OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT **2825/04**

PHYSICS A

Nuclear and Particle Physics

THURSDAY 21 JUNE 2007 Afternoon

Time: 1 hour 30 minutes

Additional materials: Electronic calculator.

Candidate Name

Centre Number | Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre Number and Candidate number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED. ANSWERS WRITTEN ELSEWHERE WILL NOT BE MARKED.

INFORMATION FOR CANDIDATES

- The number of marks for each question 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	**15**	
3	**13**	
4	**12**	
5	**10**	
6	**10**	
7	**20**	
TOTAL	**90**	

This document consists of **22** printed pages and **2** blank pages.

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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 nuclear density.

(a) Fig. 1.1 shows the relationship between the cube of the radius *r* of atomic nuclei and nucleon number *A*.

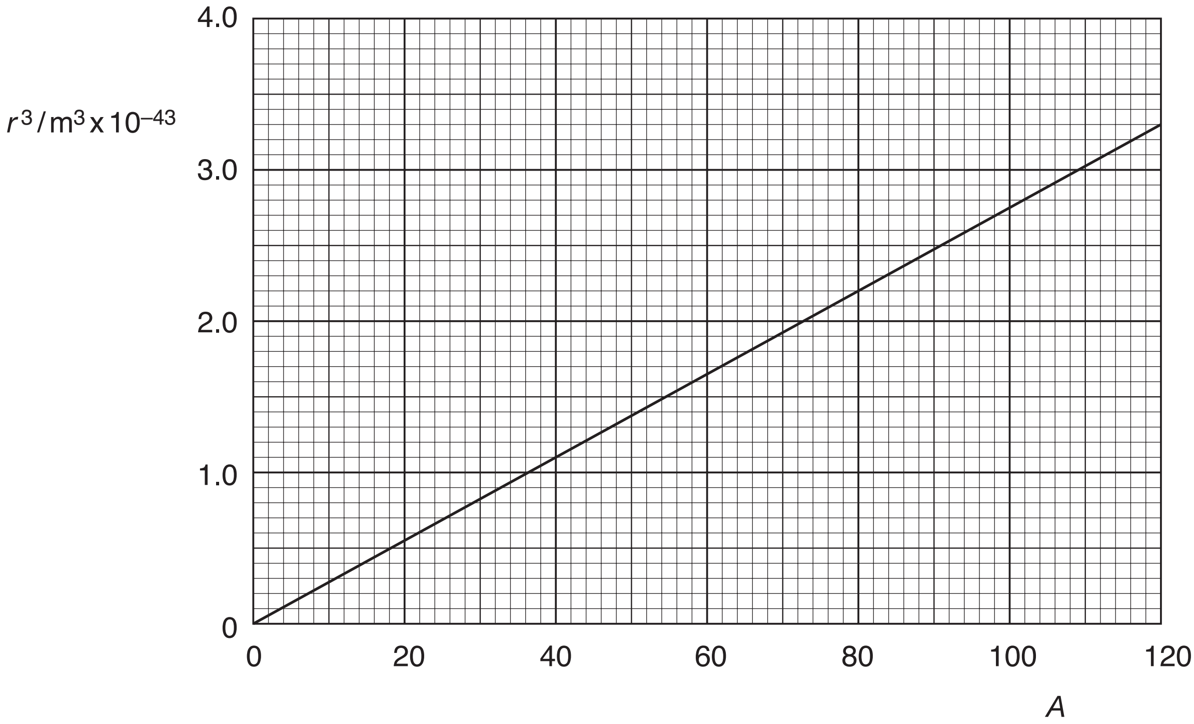

Fig. 1.1

(i) Deduce the gradient of this graph.

gradient = ... [1]

(ii) Use your answer to **(i)** to calculate the radius r_0 of a single nucleon.

radius = ... m [3]

(b) Calculate the density of a carbon-12 nucleus $^{12}_{6}C$.

density = ... $kg\,m^{-3}$ [3]

(c) Diamond is formed from carbon-12 atoms. The density of diamond is $3530\,kg\,m^{-3}$.

(i) Calculate the ratio $\dfrac{\text{density of a carbon-12 nucleus}}{\text{density of diamond}}$.

ratio = ... [1]

(ii) Explain why this ratio is so large.

....

....

....

