RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT **2865/01**

PHYSICS B (ADVANCING PHYSICS)

Advances in Physics

FRIDAY 26 JANUARY 2007 Morning

Time: 1 hour 30 minutes

Additional materials:
- Insert (Advance Notice Article for this question paper)
- Data, Formulae and Relationships Booklet
- Electronic calculator
- Ruler

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.
- Show clearly the working in all calculations, and give answers to only a justifiable number of significant figures.
- 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.
- Section A (questions 1–6) is based on the Advance Notice article, a copy of which is included as an insert. You are advised to spend about 60 minutes on Section A.
- There are four marks for the quality of written communication on this paper.
- 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.

For Examiner's Use		
Qu.	Max	Mark
1	10	
2	7	
3	13	
4	8	
5	9	
6	12	
7	14	
8	13	
QWC	4	
Total	90	

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

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Answer **all** the questions.

Section A

The questions in this section are based on the Advance Notice article.
You are advised to spend not more than 60 minutes on this section.

1 This question is about population growth and energy demand (lines 2–7 in the article).

(a) Fig. 1.1 shows how the world population changed in the twentieth century.

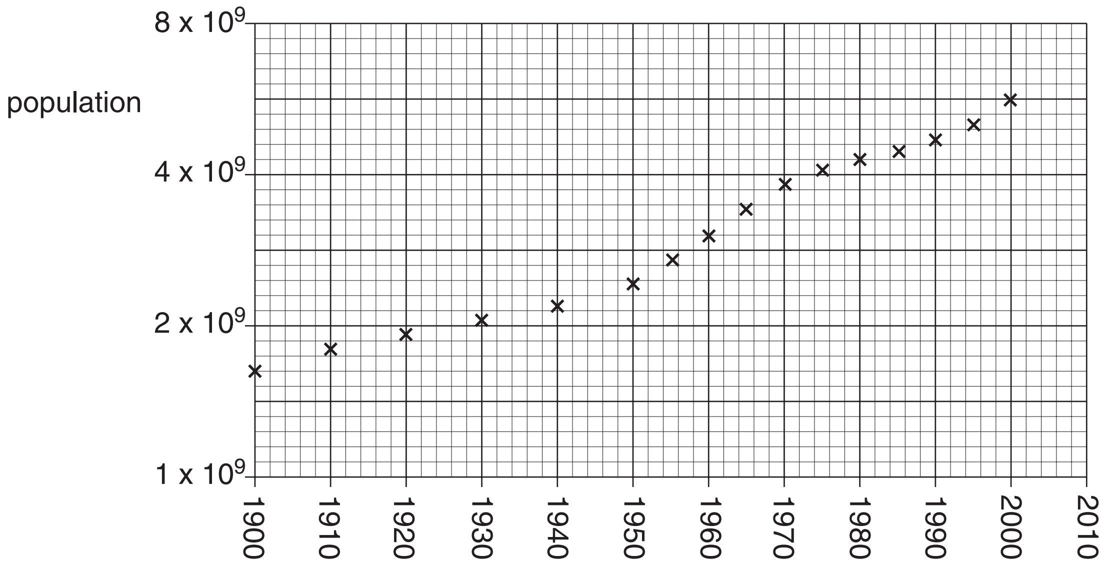

Fig. 1.1

(i) State how you can tell that the scale on the y-axis is **logarithmic**.

[2]

(ii) Explain why a graph with a logarithmic scale on the y-axis is useful for testing for exponential change.

[2]

(iii) Explain clearly how the graph shows that '…the rate of exponential growth suddenly increased significantly in the middle of the last century' (lines 3 and 4 in the article).

[2]

(b) **(i)** Assuming the annual energy consumption per capita remains at about 68 GJ per person per year, use the graph to show that the total world consumption of energy in the year 2007 is likely to be about 5×10^{20} J.

[2]

(ii) Use this value for the total world consumption of energy to estimate the maximum lifetime of the Earth's fossil fuel resources, currently estimated at about 4×10^{22} J.

lifetime = ... years [1]

(iii) Suggest why the estimate of the lifetime may prove inaccurate.

[1]

[Total: 10]

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2 This question is about the energy released in nuclear fusion (lines 15–26 in the article).

