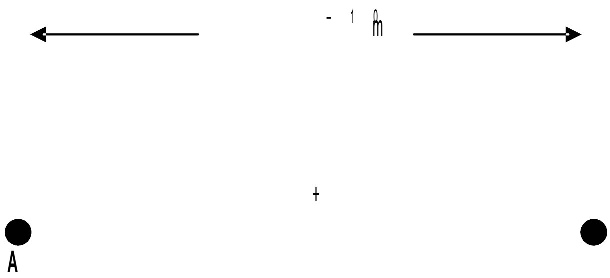
1. Define *electric field strength* at a point in space.

....

....

[Total 1 marks]

2. Ionic solids consist of a regular arrangement of positive and negative ions. The figure below shows two neighbouring ions in a particular ionic solid. The ions **A** and **B** may be considered as two point charges of equal magnitude, 1.6×10^{-19} C, and opposite sign, with a separation of 2.0×10^{-10} m. The ion **A** is positive.



(i) On the figure above, draw electric field lines to represent the field in the region around the two charges.

[3]

(ii) Calculate the magnitude of the electric field strength at the mid point between the charges.

electric field strength =..................................

[3]

(iii) State and explain a factor that might affect the tensile strength of an ionic material.

....

[1]

[Total 7 marks]

3. Fig.1 shows two capacitors, **A** of capacitance 2μF, and **B** of capacitance 4μF, connected in parallel. Fig. 2 shows them connected in series. A two-way switch **S** can connect the capacitors either to a d.c. supply, of e.m.f. 6 V, or to a voltmeter.

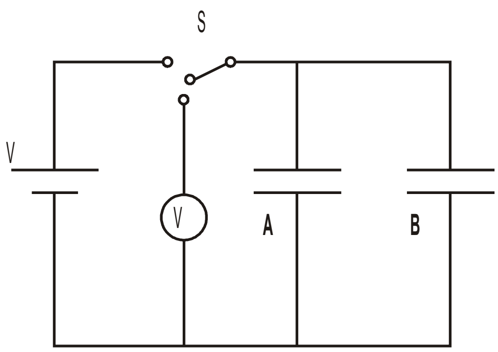


Fig. 1

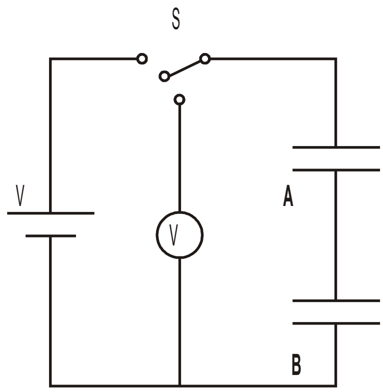


Fig. 2

(a) Calculate the total capacitance of the capacitors

(i) when connected as in Fig. 1

capacitance = ... μF

[1]

(ii) when connected as in Fig. 2

capacitance = ... μF

[2]

(b) The switch in the circuit shown in Fig. 1 is then connected to the battery. Calculate

(i) the potential difference across capacitor **A**

potential difference = ... V

[1]

(ii) the total charge stored on the capacitors.

charge = ...μC

[2]

(c) The switch in the circuit shown in Fig.2 is then connected to the battery. Calculate the total energy stored in the two capacitors.

energy = ... J

[2]

(d) The switch S in the circuit of Fig. 1 is moved to connect the charged capacitors to the voltmeter. The voltmeter has an internal resistance of 12 MΩ.

(i) Explain why the capacitors will discharge, although very slowly.

....

....

....

[1]

(ii) Calculate the time *t* taken for the voltmeter reading to fall to a quarter of its initial reading.

t = ... s

[3]

[Total 12 marks]

4. Describe briefly one scattering experiment to investigate the size of the nucleus of the atom.
Include a description of the properties of the incident radiation which makes it suitable for this experiment.

✎ In your answer, you should make clear how evidence for the size of the nucleus follows from your description.

....

....

....

....

....

....

....

....

[Total 8 marks]

5. (a) Complete the table below for the **three** types of ionising radiation.

radiation	nature	range in air	penetration ability
α			0.2 mm of paper
β	electron		
γ		several km	

[3]

(b) Describe briefly, with the aid of a sketch, an absorption experiment to distinguish between the three radiations listed above.

....

....

....

....

[3]

[Total 6 marks]

6. Fig. 1 shows a square flat coil of insulated wire placed in a region of a uniform magnetic field of flux density *B*. The direction of the field is vertically out of the paper. The coil of side x has N turns.

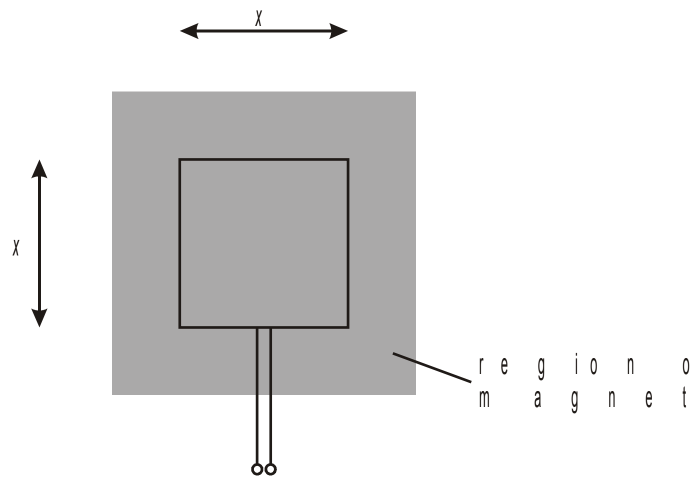


Fig. 1

(a) (i) Define the term *magnetic flux*.

....

....

....

[1]

(ii) Show that the magnetic flux linkage of the coil in Fig. 1 is NBx^2.

[2]

(b) The coil of side x = 0.020 m is placed at position **Y** in Fig. 2 The ends of the 1250 turn coil are connected to a voltmeter. The coil moves sideways steadily through the region of magnetic field of flux density 0.032 T at a speed of 0.10 m s^{-1} until it reaches position **Z**. The motion takes 1.0 s.

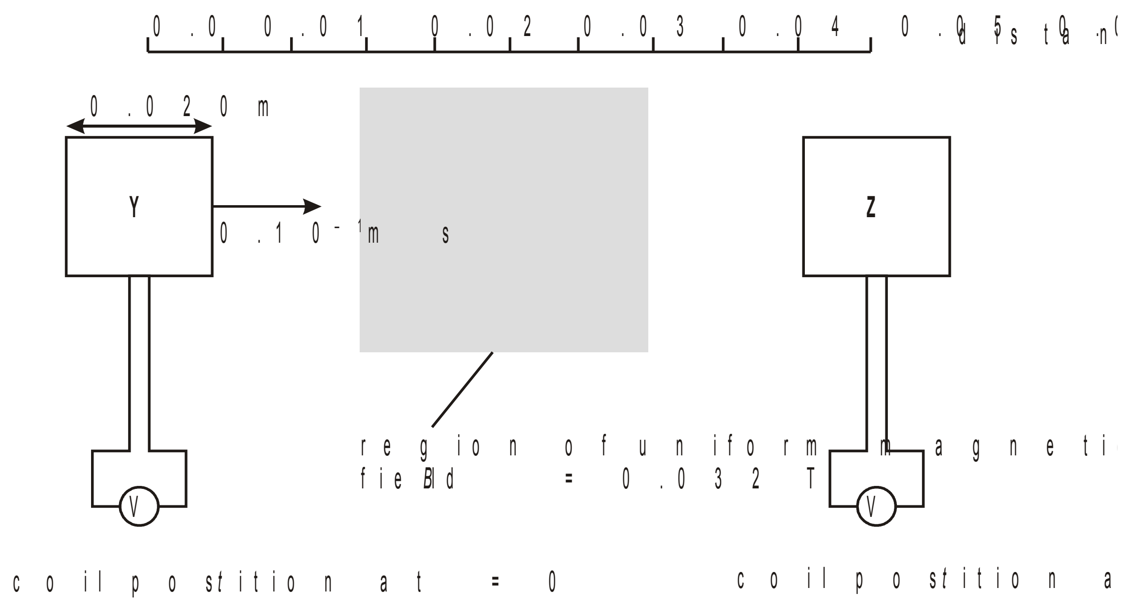


Fig. 2

(i) Show that the voltmeter reading as the coil enters the field region, after t = 0.20s, is 80 mV. Explain your reasoning fully.

[3]

(ii) On Fig. 3, draw a graph of the voltmeter reading against time for the motion of the coil from **Y** to **Z**. Label the y-axis with a suitable scale.

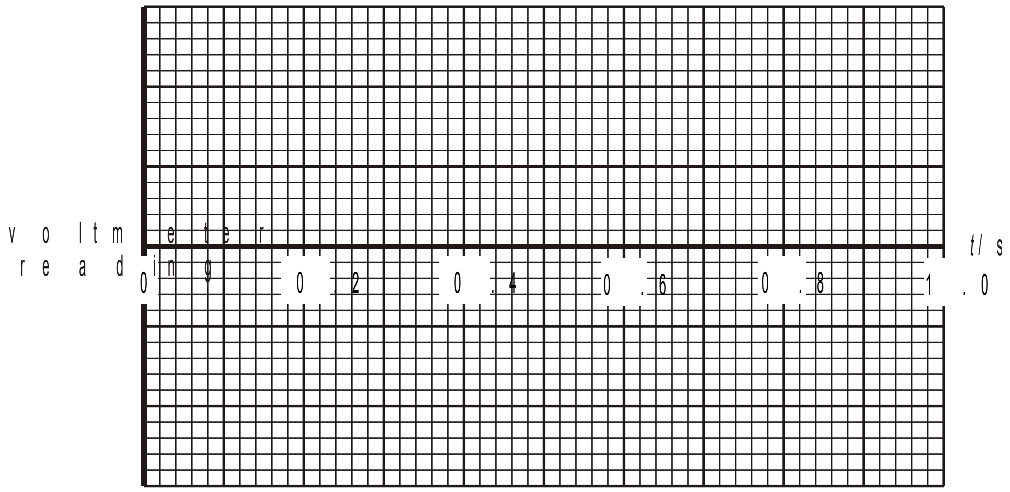


Fig. 3

[4]

[Total 10 marks]

7. State the Cosmological Principle.

....

....

....

[Total 2 marks]

8. 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.

In your answer, you should make clear how your explanation links with the evidence.

....

....

....

....

....

....

....

[Total 5 marks]

9. Explain why our understanding of the very earliest moments of the Universe is unreliable.

....

....

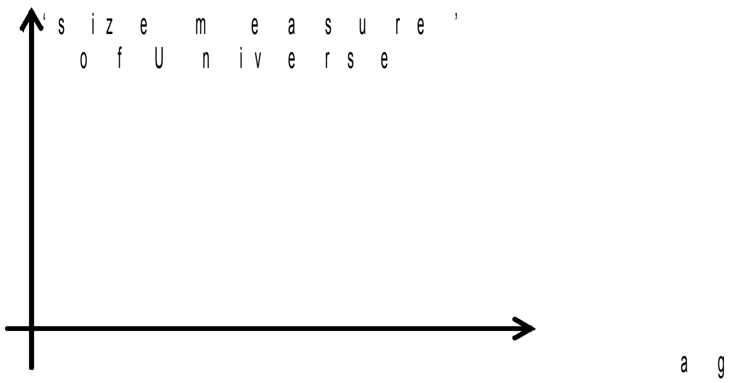
....

....

....

[Total 2 marks]

10. 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.



....

....

....

....

....

[Total 4 marks]

11. 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]

12. The quality of ultrasound images in increasing at a phenomenal pace, thanks to advances in computerised imaging techniques. The computer technology is sophisticated enough to monitor and display tiny ultrasound signals from a patient.

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 **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 of 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 the 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 above 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]

13. An average person in the UK will have at least 30 X-ray photographs taken in their lifetime.

In order to take an X-ray photograph, the X-ray beam is passed through an aluminium filter to safely 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 from the aluminium filter. Assume that the beam penetrates the aluminium filter as a parallel beam.

power = ... W

[2]

[Total 6 marks]

14. In an X-ray tube, the efficiency of conversion of the kinetic energy of the electrons into X-rays is 0.15%.

(i) Calculate the power required in the electron beam in order to produce X-rays of power 18 W.

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 7 marks]

power = ... W

[2]

[Total 6 marks]

15. Discuss briefly the advantages and disadvantages of scanning using MRI techniques.

....

