OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS
Advanced GCE

PHYSICS A — 2825/04

Nuclear and Particle Physics

Monday **26 JANUARY 2004** Morning 1 hour 30 minutes

Candidates answer on the question paper.
Additional materials:
Electronic calculator

Candidate Name	Centre Number	Candidate Number

TIME 1 hour 30 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name in the space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers in the spaces provided on the question paper.
- Read each question carefully and make sure you know what you have to do before starting your answer.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [ ] at the end of each question or part question.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- The first six questions concern Nuclear and Particle Physics. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	10	
2	12	
3	11	
4	12	
5	13	
6	12	
7	20	
TOTAL	90	

This question paper consists of 20 printed pages.

SP (AT/SLM) S52018/4

[Turn over

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall,	$g = 9.81\ \mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion, $s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

refractive index, $n = \dfrac{1}{\sin C}$

capacitors in series, $\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$

capacitors in parallel, $C = C_1 + C_2 + \ldots$

capacitor discharge, $x = x_0 e^{-t/CR}$

pressure of an ideal gas, $p = \frac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$

radioactive decay, $x = x_0 e^{-\lambda t}$

$t_{\frac{1}{2}} = \dfrac{0.693}{\lambda}$

critical density of matter in the Universe, $\rho_0 = \dfrac{3H_0^{\,2}}{8\pi G}$

relativity factor, $= \sqrt{(1 - \dfrac{v^2}{c^2})}$

current, $I = nAve$

nuclear radius, $r = r_0 A^{1/3}$

sound intensity level, $= 10 \lg \left(\dfrac{I}{I_0}\right)$

For Examiner's Use

Answer **all** the questions.

1 Fig. 1.1 shows how the strong interaction (strong force) between two neutrons varies with the distance between their centres.

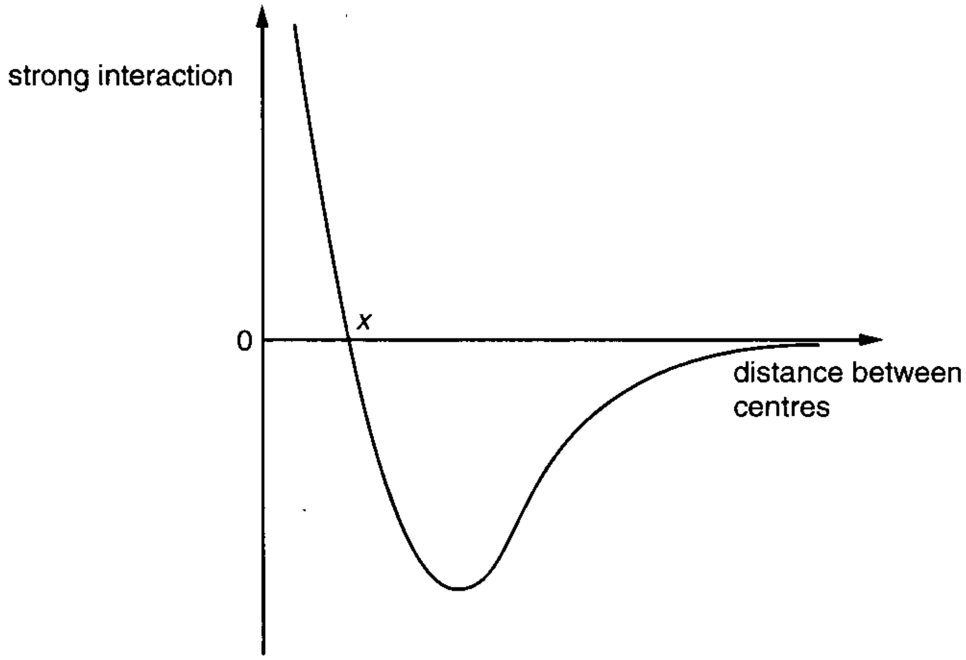

Fig. 1.1

(a) Explain why x indicates the equilibrium separation of two neutrons in a nucleus.

....

....[1]

(b) For two **neutrons**, $x = 0.82 \times 10^{-15}$ m.
For two **protons** at a separation of 0.82×10^{-15} m, calculate the electrostatic force between them.

force = ... N [3]

For Examiner's Use

(c) **(i)** On Fig. 1.1, label a point P which indicates a possible equilibrium separation for two **protons**. Explain your reasoning.

....

....

....

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....[4]

(ii) Estimate the size of the strong force for two **protons** at their equilibrium separation. Give a reason for your answer.

....

....

....