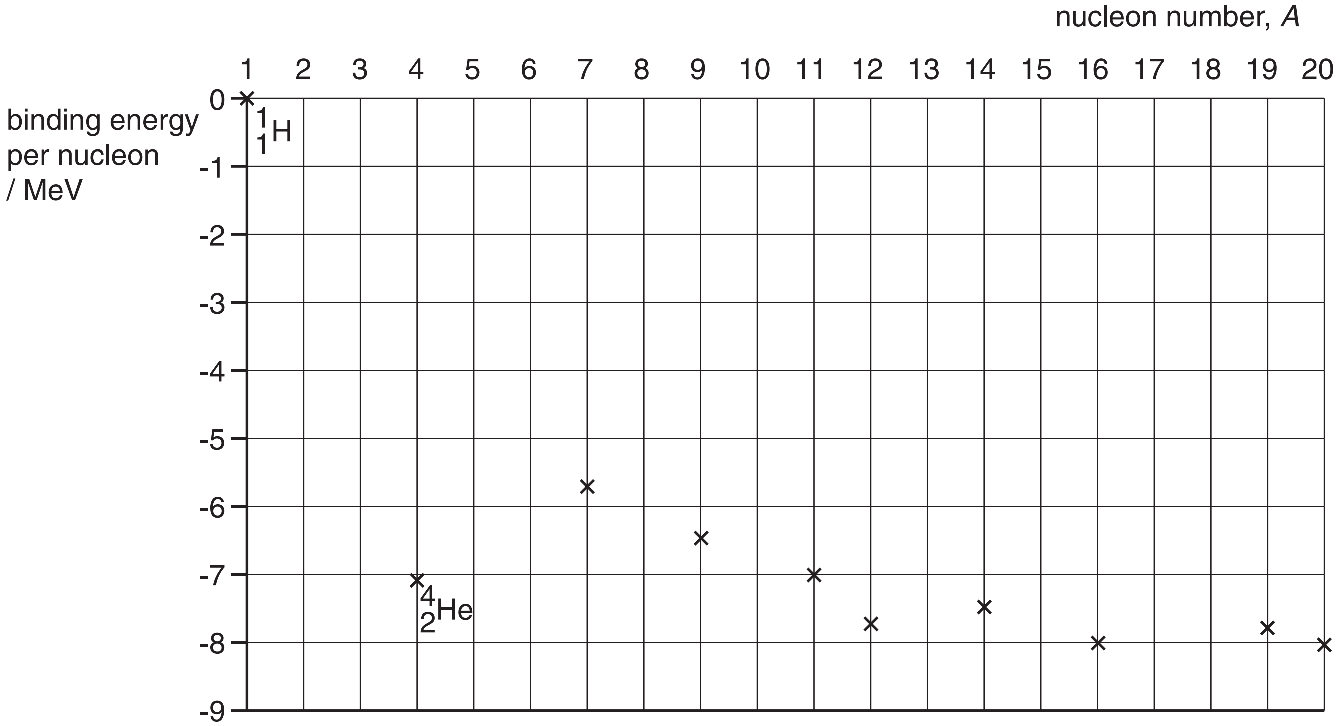

Fig. 2.1

(a) On Fig. 2.1, ring the point corresponding to the nucleus $^{19}_{9}F$.

[1]

(b) Fig. 2.1 shows that hydrogen $^{1}_{1}H$ has zero binding energy. State why this must be the case.

[1]

(c) Show that the graph gives a total binding energy for a $^{4}_{2}He$ nucleus of about –28 MeV.

[2]

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(d) The table shows the masses of different particles.

particle	mass / 10^{-27} kg
proton	1.6675
neutron	1.6693
helium-4 nucleus	6.6240

Use the data in the table to show that the total binding energy of the helium nucleus is about -4×10^{-12} J.

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

[3]

[Total: 7]

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3 This question is about the conditions in the Sun's core (lines 27–40 in the article).
The graph in Fig. 3.1 shows the potential energy of two protons as they approach each other.