....

....

....

....

....

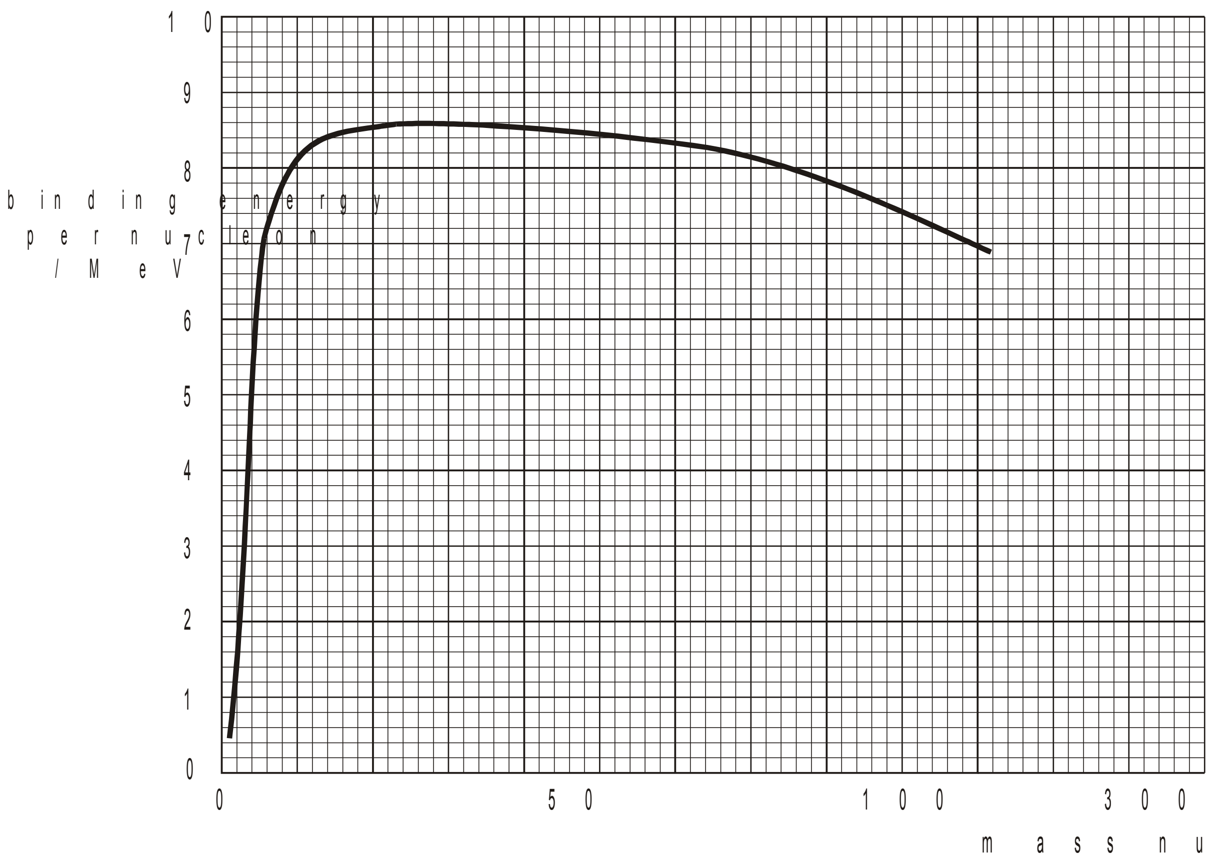
....

....

....

[Total 6 marks]

16. The figure below shows the variation with nucleon number (mass number) of the binding energy per nucleon for various nuclides.



(a) (i) State the number of nucleons in the nucleus of $^{94}_{37}Rb$ . ...

(ii) State the number of protons in the nucleus of $^{142}_{55}Cs$ . ...

(iii) State the number of neutrons in the nucleus of $^{235}_{92}U$ . ...

[2]

(b) Use the figure above to calculate the energy released when a $^{235}_{92}U$ nucleus undergoes fission, producing nuclei of $^{94}_{37}Rb$ and $^{142}_{55}Cs$.

energy = ... MeV

[4]

[Total 6 marks]

17. Discuss **two** advantages and **two** disadvantages of producing electrical power by nuclear fission.

....

....

....

....

....

....

....

....

....

....

[Total 6 marks]

18. This question is about an alpha particle making a head on collision with a gold nucleus.

(a) (i) When the alpha particle is at a large distance from the gold nucleus it has a kinetic energy of 7.6×10^{-13} J. Show that its speed is about 1.5×10^{7} m s^{-1}.

mass of alpha particle = 6.6×10^{-27} kg

[2]

(ii) As the alpha particle approaches the gold nucleus, it slows down and the gold nucleus starts to move, Fig. 1.

Fig.1

Explain this and explain how it is possible to calculate the speed of the gold nucleus.

....

....

....

....

....

[3]

(iii) Fig.2 shows the alpha particle and the gold nucleus at the distance of closest approach. At this instant the gold nucleus is moving with speed V and the alpha particle is stationary.

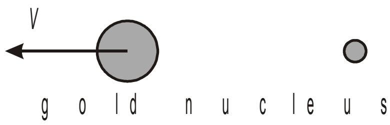


Fig. 2

Calculate the speed V of the gold nucleus.

mass of gold nucleus = 3.0×10^{-25} kg

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

[2]

(iv) The alpha particle bounces back. Its final speed approximately equals its initial speed of approach. Assume that the mean force on the nucleus is 9.0 N during the interaction.
Estimate the time of the collision.

time = ……………… s

[2]

(b)

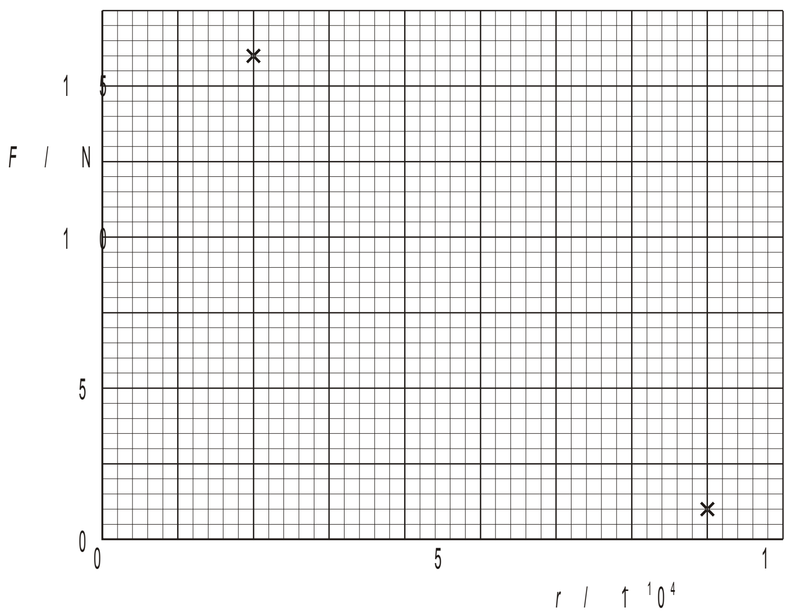


Fig. 3

(i) Fig. 3 shows two points on the graph of the electrostatic repulsive force *F* between the alpha particle and nucleus against their separation *r*. The particle and the nucleus are being treated as point charges. Use data from the graph to calculate the values of the force at distances $r = 10 \times 10^{-14}$ m and 15×10^{-14} m.

F at 10×10^{-14} m =……………N

F at 15×10^{-14} m =……………N

[3]

(ii) Plot the two points on the graph and draw the curve.

[1]

[Total 13 marks]

19. The electric motor in a washing machine rotates the drum containing the clothes by means of a rubber belt stretched around two pulleys, one on the motor shaft and the other on the drum shaft, as shown in Fig. 1.

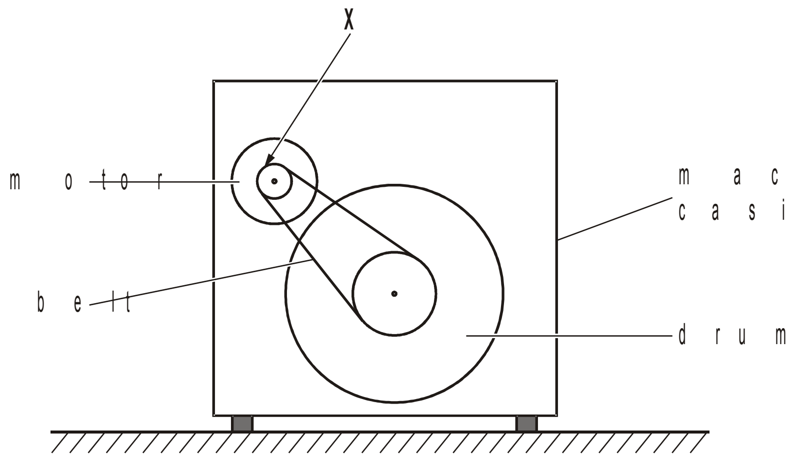


Fig. 1

(a) The motor pulley of radius 15 mm rotates at 50 revolutions per second. Calculate

(i) the speed of the belt

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

[2]

(ii) the centripetal acceleration of the belt at point **X**.

acceleration = ... m s^{-2}

[2]

(iii) When the motor speed is increased, the belt can start to slip on the motor pulley. Explain why the belt slips.

....

....

....

....

....

....

[2]

(b) When the drum is rotated at one particular speed, a metal side panel of the machine casing vibrates loudly. Explain why this happens.

....

....

....

....

[2]

(c) A fault develops in the motor, causing the coil to stop rotating. Magnetic flux from the electromagnet of the motor still links with the now stationary coil. Fig. 2 shows how the flux linkage of the coil varies with time.

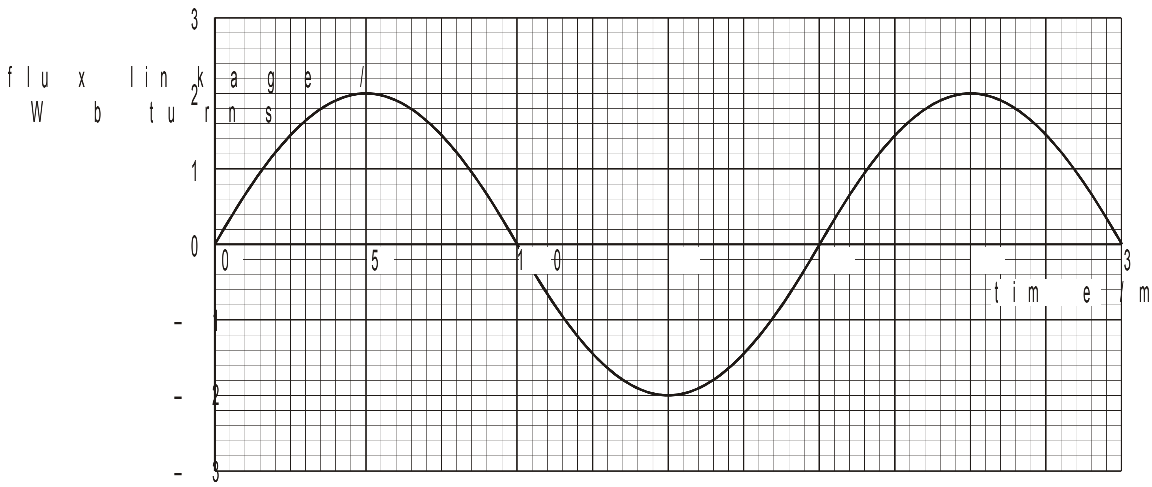


Fig. 2

(i) Using Fig. 2 state a time at which the e.m.f. induced across the ends of the coil is

1 zero .... ms

2 a maximum. .... ms

[2]

(ii) Use the graph of Fig. 2 to calculate the peak value of the e.m.f. across the ends of the coil.

peak e.m.f. = ... V

[2]

[Total 12 marks]

20. Fig. 1 shows a football balanced above a metal bench on a length of plastic drain pipe. The surface of the ball is coated with a smooth layer of an electrically conducting paint. The pipe insulates the ball from the bench.

