THIS IS A LEGACY SPECIFICATION

OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE
PHYSICS A
Nuclear and Particle Physics

2825/04

Candidates answer on the question paper

OCR Supplied Materials:
None

Other Materials Required:
- Electronic calculator

Tuesday 16 June 2009
Afternoon

Duration: 1 hour 30 minutes

Candidate Forename		Candidate Surname	

Centre Number						Candidate Number				

INSTRUCTIONS TO CANDIDATES

- Write your name clearly in capital letters, your Centre Number and Candidate Number in the boxes above.
- Use black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure that you know what you have to do before starting your answer.
- Answer **all** the questions.
- Do **not** write in the bar codes.
- Write your answer to each question in the space provided, however additional paper may be used if necessary.

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 **90**.
- 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.
- This document consists of **20** pages. Any blank pages are indicated.

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

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,	$p = \frac{1}{3}\dfrac{Nm}{V}<c^2>$
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,	$= 10\lg\left(\dfrac{I}{I_0}\right)$

Answer **all** the questions.

1 This question is about the forces which act between protons.
The graph in Fig. 1.1 shows how the **strong force** F_S between two protons varies with their separation x.

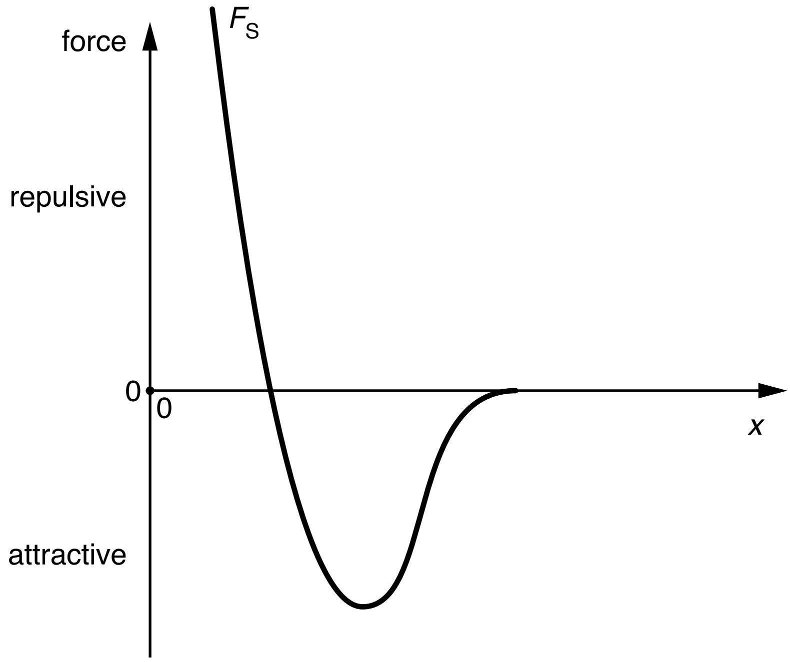

Fig. 1.1

(a) On Fig. 1.1, sketch a graph to show how the **electrostatic force** F_E between two protons varies with their separation. **[2]**

(b) Explain the features of these two graphs which indicate that the strong force is short range but the electrostatic force is not.

....

....

....

....

.... **[2]**

(c) State the relationship between the electrostatic force F_E and the separation x.

.... **[1]**

(d) The ratio $R = \dfrac{\text{electrostatic force}}{\text{gravitational force}}$.

(i) Show that R is constant whatever the separation of the protons.

....

.... **[3]**

(ii) Calculate the value of R.

R = ... **[2]**

[Total: 10]

2 This question is about nuclear fission.

(a) A uranium-235 nucleus absorbs a neutron and becomes uranium-236. This nucleus undergoes fission producing nuclei of caesium and rubidium. Two neutrons are emitted. Fig. 2.1 shows the binding energy per nucleon of the uranium (U), caesium (Cs) and rubidium (Rb) nuclei plotted against nucleon number.