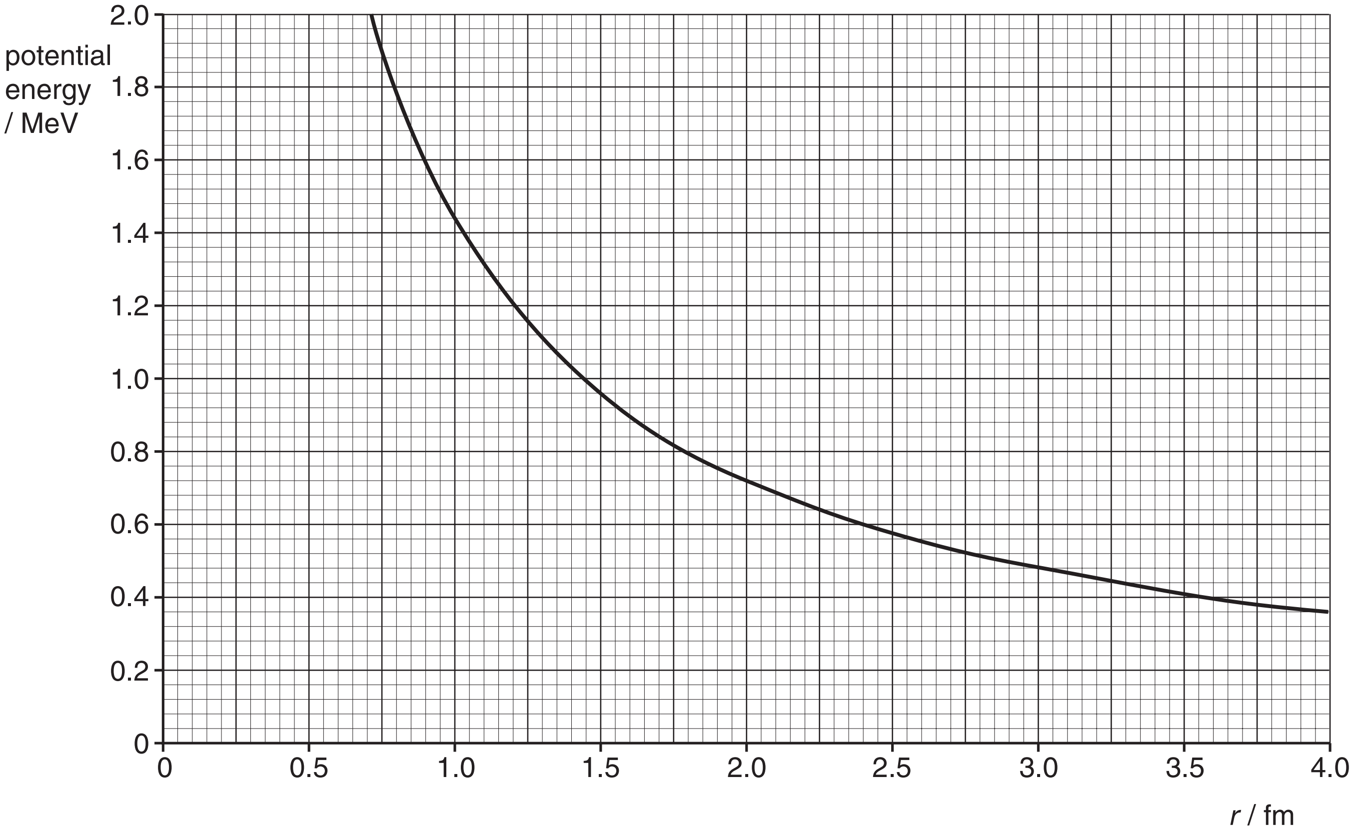

Fig. 3.1

(a) Use data from the graph to show that the potential energy is given by the equation potential energy = $\frac{\text{constant}}{r}$. Show your working clearly.

[2]

(b) **(i)** Fig. 3.1 shows that 1.44 MeV is required to bring two protons to a separation of 1 fm, where they can fuse.

Show that this requires **each** proton to have a kinetic energy of about 1×10^{-13} J.

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

[1]

(ii) Calculate the value of kT for a proton in the core of the Sun.
$k = 1.4 \times 10^{-23}$ J K^{-1}
temperature of Sun's core = 1.5×10^{7} K

kT = ... J [1]

(iii) Use the answers to **(i)** and **(ii)** to explain why 'the proportion of protons in the Sun's core … with enough energy to approach this close is so tiny that fusion would be extremely unlikely to occur.' (lines 31–32 in the article).

[2]

Question 3 continues on the next page

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(c) Fig. 3.2 shows two protons heading towards each other at two different separations. On **both** diagrams, draw labelled arrows representing the **magnitudes** and **directions** of the forces acting on **each** proton. One arrow has been drawn for you.