....[2]

[Total: 10]

For Examiner's Use

2 **(a)** Describe the mechanism of nuclear fission that occurs inside a nuclear reactor. Your description should make clear how the fission process is caused and how a chain reaction occurs. Use nuclear equations to illustrate the processes you are describing.

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....[6]

For Examiner's Use

(b) Fission reactions produce hazardous radioactive materials.

(i) State **one** safety precaution that can be used in each of the following.

1 handling radioactive materials

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....

2 the storage of radioactive materials

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3 the disposal of radioactive materials

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.... [3]

(ii) Use physical principles to explain why each precaution given in **(i)** is effective.

1 ....

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2 ....

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3 ....

.... [3]

[Total: 12]

[Turn over

For Examiner's Use

3 This question is about the properties of particles in a plasma.

(a) The total kinetic energy E_k of the particles in a plasma at temperature T is

$$E_k = 2.1 \times 10^{-23} nT$$

where n is the number of particles in the plasma.

(i) Calculate the kinetic energy of one particle of a plasma at 3.0×10^8 K.

kinetic energy = ... J [1]

(ii) State with a reason whether the value you have calculated in **(i)** represents the kinetic energy of every particle of the plasma.

....

....

....[1]

(b) Two deuterium nuclei ($^2_1$H) move with equal speeds towards each other along the same straight line until they come to rest.

Fig. 3.1

(i) Explain why each nucleus decelerates.

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....

....[2]

(ii) On the axes of Fig. 3.2, sketch a graph which shows how the velocity v of one of these nuclei varies with time t during its deceleration.

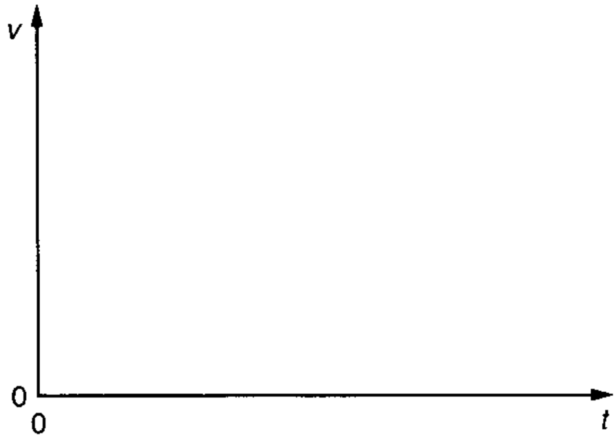

Fig. 3.2

[2]

(iii) Each of the two nuclei has the kinetic energy calculated in **(a)(i)**. When they come to rest their total potential energy is about 1.3×10^{-14} J.
Explain why.

....

....

....[2]

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

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

Calculate the separation of the deuterium nuclei when they come to rest.

separation = ... m [2]

(c) When two deuterium nuclei fuse, the products are a helium-3 nucleus (^3_2He) and a neutron. Write a nuclear equation for this reaction.

[1]

[Total: 11]

[Turn over

For Examiner's Use

4 (a) Describe the principles of operation of the cyclotron as used to accelerate protons. Your account should explain how the protons are accelerated and why they move along spiral paths consisting of a series of semicircular loops.
You should illustrate your account with a labelled sketch.

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....[7]

(b) The speed v of a proton of mass m and charge Q, moving in a circular path of radius R inside a uniform field of flux density B, is given by

$$v = \frac{BQR}{m}.$$

(i) Show that the supply frequency f for the cyclotron in which the proton is moving is given by

$$f = \frac{BQ}{2\pi m}.$$ **equation 1**

[3]

(ii) Calculate the supply frequency for a cyclotron in which the magnetic field has a flux density of 1.20 T.

frequency = ... Hz [1]

(c) The supply frequency for accelerating protons in a cyclotron depends only on the magnetic flux density. State what feature of equation 1 indicates this.

....

....

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....[1]

[Total: 12]

For Examiner's Use

5 (a) (i) Explain what is meant by *antimatter*.

....

....

....[2]

(ii) Name the antiparticle of the electron and state its symbol.

....[1]

(b) (i) A slow-moving electron reacts with its stationary antiparticle and two photons are produced. Write an equation to represent this process.

[1]

(ii) Calculate the frequency of one of these photons.

frequency = ... Hz [3]

(c) Electrons having initial energy 2.0 MeV are directed into a linear accelerator, as shown in Fig. 5.1.