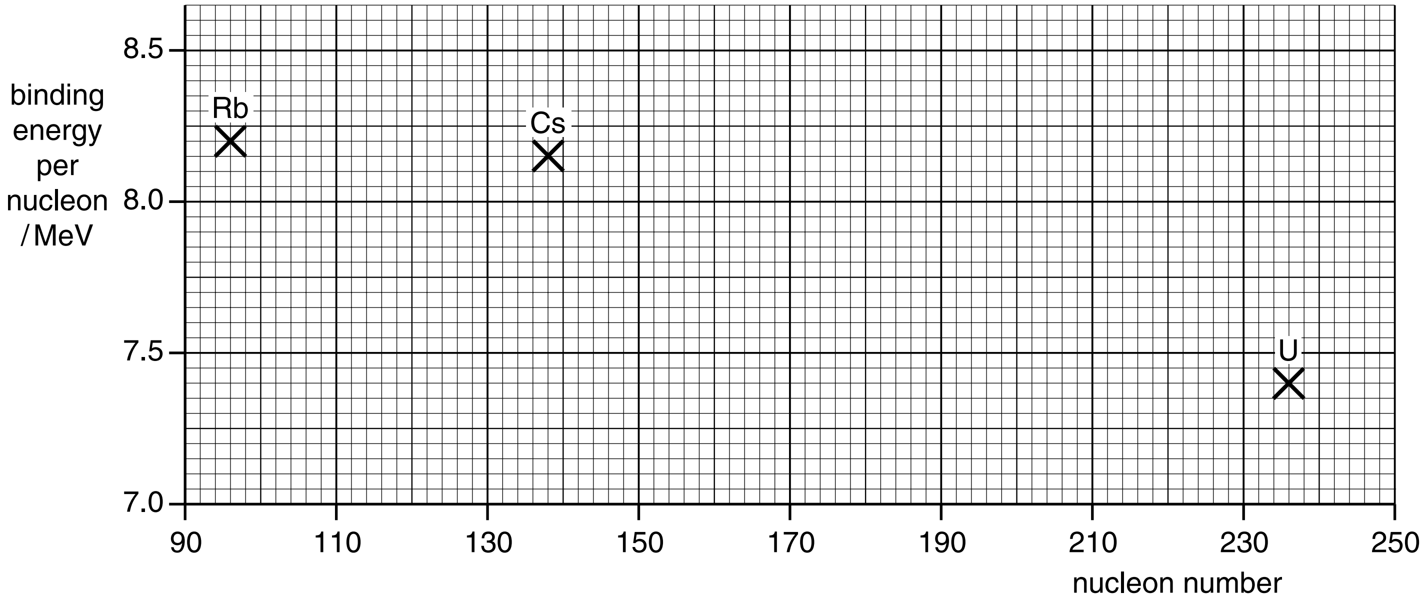

Fig. 2.1

(i) Find the energy released by this fission reaction.

energy = ... MeV **[4]**

(ii) Explain what happens to the energy released when the reaction takes place inside a sample of solid uranium.

....

....

....

....

.... **[3]**

(b) On Fig. 2.2, sketch a graph to show how the relative yield of the products of fission reactions vary with their nucleon number. **[2]**

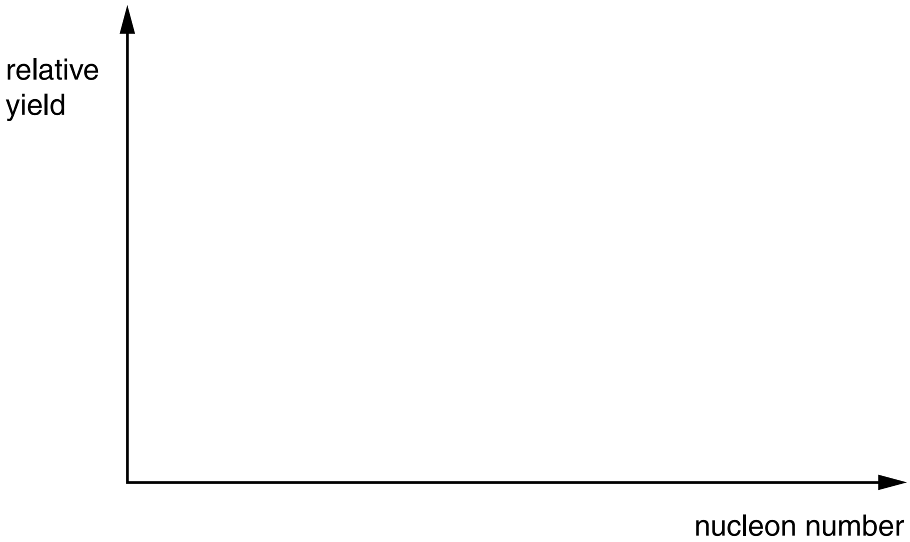

Fig. 2.2

(c) When uranium-236 nuclei $^{236}_{92}U$ undergo fission, a few split into two identical nuclei.