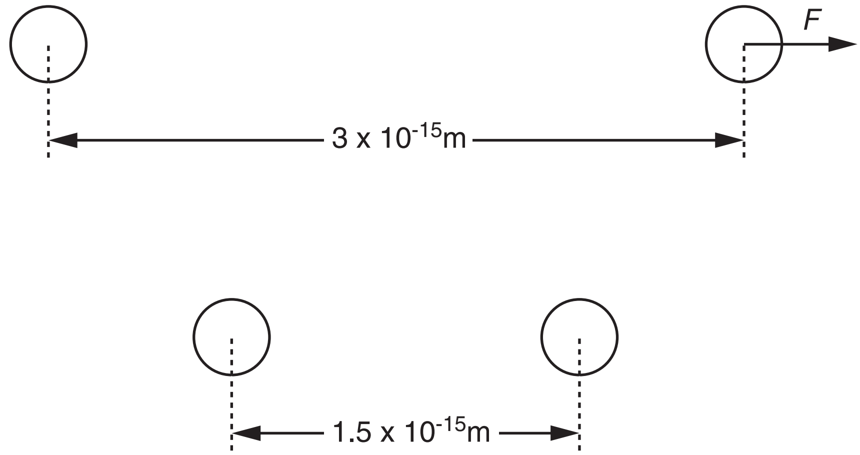

Fig. 3.2

[2]

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(d) The pressure in the core of the Sun is 3.4×10^{16} Pa.

(i) Show that the number of moles of particles per m^3 at a temperature of 1.5×10^7 K is about 3×10^8 mol m^{-3}. State an assumption that you must make to be able to do this calculation.

$R = 8.3\,\text{J mol}^{-1}\,\text{K}^{-1}$

[3]

(ii) Show that the number of particles per m^3 in the Sun's core is about 2×10^{32} m^{-3}.

$N_A = 6.0 \times 10^{23}\,\text{mol}^{-1}$

[1]

(iii) Calculate the mean separation of particles in the Sun's core.

separation = ... m [1]

[Total: 13]

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4 This question is about the magnetic field in a tokamak (lines 67–91 in the article).

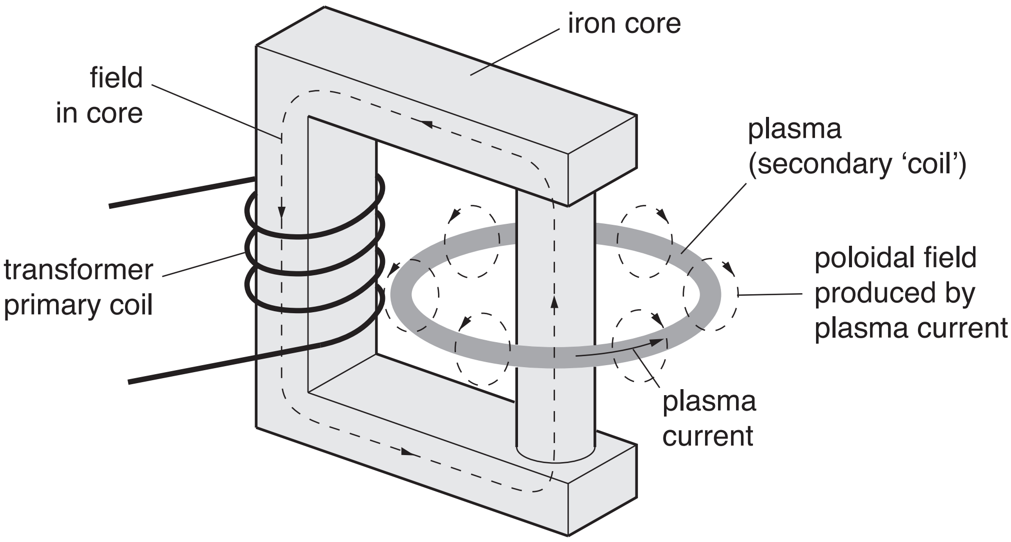

Fig. 4.1

(a) Explain in terms of magnetic circuits why a massive iron core is necessary to produce a large plasma current.

[2]

(b) Explain why a **constant** direct current in the primary coil would **not** generate a plasma current.

[2]

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(c) The graph in Fig. 4.2 shows how the magnetic flux in the iron core changes at the start of a pulse.