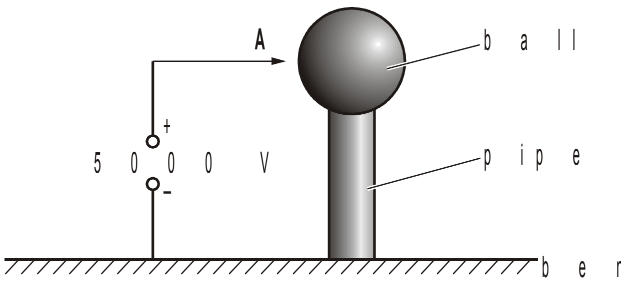


Fig. 1

(a) The ball is charged by touching it momentarily with a wire **A** connected to the positive terminal of a 5000 V power supply. The capacitance C of the ball is 1.2×10^{-11} F. Calculate the charge Q_o on the ball. Give a suitable unit for your answer.

Q_o = ... unit ....

[3]

(b) The charge on the ball leaks slowly to the bench through the plastic pipe, which has a resistance R of $1.2 \times 10^{15}\ \Omega$.

(i) Show that the time constant for the ball to discharge through the pipe is about 1.5×10^{4} s.

[1]

(ii) Show that the initial value of the leakage current is about 4×10^{-12} A.

[1]

(iii) Suppose that the ball continues to discharge at the constant rate calculated in (ii). Show that the charge Q_o would leak away in a time equal to the time constant.

[2]

(iv) Using the equation for the charge Q at time t

$$Q = Q_o e^{-t/RC}$$

show that, in practice, the ball only loses about 2/3 of its charge in a time equal to one time constant.

[2]

(c) The ball is recharged to 5000 V by touching it momentarily with wire **A**. The ball is now connected in parallel via wire **B** to an uncharged capacitor of capacitance 1.2×10^{-8} F and a voltmeter as shown in Fig. 2.

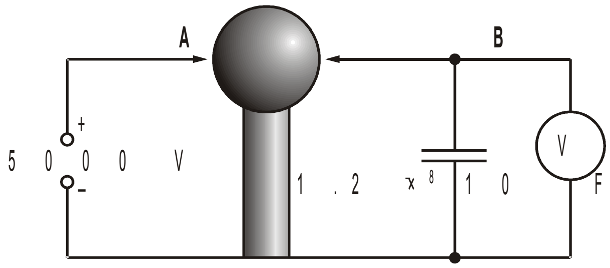


Fig. 2

(i) The ball and the uncharged capacitor act as two capacitors in parallel. The total charge Q_o is shared instantly between the two capacitors. Explain why the charge left on the ball is Q_o/1000.

....

....

....

....

....

....

[3]

(ii) Hence or otherwise calculate the initial reading V on the voltmeter.

V = ... V

[2]

[Total 14 marks]

21. This question is about the electron beam inside a television tube.

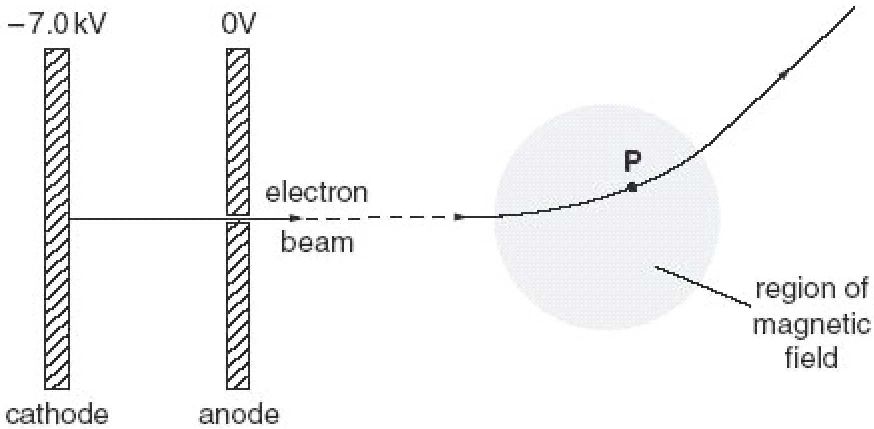


Fig. 1 **Fig. 2**

(a) Fig. 1 shows a section through a simplified model of an electron gun in an evacuated TV tube.

(i) On Fig. 1 draw electric field lines to represent the field between the cathode and the anode.

[2]

(ii) The electrons, emitted at negligible speed from the cathode, are accelerated through a p.d. of 7.0 kV. Show that the speed of the electrons at the anode is about 5.0×10^{7} m s^{-1}.

[2]

(b) Some electrons pass through a small hole in the anode. They enter a region of uniform magnetic field shown by the shaded area in Fig. 2. They follow a circular arc in this region before continuing to the TV screen.

(i) Draw an arrow through the point labelled **P** to show the direction of the force on the electrons at this point.

[1]

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

....

....

....

[2]

(iii) Calculate the radius of the arc of the path of the electron beam when the value of the magnetic flux density is 3.0×10^{-3} T.

radius = ... m

[4]

(c) The region of uniform magnetic field is created by the electric current in an arrangement of coils. Suggest how the end of the electron beam is swept up and down the TV screen.

....

[2]

[Total 13 marks]

22. This question is about the decay of an isotope of bismuth, $^{212}_{83}Bi$.

(a)

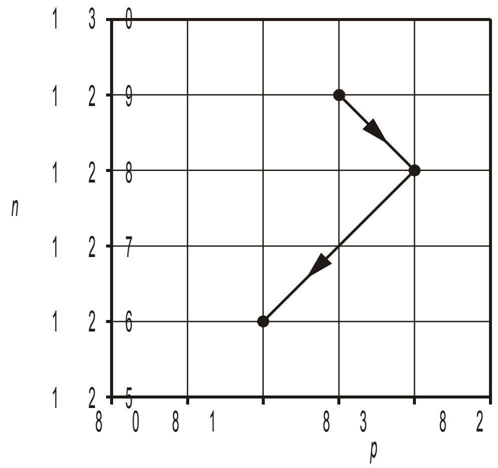


Fig. 1

Fig. 1 shows a small region of the chart of neutron number *n* against proton number *p*. An isotope of bismuth, Bi, decays to an isotope of lead, Pb, in two stages along the path shown by the two arrows on Fig. 1.
Complete the nuclear equations which describe these two decays.

(i) $^{212}_{83}Bi \rightarrow \,^{......}_{84}Po$ + ...

[2]

(ii) $^{.....}_{84}Po \rightarrow \,^{......}_{82}Pb$ + ...

[2]

(b) Imagine that you are given a sample of $^{212}_{83}Bi$ mounted on a stand. You are asked to verify experimentally that the two decays in (a)(i) and (ii) occur. Outline briefly the experiment that you would perform.

....

....

....

....

....

....

....

....

[4]

(c) The decay constant for $^{212}_{83}Bi$ is 0.0115 min^{-1}.

(i) Show that the initial activity of a sample containing 1.00×10^{-9} g of the isotope is about 3×10^{10} min^{-1}.

[3]

(ii) Calculate the half-life of the isotope.

half-life = …………min

[1]

(iii) Assume that only one decay in a million is detected in an experiment to measure the half-life. Draw a graph on the axes of Fig. 2 of the count rate against time that you would expect to observe.

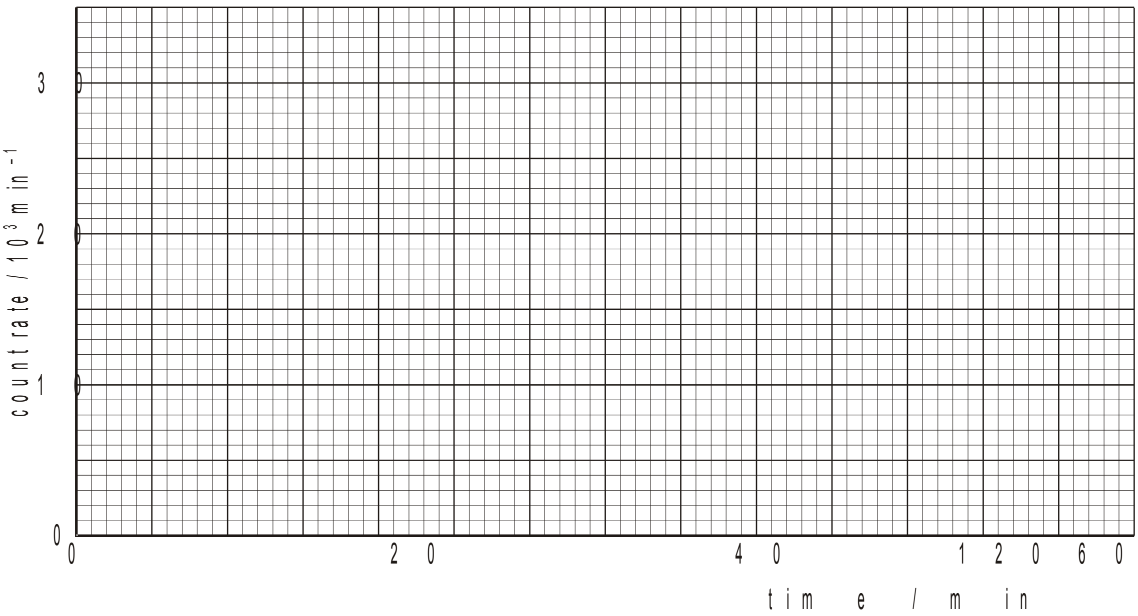


Fig. 2

[1]

[Total 13 marks]

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

Describe the processes of fission and fusion of nuclei. Distinguish clearly between them by highlighting **one** similarity and **one** difference between the two processes. State the conditions required for each process to occur in a sustained manner.

[7]

Quality of Written Communication [2]

[Total 9 marks]

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

The fission of a uranium-235 nucleus releases about 200 MeV of energy, whereas the fusion of four hydrogen-1 nuclei releases about 28 MeV. However the energy released in the fission of one kilogramme of uranium-235 is less than the energy released in the fusion of one kilogramme of hydrogen-1. Explain this by considering the number of particles in one kilogramme of each.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[4]

Quality of Written Communication [2]

[Total 6 marks]

25. (a) A student makes a transformer by winding coils of copper wire around a solid hard iron core.
He carries out an experiment to show how the efficiency of the transformer varies with the frequency of the supply. Describe the experiment, including the following aspects in your answer

- a sketch of the apparatus
- the quantities which are kept constant
- the procedure followed
- the readings taken
- how the efficiency is calculated.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[10]

(b) The student concludes that the efficiency of the transformer decreases with increasing frequency. Explain why this decrease takes place.

....

....

....

....

....

....

....

....

....

....

....

[4]

[Total 14 marks]

26. Explain what is meant by the statement that the strong interaction is a short-range force and explain what this implies about the densities of nuclei of various sizes.

....

....

....

....

....

....

....

[Total 3 marks]

27. A fuel rod inside a nuclear reactor contains uranium-238. When a $^{238}_{92}\text{U}$ nucleus is exposed to free neutrons it can absorb a neutron. The resulting nucleus decays, first to neptunium-239 $^{239}_{93}\text{Np}$ (**decay 1**) and then to plutonium-239 $^{239}_{94}\text{Pu}$ (**decay 2**).

(a) Write nuclear equations for these two decay reactions.

