RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS
Advanced GCE

PHYSICS A 2825/04

Nuclear and Particle Physics

Thursday **26 JUNE 2003** 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 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.
- 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.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	10	
2	12	
3	15	
4	12	
5	13	
6	8	
7	20	
TOTAL	90	

This question paper consists of 18 printed pages and 2 blank pages.

SP (AT/SLC) S31570/9

[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, $n = \frac{1}{\sin C}$

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

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

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

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

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

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

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

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

current, $I = nAve$

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

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

For Examiner's Use

Answer **all** the questions.

1 The radius r of a nucleus is related to its mass number A by the equation

$$r = r_0 A^{\frac{1}{3}}$$

where r_0 is a constant.

(a) On Fig. 1.1, sketch a graph of r against A.

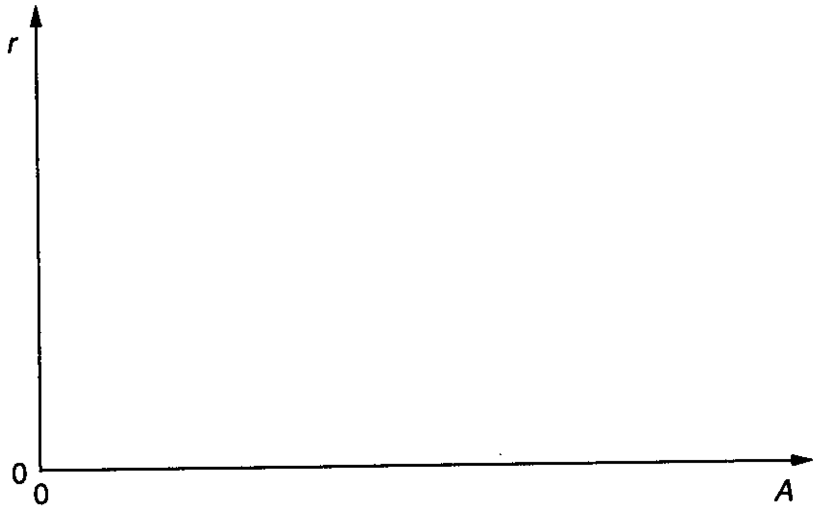

Fig. 1.1

[2]

(b) State the significance of r_0.

....

....[1]

(c) An oxygen nucleus consists of 8 protons and 8 neutrons. Its radius is 3.53×10^{-15} m.

Show that r_0 is 1.4×10^{-15} m.

[1]

For Examiner's Use

(d) A gold nucleus consists of 79 protons and 118 neutrons.

Calculate the radius of the gold nucleus.

radius = ... m [2]

(e) **(i)** Estimate the volume of a hydrogen nucleus.

volume = ... m^3 [2]

(ii) Briefly discuss whether the volume of an oxygen nucleus is exactly 16 times as great as the volume of a hydrogen nucleus. You may assume that the radii of the proton and the neutron are the same.

....

....

....[2]

[Total: 10]

For Examiner's Use

2 (a) Natural uranium consists of a mixture of the isotopes uranium-238 and uranium-235.

State **one** similarity and **one** difference between a $^{238}_{92}U$ nucleus and a $^{235}_{92}U$ nucleus.

similarity ....

....

difference ....

.... [2]

(b) Both $^{238}_{92}U$ and $^{235}_{92}U$ nuclei can absorb a neutron. For each type of nucleus, write an equation which represents the reaction.

Reaction 1

$^{238}_{92}U$ ....

....

Reaction 2

$^{235}_{92}U$ ....

.... [2]

(c) The product of Reaction 1 undergoes a β^- decay to form a neptunium (Np) nucleus. The Np nucleus then undergoes a further β^- decay to form a plutonium (Pu) nucleus.

(i) Write nuclear equations to represent these two decays.

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....[2]

(ii) Name the other particle which is emitted at the same time as a β^- particle.

....[1]

For Examiner's Use

(d) The product of Reaction 2 undergoes a fission reaction.

(i) What are the products of a fission reaction?

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....[2]

(ii) Fig. 2.1 shows the variation with mass number of the relative yield of fission products.