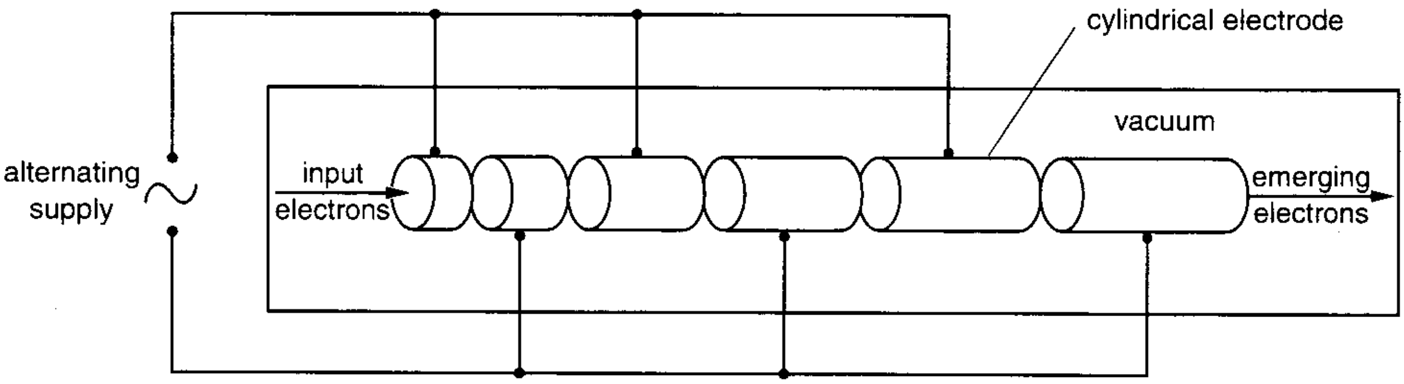

Fig. 5.1

The electrodes are connected alternately to the opposite terminals of the alternating supply. The polarity of the supply reverses by the time the electrons emerge from each cylindrical electrode. The maximum potential difference between adjacent cylinders is 3.0 MV.

(i) Calculate the maximum energy in MeV of an electron emerging from the accelerator. Explain your reasoning.

energy = ... MeV [2]

(ii) One of these emerging electrons collides with its stationary antiparticle.

Fig. 5.2

Two photons are produced. The photons have momenta of equal magnitude. On Fig. 5.2, draw arrows to represent the momenta of these two photons. Explain your sketch.

....

....

....[2]

(iii) Suggest why the length of successive electrodes increases.

....

....

....

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....[2]

[Total: 13]

For Examiner's Use

6 The atomic masses of five nuclides in unified atomic mass units, u, are plotted against proton number in Fig. 6.1. The arrows indicate the direction of nuclear decay processes.

