that 1 kg of this substance, suitably distributed, would be enough to kill everyone on Earth. Comment on the risks involved in using plutonium as a fuel for spacecraft.

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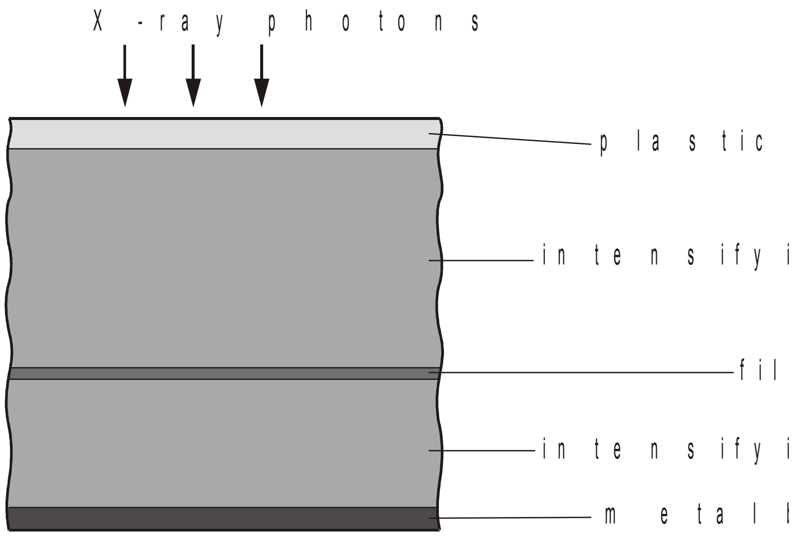
[2]

[Total 15 marks]

84. The figure below shows a cross-section of a radiographic detector which uses fIlm and intensifying screens. Describe how an image of an internal body structure may be produced using X-ray film. Within your answer you should include details of the use and advantages of an intensifying screen.



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[Total 8 marks]

85. Explain how ultrasound is produced using a piezoelectric crystal such as quartz.

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[Total 2 marks]

86. Quartz is a compound of silicon and oxygen. Each silicon atom is attached to four oxygen atoms. See Fig. 1 below. Each oxygen atom carries a negative charge. The silicon atom carries a positive charge.

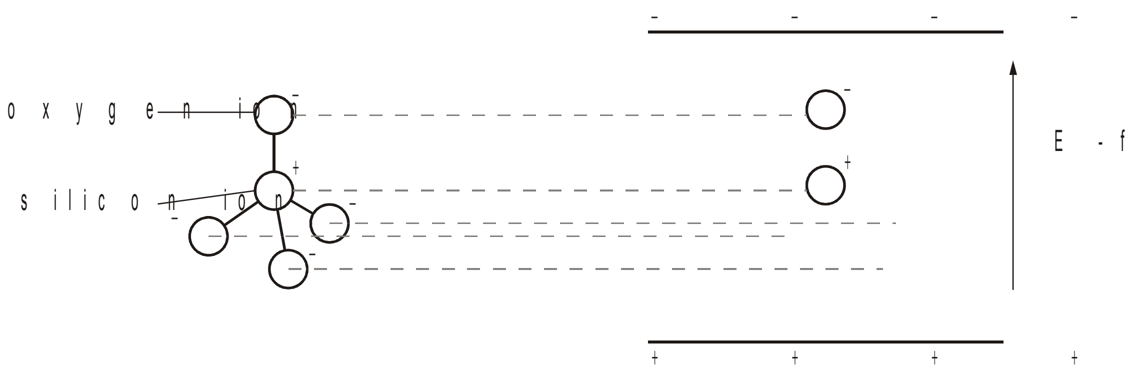


Fig. 1 **Fig. 2**

(i) On Fig. 2, draw possible positions for the negatively-charged oxygen ions when an electric field is applied in the direction shown. The central silicon ion and one oxygen ion have been drawn in for you.

[1]

(ii) Use your answer to (i) to explain why a single crystal of quartz is piezoelectric.

....

....

[1]

[Total 2 marks]

87. (a) Acoustic impedance Z is the product of the density ρ of a medium and the speed of ultrasound v.

The fraction f of ultrasound reflected at a boundary between two media of acoustic impedances Z_1 and Z_2 is given by the equation

$$f = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

medium	density ρ / kg m^{-3}	ultrasound velocity v / m s^{-1}
air	1.299	330
skin	1075	1590
coupling medium	1090	1540
bone	1750	4080

Fig. 1

(i) Use the data in Fig. 1 to find the fraction f of ultrasound reflected at an air-skin boundary.

f = ...

[2]

(ii) Hence explain the need for a coupling medium in ultrasound imaging.

....

....

....

....

[2]

(b) Fig. 2 is a CRO display showing the reflected ultrasound signal from the front edge **F** and the rear edge **R** of a bone. The time-base setting is 1.0×10^{-5} s cm^{-1}.

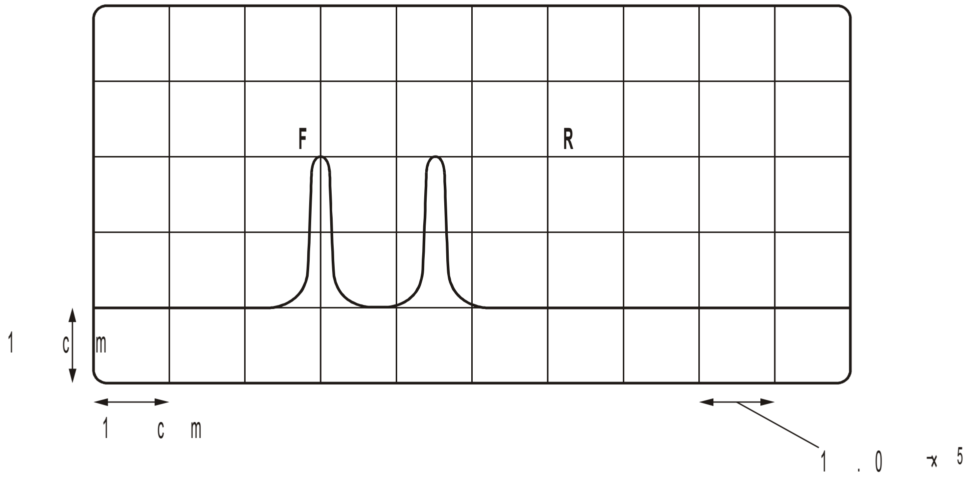


Fig. 2

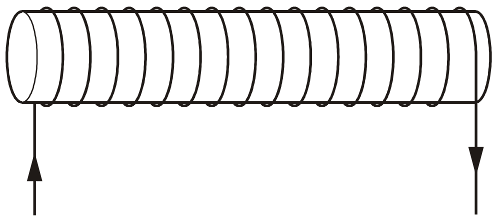
Using appropriate data from Fig. 1 and Fig. 2, calculate the thickness of the bone.

thickness = ... cm

[4]

[Total 8 marks]

88. The figure below shows a solenoid carrying an electric current.



On the figure above, sketch the pattern and show the direction of the magnetic field inside the solenoid.

[Total 3 marks]

89. This question is about nuclear fission.

When a uranium-235 ($^{235}_{92}U$) nucleus absorbs a neutron, it becomes uranium-236 ($^{236}_{92}U$) which may undergo fission.

(a) In order to increase the probability of neutron-induced fission, neutrons from a fission reaction are slowed down before they collide with another $^{235}_{92}U$ nucleus. This is achieved by causing the neutrons to collide elastically with other nuclei. Explain why these other nuclei should have a mass which is similar to the neutron mass.

....

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....

[2]

(b) The fission of $^{236}_{92}U$ can produce many different pairs of nuclei.

The table below shows 3 possible pairs of product nuclei and their relative yields.

nucleus 1	nucleus 2	relative yield
zirconium-100 ($^{100}_{40}Zr$)	tellurium-135 ($^{135}_{52}Te$)	6.4%
selenium-83 ($^{83}_{34}Se$)	cerium-152 ($^{152}_{58}Ce$)	0.40%
rhodium-110 ($^{110}_{45}Rh$)	silver-121 ($^{121}_{47}Ag$)	0.020%

Write an equation to show the fission reaction which produces $^{110}_{45}Rh$ and $^{121}_{47}Ag$.