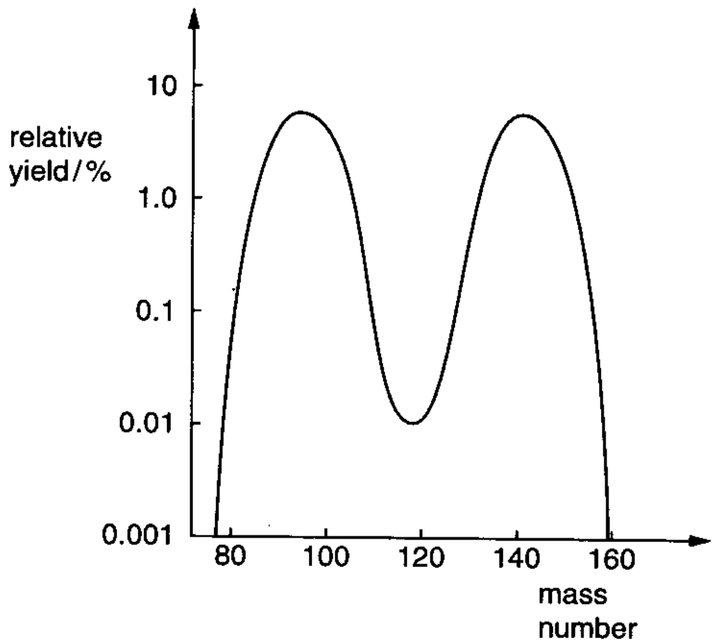

Fig. 2.1

State the approximate percentage of fissile nuclei which split into *equal* parts.

percentage = ...% [1]

(iii) Explain why the graph is symmetrical.

....

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....[2]

[Total: 12]

For Examiner's Use

3 In the JET experiment, a deuterium nucleus can fuse with a tritium nucleus, producing a helium nucleus, a neutron and energy.

(a) State **two** conditions inside the reactor which are necessary to make this reaction work. Explain why each condition is necessary.

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....[4]

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

....

....[2]

(c) The values of binding energy per nucleon for these three nuclei are plotted against nucleon number in Fig. 3.1 (opposite).

Calculate the amount of energy in J released in the reaction represented in **(b)**.

energy = ... J [4]

For Examiner's Use

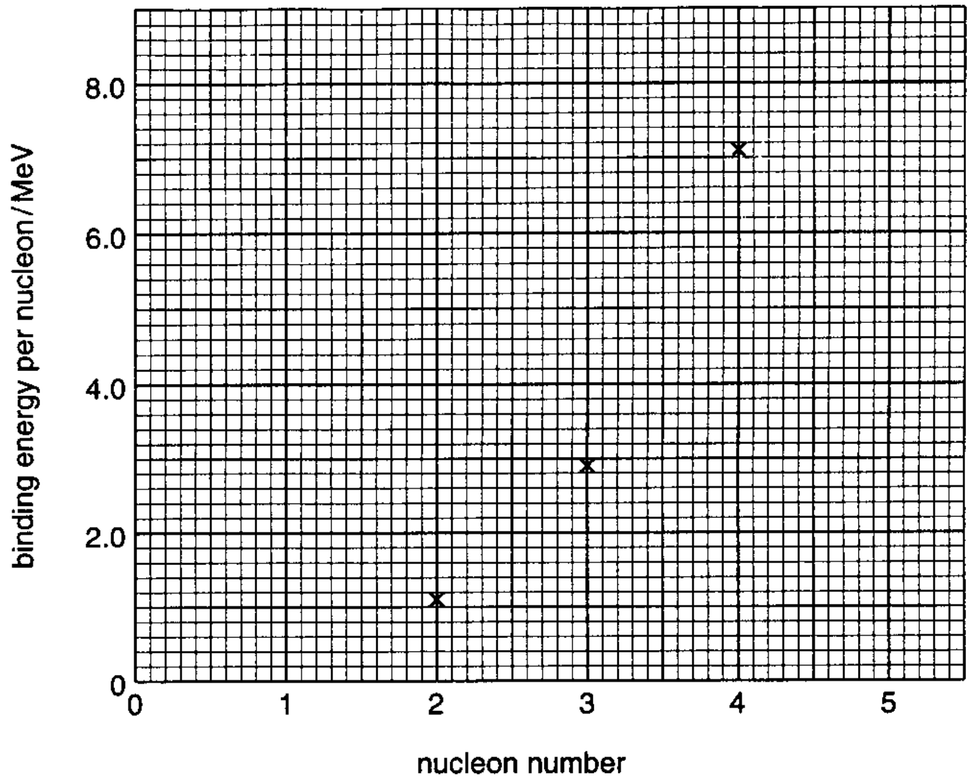

Fig. 3.1

(d) Most of this energy is carried away by the neutron. Describe in detail how, in a more advanced version of the JET reactor, this energy could be converted to a useful form.