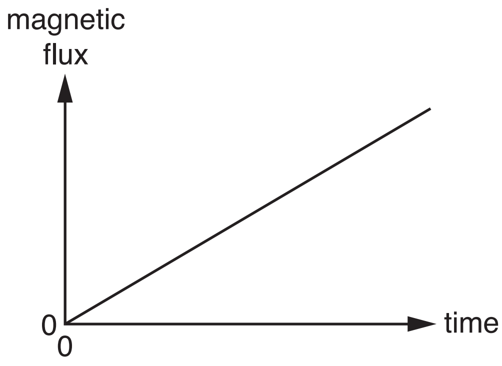
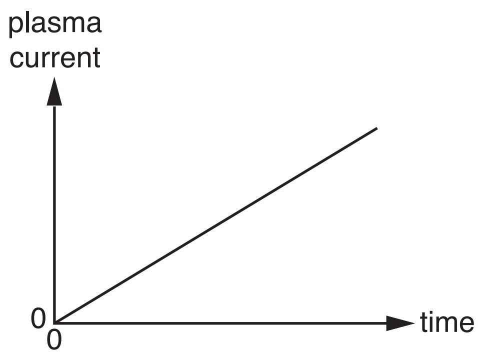
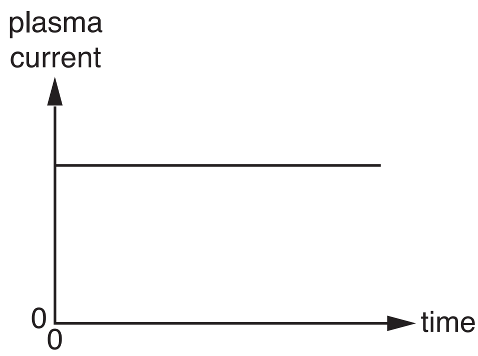


Fig. 4.2

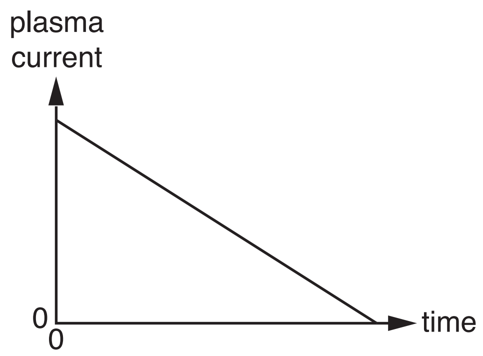
Which one of graphs **A** to **D** below shows the plasma current produced by the **changing** magnetic flux of Fig. 4.2?



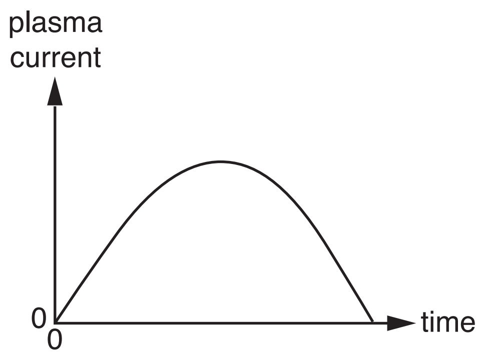
A



B



C



D

graph .... [1]

Question 4 continues on the next page

(d) The ions in the torus are moving in a complicated magnetic field pattern. State and explain how magnetic forces would affect ions travelling

(i) **parallel** to the lines of flux

(ii) **at right angles** to the lines of flux.

[3]

[Total: 8]

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5 This question is about the three methods of heating the plasma in a tokamak (lines 95–111 in the article).

(a) The plasma is heated by the plasma current.

(i) The resistance of the plasma is $5.0 \times 10^{-7}\ \Omega$.
Show that the power dissipated as heat by a current of 3.0×10^{6} A is 'at a rate of a few megawatts' (line 100 in the article).

[2]

(ii) The plasma contains deuterium ${}^{2}_{1}H^{+}$ ions. Assuming that they contribute 1.0×10^{6} A to the total plasma current, calculate the number of deuterium ions per second passing any point in the torus.

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

number of deuterium ions s^{-1} = ...[2]

(b) The ions in the plasma spiral around the magnetic field lines (lines 89–91 and Fig. 7 in the article).
The time taken for deuterium ${}^{2}_{1}H^{+}$ ions to spiral once around a magnetic field line is 4.0×10^{-8} s. This period resonates with electromagnetic radiation of the appropriate frequency.
Show that the article is correct in describing this resonant frequency as 'in the radio frequency range' (lines 102 and 103 in the article).

[1]

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(c) The plasma is also heated by neutral beams of deuterium atoms (lines 104–111 in the article).