[2]

[Total 4 marks]

90. Describe briefly the quark model of hadrons.

- Illustrate your answer by referring to the composition of **one** hadron.
- Include in your answer the names of **all** the known quarks.
- Give as much information as you can about **one** particular quark.

(Allow one lined page).

[Total 5 marks]

91. This question is about obtaining energy from fusion reactions.

(a) Energy may be generated by fusing deuterium nuclei in the reaction

$$^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n + \text{energy} \qquad \textbf{reaction 1}$$

The values of binding energy per nucleon for $^{2}_{1}H$ and $^{3}_{2}He$ are given in the table below.

nuclide	binding energy per nucleon / MeV
$^{2}_{1}H$	1.11
$^{3}_{2}He$	2.57

(i) Calculate the energy in joule released in **reaction 1**.

energy = ... J

[3]

(ii) Energy may also be generated by the fusion of deuterium and tritium in the reaction

$${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + \text{energy} \qquad \textbf{reaction 2}$$

The amount of energy generated in **reaction 2** is 2.82×10^{-12} J. State why this shows that **reaction 2** is more suitable than **reaction 1** for generating energy.

....

....

[1]

(b) The energy generated in **reaction 2** is shared between the helium-4 nucleus and the neutron.

Calculate what percentage of the energy released is gained by the neutron. Assume that the initial momentum of the products is zero.

percentage = ... %

[5]

[Total 9 marks]

92. (i) An important development in particle physics was the building of an accelerating machine capable of creating a proton-antiproton pair.

Calculate the minimum energy in GeV needed for creating this pair of particles.

energy = ... GeV

[3]

(ii) Suggest, without mathematical calculation, why it is not possible to accelerate a particle to this energy using a cyclotron.

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[3]

[Total 6 marks]

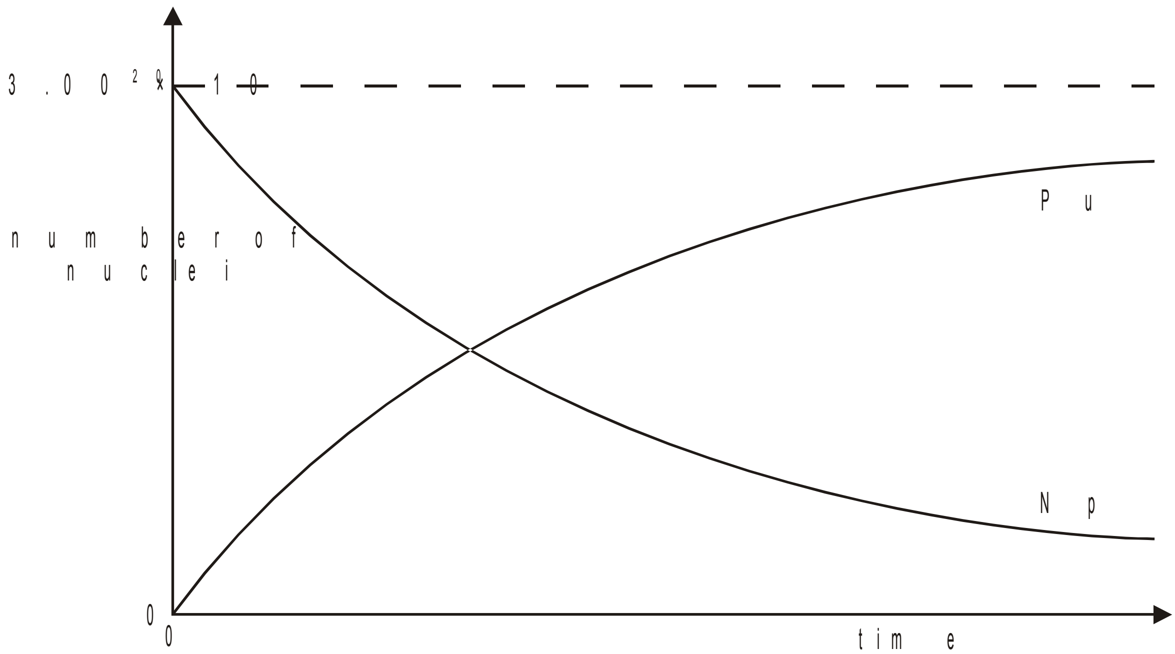
93. Neptunium-239 ($^{239}_{93}Np$) is formed in a fission reactor. This nuclide decays to form plutonium-239 ($^{239}_{94}Pu$), thus:

$$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e + ^{0}_{0}\bar{v}$$

The half-lives are: $^{239}_{93}Np$: 2.36 days; $^{239}_{94}Pu$: 24 100 years.

A sample consisting of 3.00 × 10^{20} atoms of $^{239}_{93}Np$ is isolated and the number of $^{239}_{93}Np$ nuclei is monitored. This number of nuclei is plotted against time to give the graph labelled Np in the figure below.

The number of nuclei of ${}^{239}_{94}\mathrm{Pu}$ is also monitored to give the graph labelled Pu.



(a) Explain in words the shapes of these graphs.

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[3]

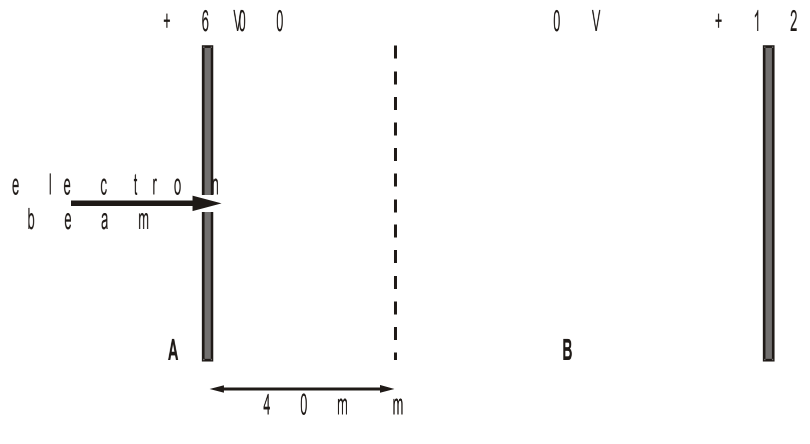
(b) Calculate the time taken in days for the number of $^{239}_{94}\text{Pu}$ nuclei to reach 2.70×10^{20}.

time = ... days

[4]

[Total 7 marks]

94. This question is about changing the motion of electrons using electric fields. The diagram below shows a horizontal beam of electrons moving in a vacuum. The electrons pass through a hole in the centre of a metal plate **A**. At **B** is a metal grid through which the electrons can pass. At **C** is a further metal sheet. The three vertical conductors are maintained at voltages of +600 V at **A**, 0V at **B** and +1200 V at **C**. The distance from plate **A** to grid **B** is 40 mm.



(a) On the diagram above draw electric field lines to represent the fields in the regions between the three plates.

[3]

(b) Show that the magnitude of the electric field strength between plate **A** and grid **B** is 1.5×10^4 V m^{-1}.

[2]

(c) Calculate the horizontal force on an electron after passing through the hole in **A**.

force = ... N

[2]

(d) Show that the minimum speed that an electron in the beam must have at the hole in **A** to reach the grid at **B** is about 1.5×10^7 m s^{-1}.

[2]

(e) Calculate the speed of these electrons when they collide with sheet **C**.

speed = ... m s^{-1}

[1]

(f) Describe and explain the effect on the current detected at **C** when the voltage of the grid **B** is increased negatively.

