

**OXFORD CAMBRIDGE AND RSA EXAMINATIONS**  
**A2 GCE**  
**G495/01**

**PHYSICS B (ADVANCING PHYSICS)**  
**Field and Particle Pictures**

**THURSDAY 19 JUNE 2014: Morning**

**DURATION: 2 hours**  
**plus your additional time allowance**

**MODIFIED ENLARGED**

<b>Candidate forename</b>		<b>Candidate surname</b>	
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<b>Centre number</b>						<b>Candidate number</b>				
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**Candidates answer on the Question Paper.**

**OCR SUPPLIED MATERIALS:**

**Data, Formulae and Relationships Booklet**  
**(sent with general stationery)**

**Insert (Advance Notice for this Question Paper) (inserted)**

**OTHER MATERIALS REQUIRED:**

**Electronic calculator**  
**Ruler (cm/mm)**

**READ INSTRUCTIONS OVERLEAF**

## **INSTRUCTIONS TO CANDIDATES**

**The Insert will be found inside this document.**

**Write your name, centre number and candidate number in the boxes on the first page. Please write clearly and in capital letters.**

**Use black ink. HB pencil may be used for graphs and diagrams only.**

**Answer ALL the questions.**

**Read each question carefully. Make sure you know what you have to do before starting your answer.**

**Write your answer to each question in the space provided. If additional space is required, you should use the additional pages at the end of this booklet. The question number(s) must be clearly shown.**

## **INFORMATION FOR CANDIDATES**

**The number of marks is given in brackets [ ] at the end of each question or part question.**

**The total number of marks for this paper is 100.**

**You may use an electronic calculator.**

**You are advised to show all the steps in any calculations.**

**The values of standard physical constants are given in the Data, Formulae and Relationships Booklet. Any additional data required are given in the appropriate question.**



**Where you see this icon you will be awarded marks for the quality of written communication in your answer.**

**This means for example, you should:**

**ensure that text is legible and that spelling, punctuation and grammar are accurate so that the meaning is clear**

**organise information clearly and coherently, using specialist vocabulary when appropriate.**

**You are advised to show all the steps in any calculations.**

**Any blank pages are indicated.**

**The questions in Section C are based on the material in the Insert.**

**Answer ALL the questions**

**SECTION A**

**1 Here is a list of units.**

**J      J C<sup>-1</sup>      J s<sup>-1</sup>      J m<sup>-1</sup>      J kg<sup>-1</sup>**

**Which unit from the list is a correct unit for:**

**(a) force**

\_\_\_\_\_ [1]

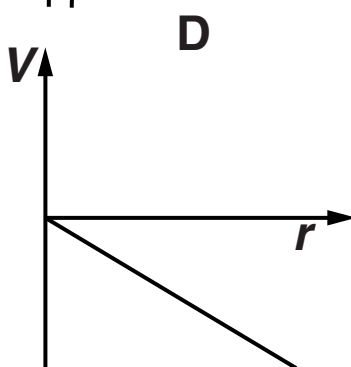
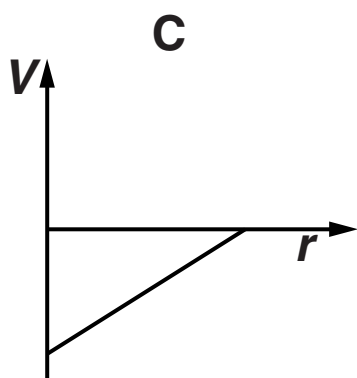
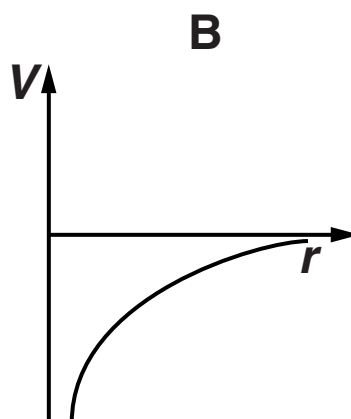
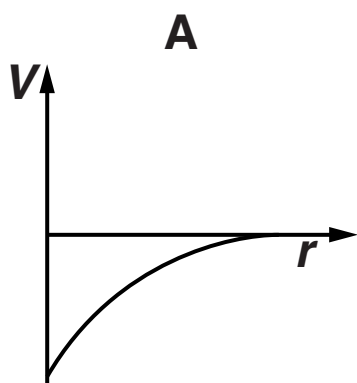
**(b) ABSORBED radiation dose**

\_\_\_\_\_ [1]

**(c) potential in an electric field?**

\_\_\_\_\_ [1]

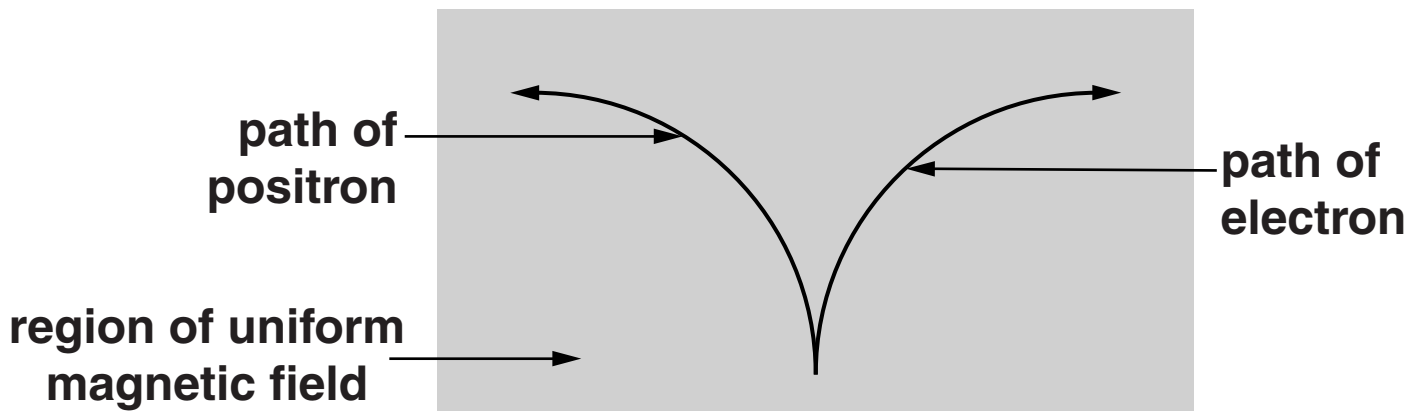
- 2 Which of the graphs, A, B, C or D, shows the variation of electrical potential  $V$  with distance  $r$  from an electron?



answer = \_\_\_\_\_ [1]

- 3 Fig. 3.1 shows the paths of an electron and a positron in a uniform magnetic field.