(i) The $^{2}_{1}H^{+}$ ions are accelerated by an electrical field to an energy of 60 keV.
State the p.d. required.

p.d. = ... V [1]

(ii) Explain why the ions must be neutralised before being injected into the plasma.

[1]

(iii) Show that the velocity of a 9.6×10^{-15} J (60 keV) deuterium atom is about 2×10^{6} m s^{-1}.

mass of deuterium atom = 3.3×10^{-27} kg

[2]

[Total: 9]

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6 This question is about the neutrons produced in nuclear fusion (lines 128–138 in the article).

(a) Deuterium-tritium fusion releases 17.5 MeV per reaction, most of which is carried by the neutrons. In Fig. 6.1, the length of each arrow is proportional to the speed of the particle.

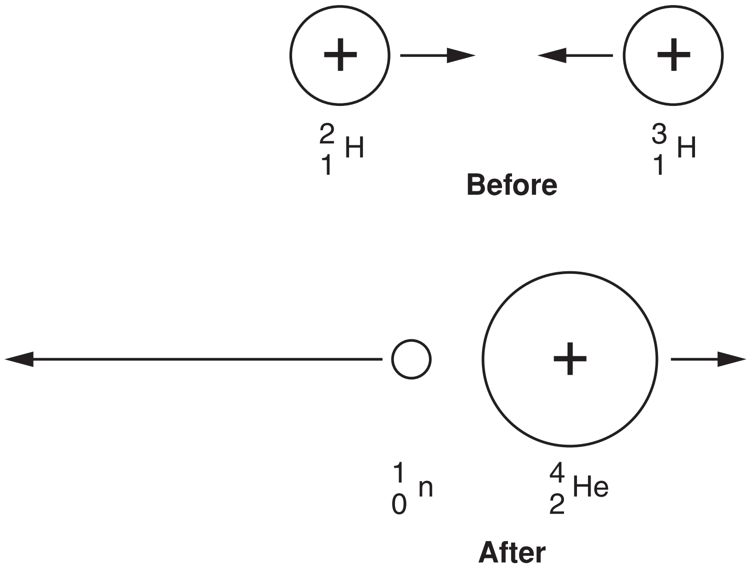

Fig. 6.1

(i) Complete the table below by measuring the lengths of the arrows.
Use data in the table to confirm that momentum is conserved in this process.

particle	length of arrow / mm
$^{2}_{1}H^{+}$	
$^{3}_{1}H^{+}$	
$^{4}_{2}H^{2+}$	
$^{1}_{0}n$	

[2]

(ii) Use data in the table to show that energy is released in the reaction.

[2]

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(b) The kinetic energy of the neutrons is absorbed in lithium surrounding the reactor. Assuming that all neutrons are absorbed, calculate the minimum number of fusions per second in a reactor designed to provide 100 MW.

energy per neutron = 15 MeV
$e = 1.6 \times 10^{-19}$ C

number of fusions per second = ... s^{-1} [2]

(c) It is to be expected that some neutrons will 'leak' from the reactor.

(i) If a 55 kg worker were to absorb 1.0×10^{11} neutrons, each of energy 2.4×10^{-12} J, per year, show that the absorbed dose would be less than 0.1 gray over a ten year period.

[2]

(ii) The neutrons have a quality factor of 10, so the equivalent dose in sievert is 10 × greater than the absorbed dose in gray.
Suggest why neutrons are more damaging than beta particles or gamma photons (lines 137 and 138 in the article).

[2]

(iii) The rule that the risk of cancer from radiation is 3% per sievert shows that the equivalent dose received by this worker is unacceptable. Suggest and explain **two** ways in which the environment of the fusion reactor could be made safe for workers.

[2]

[Total: 12]

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Section B

7 This question is about low energy mains lamps (CFLs, compact fluorescent lamps).

Fig. 7.1 shows the position of major peaks in the spectrum produced when light from a low energy fluorescent lamp passes through a diffraction grating.