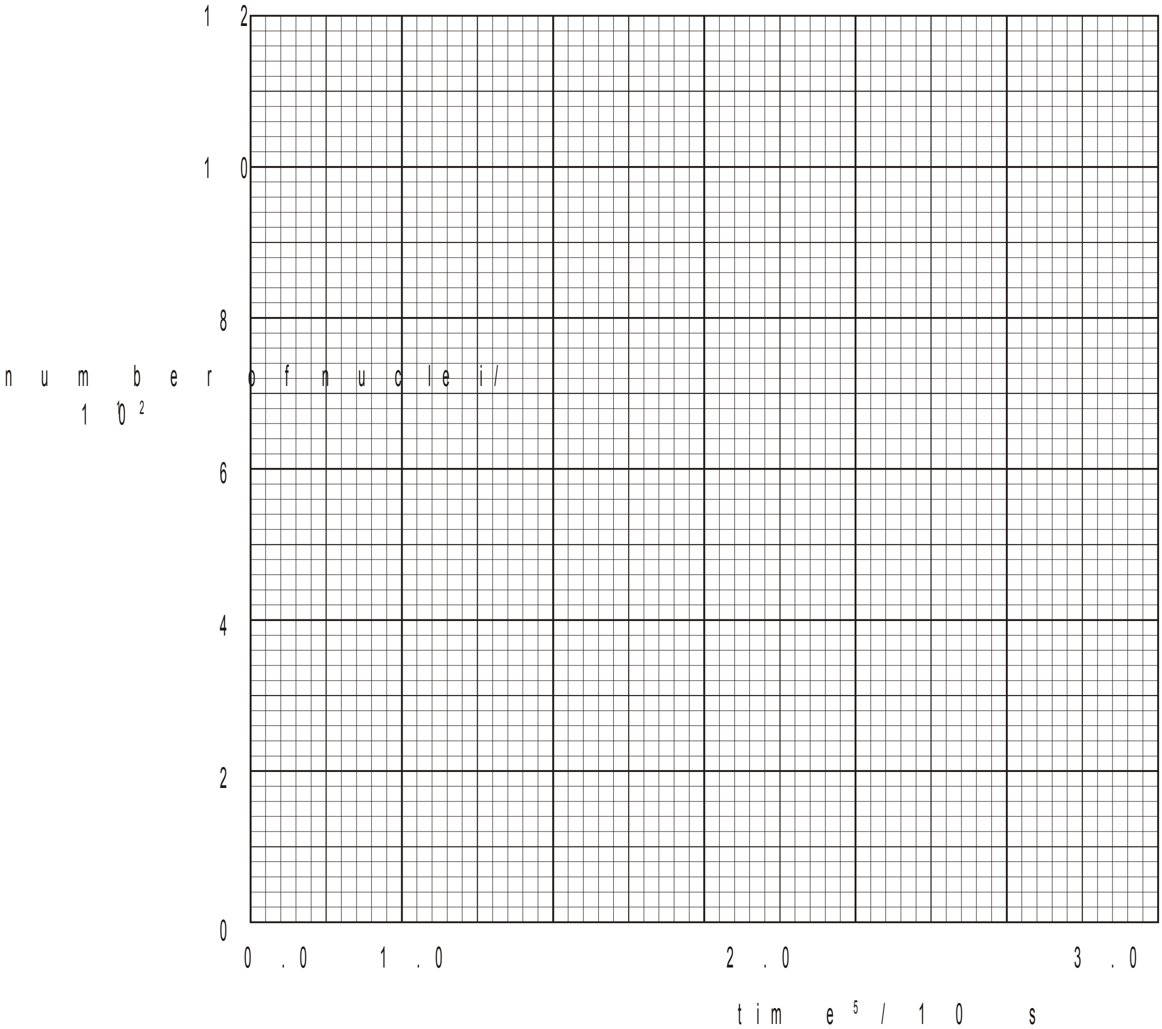
decay 1 ....

decay 2 ....

[2]

(b) In the fuel rod, ${}^{239}_{93}\text{Np}$ nuclei are produced at a constant rate of $1.80 \times 10^7\ \text{s}^{-1}$.

On the figure below, draw a graph to show how the number of ${}^{239}_{93}\text{Np}$ nuclei **produced** varies with time.
Label this graph X. Assume that initially there are no ${}^{239}_{93}\text{Np}$ nuclei.



[1]

(c) (i) State and explain, without calculation, how the number of ${}^{239}_{93}\text{Np}$ nuclei **decaying** per second varies with time.

....

....

....

[2]

(ii) State why the number of $^{239}_{93}Np$ nuclei **present** eventually becomes constant.

....

....

[1]

(iii) Calculate this constant number of $^{239}_{93}Np$ nuclei.

half-life of $^{239}_{93}Np$ = 2.04×10^5 s

number = ...

[3]

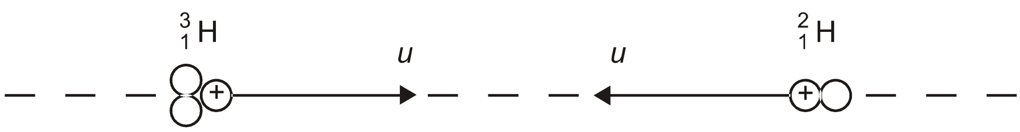
(iv) Sketch a graph on the figure above to show how the number of $^{239}_{93}Np$ nuclei present varies with time. Label this graph Y.

[1]

[Total 10 marks]

28. This question is about the possibility of fusion between a tritium nucleus and a deuterium nucleus.

A tritium nucleus ^3_1H and a deuterium nucleus ^2_1H approach each other along the same line with the **same** speed *u*.



Each nucleus decelerates, comes to rest and then accelerates in the reverse direction.

(a) (i) By considering conservation of momentum, explain why both nuclei cannot come to rest at the same time.

....

....

....

....

[1]

(ii) When the nuclei are closest together they have the same **velocity**. Show that this velocity is u / 5.

[2]

(b) (i) Energy is conserved during the interaction.

Write a word equation relating the initial energy of the two nuclei when they are far apart, to their energy when they are closest together. Your equation should make clear the kind(s) of energy involved.

....

....

[1]

(ii) Show that the total **initial** kinetic energy of the two nuclei is equal to $4.18 \times 10^{-27}\ u^2$ joule where u is in m s^{-1}.

[3]

(iii) The potential energy E of two charges Q_1 and Q_2, separated by a distance r is given by

$$E = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$$ ε_0 = permittivity of free space

For ${}^3_1\text{H}$ and ${}^2_1\text{H}$ to fuse, their separation must be no more than 1.50×10^{-15} m.

Calculate the minimum value of *u* for fusion to take place.

minimum value of *u* = ... m s^{-1}

[4]

[Total 11 marks]

29. State and explain **two** possible advantages of using nuclear fusion rather than nuclear fission for generating useful energy on a large scale.

....

....

....

....

....

....

....

....

....

[Total 4 marks]

30. A uranium-236 nucleus, ${}^{236}_{92}U$, undergoes fission, producing nuclei of zirconium-100, ${}^{100}_{40}Zr$, and tellurium-131, ${}^{131}_{52}Te$.

(a) Write a nuclear equation to represent this fission reaction.

....

[1]

(b) Each of the product nuclei is a β^- emitter.

(i) State the change, if any, in the nucleon number and the proton number caused by a β^- emission.

nucleon number ....

proton number ....

[1]

(ii) The β^- decay of zirconium-100 is followed by three more β^- decays before the product nucleus is stable.

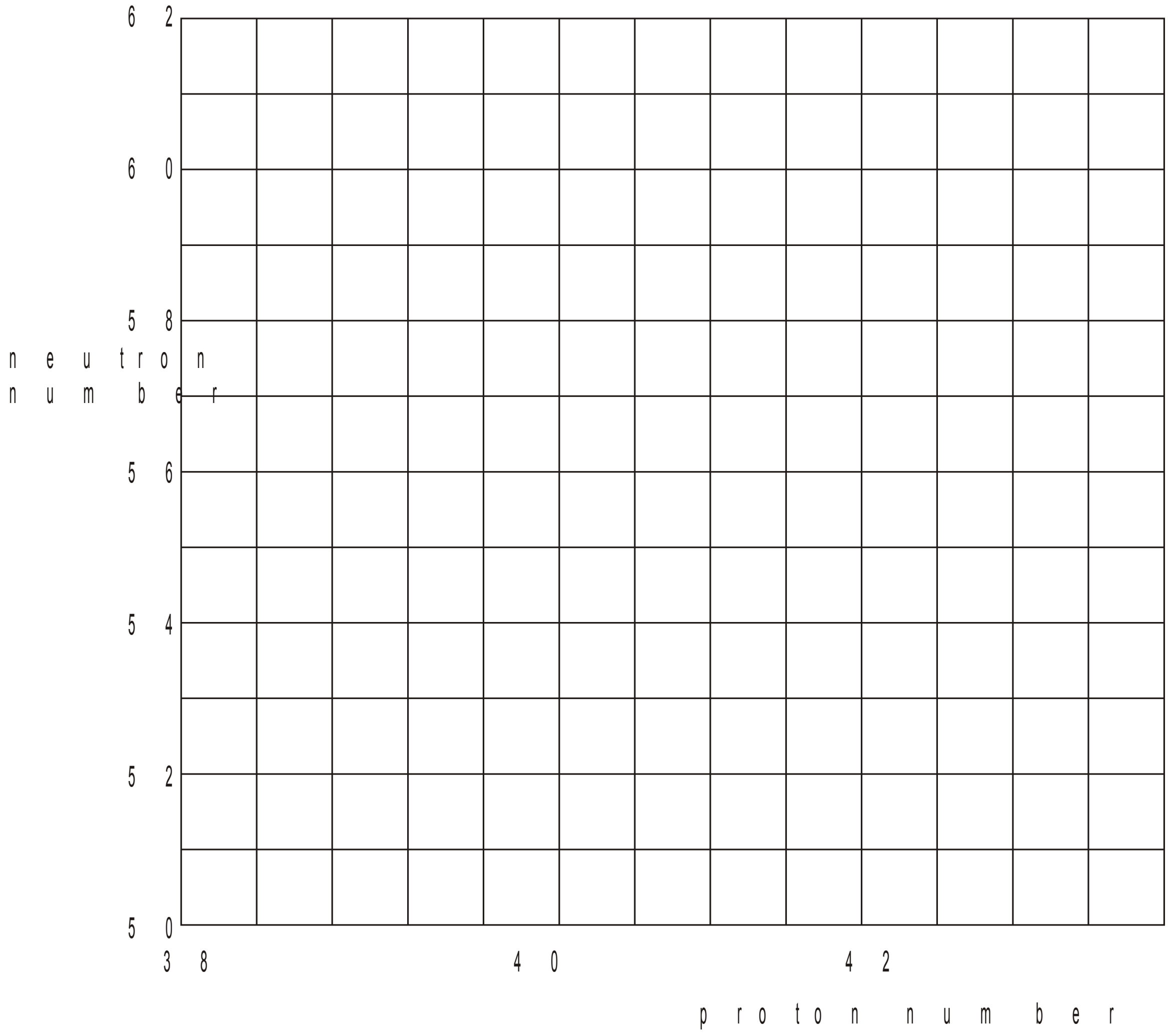
State the nucleon number and the proton number of the resulting stable nucleus.

nucleon number ....

proton number ....

[1]

(iii) On the figure below, use crosses to represent each of the nuclei involved in the series of decays by which zirconium-100 changes to a stable nucleus. Add arrows to show the direction of each reaction.



[2]

(iv) On a graph of neutron number against proton number, stable nuclei all lie close to a line. On the figure above, sketch this line.

[1]

(c) Zirconium-100 decays initially to niobium-100.

data:	nuclear masses:	zirconium-100	99.895 808 u
		niobium-100	99.891 679 u
		electron mass	0.000 549 u

(i) Calculate the mass defect for this decay reaction.

mass defect = ... u

[2]

(ii) Show that this mass defect is equivalent to about 5×10^{-13} J.

[2]

(iii) When a particular zirconium-100 nucleus decays, the emitted β^- particle has only about 2×10^{-13} J. Suggest why this is less than the energy calculated in (ii).

....

....

....

....

[2]

[Total 12 marks]

31. This question is about the energy stored in a capacitor.

(a) (i) One expression for the energy W stored on a capacitor is

$$W = \frac{1}{2} QV$$

where Q is the charge stored and V is the potential difference across the capacitor.
Show that another suitable expression for the energy stored is

$$W = \frac{1}{2} CV^2$$

where C is the capacitance of the capacitor.

[2]

(ii) Draw a graph on the axes of Fig. 1 to show how the energy *W* stored on a 2.2 F capacitor varies with the potential difference *V* across the capacitor.

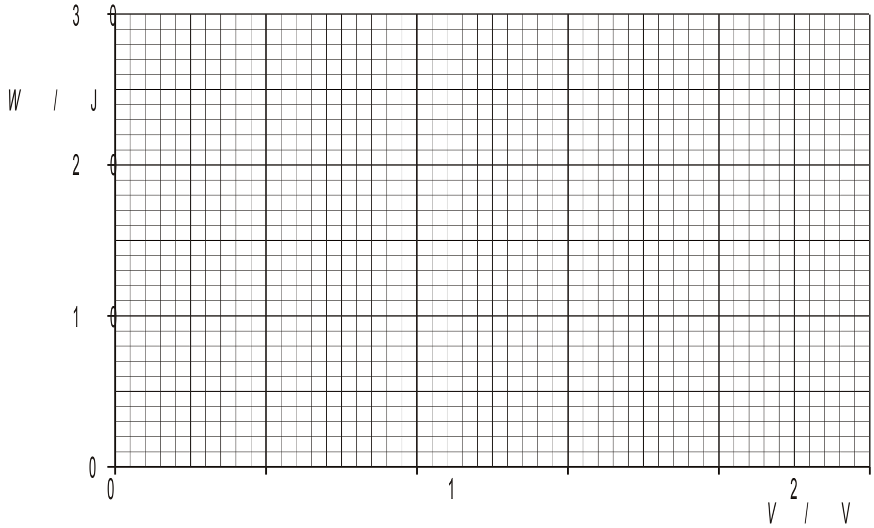


Fig. 1

[2]

(b) The 2.2 F capacitor is connected in parallel with the power supply to a digital display for a video/DVD recorder. The purpose of the capacitor is to keep the display working during any disruptions to the electrical power supply. Fig. 2 shows the 5.0 V power supply, the capacitor and the display. The input to the display behaves as a 6.8 kΩ resistor. The display will light up as long as the voltage across it is at or above 4.0 V.