**FIG. 3.1**



- (a) State the feature of the paths that shows that the electron has a different sign of charge from a positron.

[1]

- (b) State the feature of the paths that shows that the electron and the positron have the same magnitude of momentum.

[1]

- (c) Calculate the force on the positron as it moves through the uniform magnetic field with a speed of  $1.7 \times 10^7 \text{ m s}^{-1}$ .

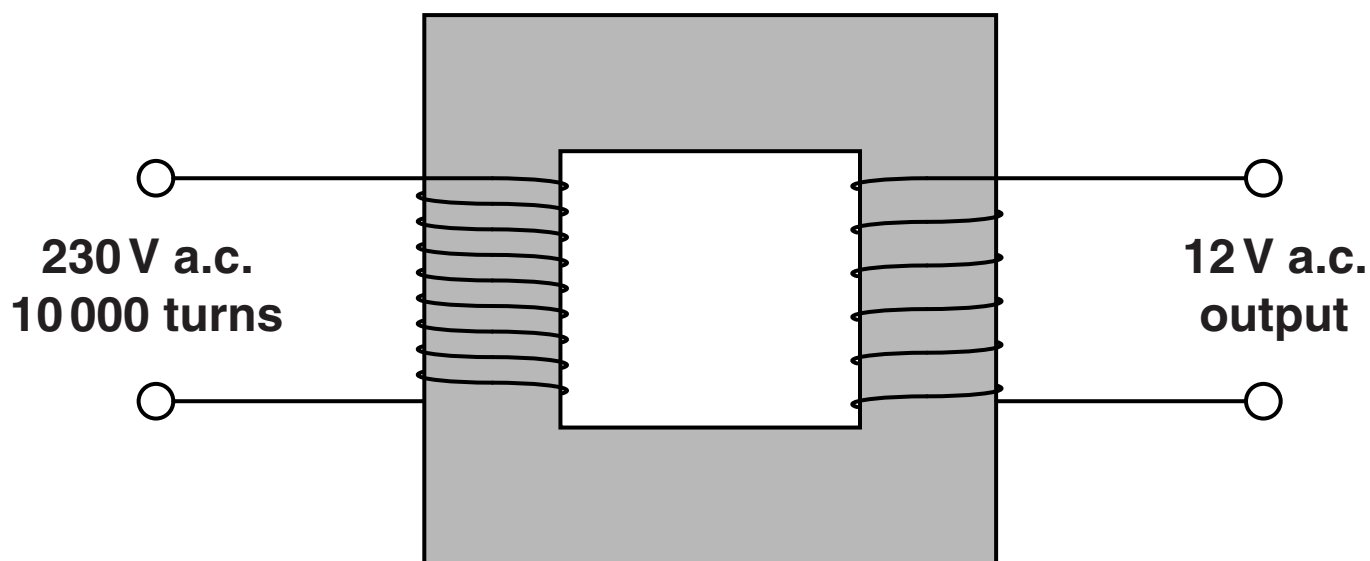
magnetic field strength = 0.45T

charge on positron =  $1.6 \times 10^{-19} \text{ C}$

force = \_\_\_\_\_ N [2]

4 Fig. 4.1 shows an ideal transformer.

FIG. 4.1



(a) State the ratio  $\frac{\text{maximum flux in primary}}{\text{maximum flux in secondary}}$ .

ratio = \_\_\_\_\_ [1]

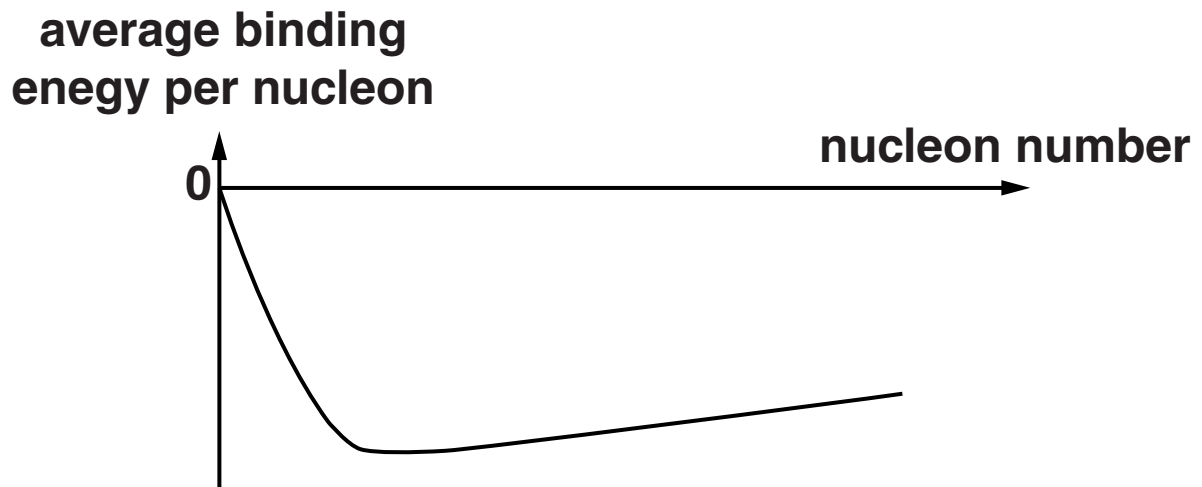
(b) Calculate the number of turns on the secondary coil.

number of turns = \_\_\_\_\_ [2]



- 5 Fig. 5.1 shows how the average binding energy per nucleon varies with nucleon number.