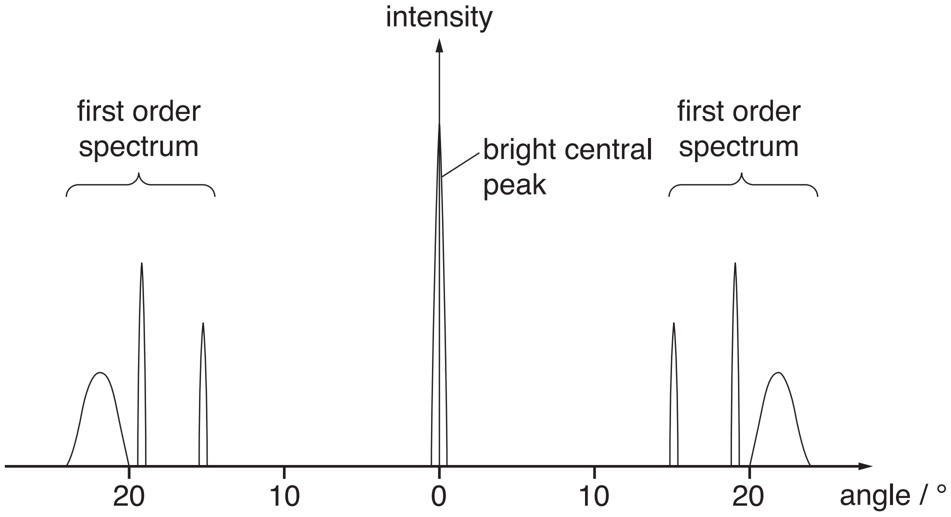

Fig. 7.1

The first order spectrum consists of three major peaks, red, green and violet.

(a) **(i)** Label the spectral peaks on Fig. 7.1 **R**, **G**, **V**, to indicate which is red, green and violet. [1]

(ii) Explain what is meant by the expression 'first order spectrum'.

[1]

(iii) Explain why the bright central peak at 0° appears white.

[1]

(iv) The diffraction grating has 600 lines per millimetre.
Calculate the wavelength of the light producing the peak at 19.1°.

wavelength = ... m [3]

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(b) Describe how the spectrum from a conventional filament lamp would differ from that above.

[1]

(c) (i) Show that the frequency of a photon of violet light, wavelength 4.4×10^{-7} m, is about 7×10^{14} Hz.

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

[2]

(ii) Calculate the energy of this violet photon.

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

energy = ... J [2]

(d) (i) Draw a diagram of a circuit that could be used to determine the power consumption of a low voltage lamp.

[2]

(ii) Explain how you would use your measurements to compare the power consumption of two lamps.

[1]

[Total: 14]

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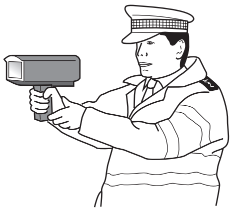
8 This question is about a new type of speed gun.



(a) A laser diode in this speed gun sends out short pulses of radiation of wavelength 900 nm. State the region of the electromagnetic spectrum containing radiation of wavelength 900 nm.

region of the spectrum ....[1]

(b) The speed gun is aimed towards an approaching vehicle. From the delay between emission and detection of reflected pulses the range of the vehicle can be found. By making such measurements every 60 ms the speed of the vehicle can be calculated.

(i) Show that if the **delay** changes by 7.0 ns between each consecutive pulse/reflection the vehicle travels about 1 m between pulses.

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

[2]

(ii) Calculate the speed of the vehicle.

speed = ... $\mathrm{m\,s^{-1}}$ [2]

(iii) The speed gun can time to an accuracy of ±0.10 ns.
Show that the speed gun is accurate to $\pm 0.25\,\mathrm{m\,s^{-1}}$.

[2]

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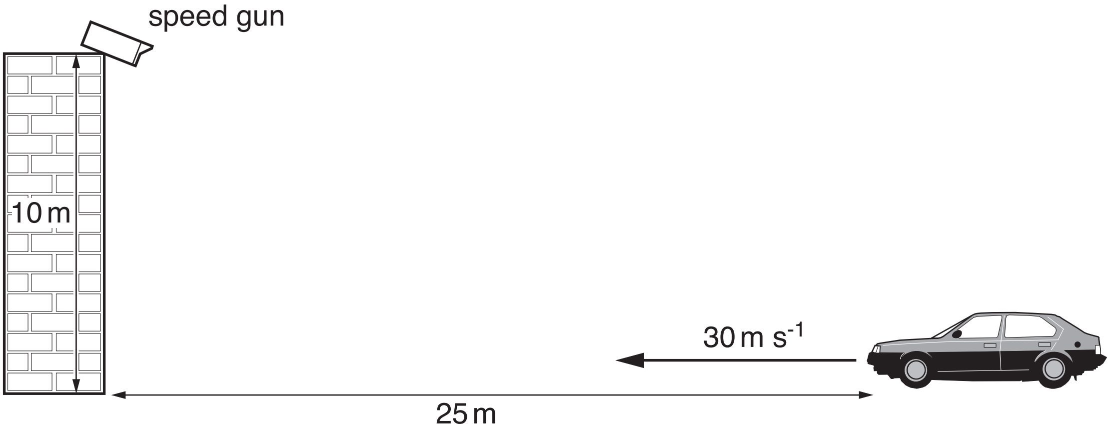
(c) Fig. 8.1 shows a car travelling at 30 m s^{-1} towards a bridge 25 m away. A speed gun is held 10 m above the road. It reads an incorrect value for the car's speed.