(i) Mark the position of these product nuclei on Fig. 2.2.
Label the point **P**. **[1]**

(ii) Write a nuclear equation to represent this fission reaction.
Use **X** to represent any unknown nucleus.
Assume that no neutrons are emitted.

.... **[1]**

[Total: 11]

3 This question is about the decay of plutonium-239 $^{239}_{94}Pu$.

Plutonium-239 decays by α-emission to uranium-235 $^{235}_{92}U$.

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

.... years **[1]**

(ii) A sample consisting of N_0 nuclei of plutonium-239 is prepared and left to decay.

On Fig. 3.1, sketch graphs to show

1 how the number of plutonium-239 nuclei varies with time

2 how the number of uranium-235 nuclei varies with time.

Label your graphs **Pu** and **U** respectively.

half-life of uranium-235 = 7.04×10^8 y **[3]**

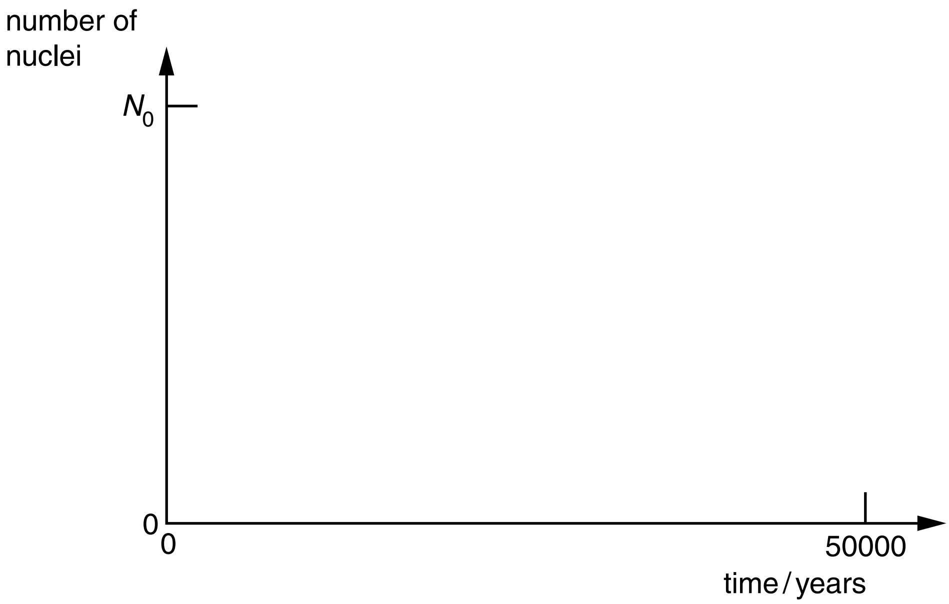

Fig. 3.1

(iii) State the approximate time at which

number of plutonium-239 nuclei = number of uranium-235 nuclei.

.... years **[1]**

(iv) Explain why your value in **(iii)** is only approximate.

....

.... **[1]**

(b) Show that the energy released when a $^{239}_{94}\text{Pu}$ nucleus decays is approximately 8×10^{-13} J.

nuclear masses	$^{239}_{94}\text{Pu}$	239.000 58 u
	$^{235}_{92}\text{U}$	234.993 45 u
	$^{4}_{2}\text{He}$	4.001 51 u

[3]

(c) (i) Calculate the speed of an α-particle which has the kinetic energy calculated in **(b)**.

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

(ii) The speed of the α-particle emitted in the plutonium decay is slightly less than the value calculated in **(i)**. Suggest a reason for this.

....

....

.... **[1]**

[Total: 12]

4 Electrons e^- and positrons e^+ are accelerated to high energies inside a synchrotron. These electrons and positrons are made to travel at identical speeds but in opposite directions, in two separate circles. Each circle has a radius of 50.0 m.
A plan view of these two circles is shown in Fig. 4.1.

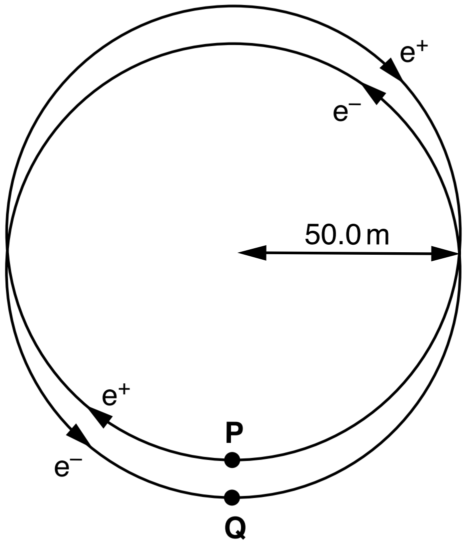

Fig.4.1

The particles are kept in these circular paths by a magnetic field.