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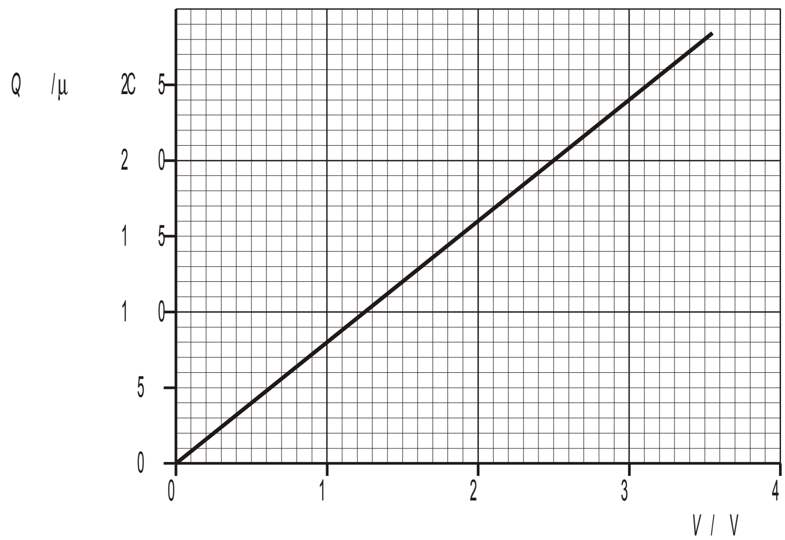
[2]

[Total 12 marks]

95. The diagram below shows the graph of charge Q stored against potential difference V across a capacitor.



(i) Use the graph to find the capacitance of the capacitor.

capacitance = ... μF

[2]

(ii) Calculate the energy in the capacitor when it is charged to 3.0 V.

energy = ... μJ

[2]

(iii) The capacitor is discharged through a resistor. The charge falls to 0.37 of its initial value in a time of 0.040 s. This is the time constant of the circuit. Calculate the resistance of the resistor.

resistance = ... Ω

[2]

(iv) Explain why the discharge time of the capacitor is independent of the initial charge on the capacitor.

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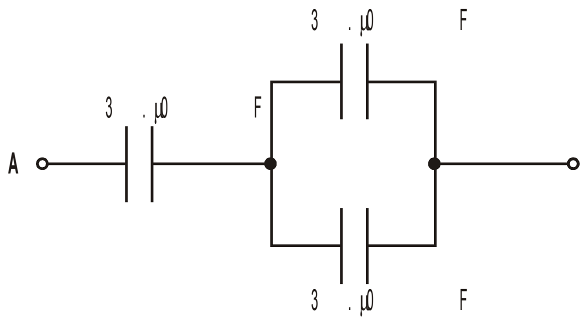
[2]

[Total 8 marks]

96. You are provided with a number of identical capacitors, each of capacitance 3.0 μ F. Three are connected in a series and parallel combination as shown in the diagram below.



(i) Show that the total capacitance between the terminals **A** and **B** is 2.0 μ F.

[3]

(ii) Draw a diagram in the space below to show how you can produce a total capacitance of 2.0 μ F using **six** 3.0 μ F capacitors.

[2]

[Total 5 marks]

97. The activity of the potassium source is proportional to the count rate minus the background count rate, that is

activity = constant × (count rate – background count rate).

(i) Explain the meaning of the terms

activity. ....

....

[1]

background count rate ....

....

[1]

(ii) Suggest, with a reason, **one** of the factors which affect the value of the **constant** in the equation above.

....

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[2]

[Total 4 marks]

98. The activity of the potassium source is proportional to the count rate minus the background count rate, that is

activity = constant × (count rate – background count rate).

(i) The radioactive decay law in terms of the count rate C corrected for background can be written in the form

$$C = C_o e^{-\lambda t}$$

where λ is the decay constant.
Show how the law can be written in the linear form

$$\ln C = -\lambda t + \ln C_o$$

[2]

(ii) Fig. 2 shows the graph of ln C against time t for the beta-decay of potassium.

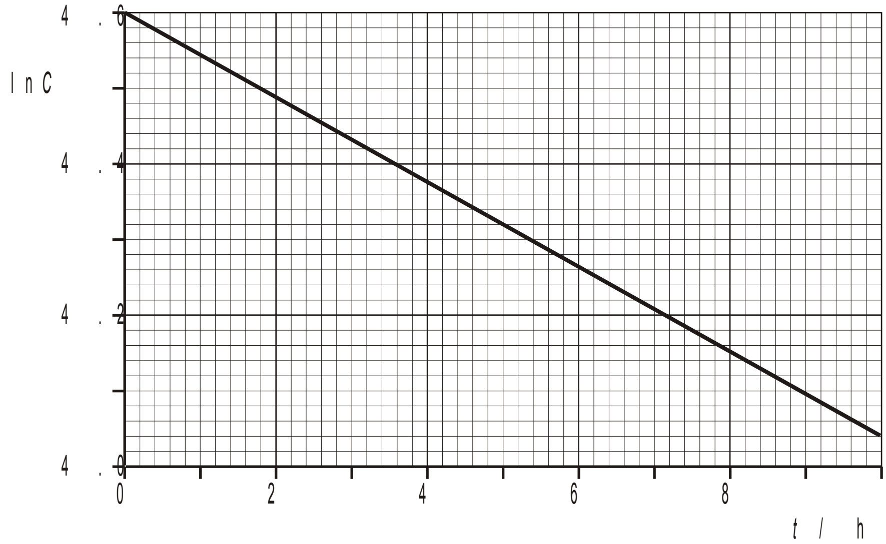

Fig. 2

Use data from the graph to estimate the half-life of the potassium nuclide.

half-life = ………………….h

[3]

[Total 5 marks]

99. State **three** ways in which decay by emission of an α -particle differs from decay by emission of a β -particle.

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[Total 3 marks]

100. A single-turn square coil of side 0.050m is placed in a magnetic field of flux density *B* of magnitude 0.026 T.

(a) The coil is placed in three different orientations to the field as shown in Fig. 1(a), (b) and (c).

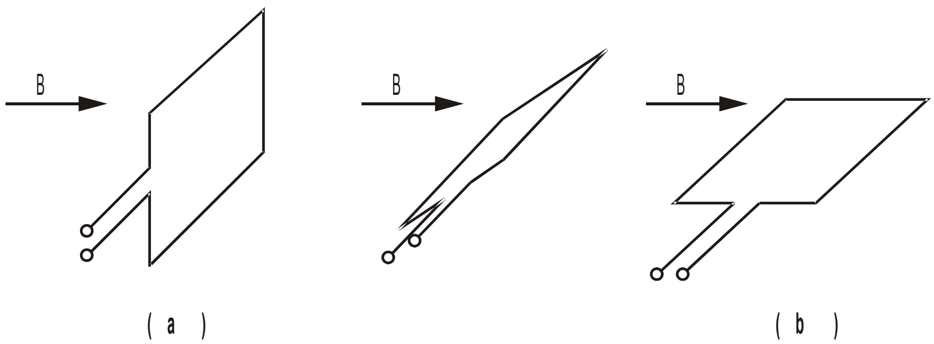

Fig. 1

In Fig. 1(a), the plane of the coil is perpendicular to the field. In (b), it is at 45° to the field and in (c), it is parallel to the field. Calculate the value, giving a suitable unit, of the magnetic flux linking the coil for the position shown in

(i) Fig. 1(a)

magnetic flux = …………..unit………

[3]

(ii) Fig. 1(b)

magnetic flux = …………..unit………

[1]

(iii) Fig. 1(c).

magnetic flux = …………..unit………

[1]

(b) The coil is rotated in the magnetic field to generate an e.m.f. across its ends. The graph of the variation of e.m.f. with time is shown in Fig. 2.

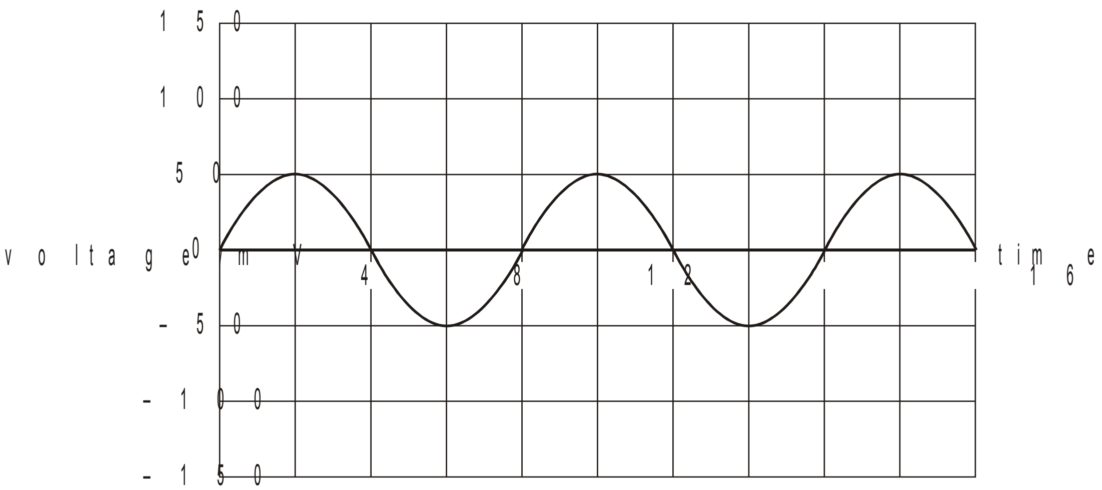

Fig. 2

(i) On Fig. 2 mark, with an **X**, a point on the graph at a time when the flux linking the coil is a maximum.