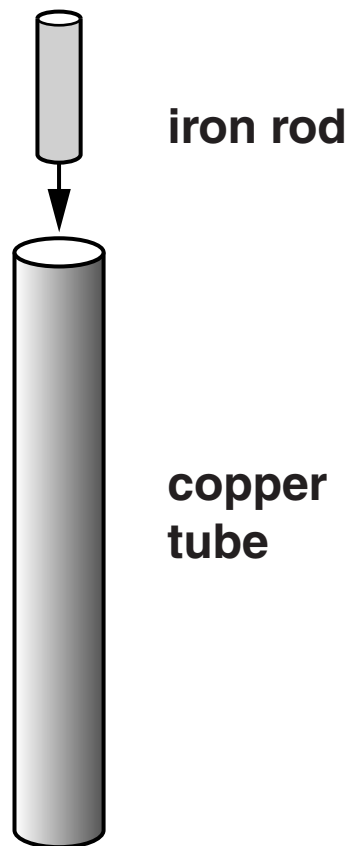
FIG. 5.1



Draw a ring around the section on the graph in which energy can be released from nucleons by the process of fusion. [1]

- 6 In a demonstration, a short unmagnetised iron rod is dropped through a vertical copper tube as shown in Fig. 6.1.**

**FIG. 6.1**



**An identical, MAGNETISED iron rod takes considerably longer to fall through the copper tube. Explain this demonstration using ideas about the induced emf in the copper tube.**

**[3]**

- 7 The kinetic energy  $E$  of a particle of mass  $m$  with momentum  $p$  is given by

$$E = \frac{p^2}{2m}.$$

Calculate the de Broglie wavelength of a proton of kinetic energy  $2.8 \times 10^{-15} \text{ J}$ .

$$\text{mass of proton} = 1.7 \times 10^{-27} \text{ kg}$$

$$h = 6.6 \times 10^{-34} \text{ J s}$$

wavelength = \_\_\_\_\_ m [3]

**8 A radioactive source contains two isotopes, X and Y.**

**Isotope X has a half life of 3 hours**

**Isotope Y has a half life of 6 hours**

**At the beginning of an experiment the source contains twice as many X nuclei as Y nuclei.**

**Here is a list of numbers:**

**2            3            4            6            9**

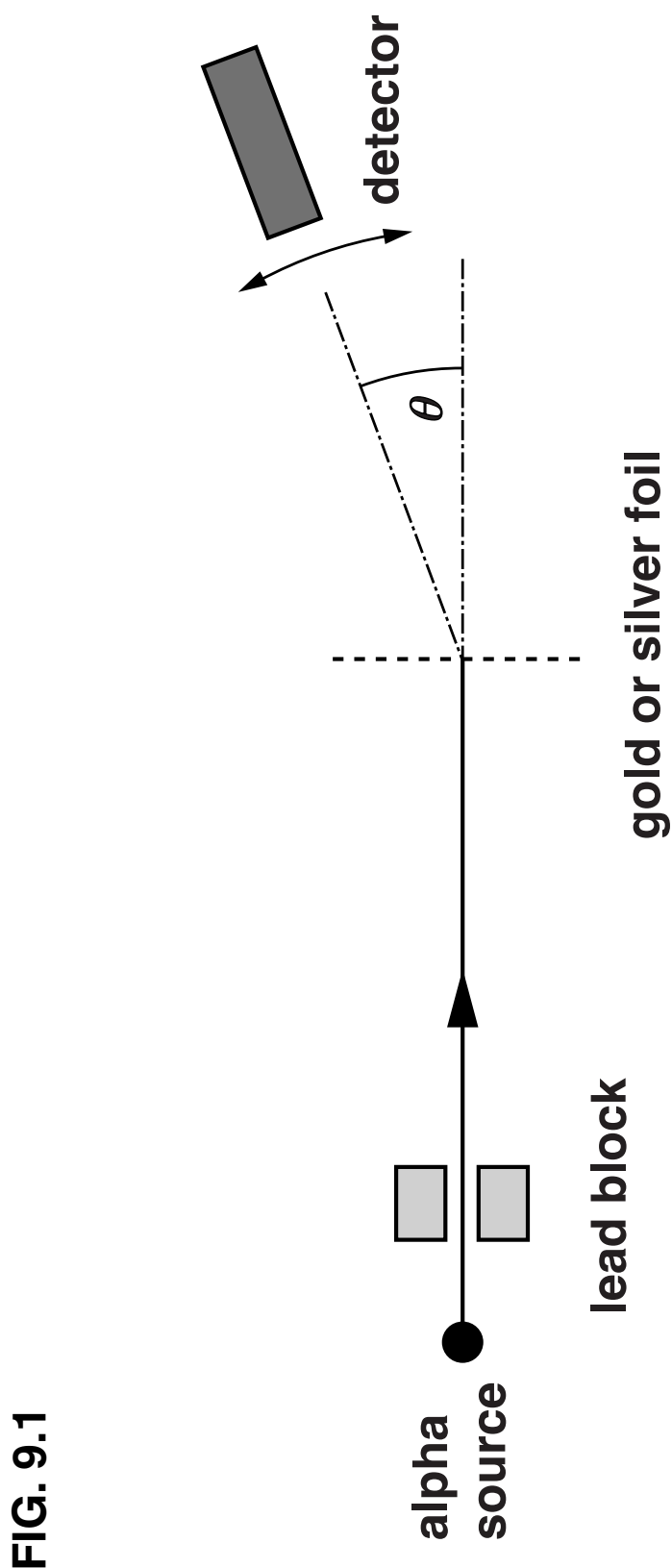
**Which number represents the ratio  $\frac{\text{activity of X}}{\text{activity of Y}}$  at the beginning of the experiment?**

**\_\_\_\_\_ [1]**

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## SECTION B

- 9 This question is about an alpha particle scattering experiment. Fig. 9.1 shows the basic experimental set up.