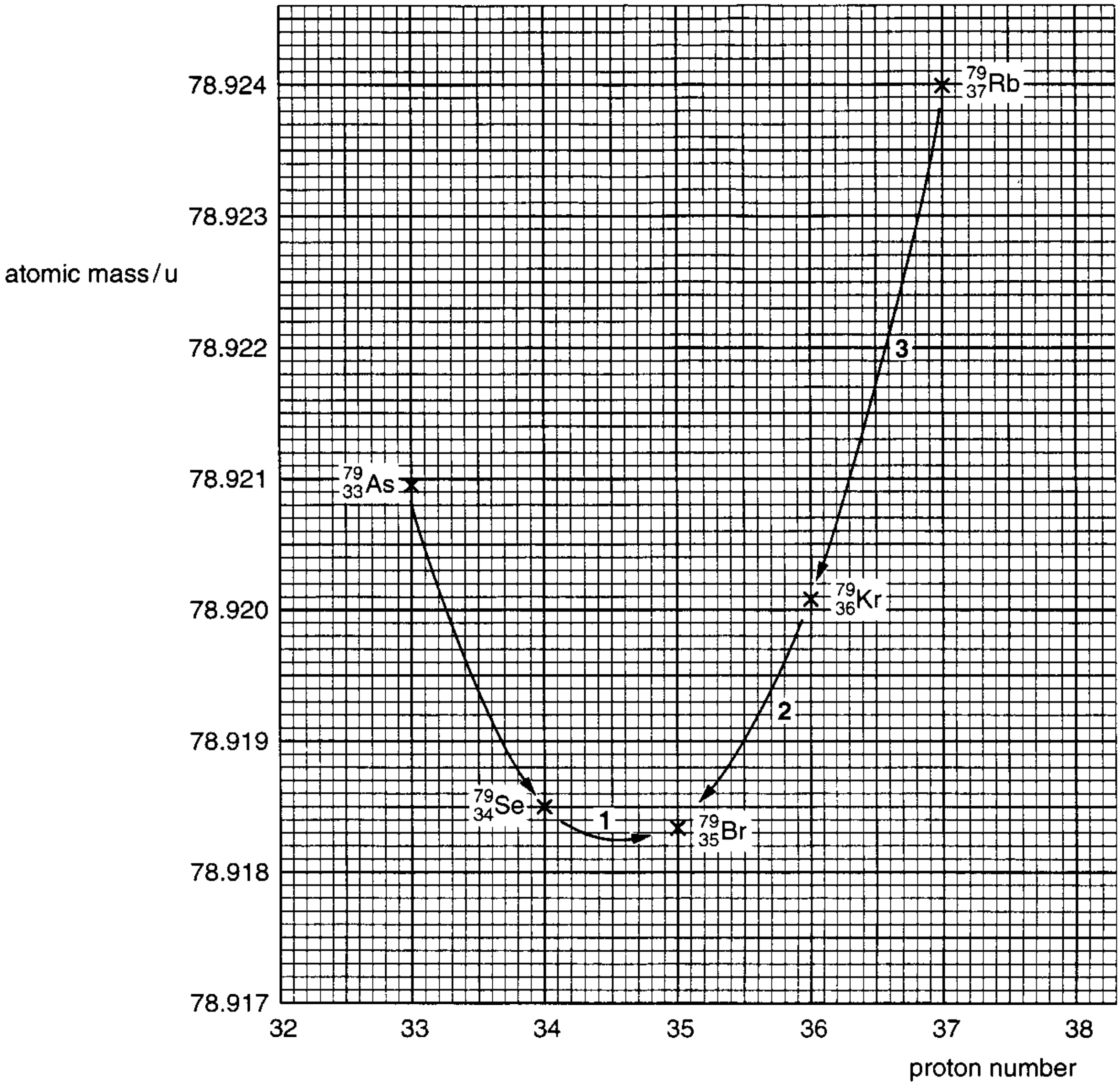


Fig. 6.1

For Examiner's Use

(a) Complete Fig. 6.2 to show the numbers of protons and neutrons in the nuclei of $^{79}_{34}Se$, $^{79}_{35}Br$ and $^{79}_{36}Kr$.

	number of protons	number of neutrons
$^{79}_{34}Se$	....	....
$^{79}_{35}Br$	....	....
$^{79}_{36}Kr$	....	....

Fig. 6.2 [1]

(b) Name the particles which are emitted in the decay processes labelled **1** and **2** on Fig. 6.1.

1 ....

2 ....[2]

(c) **(i)** Write an equation to represent the decay process labelled **3** on Fig. 6.1.

[2]

(ii) State the kind of nuclear force which is responsible for this decay process.

....[1]

(iii) Use Fig. 6.1 to determine the loss of mass in the decay process referred to in **(i)**.

mass = ... u [1]

(iv) Hence calculate the energy in joules released in this decay process.

energy = ... J [3]

(v) Explain why the $^{79}_{36}Kr$ nucleus has only a small fraction of the kinetic energy released in this decay process.

....

....

....[2]

[Total: 12]

7 Scintillation counters have been widely used to detect particles in high energy physics experiments. A scintillation counter consists of a sheet of plastic scintillator material coupled to a photomultiplier tube, as shown in Fig. 7.1.

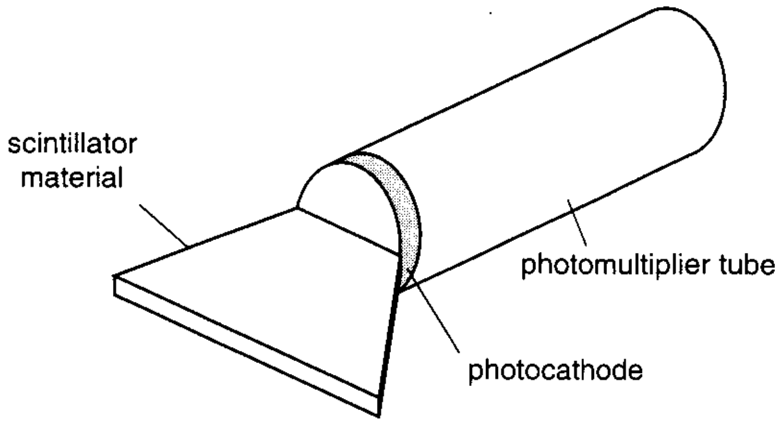


Fig. 7.1

The scintillator material produces a tiny flash of light when struck by a high energy particle. This light undergoes total internal reflection within the scintillator material until it reaches the photocathode of the photomultiplier tube. Fig. 7.2 shows this and also the internal structure of the photomultiplier tube.