[1]

(ii) Give your reasoning for your choice of position **X**.

....

....

....

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....

[2]

(iii) The rate of rotation of the coil is doubled. On Fig. 2 draw a graph showing at least two cycles of the e.m.f. now generated across the ends of the coil.

[3]

[Total 11 marks]

101. In this question, two marks are available for the quality of written communication.

Describe what conclusions can be drawn about the structure of the atom from Rutherford's experiment in which α -particles are scattered by gold nuclei. Explain how and why the experiment differs when high-speed electrons are fired at nuclei.

(Allow one lined page)

[7]

Quality of Written Communication [2]

[Total 9 marks]

102. (a) The cosmic microwave background radiation is evidence for the way in which the Universe began. State a feature of the intensity of this microwave background radiation.

....

[1]

(b) The first stars are thought to have formed many years after the Universe came into being. What are the similarities and differences between the **composition** of the Sun and that of the very first stars?

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[3]

[Total 4 marks]

103. In 1929 Edwin Hubble showed that the Universe was expanding by studying the light from stars and galaxies. Explain how.

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[Total 5 marks]

104. (a) Suggest why many stars within our galaxy do not conform with Hubble's law.

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[2]

(b) Estimate the age of the Universe, giving your answer in seconds. Show your working and take the Hubble constant to be 75 km s^{-1} Mpc^{-1}.

age = ... s

[3]

[Total 5 marks]

105. Describe how the fate of the Universe depends upon its mean density and explain why this ultimate fate is not yet known.

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[Total 5 marks]

106. The primary coil of a transformer is connected to the 230 V mains supply. The 12 V output of the secondary coil is applied to a bulb which draws a current of 3.0 A. At the frequency of the mains the transformer operates with an efficiency of 96 %. Calculate

(i) the power supplied to the bulb

power = ... W

[2]

(ii) the current in the primary coil.

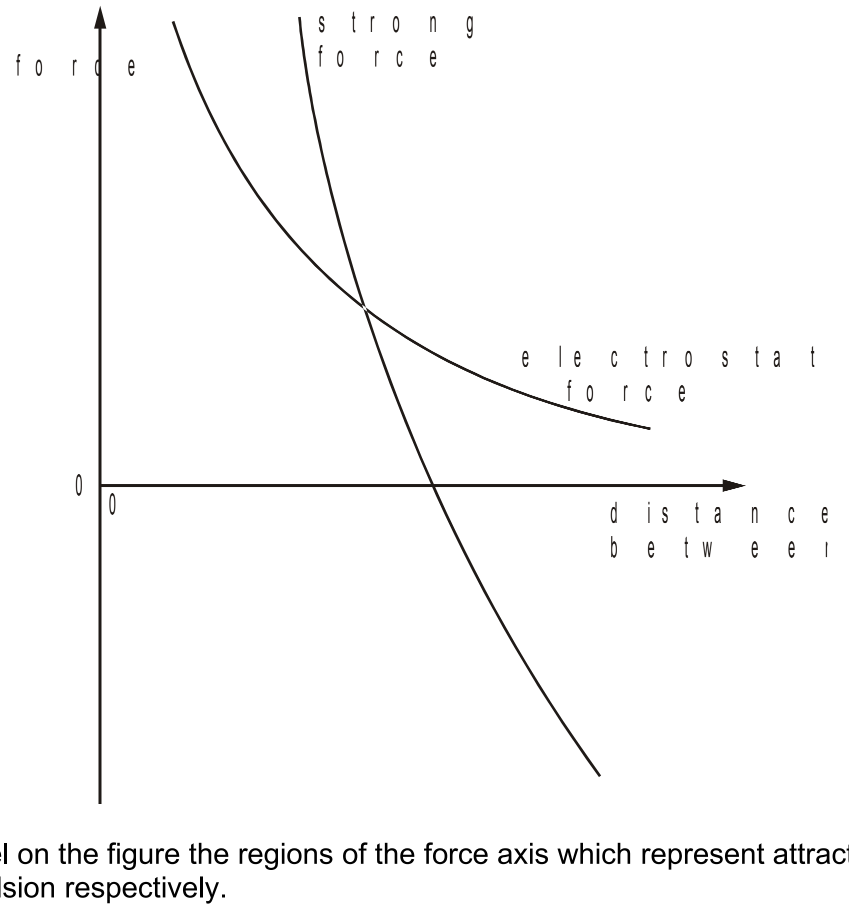
current = ... A

[3]

[Total 5 marks]

107. This question is about the strong and electrostatic forces inside a nucleus.

The figure below shows how the strong force (strong interaction) and the electrostatic force between two **protons** vary with distance between the centres of the protons.



(a) Label on the figure the regions of the force axis which represent attraction and repulsion respectively.

[1]

(b) (i) On the figure above, mark a point which represents the distance between the centres of two adjacent **neutrons** in a nucleus. Label this point **N**.

Explain why you chose point **N**.

....

....

....

....

....

[2]

(ii) On the figure, mark a point **P** which represents the distance between two adjacent **protons** in a nucleus.

Explain why you chose point **P**.

....

....

....

....

[2]

(c) On the figure, sketch a line to show how the **resultant force** between two **protons** varies with the distance between their centres. Pay particular attention to the points at which this line crosses any other line.

[3]

(d) (i) Write an expression for the electrostatic force between two point charges Q which are situated at a distance x apart.

[1]

(ii) The electrostatic force between two protons in contact in a nucleus is 25 N. Calculate the distance between the centres of the two protons.

distance = ... m

[2]

[Total 11 marks]

108. This question is about two isotopes of plutonium.

(a) State briefly (without nuclear equations) how plutonium-239 can be produced.

....

....

....

....

....

[2]

(b) (i) State what particle is emitted when plutonium-239 decays.

....

[1]

(ii) Write a nuclear equation for the decay of plutonium-239 ($^{239}_{94}Pu$).

....

....

[2]

(c) A sample contains 5.00×10^{20} atoms of plutonium-239 and 40.0×10^{20} atoms of plutonium-240.

(i) State the half-life of plutonium-239.

....

[1]

(ii) Show that after 9000 years there will be 3.85×10^{20} atoms of plutonium-239 left in the mixture.

[2]

(d) After 9000 years, there will be 15.4×10^{20} atoms of plutonium-240 left in the mixture.

(i) State the ratio

$$\frac{\text{number of atoms of plutonium - 240}}{\text{number of atoms of plutonium - 239}} \text{ after 9000 years.}$$

ratio = ... to two significant figures only

[1]

(ii) Use this ratio, together with the numbers of atoms in the original mixture, to deduce the **total** time (from the start) before the number of atoms of plutonium-239 and plutonium-240 are **equal**.

time = ... years

[3]

[Total 12 marks]

109. When a helium nucleus (^4_2He) is produced by hydrogen fusion, 28.4 MeV of energy is released.

Calculate how much energy is released when 1.00 kg of ^4_2He nuclei is produced. Give your answer in joule.

energy = ... J

[3]

[Total 3 marks]

110. In the Sun there is a series of reactions called the hydrogen cycle.

(a) In one of these reactions, a hydrogen nucleus (^1_1H) fuses with a deuterium nucleus (^2_1H). Write an equation for this fusion reaction.

....

....

[1]

(b) Fusion of a hydrogen nucleus and a deuterium nucleus is most likely when they approach each other along the same line. The figure below illustrates this.

In one such interaction, the two nuclei both decelerate and come to rest.

(i) Describe the energy changes which occur during this deceleration.

....

....

....

....

[2]

(ii) The electric potential energy E_P of two particles carrying charges Q_1 and Q_2 at a separation r is given by

$$E_P = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$$

where ε_0 is the permittivity of free space.

The hydrogen and deuterium nuclei come to rest at a separation of 3.07×10^{-13} m.
Show that their combined initial kinetic energy is 7.5×10^{-16} J.