**Fig. 9.2 opposite, shows the graph of the results of the original experiment published in 1913. It shows the number of alpha particles scattered at different angles  $\theta$ . The experiment was carried out with gold foil ( $^{197}_{79}\text{Au}$ ) and silver foil ( $^{108}_{47}\text{Ag}$ ). You may assume that there were the same number of target nuclei in the path of the alpha particle in each foil.**

- (a) The experimenters looked at the numbers of particles scattered at a wide range of angles, over times long enough to count many particles at each angle. Describe what the graph shows about the scattering from gold foil. Compare this with the observations using silver foil.**

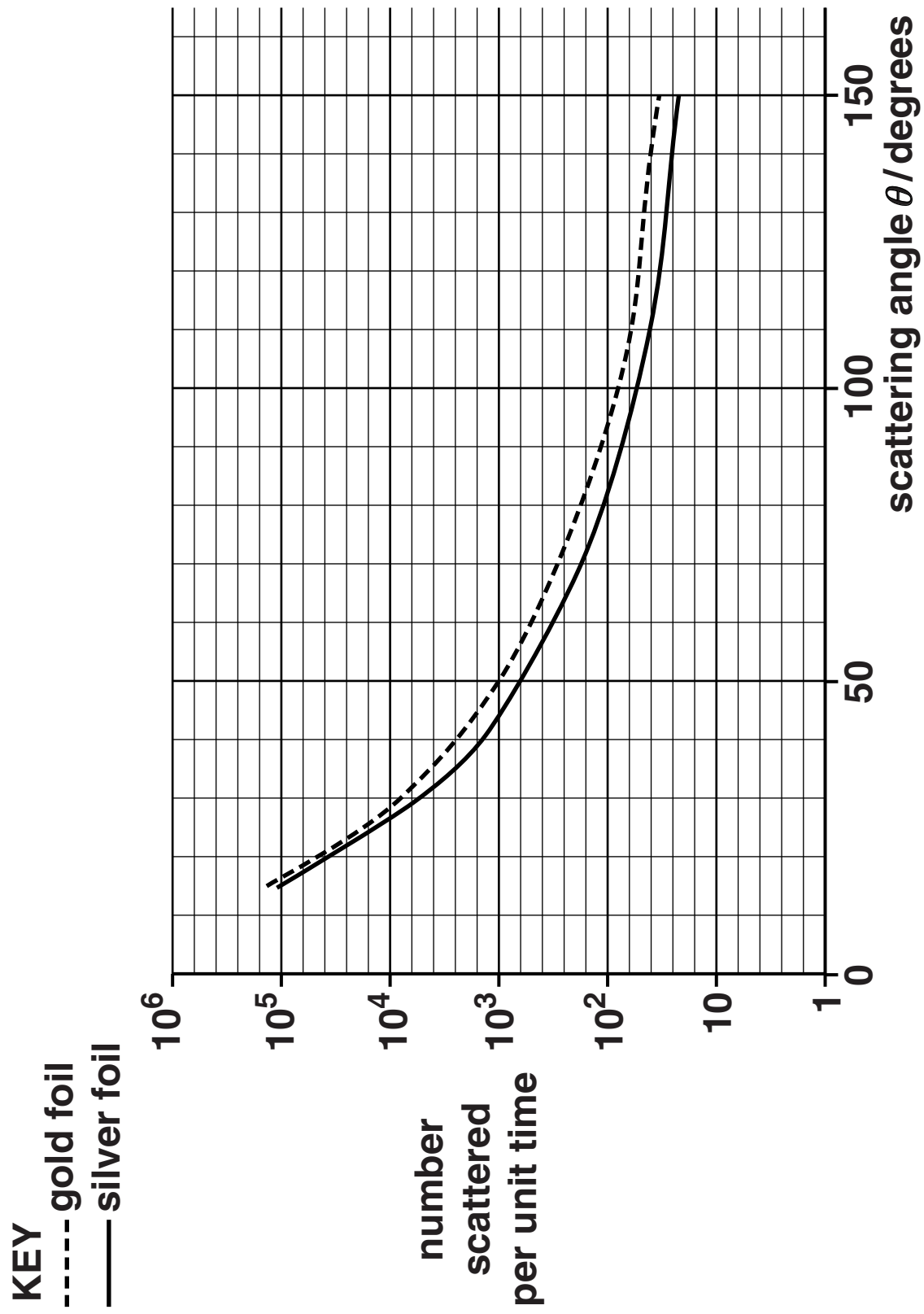


**Your answers should clearly link to the data from the graph.**

**[4]**



FIG. 9.2



- (b) Consider a 6.0 MeV alpha particle striking the foil and bouncing directly back. Calculate the distance between the alpha particle and the centre of a target gold nucleus at the instant of closest approach. Assume that at this point all the initial kinetic energy of the alpha particle is electrical potential energy.

electronic charge,  $e = 1.6 \times 10^{-19} \text{ C}$

electric force constant,  $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

charge on a gold nucleus =  $+79e$

charge on an alpha particle =  $+2e$

closest distance = \_\_\_\_\_ m [3]

**(c) Further experiments show that the radii of nuclei are proportional to  $A^{1/3}$ , where  $A$  is the number of nucleons in a nucleus.**

**(i) Explain why this relationship suggests that the density of nuclei is independent of the number of nucleons within a nucleus.**

**[2]**

**(ii) Calculate the ratio**

$$\frac{\text{radius of a gold-197 nucleus}}{\text{radius of an aluminium-27 nucleus}} .$$

**ratio = \_\_\_\_\_ [2]**

**[TOTAL: 11]**

**10 This question is about beta decay.**

**In beta decay the following two processes can occur:**

**neutron  $\rightarrow$  proton + electron + anti-neutrino**

**proton  $\rightarrow$  neutron + positron + neutrino.**

- (a) State TWO of the quantities that must be conserved in beta decay processes.**

**[2]**

- (b) (i) A neutron can spontaneously decay into a proton. Assuming a neutrino has zero mass, calculate the amount of energy, in J, released when a neutron undergoes beta decay.**

**Data: neutron mass =  $1.6749 \times 10^{-27}$  kg  
proton mass =  $1.6726 \times 10^{-27}$  kg  
electron mass =  $0.0009 \times 10^{-27}$  kg**

**energy = \_\_\_\_\_ J [2]**

- (ii) Explain why a free proton cannot spontaneously undergo beta decay to a neutron, positron and neutrino.**

**[1]**

**(c) In particle physics energies are given in units of eV where  $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$ . Similarly, the mass of particles is often given in units of  $\text{eV}/c^2$  where  $c$  is the speed of light.**

**(i) Show that  $\text{eV}/c^2$  is a unit of mass.**

**[2]**

- (ii) Particle physicists have not been able to assign a precise value to the mass of a neutrino but estimate that it is no more than  $2\text{eV}/c^2$ .