.... [2]

[Total: 10]

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

(a) (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]

(b) 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 of Fig. 2.1. [1]

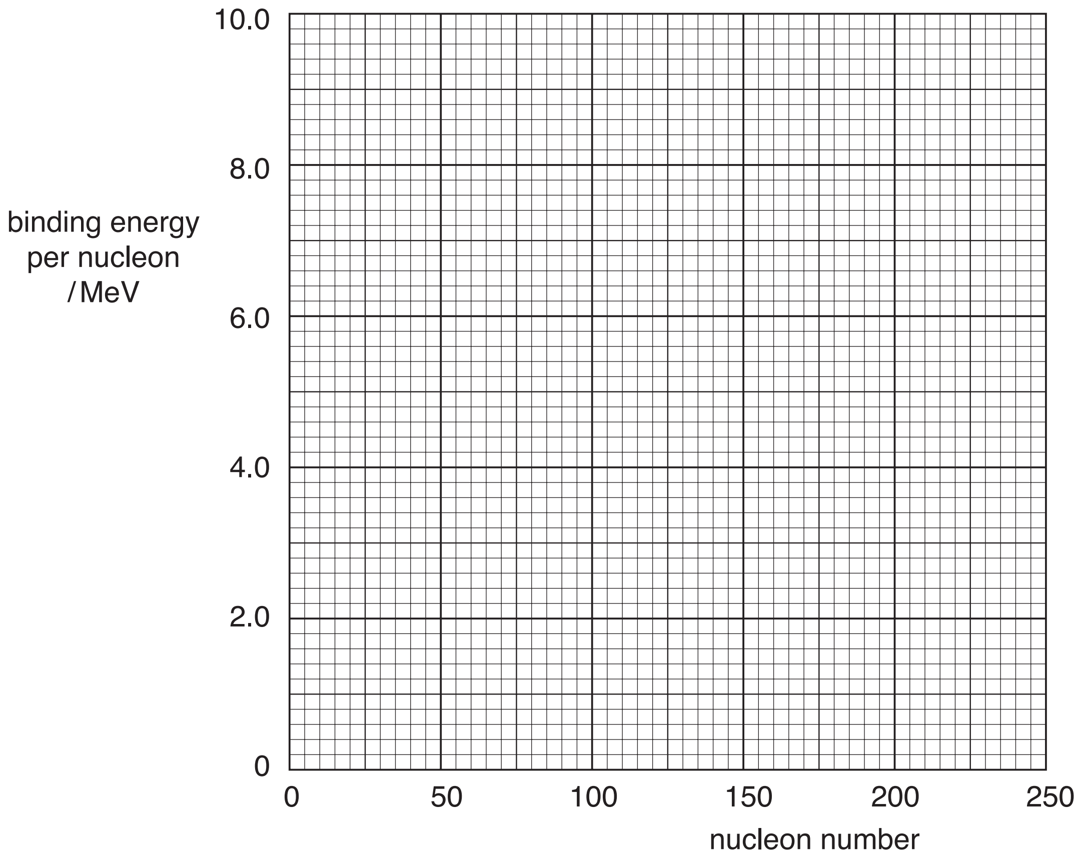

Fig. 2.1

(ii) Sketch a graph on Fig. 2.1, 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]

(iv) Sketch a graph on Fig. 2.2, to show how the relative yield of fission products for uranium-235 varies with nucleon number. [2]