[2]

(iii) The deuterium nucleus has an initial speed v.
Show that the initial speed of the hydrogen nucleus is $2v$.

[2]

(iv) Using the answers to (ii) and (iii), calculate the initial kinetic energies of the hydrogen nucleus and the deuterium nucleus.

kinetic energy of hydrogen nucleus = ... J

kinetic energy of deuterium nucleus = ... J

[4]

[Total 11 marks]

111. (a) The table of Fig. 1 shows four particles and three classes of particle.

	hadron	baryon	lepton
neutron			
proton			
electron			
neutrino			

Fig. 1

Indicate using ticks, the class or classes to which each particle belongs.

[2]

(b) The neutron can decay, producing particles which include a proton and an electron.

(i) State the approximate half-life of this process.

....

[1]

(ii) Name the force which is responsible for it.

....

[1]

(iii) Write a **quark** equation for this reaction.

....

....

[2]

(iv) Write number equations which show that charge and baryon number are conserved in this quark reaction.

charge ....

....

baryon number ....

....

[2]

(c) Fig. 2 illustrates the paths of the neutron, proton and electron only in a decay process of the kind described in (b).

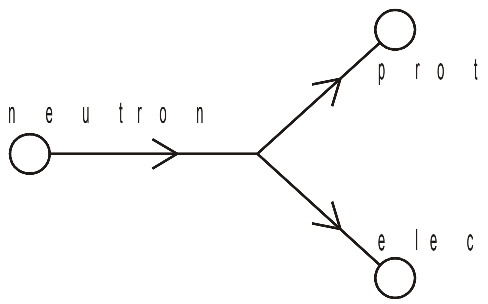


Fig. 2

Fig. 3 represents the momenta of the neutron, p_n, the proton, p_p and the electron, p_e on a vector diagram.

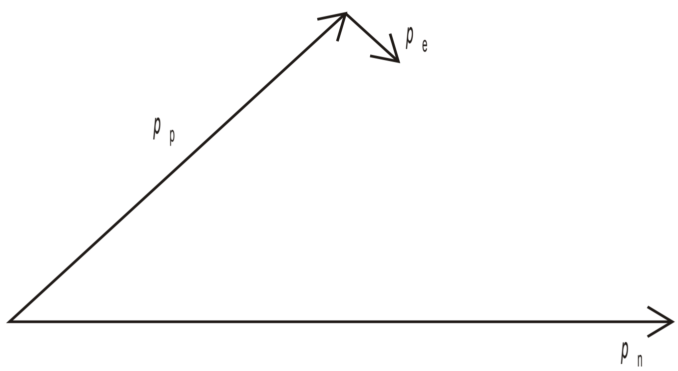


Fig. 3

(i) Draw and label a line on Fig. 3 which represents the resultant p_r of vectors p_p and p_e.

[1]

(ii) According to the law of momentum, the **total** momentum of an isolated system remains constant.
Explain in as much detail as you can, why the momentum p_r is **not** the same as p_n.

....

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....

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[3]

[Total 12 marks]

112. In nuclear fission, energy is released.

(a) Explain what is meant by *nuclear fission*.

....

....

[1]

(b) In a possible fission reaction $^{235}_{92}U$ captures a neutron to become a compound nucleus before splitting into $^{141}_{56}Ba$ and $^{92}_{36}Kr$ releasing three neutrons.

Write down the nuclear reaction equation for this event.

....

[2]

(c) The total mass of the compound nucleus $^{236}_{92}U$ before fission is 236.053 u. The total mass of the fission products is 235.867 u. Use these data to calculate the energy released in the fission process.

energy = …………………..J

[3]

(d) Most of the energy released arises from the electrostatic repulsion of the two nuclei as they move apart. Use the information in (b) to show that the force *F* between the two nuclei at the instant after fission occurs is about 3000N. Assume the nuclei act as point charges a distance *r* apart of 1.3×10^{-14} m.

[4]

[Total 10 marks]

113. (a) Define *magnetic flux density*.

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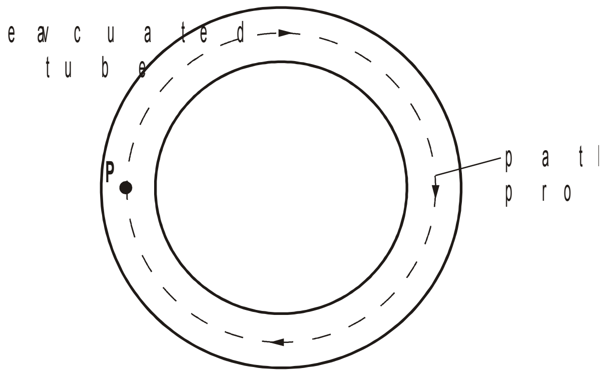
[2]

(b) The figure below shows an evacuated circular tube in which charged particles can be accelerated. A uniform magnetic field of flux density B acts in a direction perpendicular to the plane of the tube.
Protons move with a speed v along a circular path within the tube.



(i) On the figure above draw an arrow at **P** to indicate the direction of the force on the protons for them to move in a circle within the tube.

[1]

(ii) State the direction of the magnetic field. Explain how you arrived at your answer.

....

....

....

[2]

(iii) Write down an algebraic expression for the force F on a proton in terms of the magnetic field at point **P**.

....

[1]

(iv) Calculate the value of the flux density *B* needed to contain protons of speed 1.5×10^7 m s^{-1} within a tube of radius 60 m. Give a suitable unit for your answer.

B = …………………unit………………

[5]

(v) State and explain what action must be taken to contain protons, injected at twice the speed (2*v*), within the tube.

....

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[2]

[Total 13 marks]

114. In this question, two marks are available for the quality of written communication.

State and compare the nature and properties of the three types of ionising radiations emitted by naturally occurring radioactive substances.

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[6]

Quality of Written Communication [2]

[Total 8 marks]

115. In this question, two marks are available for the quality of written communication.

Describe experiments which would enable you to determine the **nature** and **energy** of the emissions from a sample of rock containing several radioactive nuclides. A space has been left for you to draw suitable diagram(s), if you wish to illustrate your answer.

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[6]

Quality of Written Communication [2]

[Total 8 marks]

116. State Kepler's laws of planetary motion.

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[Total 3 marks]

117. Astronomers are searching for planets which orbit distant stars. The planets are not visible from the Earth. Their existence is revealed by the star's motion which causes a shift in the wavelength of the light it emits.
A large planet **P** is shown orbiting a star **S** in the Fig. 1. Both the star and the planet rotate about their common centre of mass **C**.

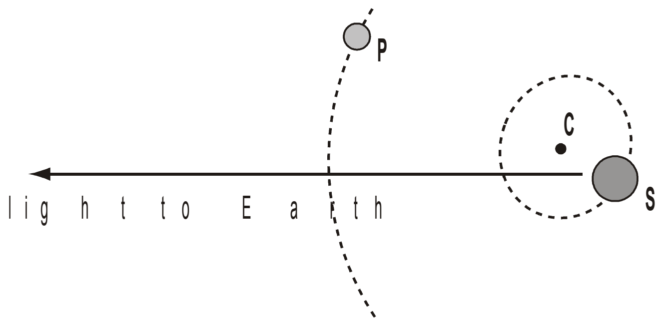

Fig. 1

When measured from a stationary source in the laboratory, a spectral line has a wavelength λ of 656.3 nm.
The light from star **S** is examined over a period of 74 hours. The change in wavelength $\Delta\lambda$ for the same spectral line is recorded. The velocity has been calculated and the data shown in Fig. 2.

time / h	$\Delta\lambda$ /10^{-15} m	velocity / m s^{-1}
1	6.7	3.1
6	38.1	17.5
12	66.0	30.3
19	76.0	34.9
23	69.1	31.7
29	43.8	20.1
35	6.8	3.1
41	–32.2	–14.8
48	–66.0	–30.3
55	–76.0	–34.9
61	–62.5	–28.7
67	–32.2	–14.8
74		6.1

Fig. 2

(i) Use the Doppler equation relating $\Delta\lambda$ with velocity v to calculate the change in wavelength for the final velocity of 6.1 m s^{-1}.

change in wavelength = ………….........m

[3]

(ii) Plot a graph of the star's velocity against time using the grid in Fig. 3. The first seven points are already completed. The data required from Fig. 2 are repeated beneath the grid.