(a) State the direction of the magnetic field at points **P** and **Q**.

P .... **Q** .... **[1]**

(b) Explain why synchrotrons are always designed with a large radius.

....

....

....

.... **[2]**

(c) The particles make 9.25×10^5 revolutions per second.
The mean flux density of the magnetic field is 1.30×10^{-4} T.

(i) Show that the speed of the electrons is about $2.9 \times 10^8\,\text{m s}^{-1}$.

[2]

(ii) Calculate the mass of each electron.

mass = ... kg **[3]**

(iii) Explain why your answer to **(ii)** is different from the value given in the data on page 2.

....

....

....

.... **[2]**

(d) When an electron meets a positron travelling at an identical speed in the opposite direction, the two particles annihilate and two γ-photons may be produced. These travel in opposite directions, as illustrated in Fig. 4.2.

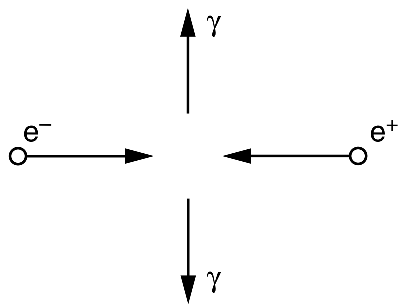

Fig. 4.2

Use the principle of conservation of momentum to explain why such an annihilation **never** produces **only one** photon.

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.... **[3]**

[Total: 13]

5 This question is about the stability of baryons.

(a) The following are four suggested baryon decay reactions.

$n^0 \rightarrow \Sigma^0 + \pi^+$ **reaction 1**

$n^0 \rightarrow p^+ + e^- + \bar{\nu}$ **reaction 2**

$p^+ \rightarrow \pi^+ + \pi^0$ **reaction 3**

$p^+ \rightarrow n^0 + e^+ + \nu$ **reaction 4**

By comparing values of charge *Q*, baryon number *B* and strangeness *S*, deduce which of these reactions might be possible.

data:

particle	*Q*	*B*	*S*
Σ^0	0	1	–1
π^+	+1	0	0
π^0	0	0	0

reaction 1

Is reaction 1 possible? ....

reason ....

reaction 2

Is reaction 2 possible? ....

reason ....

reaction 3

Is reaction 3 possible? ....

reason ....

reaction 4

Is reaction 4 possible? ....

reason ....
[6]

(b) When a baryon decays, another baryon is always produced.

Explain this.

....

....

.... **[1]**

(c) Use the data below to explain why a free proton is stable but a free neutron is not.
Give the relevant nuclear equation.

particle	rest mass/MeV
electron	0.51
proton	938.27
neutron	939.57
all other baryons	>1000

....

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....

.... **[4]**

(d) State the circumstance in which a neutron is stable.

....

.... **[1]**

[Total: 12]

6 **(a)** Describe the **conditions** inside the Sun which make nuclear fusion possible.
Explain
- how these conditions occur
- how they make fusion possible.

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.... **[5]**

(b) Describe the **process** of nuclear fusion inside the Sun.
Your account should
- give a nuclear equation which summarises the reactions in which protons fuse to form a helium nucleus
- explain why these reactions generate energy
- explain why only a very small proportion of proton-proton collisions result in fusion.

....

....

....

....

[7]

[Total: 12]

7 A Physics student receives a present of a torch which requires neither batteries nor a filament light bulb. The basic arrangement of the torch is shown in Fig. 7.1 and has the following features:

- a rechargeable capacitor instead of batteries
- a fixed coil of wire through which a powerful magnet can move inside the body of the torch
- a circuit board with diodes and the rechargeable capacitor

The capacitor can be charged by making the magnet move back and forth through the coil.
The capacitor can be discharged through an LED to provide the light.