Calculate the maximum value of the mass of a neutrino.

maximum mass = \_\_\_\_\_ kg [2]

[TOTAL: 9]

- 11 This question is about the emf induced in a simple generator. Fig. 11.1 shows a square coil initially perpendicular to a uniform magnetic field.

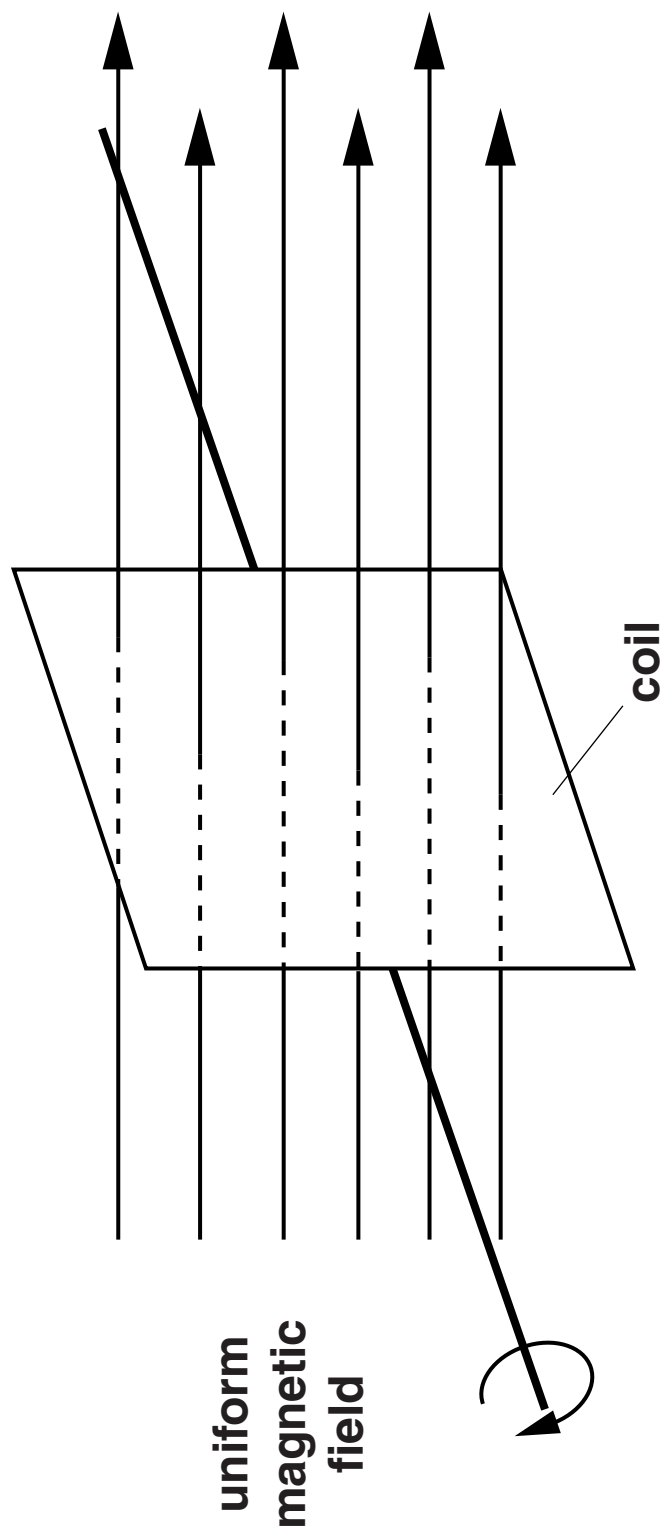
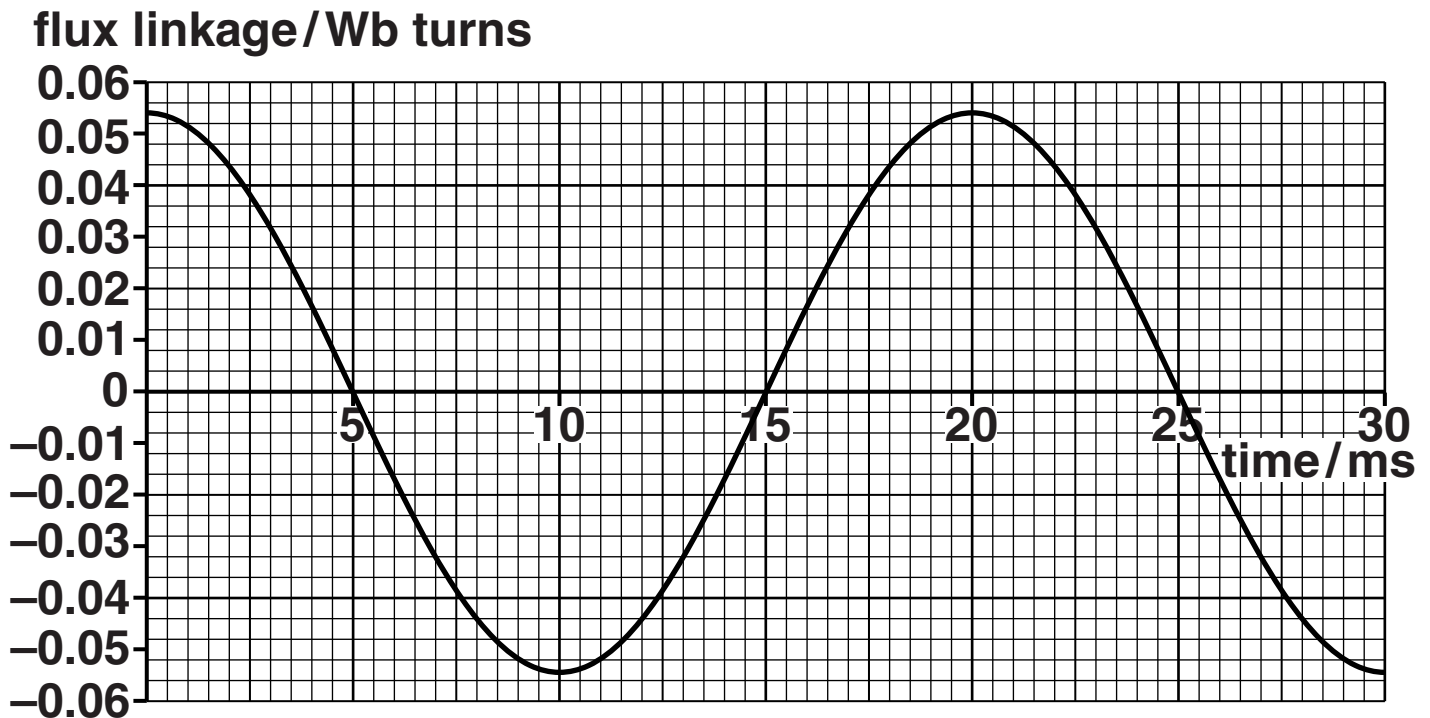