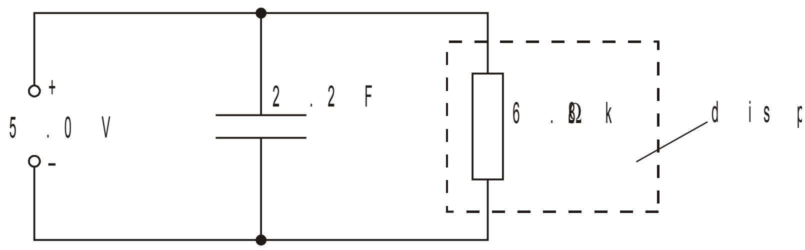


Fig. 2

Suppose the power supply is disrupted.

(i) Show that the time constant of the circuit of Fig. 2 is more than 4 hours.

[2]

(ii) Find the energy lost by the capacitor as it discharges from 5.0 V to 4.0 V.

energy lost = ...J

[2]

(iii) The voltage V across the capacitor varies with time t according to the equation

$$V = V_o e^{-t/RC}.$$

Calculate the time that it takes for the voltage to fall to 4.0 V.

time = ... s

[2]

(iv) Calculate the mean power consumption of the display during this time.

mean power = ... W

[1]

[Total 11 marks]

32. This question is about a simple model of a hydrogen iodide molecule.
Fig. 1 shows a simple representation of the hydrogen iodide molecule. It consists of two ions, ${}^{1}_{1}H^{+}$ and ${}^{127}_{53}I^{-}$, held together by electric forces.

Fig. 1

(a) (i) Draw on **Fig. 1** lines to represent the resultant electric field between the two ions.

[2]

(ii) Calculate the electrical force *F* of attraction between the ions.
Treat the ions as point charges a distance 5.0×10^{-10} m apart. Each ion has a charge of magnitude 1.6×10^{-19} C.

F = ... N

[4]

(b) The electrical attraction is balanced by a repulsive force so that the two ions are in equilibrium.
When disturbed the ions oscillate in simple harmonic motion. Fig. 2 shows a simple mechanical model of the molecule consisting of two unequal masses connected by a spring of negligible mass.

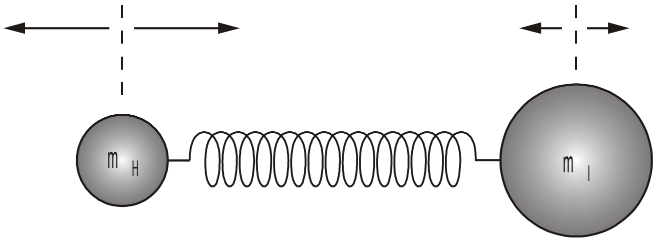


Fig. 2

Use Newton's laws of motion and the definition of simple harmonic motion to explain why the amplitude of oscillation of the hydrogen ion is 127 times the amplitude of oscillation of the iodine ion.

....

....

....

....

....

....

....

....

[4]

(c) The natural frequency of oscillation of the hydrogen ion is 6.7×10^{13} Hz. Take the amplitude of oscillation to be 8.0×10^{-12} m.

(i) Sketch on Fig. 3 a displacement against time graph for the hydrogen ion.

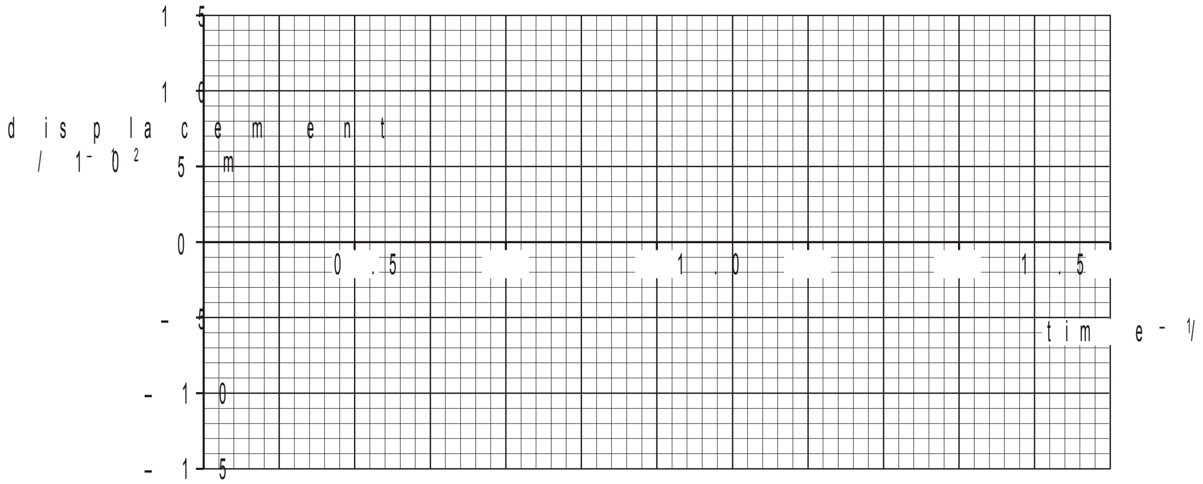


Fig .3

[3]

(ii) It is found that infra-red radiation of frequency close to 6.7×10^{13} Hz, incident on the molecules, can cause this oscillation, but other frequencies of infra-red do not. Suggest how this result can be explained.

....

....

....

....

[2]

[Total 15 marks]

33. The activity *A* of a sample of a radioactive nuclide is given by the equation

$$A = \lambda N$$

Define each of the terms in the equation.

A ....

....

λ ....

....

N ....

....

[Total 3 marks]

34. A 1000 MW coal-fired power station burns 7.0×10^6 kg of coal in one day. Two parts per million of the mass of the coal is ${}^{238}_{92}U$. The uranium remains in the residue left after the coal is burnt.
The uranium nuclide ${}^{238}_{92}U$ decays by α -particle emission with a half-life of 4.5×10^9 years to an isotope of thorium.

(i) Write down

1 the proton number *Z* of thorium ....

2 the nucleon number *A* for this isotope of thorium ....

[1]

(ii) Calculate the mass of uranium produced in the residue in one day.

mass = ... kg

[1]

(iii) Hence show that the number of uranium atoms in this mass of uranium is 3.5×10^{25}.

[1]

(iv) Calculate the activity of this mass of uranium. Give a suitable unit with your answer.

1 year = 3.2×10^{7} s

activity = ... unit ....

[3]

[Total 6 marks]

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

Faraday invented the concept of a field of force. Starting from the definitions of electric, gravitational and magnetic field strengths, discuss the similarities and differences between the three force fields.

[7]

Quality of Written Communication [2]

[Total 9 marks]

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

To explain the laws of electromagnetic induction (Faraday's law and Lenz's law) Faraday introduced the concept of magnetic flux. Describe how the flux model is used in these laws.
Start by defining *magnetic flux* and *magnetic flux linkage*.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[5]

Quality of Written Communication [2]

[Total 7 marks]

37. Full-body CT scans produce detailed 3-D information about a patient and can identify cancers at an early stage in their development.

(a) Describe how a CT scan image is produced, referring to the physics principles involved.

....

....

....

....

....

....

....

....

....

....

[7]

(b) State and explain **two** reasons why full-body CT scans are not offered for regular checking of healthy patients.

....

....

....

....

[3]

[Total 10 marks]

38. Describe the principles of the production of a short pulse of ultrasound using a piezoelectric transducer.

....

....

....

....

....

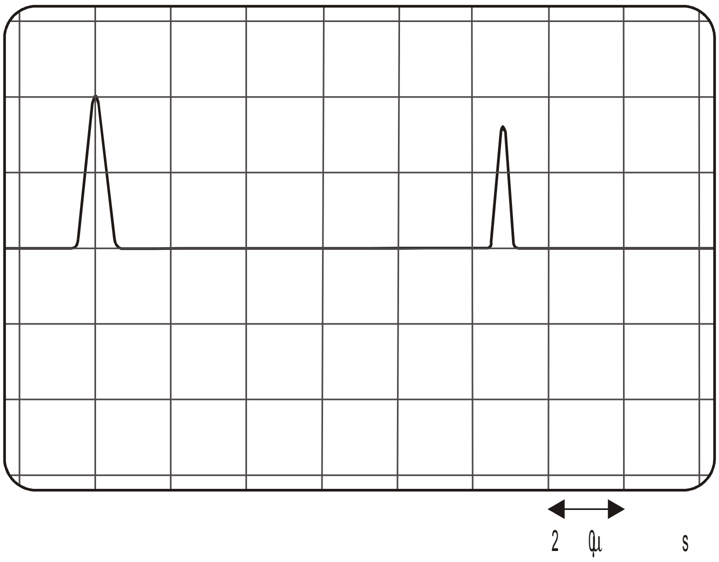
....

....

....

[Total 5 marks]

39. The diagram below shows a trace on a cathode-ray oscilloscope (CRO) of an ultrasound reflection from the front edge and rear edge of a foetal head.



The CRO timebase is set to 20 μ s cm^{-1}. The speed of ultrasound in the foetal head is 1.5×10^3 m s^{-1}.

(i) Calculate the size of the foetal head.

size = ... cm

[4]

(ii) State and explain what would be seen on the CRO screen if gel had **not** been applied between the ultrasound transducer and the skin of the mother.

....

....

....

....

....

....

[3]

[Total 7 marks]

40. This question is about nuclear fission of uranium-235.

(i) State what is meant by a *thermal neutron*.

....

....

[1]

(ii) State the importance of thermal neutrons in relation to the fission of uranium-235.

....

....

....

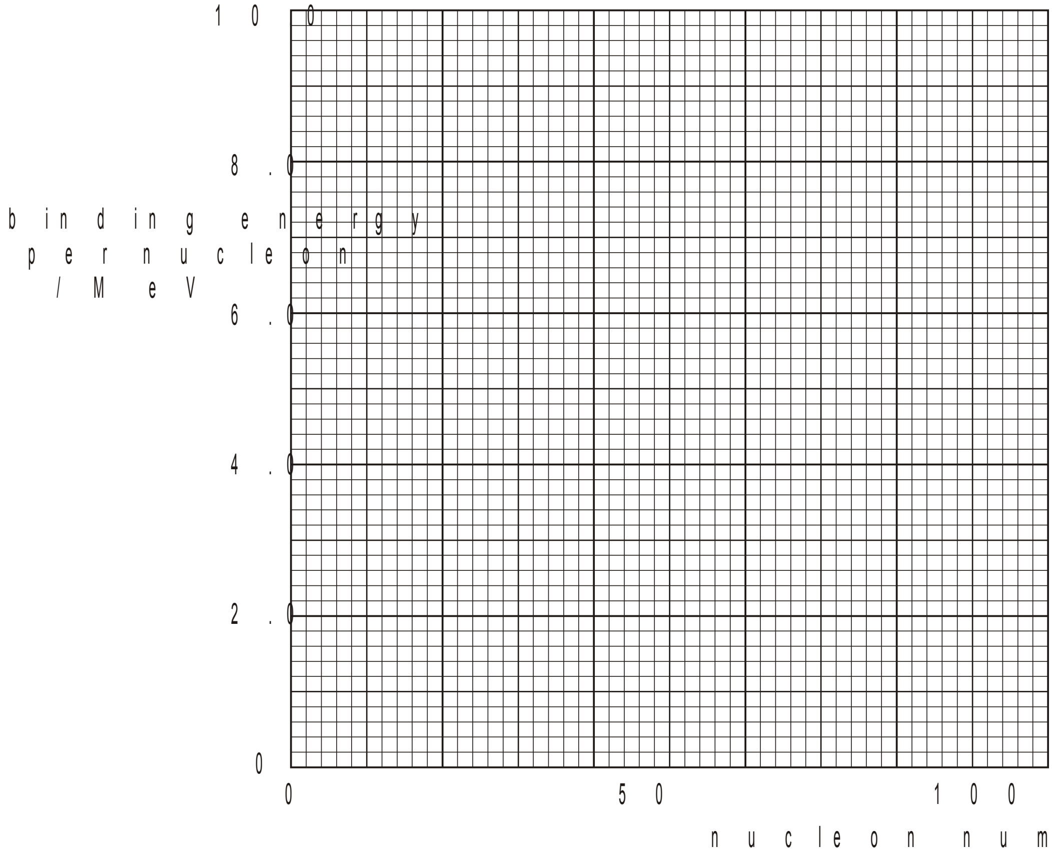
[1]

[Total 2 marks]

41. A uranium-235 nucleus ${}^{235}_{92}U$ undergoes fission, producing nuclei of lanthanum-146 ${}^{146}_{57}La$ and bromine-87 ${}^{87}_{35}Br$. The binding energies per nucleon of these nuclides are shown below.

nuclide	binding energy per nucleon / MeV
${}^{235}_{92}U$	7.6
${}^{146}_{57}La$	8.2
${}^{87}_{35}Br$	8.6

(i) Plot these values on the grid below.