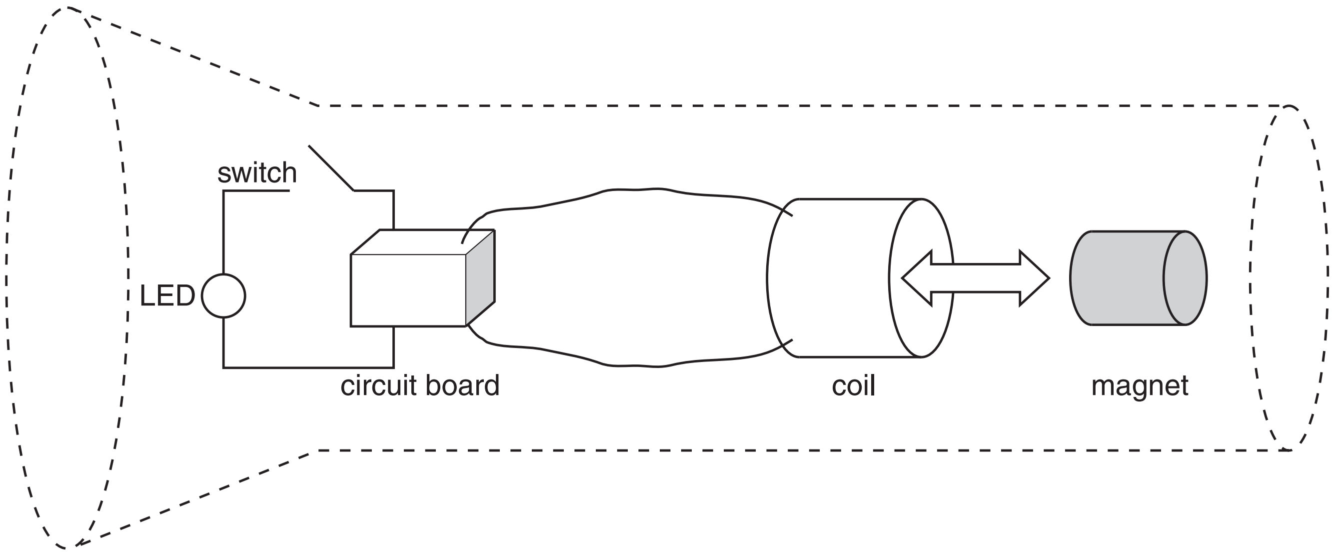

Fig. 7.1

To charge the capacitor in the circuit board, the torch is repeatedly inverted. In this way, the magnet is lifted through a vertical height *h* and then allowed to fall through the coil. It is then lifted through *h* again and allowed to fall. The process is shown in Fig. 7.2.

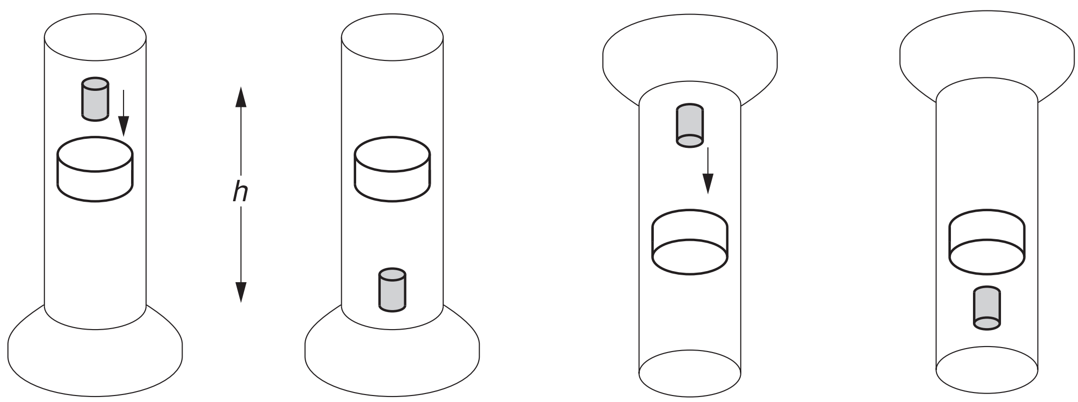

Fig. 7.2

(a) The mass of the magnet is 240 g and the height h through which it falls is 6.0 cm.

(i) Calculate the loss in gravitational potential energy in each fall.

loss in GPE = ... J **[2]**

(ii) Calculate the work done on the magnet in making 84 inversions.

work done = ... J **[1]**

(iii) Explain why the total work done by the student will be much greater than your answer to **(ii)**.

....

.... **[1]**

(b) The energy stored in the capacitor after 84 inversions is 10.5 J.
The mean power dissipation of the LED in the torch is 55 mW.

Calculate how long the light will operate after the 84 inversions.

time = ... s **[2]**

(c) To find out more about the torch, the student connects a voltmeter and data logger to the coil when the magnet falls through it. The magnet is released from rest at time **A** and finishes at rest at time **C**. The resulting induced e.m.f. is shown in Fig. 7.3.