FIG. 11.1



- (a) Fig. 11.2 shows how the flux linkage through the coil changes as it rotates in the field.

**FIG. 11.2**



The coil has 200 turns. The magnetic field has a flux density of  $7.5 \times 10^{-2} \text{ T}$ .

Use these data and data from the graph to calculate the length of a side of the square coil.

length of side = \_\_\_\_\_ m [2]

- (b) An emf is induced in the coil as it rotates. Data from the graph may be used to estimate the maximum emf by two methods. Method 1 uses the maximum gradient of the graph.

Method 2 uses the equation

$$\text{emf} = \text{maximum flux linkage} \times 2\pi f \sin(2\pi ft)$$

where  $f$  is the frequency of the emf and  $t$  is the time.

Use both methods to calculate the maximum emf. Explain which answer you have most confidence in.

Method 1:

maximum emf = \_\_\_\_\_ V

## Method 2:

maximum emf = \_\_\_\_\_ V

Comments on the methods and results:

[8]

[TOTAL: 10]

- 12 This question is about a test of Special Relativity. In 1962 William Bertozzi designed an experiment which measured the velocity of electrons with a range of kinetic energies. He wanted to test Einstein's prediction that particles could not travel faster than the speed of light.**

**Electrons are accelerated in a region of uniform electric field. The time taken to travel the 8.4 m between timing sensors  $T_1$  and  $T_2$  is recorded. The experiment is carried out in a vacuum.**

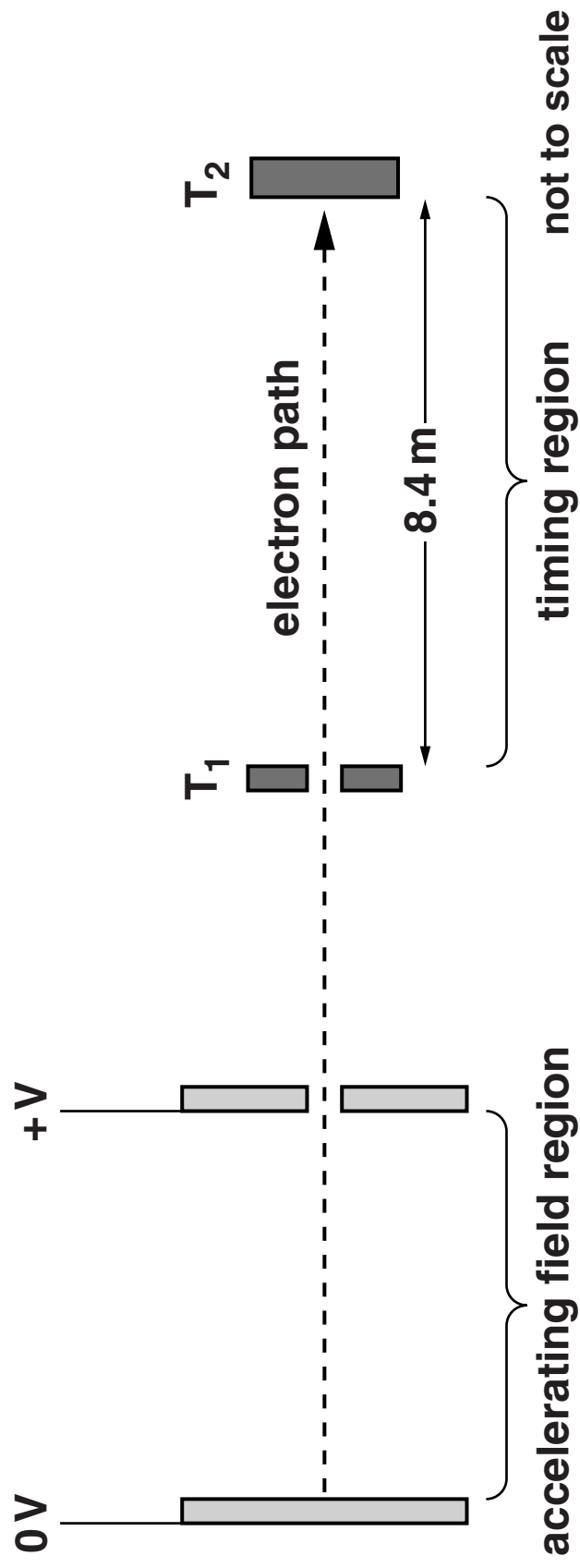
- (a) Draw four field lines on the diagram opposite, representing the uniform electric field in the accelerating region. [2]**
- (b) In one run of the experiment the accelerating p.d. was  $5.0 \times 10^5 \text{ V}$ .**
- (i) Show that the kinetic energy gained by the electrons passing through the accelerating field region is  $8.0 \times 10^{-14} \text{ J}$ .**

$$e = 1.6 \times 10^{-19} \text{ C}$$

**[1]**

**FIG. 12.1**

**Simplified experimental design of Bertozzi's experiment.**



- (ii) Show that the speed  $v$  of an electron of kinetic energy  $8.0 \times 10^{-14} \text{ J}$  would be calculated to be about  $4 \times 10^8 \text{ m s}^{-1}$  when relativistic effects are ignored.