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....[5]

[Total: 15]

For Examiner's Use

4 A cyclotron has two hollow, D-shaped electrodes X and Y which are connected to a source of alternating potential difference. Fig. 4.1 represents the dees inside a uniform magnetic field of flux density *B* at right angles to the plane of the diagram.

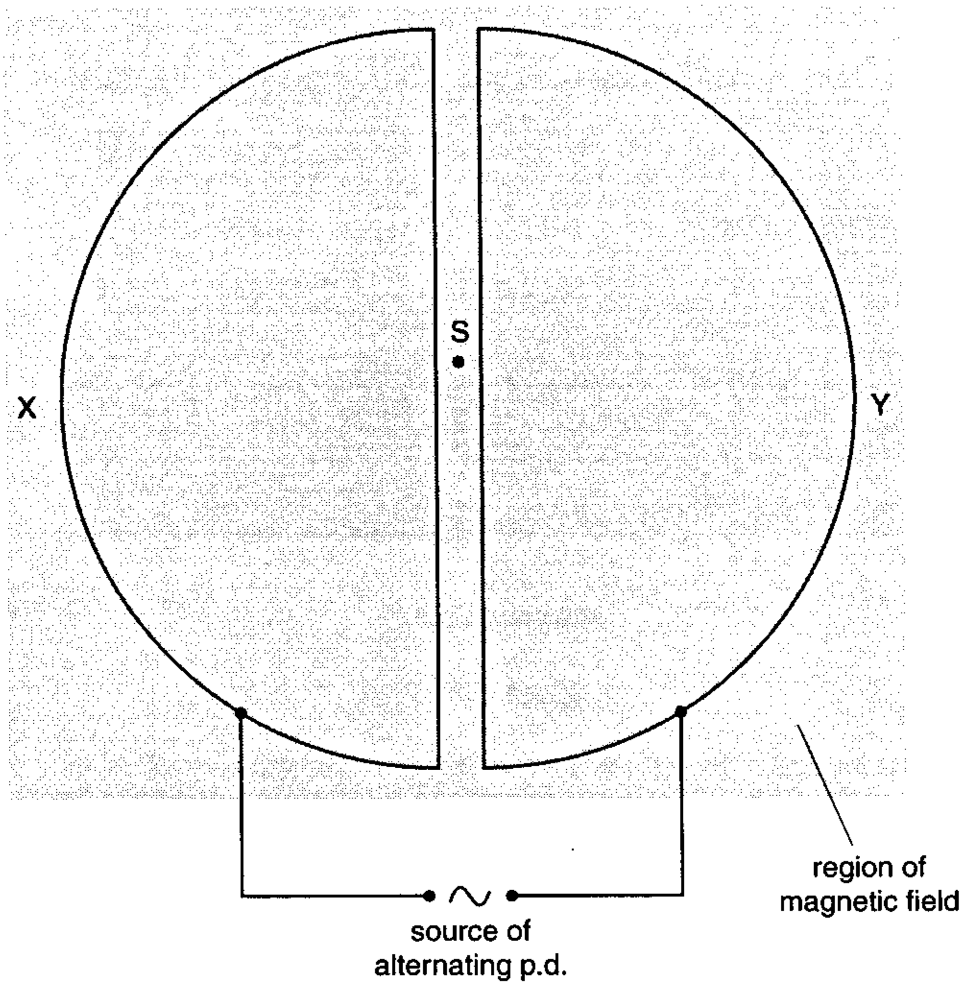

Fig. 4.1

A proton of mass *m* and charge *Q* is released from a source S, situated in the space between the dees.

(a) On Fig. 4.1, sketch a possible path for this proton. [2]

(b) Show that

(i) the speed *v* of the proton moving along a path of radius *R* is given by

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

[2]

For Examiner's Use

(ii) the time t taken by the proton to travel round a semicircle of radius R is given by

$$t = \frac{\pi m}{BQ}$$

[2]

(c) **(i)** Use the expression in **(b)(ii)** to explain why an **alternating** source of p.d. of **constant** frequency is required to accelerate protons.