[1]

(ii) Sketch a graph on the grid above, to show how the binding energy per nucleon varies with nucleon number for **all** nuclei.

[2]

(iii) Use information from the table to calculate how much energy in MeV is released when a $^{235}_{92}U$ nucleus undergoes fission.

energy = ... MeV

[3]

[Total 6 marks]

42. This question is about nuclear fusion reactions inside the Sun.

Explain the importance of gravity in making fusion reactions possible inside the Sun.

....

....

....

....

....

....

[Total 3 marks]

43. This question is about nuclear fusion reactions inside the Sun.

Two hydrogen nuclei ${}^{1}_{1}H$, which are initially a long way apart, approach each other along the same straight line.

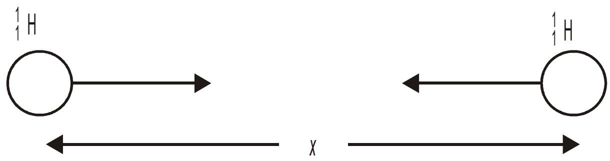


Fig .1

The repulsive force F_e between them varies with their separation x as shown in Fig. 2.

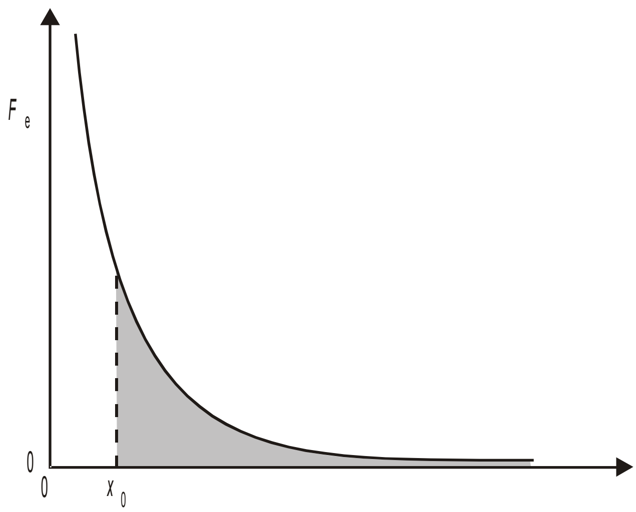


Fig. 2

The nuclei fuse if their separation becomes equal to or less than a critical separation x_0. What is the physical significance of the shaded area?

....

....

....

....

[Total 2 marks]

44. The hydrogen cycle of fusion reactions is responsible for most of the energy generated inside the Sun. In one of these reactions two ${}^{1}_{1}H$ nuclei fuse to make a deuterium nucleus ${}^{2}_{1}H$ thus:

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}H + {}^{0}_{1}e + {}^{0}_{0}\upsilon$$

(i) Calculate the energy in joule generated by this reaction.

	mass / u
${}^{1}_{1}H$ nucleus	1.007 276
${}^{2}_{1}H$ nucleus	2.013 553
${}^{0}_{1}e$	0.000 549

energy = ... J

[3]

(ii) State how the positron ${}^{0}_{1}e$ created in the reaction will result in **further** generation of energy.

....

....

....

[1]

[Total 4 marks]

45. Uranium-238 ${}^{238}_{92}\text{U}$ decays to lead-206 ${}^{206}_{82}\text{Pb}$ by means of a series of decays.

One nucleus of ${}^{238}_{92}\text{U}$ decays eventually to one nucleus of ${}^{206}_{82}\text{Pb}$.

This means that, over time, the ratio of lead-206 atoms to uranium-238 atoms increases. This ratio may be used to determine the age of a sample of rock.

In a particular sample of rock, the ratio

$$\frac{\text{number of lead-206 atoms}}{\text{number of uranium-238 atoms}} = \frac{1}{2}.$$

(a) Show that the ratio

$$\frac{\text{number of uranium-238 atoms left}}{\text{number of uranium-238 atoms initially}} = \frac{2}{3}.$$

Assume that the sample initially contained only uranium-238 atoms and subsequently it contained only uranium-238 atoms and lead-206 atoms.

[2]

(b) Calculate the age of the rock sample.

The half-life of $^{238}_{92}U$ is 4.47×10^9 years.

age = ... years

[3]

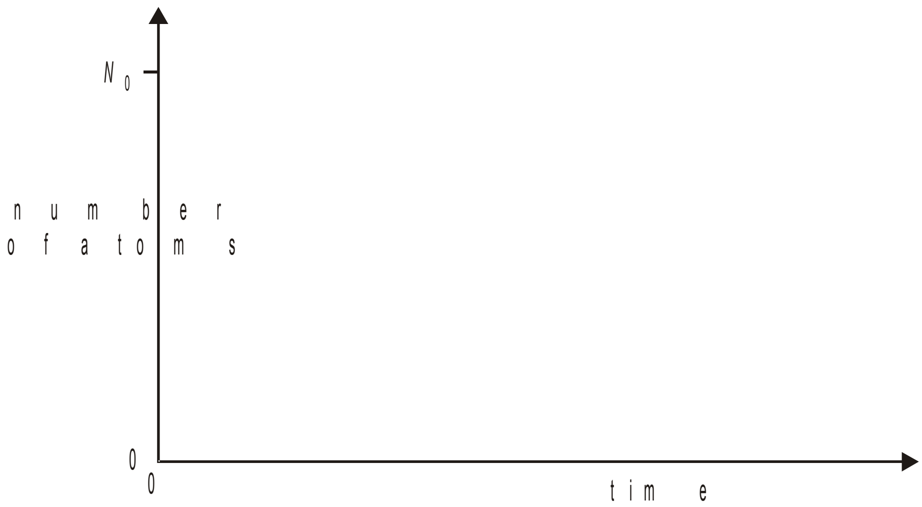
(c) The rock sample initially contained 5.00 g of uranium-238. Calculate the initial number N_0 of atoms of uranium-238 in this sample.

number = ...

[2]

(d) On the figure below, sketch graphs to show how the number of atoms of uranium-238 and the number of atoms of lead-206 vary with time over a period of several half-lives.

Label your graphs ‘U’ and ‘Pb’ respectively.



[3]

[Total 10 marks]

46. (i) Name the group of particles of which the electron and the positron are members.

....

[1]

(ii) Name another member of this group.

....

[1]

[Total 2 marks]

47. (i) State the quark composition of the neutron.

....

[1]

(ii) Complete the table to show the charge *Q*, baryon number *B* and strangeness *S* for the quarks in the neutron.

quark	*Q*	*B*	*S*

[2]

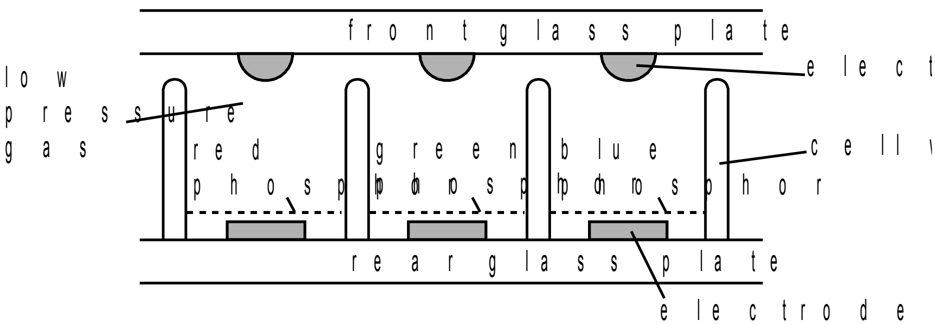
(iii) Hence deduce the values of *Q*, *B* and *S* for the neutron.

Q .... *B* .... *S* ....

[1]

[Total 4 marks]

48. Many televisions are now produced with flat panel screens. One type of flat panel screen is the plasma screen. In a plasma screen millions of tiny cells are sandwiched between two glass plates which enclose low pressure gas. In order to make a cell emit light a voltage is applied across the cell between two electrodes. This ionises the gas and ultra-violet radiation is emitted. This radiation falls on a phosphor which then emits light. One third of all the phosphors emit red light, one third emit green light and one third emit blue light. Three of the cells, one for each colour, are shown in the figure below.



(a) Explain the meaning of the word *ionise.*

....

....

[1]

(b) Calculate the photon energy of ultra-violet radiation of wavelength 238 nm.

energy = ... J

[3]

(c) Explain why it is possible to use ultra-violet photons to create photons of visible light in a phosphor, but it would **not** be possible to create ultra-violet photons from any photons of visible light.

....

....

....

....

[2]

(d) A cell will emit light when a voltage of +15 V is applied to its positive electrode and a voltage of −15 V to its negative electrode. The electrode separation is 0.20 mm. Calculate the value of the uniform electric field causing the ionisation. State the SI unit for electric field.

electric field = ... unit ……….

[3]

[Total 9 marks]

49. This question is about electric forces.

A very small negatively-charged conducting sphere is suspended by an insulating thread from support **S**. It is placed close to a vertical metal plate carrying a positive charge. The sphere is attracted towards the plate and hangs with the thread at an angle of 20° to the vertical as shown in Fig. 1.

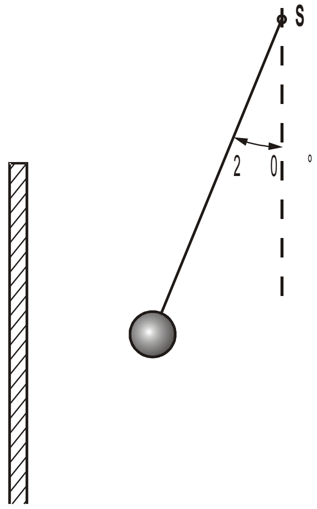


Fig. 1

(a) Draw at least **five** electric field lines on Fig. 1 to show the pattern of the field between the plate and the sphere.

[3]

(b) The sphere of weight 1.0×10^{-5} N carries a charge of -1.2×10^{-9} C.

(i) Show that the magnitude of the attractive force between the sphere and the plate is about 3.6×10^{-6} N.

[3]

(ii) Hence show that the value of the electric field strength at the sphere, treated as a point charge, is 3.0×10^3 in SI units. State the unit.

unit for electric field strength is ....

[3]

(c) The plate is removed. Fig. 2 shows an identical sphere carrying a charge of $+1.2 \times 10^{-9}$ C, mounted on an insulating stand. It is placed so that the hanging sphere remains at 20° to the vertical.

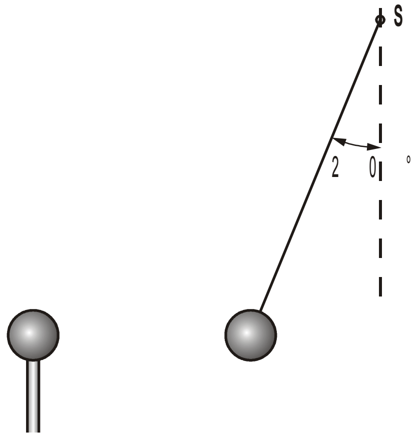


Fig. 2

Treating the spheres as point charges, calculate the distance *r* between their centres.

r = ... m

[3]

(d) On Fig. 2, sketch the electric field pattern between the two charges. By comparing this sketch with your answer to (a), suggest why the distance between the plate and the sphere in Fig. 1 is half of the distance between the two spheres in Fig. 2.