$$\text{mass of electron} = 9.1 \times 10^{-31} \text{ kg}$$

[2]

- (c) In the experiment, the  $8.0 \times 10^{-14} \text{ J}$  electrons took  $3.2 \times 10^{-8} \text{ s}$  to travel across the timing region. Show that the measured velocity of the electrons was  $2.6 \times 10^8 \text{ m s}^{-1}$ .

[1]

- (d) (i) Show that the kinetic energy  $8.0 \times 10^{-14} \text{ J}$  is comparable to the rest energy of an electron. Hence calculate the relativistic factor  $\gamma$ .

$$\text{speed of light} = 3.0 \times 10^8 \text{ m s}^{-1}$$

relativistic factor  $\gamma =$  \_\_\_\_\_ [2]

- (ii) Use your value for the relativistic factor  $\gamma$  to calculate a value for the velocity of the electron when relativistic effects are considered.

velocity of electron = \_\_\_\_\_  $\text{m s}^{-1}$  [2]

- (iii) Comment on your answer to d(ii).

[1]

- (e) Bertozzi could have designed this experiment to use protons. Suggest and explain why he chose to use electrons in the experiment rather than protons.

[2]

[TOTAL: 13]

## **SECTION C**

**THE QUESTIONS IN THIS SECTION ARE BASED ON THE INSERT.**

- 13 LiF chips have taken over from photographic film as a means of monitoring ionising radiation dose. State and explain THREE properties of the LiF chips which make them better than photographic film for this purpose.**

**Property 1**

**Property 2**



**Property 3**

**[6]**

**[TOTAL: 6]**

- 14 (a) Explain why 'dose equivalent' in Sv (line 4) rather than 'absorbed dose' in Gy is used to monitor radiation exposure.

[2]

- (b) Physicists in hospital departments have their absorbed dose monitored continuously to check if their dose equivalents lie within safe margins. Use the data in Fig. 14.1 to calculate the total dose equivalent for a particular physicist in one year. The radiation received is a mixture of gamma rays and neutrons; assume the radiation is received by the whole mass.

**FIG. 14.1**

<b>Mass of physicist</b>	<b>62 kg</b>
<b>Total ionising radiation received</b>	<b>0.12 J</b>
<b>Gamma ray percentage of total energy</b>	<b>75%</b>
<b>Neutron percentage of total energy</b>	<b>25%</b>
<b>Gamma ray quality factor</b>	<b>1</b>
<b>Neutron quality factor</b>	<b>10</b>

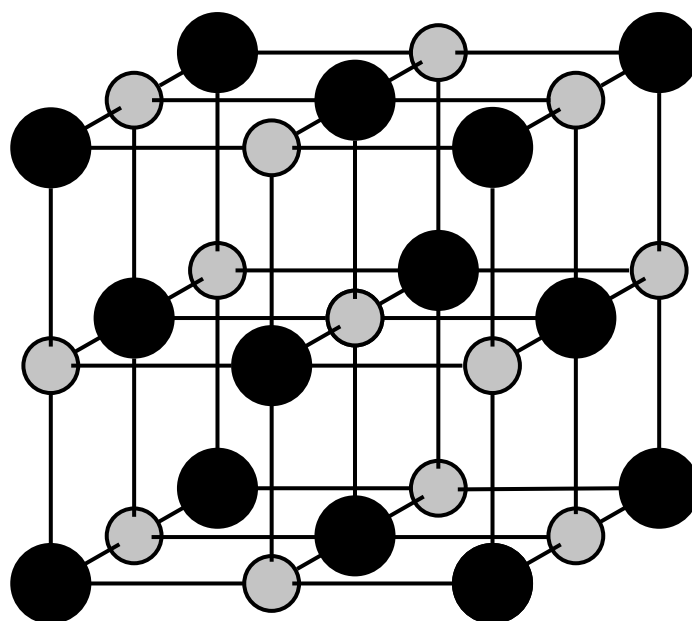
**total dose equivalent = \_\_\_\_\_ Sv [4]**

**[TOTAL: 6]**

**15 This question is about the physical properties of lithium fluoride crystals (TLD ‘chips’).**

**The mechanical properties of the material of the chips require them to be handled with some care. Use the internal structure of such ionic crystals (Fig. 15.1) to explain how this structure gives them these properties.**

**FIG. 15.1**





**In your answer you should clearly identify the relevant properties and link them to the structure.**

**[3]**

**[TOTAL: 3]**

**16 This question is about the use of lithium fluoride (LiF) crystals in measuring radiation dose.**

- (a) Show that the number of magnesium defect sites in a single chip is about  $5 \times 10^{17}$ . Assume a doping level of one magnesium ion per thousand pairs of LiF ions.**

**dimensions of a chip:  $3.0 \text{ mm} \times 2.0 \text{ mm} \times 1.5 \text{ mm}$**

**density of LiF =  $2600 \text{ kg m}^{-3}$**

**molar mass of LiF ion pairs =  $26 \times 10^{-3} \text{ kg mol}^{-1}$**

**Avogadro constant =  $6.0 \times 10^{23} \text{ mol}^{-1}$**

**[4]**

- (b) The energy received by a single chip from a dose of 2 Gy is about  $6 \times 10^{-5}$  J. 0.5% of this is used to promote electrons within the crystal (line 20). For this dose, 1 in  $10^6$  defect sites gain a promoted electron. Show that the energy provided for each electron transition is about 4 eV.