(not to scale)

Fig. 8.1

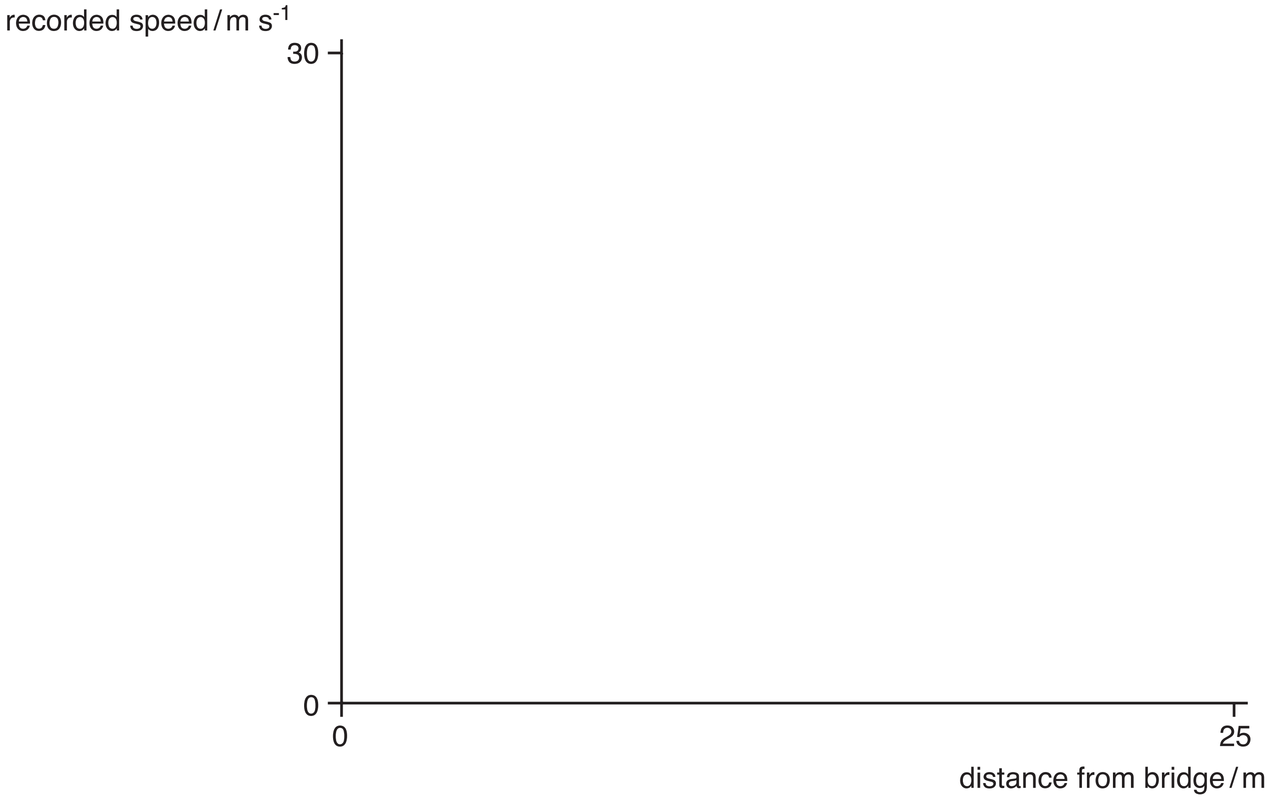
(i) Draw an arrow on Fig. 8.1 to show the component of the car's velocity towards the speed gun. [1]

(ii) Calculate the speed that the speed gun would register.

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

Question 8 continues on the next page

(iii) Sketch on the axes below how you would expect the speed recorded by the speed gun to change as the car approaches the bridge. Explain the shape of the curve you have drawn.



[2]

[Total: 13]

[Quality of Written Communication: 4]

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