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....[2]

(ii) Deduce an expression for the frequency of the source of p.d.

[2]

(d) Calculate the frequency required for accelerating protons inside a cyclotron having a magnetic field of flux density 1.50 T. Give an appropriate unit for your answer.

frequency = ... unit .... [2]

[Total: 12]

[Turn over

For Examiner's Use

5 This question is about hadrons.

(a) **(i)** Name the force that holds together the hadrons in a nucleus.

....[1]

(ii) On Fig. 5.1, sketch a graph to show how this force varies with the distance between two nucleons. Label the axes to show where the force is attractive and where it is repulsive.

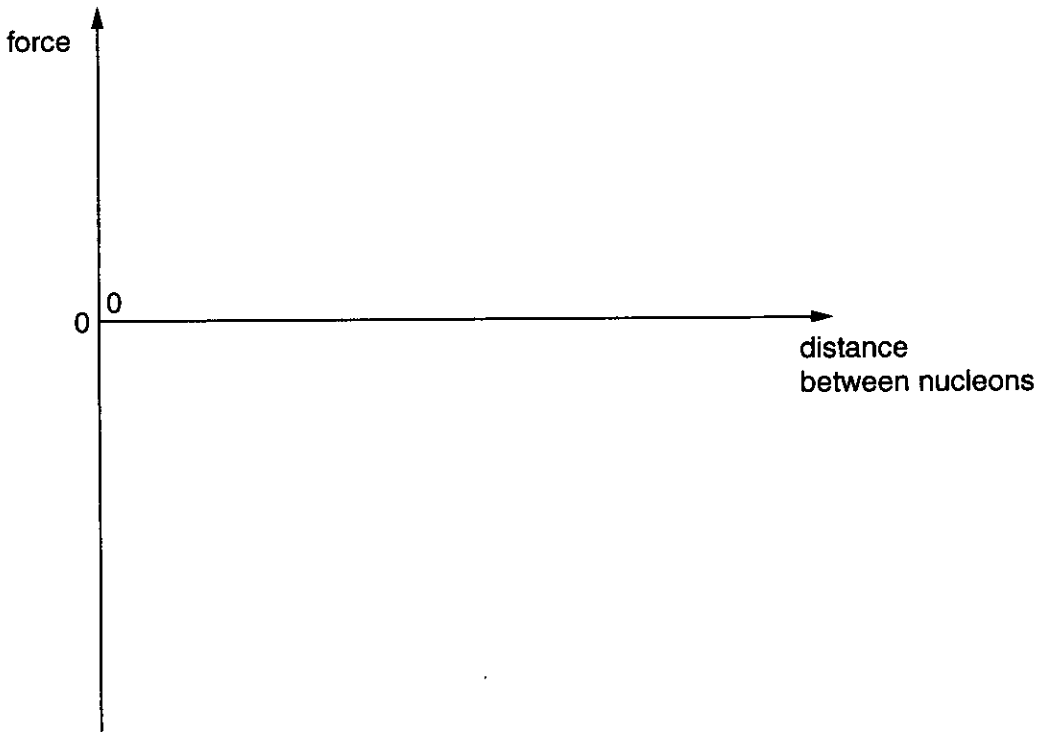

Fig. 5.1

[3]

For Examiner's Use

(b) Discuss the stability of the neutron (n^0) and the proton (p^1). Consider the cases when each particle is combined with others in a nucleus and when it is free.

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....[5]

(c) Two other kinds of hadron are the π^0 and π^- particles. Each of these has a baryon number of zero and strangeness of zero. By writing number equations for the values of charge, baryon number and strangeness, explain whether the reaction

$$\pi^- + p^+ \rightarrow n^0 + \pi^0$$

may take place.

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....[4]

[Total: 13]

[Turn over

For Examiner's Use

6 α-particles are directed through helium gas. An α-particle collides with a stationary helium nucleus and is deflected from its original direction. The helium nucleus moves off in a different direction. Fig. 6.1 shows the paths of these particles.