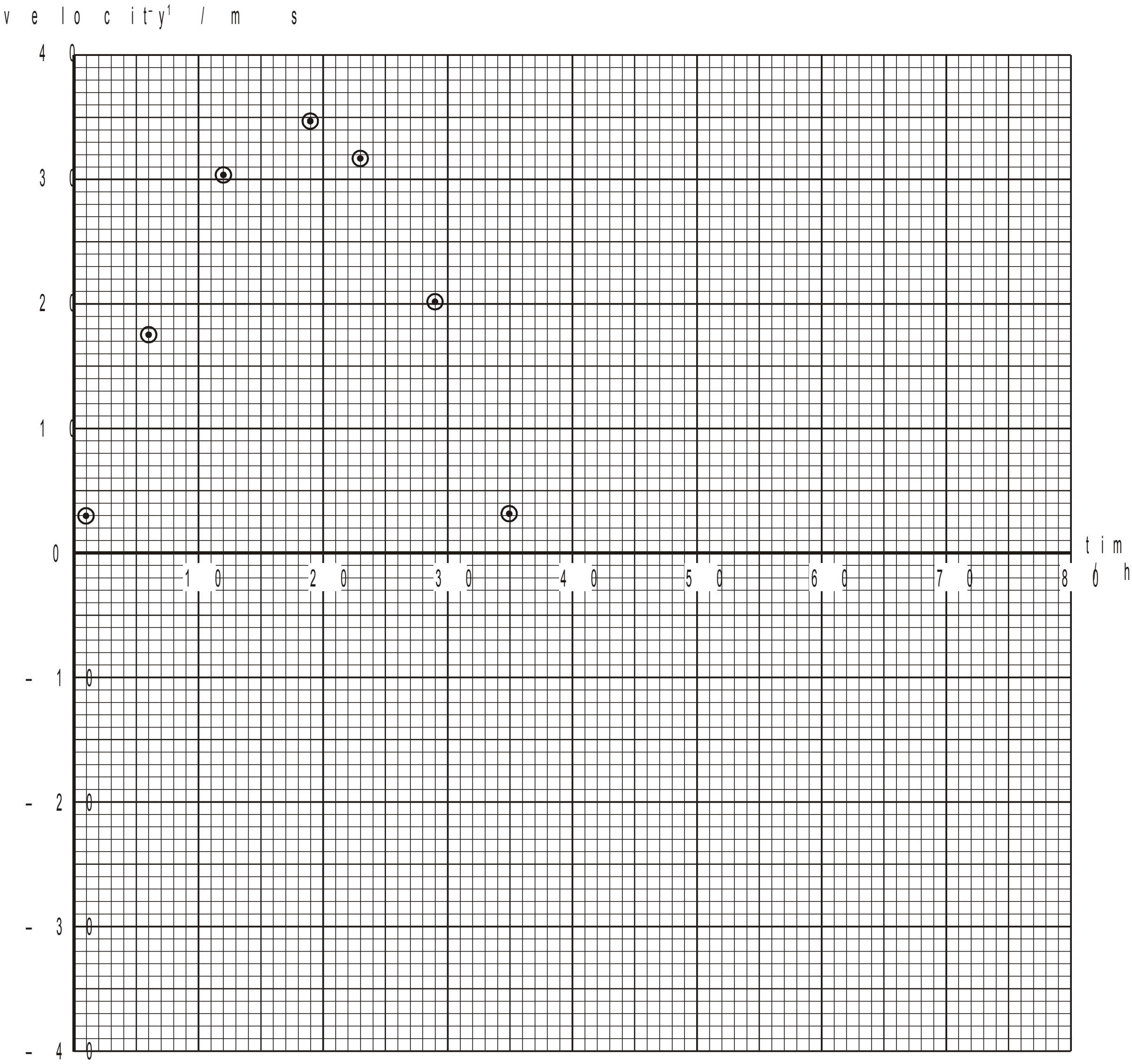

Fig. 3

[2]

time / h	velocity / m s^{-1}
41	–14.8
48	–30.3
55	–34.9
61	–28.7
67	–14.8
74	6.1

(iii) Draw a curve through all the points on the graph.

[1]

(iv) On Fig. 1, mark a point on the star's orbit that would correspond to a velocity of zero on the graph. Label this point **X**.

[1]

(v) Use your graph to estimate the time *T* for the planet to make one complete revolution around the star.

time ....h

[1]

(vi) The mass *M* of the star is estimated to be 4×10^{30} kg. Calculate the radius of the planet's orbit using the relationship below.

$$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$$

radius = ...m

[2]

[Total 10 marks]

118. Large distances in the Universe may be measured in parsecs. Explain what is meant by a *parsec*.

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[Total 2 marks]

119. Explain how a main sequence star can develop into a supernova. Discuss what may remain after the explosion.

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[Total 6 marks]

120. It is estimated that the Sun radiates energy at the rate of 3.8×10^{26} W and that a supernova explosion may produce 10^{44} J of energy.

(i) Calculate the rate at which mass is converted into energy within the Sun.

mass rate = ... kg s^{-1}

[2]

(ii) Calculate the time, in years, that it would take the Sun to produce the same amount of energy as that released in a supernova explosion. Assume 1 year to be 3.2×10^{7} s.

time = ... y

[2]

[Total 4 marks]

121. What is the *Cosmological Principle*?

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[Total 2 marks]

122. Describe the important properties of the cosmic microwave background radiation and how the standard model of the Universe explains these properties. Explain their significance as evidence for the past evolution of the Universe.

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[Total 5 marks]

123. Why is our understanding of the very earliest moments of the Universe unreliable?

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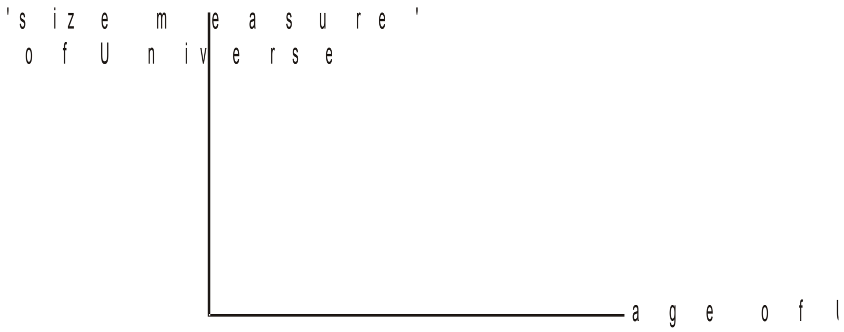
[Total 2 marks]

124. The future of the Universe may be *open*, *closed* or *flat*. Explain the meaning of the terms in italics, using a graph to illustrate your answer.



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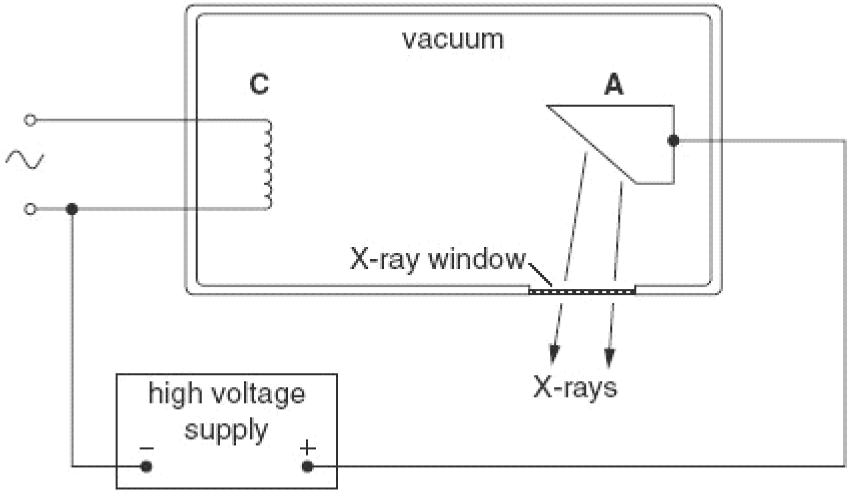
[Total 4 marks]

125. The mean density of the Universe, ρ_0, is thought to be approximately 1×10^{-26} kg m^{-3}. Calculate a value for the Hubble constant H_0.