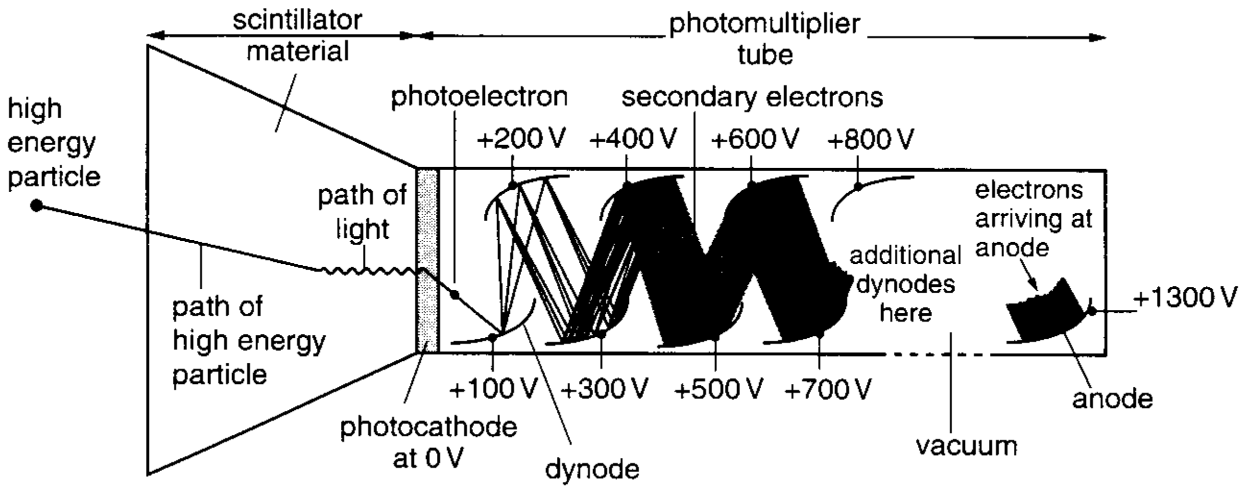


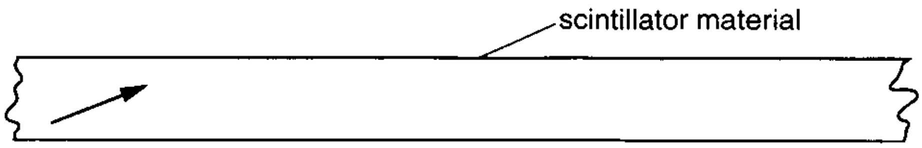
Fig. 7.2

When the flash of light reaches the photocathode, the photoelectric effect causes an electron, called a photoelectron, to be emitted from the photocathode. This electron is attracted by a potential difference between the photocathode and the first curved plate, called a dynode. When the electron hits the first dynode, with 100 eV energy in this case, several *secondary* electrons are emitted. These are accelerated to the next dynode, where the process is repeated. The pulse of charge at the final dynode, called the anode, can be measured by an electronic system.

For Examiner's Use

(a) The diagram below shows a section of the scintillator viewed from the side.

(i) Explain, with the aid of the diagram, how the light may be transmitted along the scintillator by total internal reflection.



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....

....

....[3]

(ii) The scintillator material has a refractive index of 1.58. Calculate the critical angle C for this material in air.

critical angle = ...° [2]

(b) In a particular experiment, a single high energy particle loses 1.5 MeV of energy in the scintillator material and in losing this energy produces 1.0×10^4 photons of wavelength 413 nm.

(i) Show that the energy of one photon of wavelength 413 nm is about 3.0 eV.

[2]

(ii) What percentage of the particle's energy loss has been converted into light in the scintillator material?

percentage = ...% [2]

(c) The photocathode is coated with potassium which has a work function ϕ of 2.2 eV.

(i) Calculate the threshold wavelength for potassium.

threshold wavelength = ... nm [2]

(ii) Why would zinc, which has a work function of 4.3 eV, be unsuitable for the photocathode coating?

....

....[1]

(iii) Calculate the maximum speed v_{max} of the photoelectrons emitted from the potassium photocathode.

v_{max} = ... m s^{-1} [3]

Question 7 continued over the page.

[Turn over

For Examiner's Use

(d) **(i)** In the photomultiplier tube, there are 13 dynodes, including the anode, and 3 secondary electrons are emitted at each dynode per incident electron. Calculate the number of electrons received at the anode for one electron leaving the photocathode.

number = ... [2]

(ii) This pulse of electrons lasts 3.0×10^{-9} s. Calculate the average current during this pulse.

average current = ... A [3]

[Total: 20]

END OF QUESTION PAPER