....

....

....

[2]

[Total 14 marks]

50. The radioactive nickel nuclide $^{63}_{28}Ni$ decays by beta-particle emission with a half-life of 120 years.

(a) A copper nucleus is produced as the result of this decay. State the number of nucleons in the copper nucleus which are

protons ....

neutrons ....

[2]

(b) Show that the decay constant of the nickel nuclide is $1.8 \times 10^{-10}\ s^{-1}$.

1 year = 3.2×10^{7} s

[1]

(c) A student designs an electronic clock, powered by the decay of nuclei of $^{63}_{28}Ni$.

One plate of a capacitor of capacitance 1.2×10^{-12} F is to be coated with this isotope. As a result of this decay, the capacitor becomes charged. The capacitor is connected across the terminals of a small neon lamp. See Fig. 1. When the capacitor is charged to 90 V, the neon gas inside the lamp becomes conducting, causing it to emit a brief flash of light and discharging the capacitor. The charging starts again. Fig. 2 is a graph showing how the voltage *V* across the capacitor varies with time.

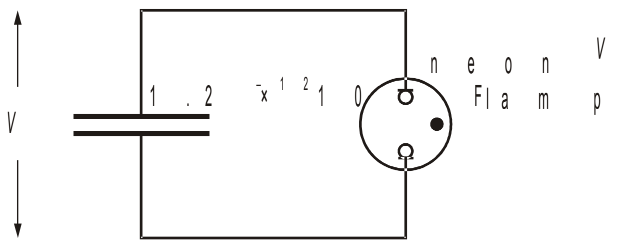


Fig. 1

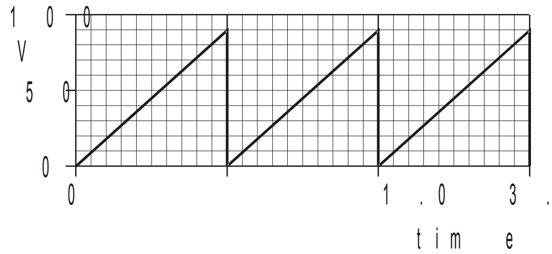


Fig. 2

(i) Show that the maximum charge stored on the capacitor is 1.1×10^{-10} C.

[2]

(ii) When a nickel atom emits a beta-particle, a positive charge of 1.6×10^{-19} C is added to the capacitor plate. Show that the number of nickel nuclei that must decay to produce 1.1×10^{-10} C is about 7×10^{8}.

[2]

(iii) The neon lamp is to flash once every 1.0 s. Using your answer to (b), calculate the number of nickel atoms needed in the coating on the plate.

number = ...

[3]

(iv) State, giving a reason, whether or not you would expect the clock to be accurate to within 1% one year after manufacture.

....

....

....

[1]

[Total 11 marks]

51. This question is about forcing a liquid metal, such as molten sodium, through a tube.

(a) The liquid metal is in a tube of square cross-section, side *w*, made of electrically insulating material. See Fig. 1. Two electrodes are mounted on opposite sides of the tube and a magnetic field of flux density *B* fills the region between the electrodes. An electric current I passes across the tube between the electrodes, perpendicular to the magnetic field. The interaction between the current and the field provides the force to move the liquid.

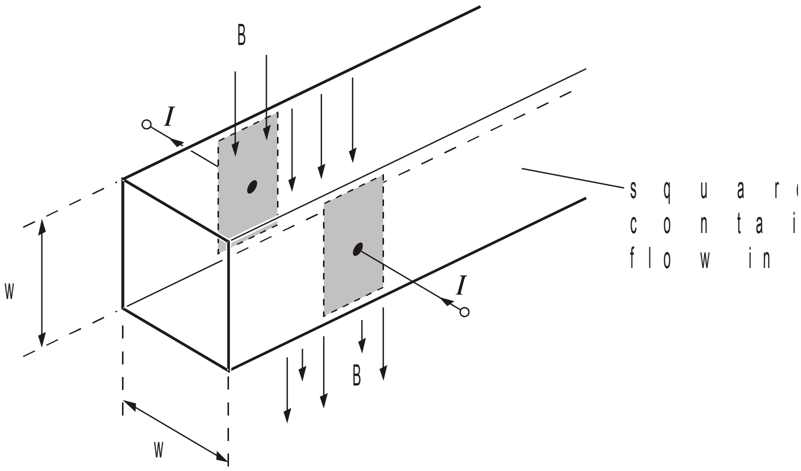


Fig. 1

(i) Draw on Fig. 1 an arrow labelled **F** to indicate the direction of the force on the liquid metal. Explain how you determined the direction.

....

....

[2]

(ii) State a relationship for the force *F* in terms of the current I, the magnetic field *B* and the width *w* of the tube.

....

[1]

(iii) Data for this device are shown below.

B = 0.15 T
I = 800 A
w = 25mm

Calculate the force on the liquid metal in the tube.

force = ... N

[2]

(b) To monitor the speed of flow of the liquid metal, a similar arrangement of electrodes and magnetic field is set up further down the tube. See Fig. 2. A voltmeter is connected across the electrodes instead of a power supply.

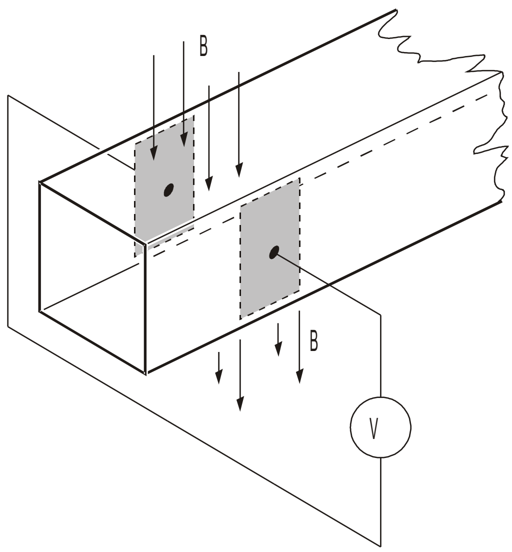


Fig. 2

(i) Explain, using the law of electromagnetic induction, why the voltmeter will register a reading which is proportional to the speed of flow of the metal.

....

....

....

....

....

....

....

[3]

(ii) State how and explain why the voltmeter reading changes when the magnetic flux density across the tube is doubled.

....

....

....

....

[2]

[Total 10 marks]

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

This question is about helium nuclei.

Describe the nature of alpha-particles and the main features of alpha-particle decay.
Describe **one** experiment where alpha-particles have been used to learn about atomic structure. Explain how the experiment led to the discovery of the nucleus.
A space has been left for you to draw suitable diagram(s), if you wish to illustrate your answer.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[7]

Quality of Written Communication [2]

[Total 9 marks]

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

A method of producing helium nuclei is shown by the following nuclear equation.

$$4\,{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2\,{}^{0}_{1}\text{e}$$

Describe this process of fusion giving as much detail as you can.
Compare the energy release in this process with the energy released in alpha-particle decay.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[5]

Quality of Written Communication [2]

[Total 7 marks]

54. The average orbital radius of Jupiter is approximately 5.2 AU.
Calculate the orbital radius of Jupiter in metres.

radius = ... m

[Total 1 mark]

55. Describe and explain the stages which take place in the birth of a Main Sequence star.

....

....

....

....

....

....

....

....

....

....

....

[Total 5 marks]

56. State Hubble's law and define any symbols used.

....

....

....

[Total 2 marks]

57. Describe Olbers' paradox and explain how the work of Edwin Hubble provides an answer.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[Total 5 marks]

58. (i) Describe the shape and structure of our galaxy. Illustrate your answer with a sketch.

....

....

....

....

[2]

(ii) Mark **X** on your sketch at the approximate position of the Sun within the galaxy.

[1]

[Total 3 marks]

59. Some Cosmologists have estimated that as much as 90% of the total mass of a galaxy is made up of gas, referred to as dark matter.

(i) Suggest the nature and origin of this gas.

....

....

....

[2]

(ii) The precise amount of dark matter in the Universe is unknown. Explain how the presence of dark matter affects the average density of the Universe and thus has a role in determining the ultimate fate of the Universe itself.

....

....

....

....

....

....

[4]

[Total 6 marks]

60. Describe the use of a contrast medium, such as barium, in the imaging of internal body structures. Your answer should include

- how an image of an internal body structure is produced from an X-ray beam
- an explanation of the use of a contrast medium
- examples of the types of structure that can be imaged by this process.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[Total 8 marks]

61. Fig. 1 shows data for the intensity of a parallel beam of X-rays after penetration through varying thicknesses of a material.

intensity / MW m^{-2}	thickness / mm
0.91	0.40
0.69	0.80
0.52	1.20
0.40	1.60
0.30	2.00
0.23	2.40
0.17	2.80

Fig. 1

(a) On Fig. 2 plot a graph of transmitted X-ray intensity against thickness of absorber.

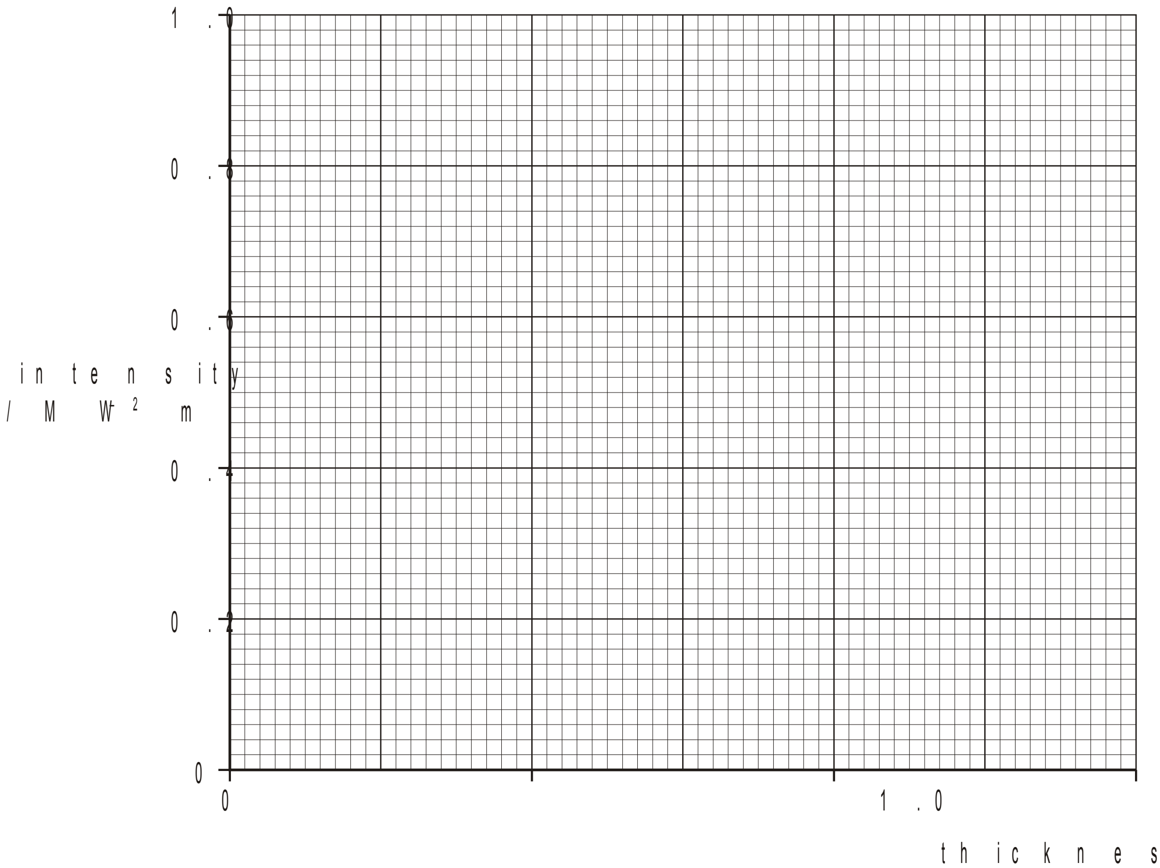


Fig. 2

[3]

(b) (i) Find the thickness that reduces the intensity of the incident beam by one half.

thickness = …………….. mm

[1]

(ii) Use your answer to (b)(i) to calculate the linear attenuation coefficient μ. Give the unit for your answer.