H_0 = ...s^{-1}

[Total 2 marks]

126. The figure below shows a simplified X-ray tube.



Explain briefly, with reference to the parts labelled **C** and **A**,

- how X-rays are generated
- the energy conversions that occur.

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[Total 7 marks]

127. In order to take an X-ray photograph, the X-ray beam is passed through an aluminium filter to remove low energy X-ray photons before reaching the patient.

(a) Suggest why it is necessary to remove these low-energy X-rays.

....

....

[1]

(b) The average linear attenuation coefficient for X-rays that penetrate the aluminium is 250 m^{-1}. The intensity of an X-ray beam after travelling through 2.5 cm of aluminium is 347 W m^{-2}.

Show that the intensity incident on the aluminium is about 2×10^5 W m^{-2}.

[3]

(c) The X-ray beam at the filter has a circular cross-section of diameter 0.20 cm.
Calculate the power of the X-ray beam emerging from the aluminium filter.
Assume that the beam penetrates the aluminium filter as a parallel beam.

power = ... W

[2]

(d) The total power of X-rays generated by an X-ray tube is 18W.
The efficiency of conversion of kinetic energy of the electrons into X-ray photon energy is 0.15%.

(i) Calculate the power of the electron beam.

power = ... W

[2]

(ii) Calculate the velocity of the electrons if the rate of arrival of electrons is $7.5 \times 10^{17}\ s^{-1}$. Relativistic effects may be ignored.

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

[2]

(iii) Calculate the p.d. across the X-ray tube required to give the electrons the velocity calculated in **(ii)**.

p.d.= V

[3]

[Total 13 marks]

128. The ratio of reflected intensity to incident intensity for ultrasound reflected at a boundary is related to the acoustic impedance Z_1 of the medium on one side of the boundary and the acoustic impedance Z_2 of the medium on the other side of the boundary by the following equation.

$$\frac{\text{reflected intensity}}{\text{incident intensity}} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

(a) State the **two** factors that determine the value of the acoustic impedance.

....

....

[2]

(b) An ultrasound investigation was used to identify a small volume of substance in a patient. It is suspected that this substance is either blood or muscle.

During the ultrasound investigation, an ultrasound pulse of frequency 3.5×10^6 Hz passed through soft tissue and then into the small volume of unidentified substance. A pulse of ultrasound reflected from the front surface of the volume was detected 26.5 μs later. The ratio of the reflected intensity to incident intensity for the ultrasound pulse reflected at this boundary was found to be 4.42×10^{-4}. The table below shows data for the acoustic impedances of various materials found in a human body.

medium	acoustic impedance Z /kg m^{-2} s^{-1}
air	4.29×10^2
blood	1.59×10^6
water	1.50×10^6
brain tissue	1.58×10^6
soft tissue	1.63×10^6
bone	7.78×10^6
muscle	1.70×10^6

(i) Use appropriate data from the table to identify the unknown medium. You must show your reasoning.

medium = ...

[4]

(ii) Calculate the depth at which the ultrasound pulse was reflected if the speed of ultrasound in soft tissue is 1.54 km s^{-1}.

depth = ... cm

[2]

(iii) Calculate the wavelength of the ultrasound in the soft tissue.

wavelength = ... m

[2]

[Total 10 marks]

129. A transformer is assumed to be 100% efficient in its operation. The primary coil is connected to a 230 V a.c. source. The secondary coil is connected to a 50 Ω resistor. The potential difference across the resistor is 12 V a.c.

Calculate

(i) the current through the 50 Ω resistor

current = ... A

[2]

(ii) the current in the primary circuit.

current = ... A

[2]

[Total 4 marks]

130. (a) (i) State what is meant by *nuclear binding energy.*

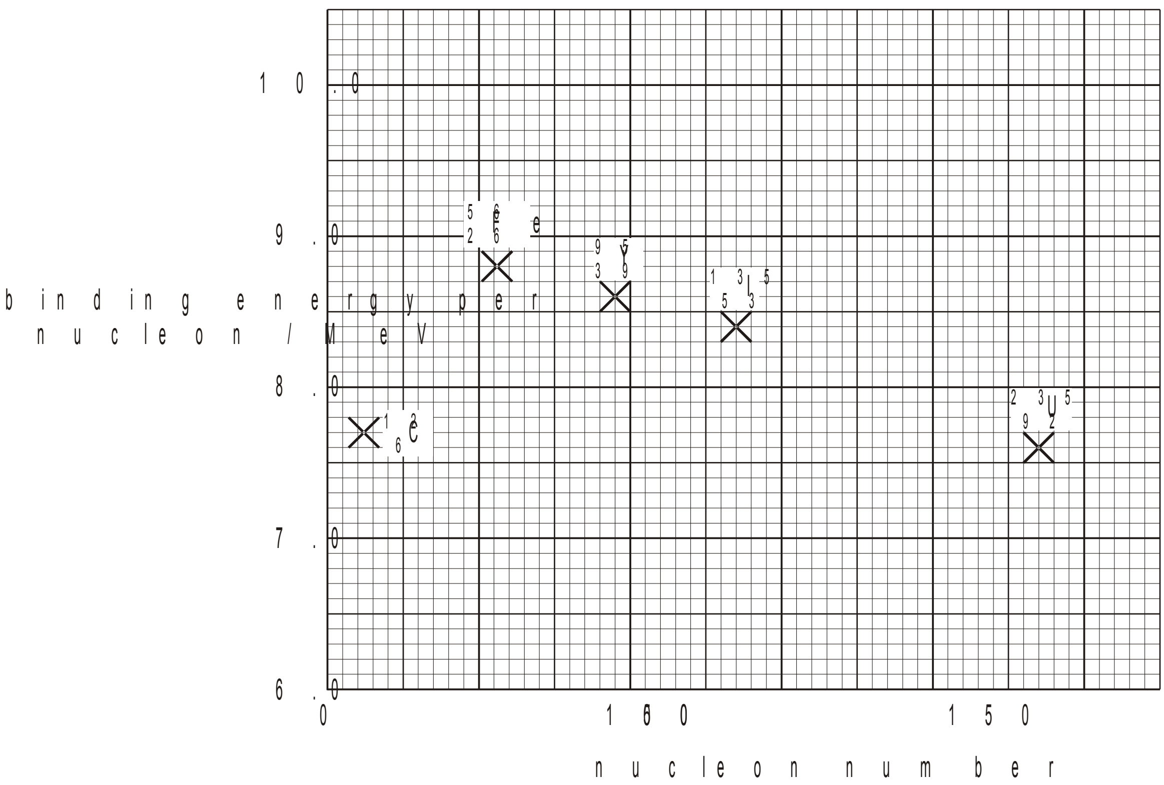
....

....

....

[1]

(ii) The diagram below shows the binding energy per nucleon for five nuclides, plotted against nucleon number.



$^{56}_{26}Fe$ has the highest binding energy per nucleon. $^{12}_{6}C$ and $^{235}_{92}U$ have less binding energy per nucleon.
Explain how these values relate to the possibility of fission or fusion of the nuclides $^{56}_{26}Fe$, $^{12}_{6}C$ and $^{235}_{92}U$.

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....

[4]

(b) (i) A $^{235}_{92}U$ nucleus inside a nuclear reactor can absorb a thermal neutron.
State what is meant by a *thermal neutron*.

....

....

....

[1]

(ii) Write a nuclear equation for this reaction.

[1]

(iii) The resulting nucleus undergoes fission. Iodine-135 ($^{135}_{53}\mathrm{I}$) and yttrium-95 ($^{95}_{39}\mathrm{Y}$) are produced.
Write a nuclear equation for this reaction.

[1]

(iv) Use data from the diagram above to deduce how much energy in MeV is released when one nucleus of $^{235}_{92}\mathrm{U}$ undergoes these reactions.

energy = ... MeV

[4]

[Total 12 marks]

131. In the JET fusion experiment, a plasma consisting of a mixture of deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) is confined within a magnetic field of high flux density.
The plasma is heated using two methods.

method 1 A very large current is passed through the plasma.
Fig. 1 shows the variation with time of this current.
The average electromotive force driving this current is 1.2 V.