electronic charge =  $1.6 \times 10^{-19}$  C

energy provided by radiation for each electron

transition = \_\_\_\_\_ eV [4]

- (c) Calculate the wavelength of the light emitted when an electron returns to the ground level after heating (lines 58–59). Assume that all this energy is given to the emitted photon.

$$h = 6.6 \times 10^{-34} \text{ J s}$$

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

wavelength = \_\_\_\_\_ m [2]

[TOTAL: 10]



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- 17** Electrons promoted to the higher energy level by incident radiation will naturally fall back to their ground state in time. This is called *fading* (line 49) and can amount to 5% over a three month period. Assuming the decay is exponential, the half life can be calculated as follows:

$$N = N_0 e^{-\lambda t}$$

$$\frac{N}{N_0} = 0.95 = e^{-\lambda t} \quad (1)$$

$$\ln 0.95 = -\lambda t \quad (2)$$

$$\lambda = -\ln 0.95 / 3 \text{ month} = 0.017 \text{ month}^{-1} \quad (3)$$

$$t_{1/2} = 0.69 / 0.017 \text{ month}^{-1} = 41 \text{ months} \quad (4)$$

**Explain each of the steps (1) to (4) in this correct calculation:**

**(1)**

**(2)**

**(3)**

**(4)**

**[4]**

**[TOTAL: 4]**

**18 During the TLD reading process, the photons emitted from the heated LiF chips are detected by a sensitive photomultiplier tube (line 86 and Fig. 18.1 opposite). Electrons are emitted from the photocathode. Secondary electron emission from a series of dynodes along the tube produces a small but measurable current at the anode.**

**(a) The expression**

$$eV = \frac{1}{2} mv^2$$

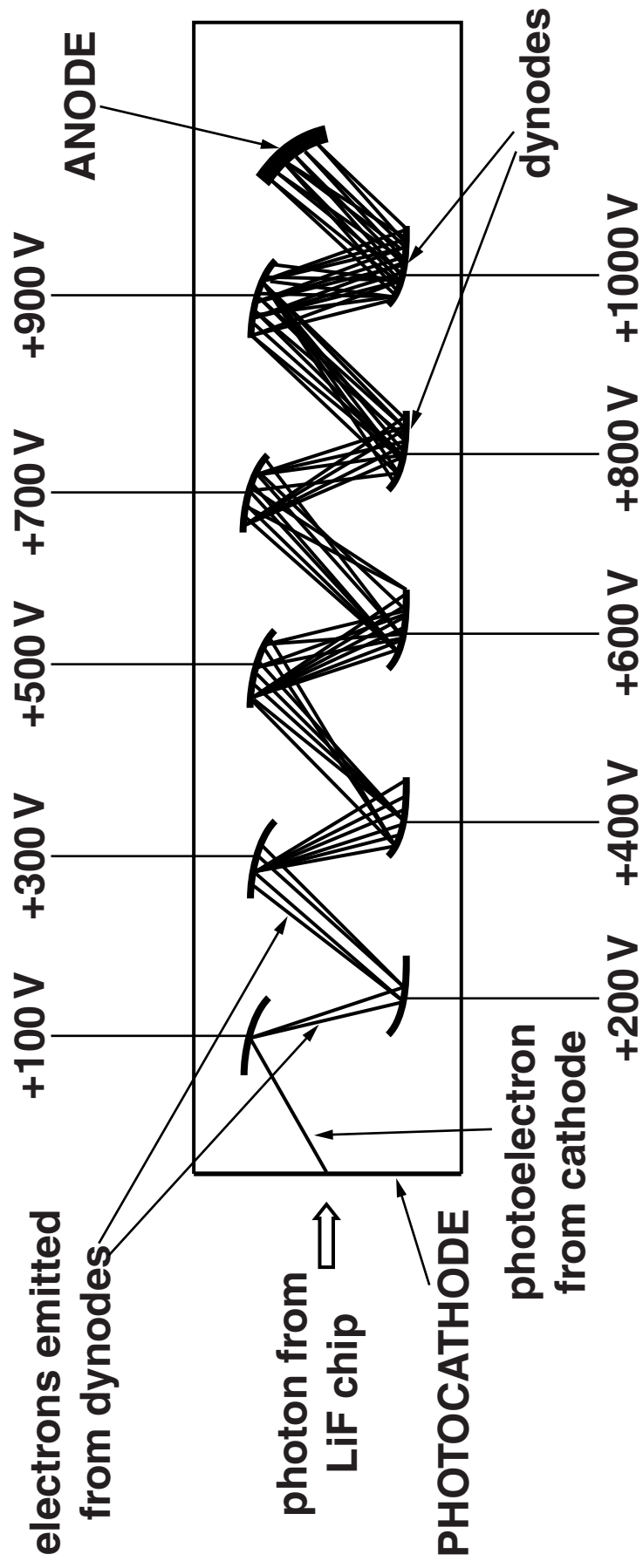
**can be used to calculate the speed with which the photoelectron reaches the +100V dynode. State two assumptions necessary for this to be a valid calculation.**

**(i) Assumption 1**

**(ii) Assumption 2**

**[2]**

**FIG. 18.1**



- (b) Explain why electrons reaching the last dynode have approximately the same speed as those reaching the first dynode.**

**[2]**

**[TOTAL: 4]**

**19 Electrons reach the anode at the far end of the photomultiplier tube to produce a small current.**

- (a) For an anode current of  $5 \times 10^{-13} \text{ A}$ , show that the number of electrons reaching the anode each second is about  $3 \times 10^6$ .**

**electronic charge =  $1.6 \times 10^{-19} \text{ C}$**

**[2]**

- (b) If three electrons are emitted from each dynode for each incident electron, calculate the number of electrons per second that must be incident upon the first dynode.**

**number of electrons per second = \_\_\_\_\_  $\text{s}^{-1}$  [3]**

**[TOTAL: 5]**

**END OF QUESTION PAPER**

**ADDITIONAL ANSWER SPACE**

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




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