μ = …………….. unit ………

[4]

[Total 8 marks]

62. Fig. 1 shows two protons **A** and **B** in contact and at equilibrium inside a nucleus.

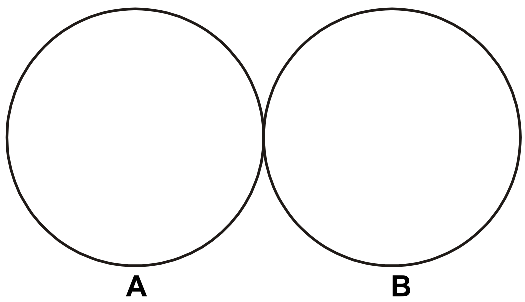


Fig. 1

Proton **A** exerts three forces on proton **B**. These are an electrostatic force F_E, a gravitational force F_G and a strong force F_S.

(a) On Fig. 1, mark and label the three forces acting on proton **B**. Assume that every force acts at the centre of the proton.

[2]

(b) Write an equation relating F_E, F_G and F_S.

[1]

(c) The radius of a proton is 1.40×10^{-15} m.

Calculate the values of

(i) F_E

F_E = ... N

[2]

(ii) F_G

F_G = ... N

[2]

(iii) F_S.

F_S = ... N

[1]

(d) Comment on the relative magnitudes of F_E and F_G.

....

....

[1]

(e) Fig. 2 shows two **neutrons** in contact and at equilibrium inside a nucleus.

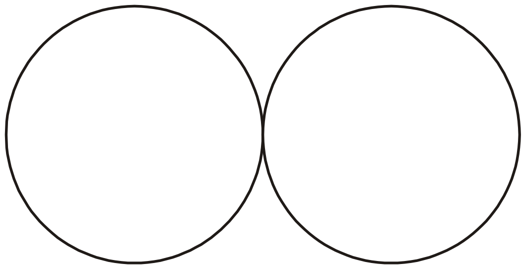


Fig. 2

Without further calculation, state the values of F_E, F_G and F_S for these neutrons.

(i) F_E = ... N

[1]

(ii) F_G = ... N

[1]

(iii) F_S = ... N

[1]

[Total 12 marks]

63. This question is about the production and use of plutonium-239 ($^{239}_{94}Pu$).

In a uranium fission reactor, uranium-238 ($^{238}_{92}U$) is bombarded with neutrons.

A nucleus of $^{238}_{92}U$ can absorb a neutron.

The product of this reaction then undergoes two decay reactions to produce $^{239}_{94}Pu$.

(a) Write nuclear equations for these three reactions.
Use X to represent any intermediate nuclide.

(i) absorption of a neutron

[1]

(ii) first decay reaction

[2]

(iii) second decay reaction

[1]

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

half-life = ... y

[1]

(ii) Calculate the decay constant λ of plutonium-239.

decay constant = ... s^{-1}

[2]

(c) Plutonium-239 can be used (with uranium-235) in a different kind of reactor. A particular fuel rod for such a reactor has a mass of 4.4 kg, of which 5.0 % is plutonium-239.

(i) Show that the number of atoms of plutonium in this fuel rod is 5.5×10^{23}.

[2]

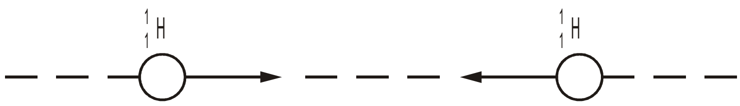
(ii) Calculate the activity of the plutonium in this fuel rod.
State the unit of your answer.

activity = ... unit........

[3]

[Total 12 marks]

64. The Sun’s energy is generated by fusion reactions.
Fusion is most likely to occur when reacting nuclei approach each other along the same straight line. The figure below shows two protons which have the same initial speed.



(a) Describe the energy changes in this system as the protons approach each other and come to rest.

....

....

....

....

[3]

(b) In order to fuse, the centres of the protons must reach a separation of 2.1×10^{-15} m or less. Calculate the minimum initial kinetic energy of **each** proton for fusion to occur.
The total potential energy E_P of **two** charges Q_1 and Q_2 at separation r is given by

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

kinetic energy = ... J

[2]

(c) Using the equation

$$E_K = 2.07 \times 10^{-23}\ T$$

calculate the temperature T of a plasma such that the kinetic energy of the protons is equal to your answer to **(b)**.

temperature = ... K

[1]

(d) Proton fusion occurs at a temperature of about 1.5×10^7 K. Suggest why this fusion can occur at a much lower temperature than your answer to **(c)**.

....

....

....

....

[2]

(e) Two series of fusion reactions in the Sun are particularly important. One is the **hydrogen cycle** which consists of the following reactions. The energy outputs from each reaction are shown.

$$2(^{1}_{1}\text{H}) \rightarrow {}^{2}_{1}\text{H} + {}^{0}_{1}\text{e} + {}^{0}_{0}\nu + 2.3\times10^{-13}\text{ J}$$
$${}^{2}_{1}\text{H} + {}^{1}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + 8.8\times10^{-13}\text{ J}$$
$$2(^{3}_{2}\text{He}) \rightarrow {}^{4}_{2}\text{He} + 2(^{1}_{1}\text{H}) + 20.6\times10^{-13}\text{ J}$$

The hydrogen cycle of reactions may be summarised in the equation 4 (11

$$4(^{1}_{1}\text{H}) \rightarrow {}^{4}_{2}\text{He} + 2(^{0}_{1}\text{e}) + 2(^{0}_{0}\nu) + E$$

(i) Calculate the value of E, the total energy output for this reaction.

E = ... J

[2]

(ii) Suggest why the amount of heat generated inside the Sun by the hydrogen cycle of reactions is less than would be expected from your answer to **(i)**.

....

....

....

[1]

(f) Another series of reactions which occurs in the Sun is the **carbon cycle**. This involves the fusion of protons with carbon and nitrogen nuclei. It happens to a greater extent inside stars hotter than the Sun. Suggest why these reactions require higher temperatures than the hydrogen cycle.

....

....

....

....

[2]

[Total 13 marks]

65. This question is about the ways in which a gold isotope might undergo spontaneous decay.

Data.

name	symbol	mass / u
gold-192	$^{192}_{79}Au$	191.92147
platinum-192	$^{192}_{78}Pt$	191.91824
mercury-192	$^{192}_{80}Hg$	191.92141
electron	$^{0}_{-1}e$	0.00055

A student suggests that $^{192}_{79}Au$ should undergo either β^+ or β^- decay.

(a) Write nuclear equations for each of these suggested reactions.

β^+

β^-

[2]

(b) Deduce whether either of these reactions can take place.

[5]

(c) Calculate the maximum kinetic energy, in joule, of any emitted β particle.

energy = ... J

[4]

[Total 11 marks]

66. With particular reference to **two** kinds of hadron, discuss the stability or otherwise of hadrons.

....

....

....

....

....

....

....

....

....

....

....

[Total 5 marks]

67. Tritium-3 ($^{3}_{1}H$) decays to helium-3 ($^{3}_{2}He$) with the emission of a β^{-} particle.

(i) Name the force responsible for this decay process.

....

[1]

(ii) Write a nuclear equation to represent this process.

[1]

(iii) Write a quark equation, in its simplest form, to represent this process.

[2]

[Total 4 marks]

68. State what is meant by fission and fusion

....

....

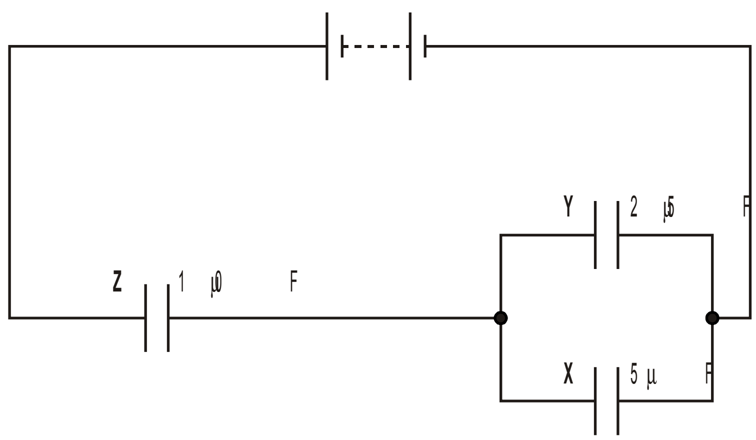
....

....

....

[Total 2 marks]

69. The charge stored in the capacitor **X** of capacitance 5 μF in the circuit given in the figure below is 30 μC.



(a) (i) Complete the table for this circuit.

capacitor	capacitance / μF	charge / μC	p.d. / V	energy / μJ
X	5	30		
Y	25			
Z	10			

[9]

(ii) Using data from the table find

1 the e.m.f. of the battery

e.m.f. = ... V

[1]

2 the total charge supplied from the battery

charge = ... μC

[1]

3 the total circuit capacitance

capacitance = ... μF

[1]

4 the total energy stored in all the capacitors.

energy = ... μJ

[1]

(b) (i) What law or principle of physics was used to determine **(a)(ii)1**?

....

[1]

(ii) What law or principle of physics was used to determine **(a)(ii)2**?

....

[1]

(c) The battery is removed and replaced by a resistor of resistance 200 kΩ. The capacitors now discharge through this resistor. Calculate

(i) the time constant of the circuit

time constant = ... s

[2]

(ii) the fraction of the total charge remaining on the capacitors after a time equal to **four** time constants.

fraction remaining = ...

[2]

[Total 19 marks]

70. The following is adapted from an article about superconducting devices written by Archie M. Campbell for "Physics World". Read the following paragraphs and answer the questions which follow.

The electrical resistance of a mat
superconducting. This remarkable tr
which is within a few degrees of
materials. Certain materials have (
above absolute zero. Yttrium bar
temperature of 92 K and below thi
materials are extremely useful for
high currents that can be passed
used to generate large magnetic
separation of charged particles or i

A problem is that heat will enter i
work needs to be done to remove tl
the operating temperature is lowere
requires 30 W of power to be suppl
constant temperature. At 4.2 K the
for each watt leaking in.

(a) State the resistance of a superconducting material below the critical temperature.

Ω ....

[1]

(b) Calculate the power required by the cooling mechanism at 4.2 K if heat is leaking into a superconducting device at a rate of 20W.

power = ... W

[1]

(c) Suggest why a superconducting device using YBCO will be run at a temperature of, say, 77 K when its critical temperature is 92 K.

....

....

....

[2]

(d) A large electromagnet is made out of superconducting wire of square cross-section having area 1.0 mm^2. It is a circular coil containing 3200 turns of average radius 0.30 m.
A cut-away diagram is shown in Fig. 1. The wire, when superconducting, has current density through it of 2.0×10^8 amperes per square metre ($A\ m^{-2}$) of cross-section.

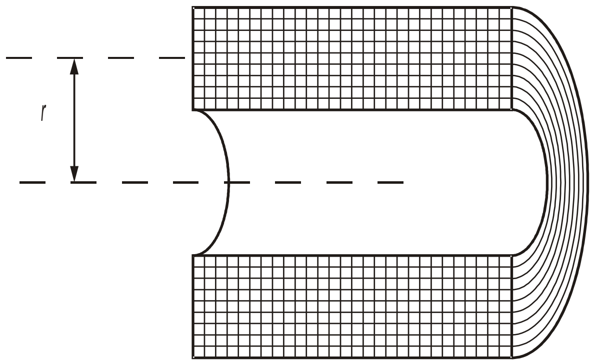


Fig. 1

(i) Show that the current in the wire is 200 A.

[2]

(ii) The magnetic flux density B caused by such a coil can be estimated using the equation

$$B = \frac{\mu_o I N}{2r}$$

where I is the current, N the number of turns, r the average radius of the coil and μ_o is a constant equal to 1.26×10^{-6} T m A^{-1}.
Calculate the resulting magnetic flux density.

magnetic flux density = ... T

[2]

(e) Isotopes of an element can be separated by first ionising them and then firing them into a magnetic field. For example, if singly ionised atoms of U-235 and U-238 are fired into a magnetic field they are deflected into circular paths of different radii.

(i) State the equation for the force F acting on a charge Q moving with velocity v at right angles to a magnetic field of flux density B.

....

[1]

(ii) Calculate the radius of the circular path of a singly-charged U-235^+ ion when it is fired with a velocity of 8.3×10^5 m s^{-1} at right angles into the magnetic field caused by the superconducting coil in (d)(ii). Assume that the charge on this ion is $+1.60 \times 10^{-19}$ C.

radius of path = ... m

[4]