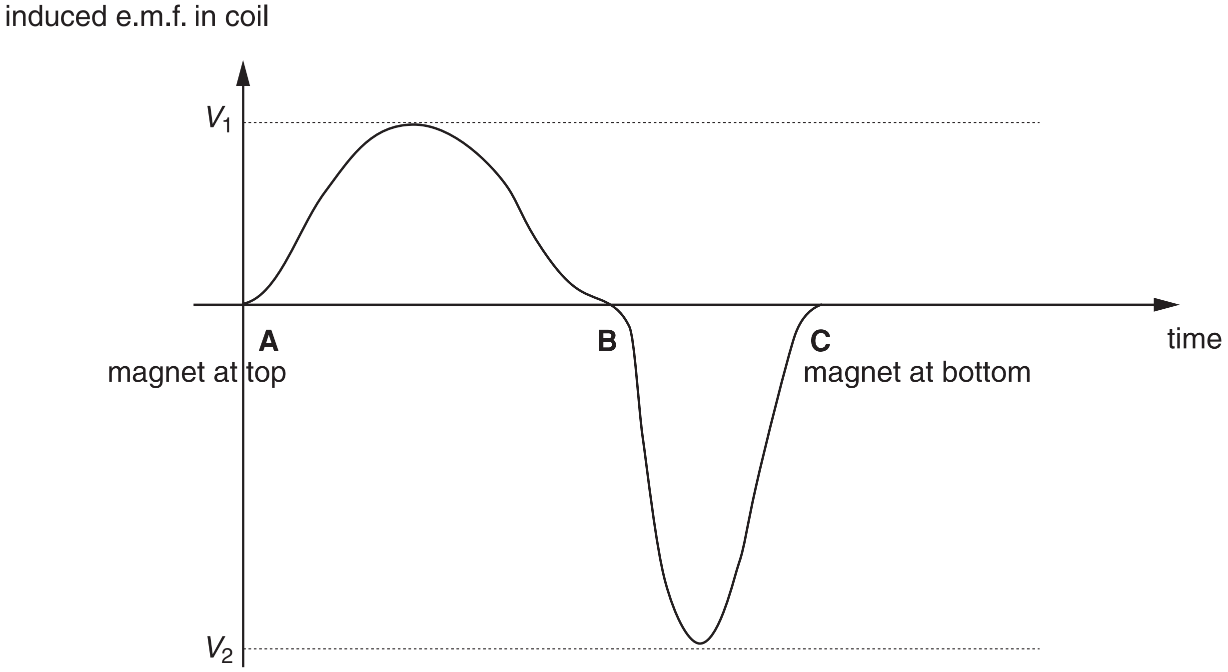

Fig. 7.3

Explain the following:

(i) The time **AB** in the positive region is greater than the time **BC** in the negative region.

....

.... **[2]**

(ii) Why an e.m.f is induced in the coil.

....

.... **[1]**

(iii) The peak induced e.m.f. V_1 is less than the peak induced e.m.f. V_2.

....

.... **[2]**

(iv) The induced e.m.f. consists of a positive voltage region and a negative voltage region.

....

.... **[1]**

(d) The characteristics of the magnet, coil and capacitor are as follows:

• magnetic flux ϕ emerging from one pole of magnet	0.54 mWb
• number of turns N on coil	420
• resistance R of coil and circuit	28 Ω
• capacitance C of capacitor	88 mF

(i) The average current I charging the capacitor during the positive voltage time interval **AB** is given by

$$I = \frac{Q}{t}$$

where Q is the total charge which has flowed and t is the time interval **AB**.

The mean induced e.m.f. E is given by

$$E = \frac{N\phi}{t}.$$

1 Show that the total charge Q is given by

$$Q = \frac{N\phi}{R}.$$

[2]

2 Show that the charge Q on the capacitor at time **B** is about 8 mC.

[1]

(ii) Explain why diodes are necessary between the coil and the capacitor.

....

.... **[1]**

(iii) Explain why a charge of about 16 mC is stored on the capacitor after one fall of the magnet.

....

.... **[1]**

Question 7 continues on the next page.

(iv) Show that 10.5 J of energy are stored in the capacitor after the student makes 84 inversions.
You may assume the capacitor is initially uncharged and that the diodes are ideal.

[3]

[Total: 20]

END OF QUESTION PAPER