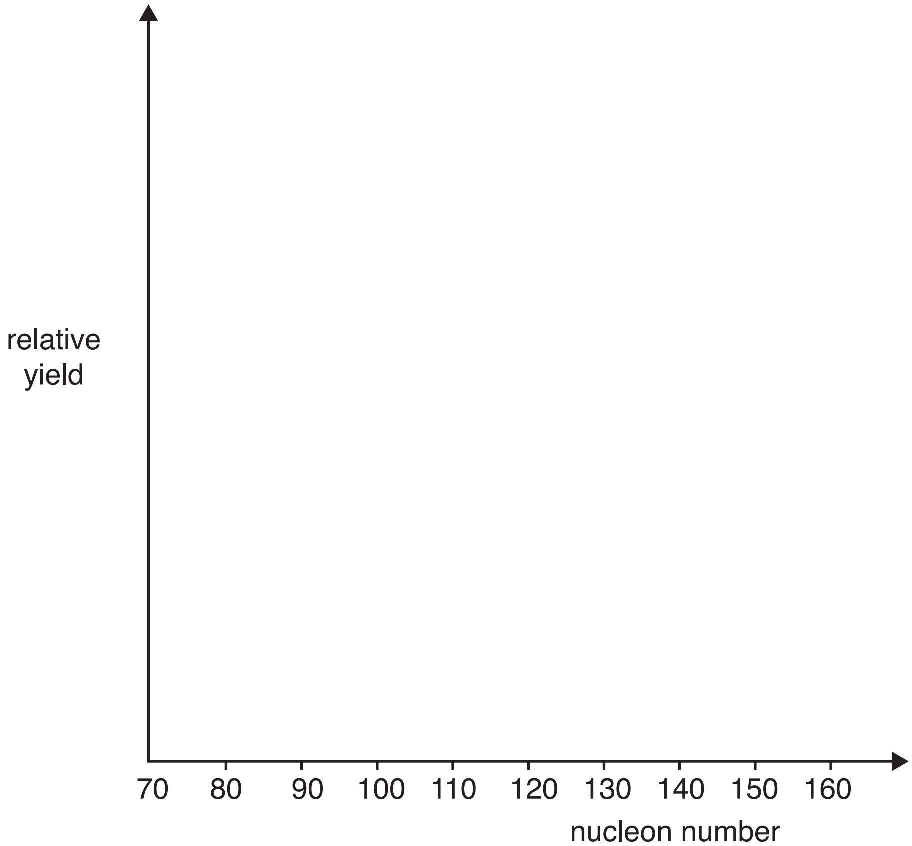

Fig. 2.2

(v) Use information from Fig. 2.2 to mark **on Fig. 2.1** the regions of the graph where **most** of the fission products lie. Label these regions 'F'. [2]

(c) (i) Neutrons emitted from a fission reaction may be slowed down by colliding with carbon-12 nuclei $^{12}_{6}C$. The initial speed of a neutron is $1.5 \times 10^{7}\,m\,s^{-1}$. On average the neutron's speed after each collision is equal to 0.93 of its speed before the collision. Show that after 120 collisions its speed has been reduced to about $2.5 \times 10^{3}\,m\,s^{-1}$.

[2]

(ii) When a neutron collides head-on with a $^{12}_{6}C$ nucleus, as shown in Fig. 2.3, its speed is reduced by about 15%.

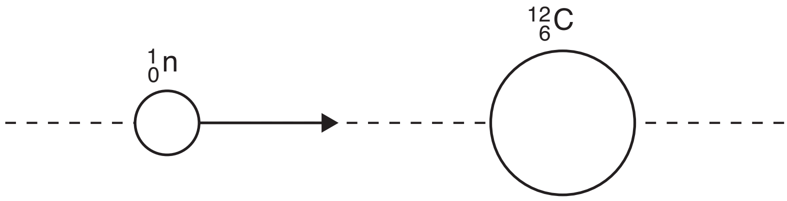

Fig. 2.3

Suggest why this speed reduction is different from the reduction stated in **(i)**.

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.... [1]

[Total: 15]

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

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

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.... [3]

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

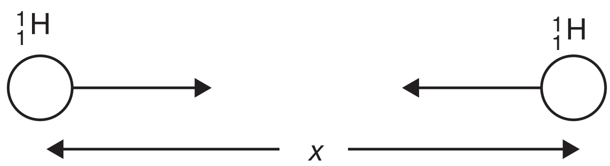

Fig. 3.1

The repulsive force F_e between them varies with their separation x as shown in Fig. 3.2.

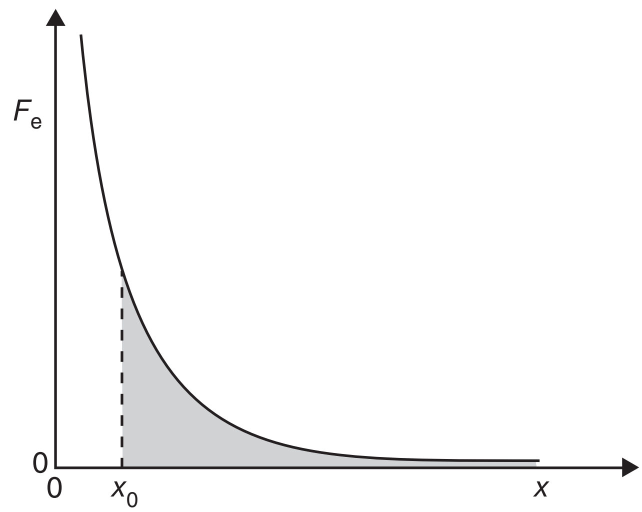

Fig. 3.2

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?

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.... [2]

(c) The average kinetic energy E_k in joule, of ${}^1_1$H nuclei inside a star is given by the equation

$$E_k = 2.07 \times 10^{-23}\,T.$$

The temperature T of the Sun's interior is 15×10^6 K.