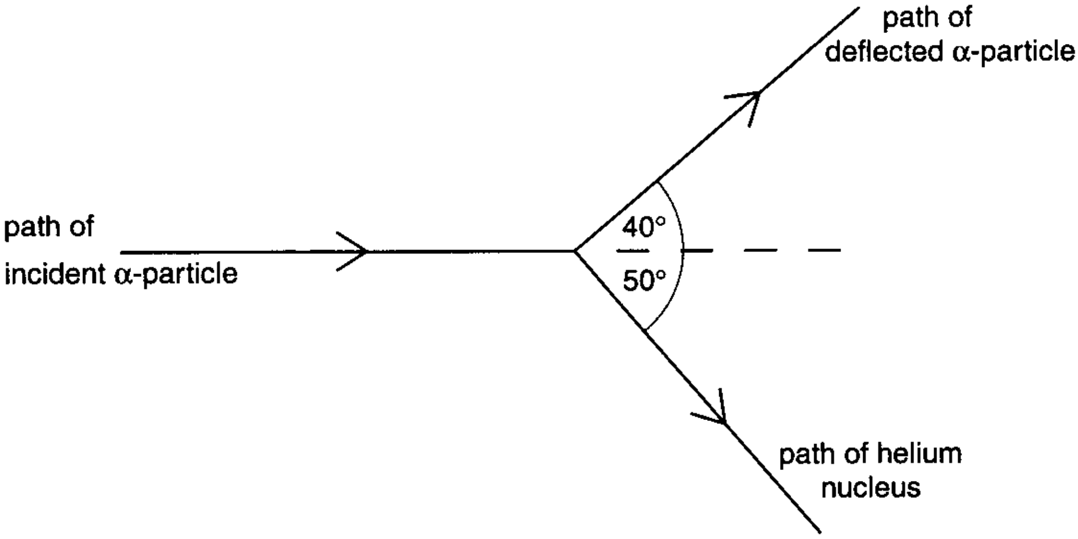

Fig. 6.1

speed of incident α-particle = 1.80×10^7 m s^{-1}
kinetic energy of incident α-particle = 1.08×10^{-12} J
speed of deflected α-particle = 1.38×10^7 m s^{-1}
speed of helium nucleus = 1.15×10^7 m s^{-1}
mass of α-particle = mass of helium nucleus = 6.68×10^{-27} kg

(a) Calculate the momentum of the incident α-particle.

momentum of incident α-particle = ... N s [2]

For Examiner's Use

(b) Calculate the kinetic energy of each particle after collision.

k.e. of α-particle = ... J

k.e. of helium nucleus = ... J
[3]

(c) **(i)** Compare the total kinetic energy of the particles after the collision with the kinetic energy of the incident α-particle.

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....[2]

(ii) Use your answer to **(i)** to comment on the nature of the collision.

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....[1]

[Total: 8]

For Examiner's Use

7 Electric vehicles offer many advantages over those powered by internal combustion engines. However, they suffer from one overwhelming problem – storing the energy. In spite of massive research into battery technology, the traditional lead-acid car battery is still best for storing energy. It can hold 20 times more energy per kg than its nearest competitor, the nickel-cadmium rechargeable cell.

A typical lead-acid battery has the following properties.

storage capacity = 0.75 kW h
volume = $7.0 \times 10^{-3}\,m^3$
mass = 16 kg
terminal voltage = 12 V

Petrol has the following properties.

energy available = 50 MJ kg^{-1}
density = 700 kg m^{-3}

(a) Suggest **two possible** advantages of electric vehicles over conventional petrol powered vehicles.

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....[2]

(b) The storage capacity of a battery is often quoted in ampere-hours. This is the number of hours for which a fully charged battery can supply a current of 1 A. Use the data to estimate the capacity in ampere-hours of a typical lead-acid battery.

capacity = ... ampere-hour [3]

(c) A bank of lead-acid batteries of total mass 960 kg is used to power a car.

(i) Calculate the total energy (in MJ) available.

energy = ... MJ [3]

(ii) The drag force on the car at 25 m s^{-1} is 300 N. Estimate how far it could travel at this speed on a level road using the energy stored in these batteries.

distance = ... m [3]

(d) **(i)** Calculate the mass and volume of petrol that provides the same energy as the 960 kg of lead-acid batteries.

mass of petrol = ... kg

volume of petrol = ...m^3 [4]

(ii) The volume of petrol calculated in **(d)(i)** is very small.

Explain why, in practice, a greater volume of petrol is needed to travel the distance calculated in **(c)(ii)**.

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....[2]

(e) Discuss the significance of your answers for the future adoption of electric vehicles rather than petrol vehicles.

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....[3]

[Total: 20]

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