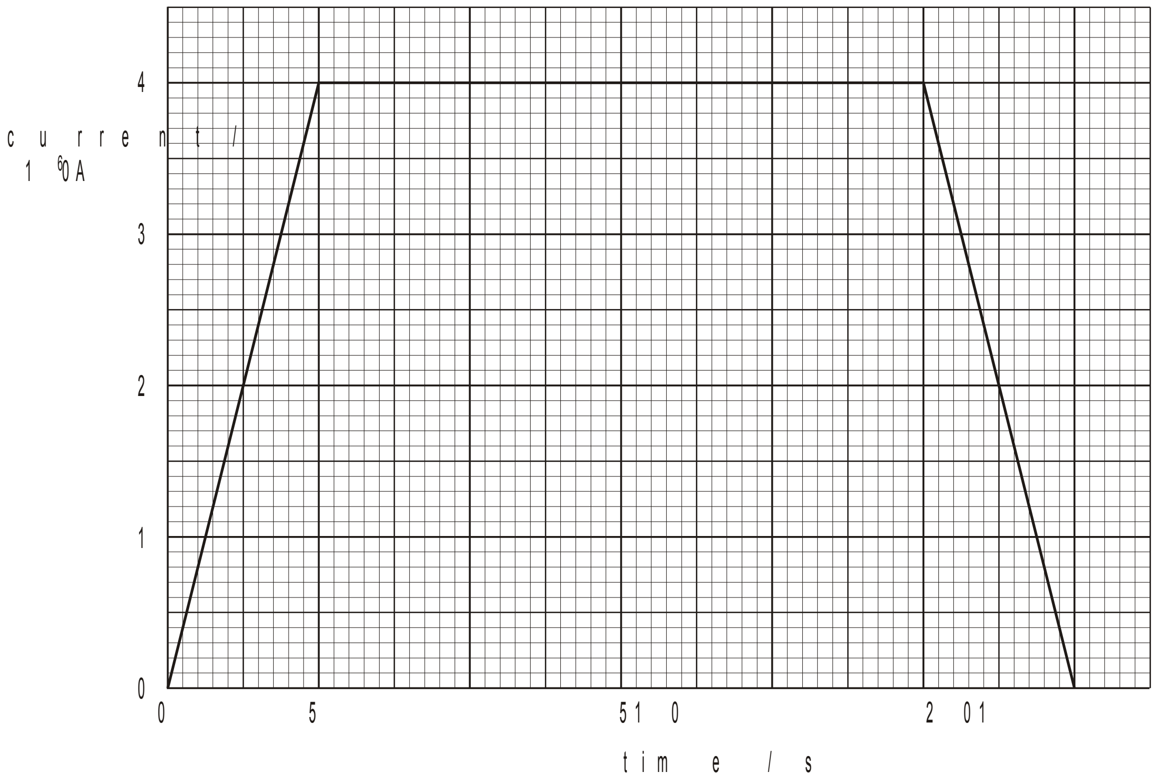


Fig. 1

method 2 Fast-moving deuterium atoms are injected into the plasma. The nuclei of the injected deuterium atoms collide with nuclei in the plasma and so transfer energy to it.

When the plasma temperature is high enough, deuterium and tritium nuclei fuse, producing a helium nucleus and a neutron. This reaction may be represented as follows.

$$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + \text{energy}$$

The energy released is shared between the helium nucleus and the neutron, which move off in opposite directions.

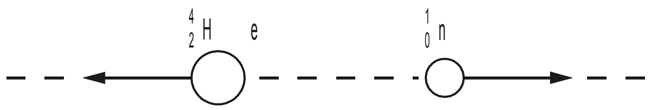


Fig. 2

(a) For **method 1**, calculate the **total** energy input provided by the current source.

energy = ... J

[4]

(b) Explain why in **method 2** a beam of neutral deuterium **atoms** is injected, rather than a beam of deuterium **nuclei**.

....

....

....

....

....

[2]

(c) Show that the helium nucleus gains 20% of the total energy released in the fusion reaction, and the neutron gains 80% of the energy released.
You may assume that the initial momentum of the helium-neutron system is zero.

[4]

[Total 10 marks]

132. This question is about the properties of **baryons**.

Choose **two** examples of **baryons**

For each example discuss

- their composition
- their stability.

(Allow one lined page).

[Total 6 marks]

133. This question is about the properties of **leptons**.

Choose **two** examples of **leptons**

For each example discuss

- their composition
- the forces which affect them
- where they may be found.

(Allow one lined lage).

[Total 6 marks]

134. (a) The mathematical term **proportion** is used a great deal in physics to describe in certain situations how one quantity varies with another. Answer the questions in the table and explain under what circumstances the relationships correctly do show direct proportion.
The first one is done for you to show you the way answers should be presented.

terms used	in equation	question	answer
s distance moved *u* initial velocity *t* time taken *a* acceleration	$s = ut + \frac{1}{2}at^2$	Is $s \propto t$?	No, but when the acceleration is zero then s is directly proportional to t since u is constant.
v final velocity *u* initial velocity *a* acceleration *t* time taken	$v = u + at$	Is $v \propto t$?	[2]
p pressure *V* volume *n* amount of gas *R* gas constant *T* temperature	$pV = nRT$	Is $p \propto T$?	[2]
P power *F* force *v* velocity	$P = Fv$	Is $P \propto F$?	[2]
A area of circle *r* radius of circle	$A = \pi r^2$	Is $A \propto r^2$?	[1]

(b) What features of a graph plotting one variable against another would determine whether the two variables were directly proportional?

....

....

[2]

[Total 9 marks]

135. A radioactive material is known to contain a mixture of two nuclides **X** and **Y** of different half-lives. Readings of activity, taken as the material decays, are given in the table, together with the activity of nuclide **X** over the first 12 hours.

time / hour	activity of material / Bq	activity of nuclide **X** /Bq	activity of nuclide **Y** /Bq
0	4600	4200	400
6	3713	3334	
12	3002	2646	
18	2436		
24	1984		
30	1619	1323	296
36	1333		

(a) State the meaning of the terms

(i) *radioactive*

....

....

[1]

(ii) *nuclide*

....

....

[1]

(iii) *half-life*.

....

....

[1]

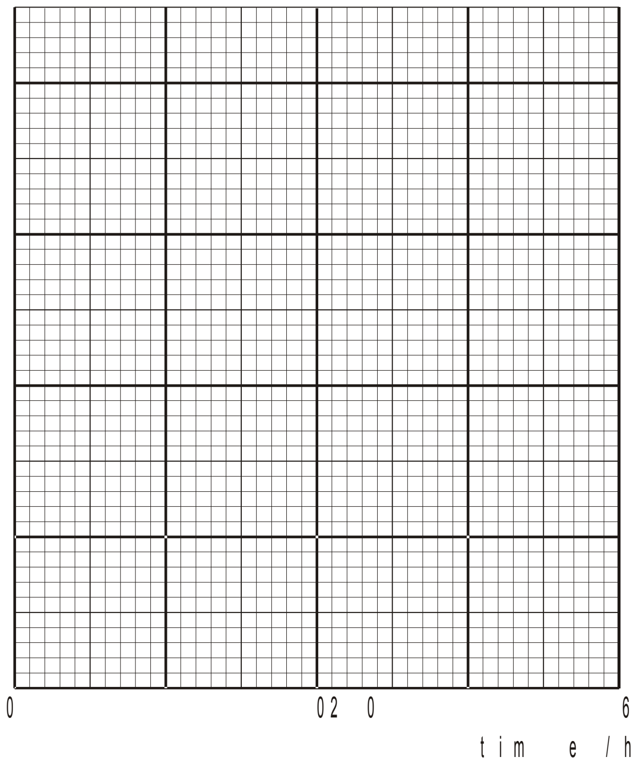
(b) (i) The half-life of nuclide **X** is 18 hours. Complete the *activity of nuclide* **X** column.

[3]

(ii) Using your answer to (i) complete the *activity of nuclide* **Y** column.

[2]

(c) Calculate, or use a graph to determine, the half-life of nuclide **Y**.



half-life of **Y** = ... hours

[3]

(d) Indicate briefly how it would be possible **experimentally** to obtain the initial activity (4200 Bq in this case) of nuclide **X** by itself.

....

....

....

[2]

(e) Explain why it is **not** possible to give a half-life for a **mixture** of two nuclides.

....

....

....

....

....

....

....

[3]

[Total 16 marks]