Calculate the combined average kinetic energy of **two** ${}^1_1$H nuclei inside the Sun.

kinetic energy = ... J [1]

(d) The interior of the Sun is mainly composed of ${}^1_1$H nuclei and these nuclei collide continually. Two nuclei will fuse if their combined energy exceeds 1.1×10^{-12} J. Use your answer from **(c)** to explain why only a very small proportion of the head-on collisions between ${}^1_1$H nuclei result in a fusion reaction.

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.... [3]

(e) 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:

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

(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.

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.... [1]

[Total: 13]

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4 The cyclotron and the synchrotron are two machines used to accelerate charged particles. Discuss the similarities and differences between these two machines.

Your answer should include

- the method of accelerating the charged particles
- the synchronisation of the accelerating force with the particle motion
- the method of maintaining the charged particles in a curved path
- the energies which each machine is capable of imparting to the charged particles (numerical values are not required)
- the relative advantages of the two types of machine.

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.... [12]

[Total: 12]

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

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

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 Fig. 5.1, 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]

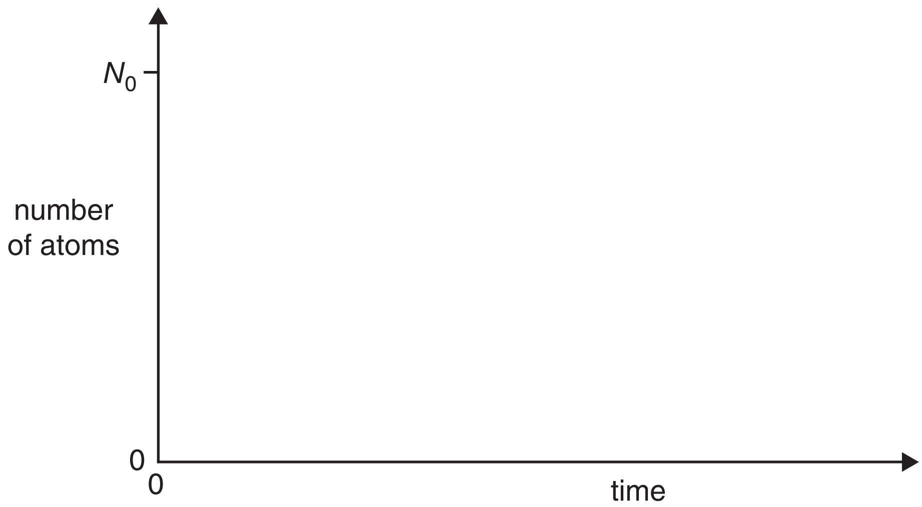

Fig. 5.1

[Total: 10]

6 **(a)** **(i)** Name the group of particles of which the electron and the positron are members.

.... [1]

(ii) Name another member of this group.

.... [1]

(b) **(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. [2]

quark	*Q*	*B*	*S*

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

Q .... *B* .... *S* .... [1]

(c) It is suggested that a proton p^+ can react with a pi particle π^- to form a kaon K^0 and a neutron, thus

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

data

particle	quark composition
π^-	$\bar{u}$ d
K^0	d $\bar{s}$

Deduce whether the reaction is possible.

[4]

[Total: 10]

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7 The suspension system for road vehicles can be modelled using springs and masses. The natural frequency of oscillation *f* for a mass *m* supported by a spring is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where *k* is the spring constant.

(a) (i) A spring is found to compress by 40 mm when loaded with a mass of 5000 kg. Show that the spring constant *k* is $1.2 \times 10^6\,\mathrm{N\,m^{-1}}$.

[2]

(ii) A 5000 kg mass is supported by four such springs as shown in Fig. 7.1.

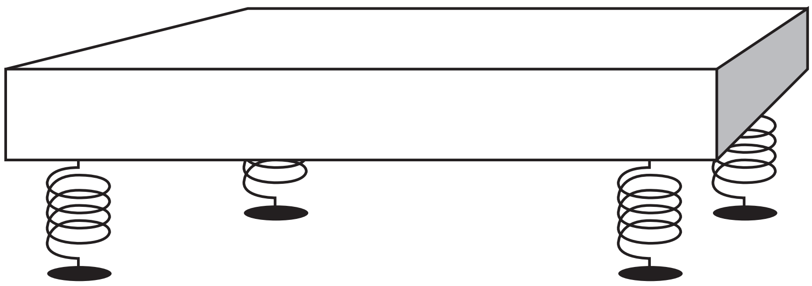

Fig. 7.1

Calculate the natural frequency of oscillation of the mass.

natural frequency = ... Hz [2]

(b) The suspension systems of large lorries require springs made from rods which may be several centimetres thick. Steel rod of this diameter would snap if bent into shape at room temperature. To prevent this the rod is 'hot-coiled': it is heated from 20 °C to 1000 °C before being wound into a spring.

The method of heating is electrical, using a supply of 50 V, which passes a current of 12 000 A through the steel rod. Large contacts at each end of the rod are necessary and these are water-cooled (see Fig. 7.2).

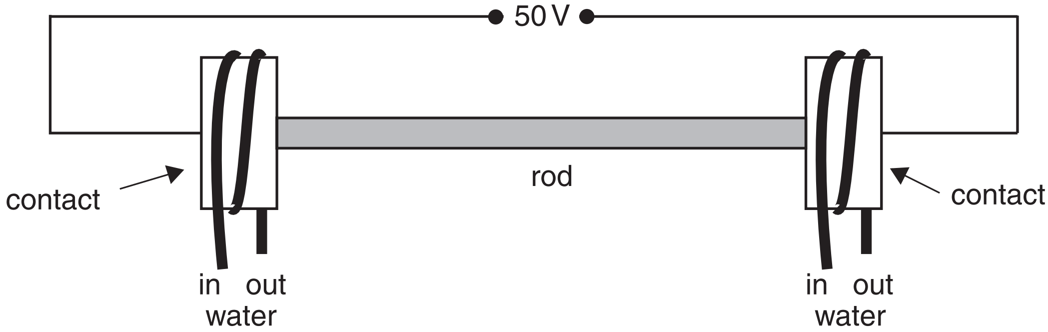

Fig. 7.2

(i) Calculate the resistance of the rod, assuming that the voltage across it is 50 V.

resistance = ... Ω [1]

(ii) Show that the electrical power generated in the rod is 600 kW.

[1]

The mass of the rod is 15 kg.

The specific heat capacity of steel is 420 J kg^{-1} K^{-1}.

(iii) Calculate the energy required to heat the rod from 20 °C to 1000 °C.

energy = ... J [2]

(iv) Calculate the minimum time required to heat the rod to 1000 °C.

minimum time = ... s [2]

(c) In practice the time taken to reach 1000 °C is greater than the value found in **(b)(iv)**. Consequently, the total energy supplied is found to vary according to the time taken for the heating process. The relationship between the energy supplied and time taken is shown in Fig. 7.3.

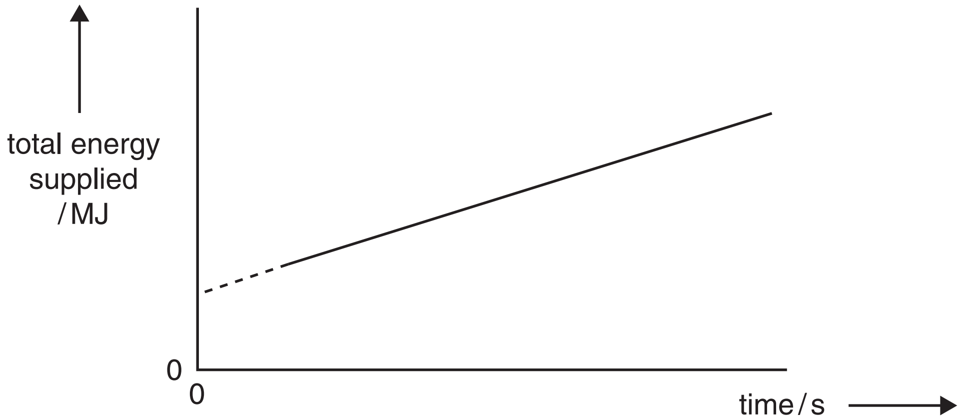

Fig. 7.3

Discuss **two** ways in which energy is lost from the rod during heating and explain the trend shown by the graph in Fig. 7.3.

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.... [3]

(d) A spring is made from a steel rod of the same length but with **twice** the radius.

Suggest, **with reasons**, how the following will change.

(i) The resistance of the rod.

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.... [2]

(ii) The time taken to heat the rod from 20 °C to 1000 °C, using the same voltage across the rod.

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.... [3]

(iii) The natural frequency of the mass-spring system in **(a)**.

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.... [2]

[Total: 20]

END OF QUESTION PAPER

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