Thursday 19 June 2014 – Morning

A2 GCE PHYSICS A

G485/01 Fields, Particles and Frontiers of Physics

Candidates answer on the Question Paper.

OCR supplied materials:
- Data, Formulae and Relationships Booklet (sent with general stationery)

Other materials required:
- Electronic calculator

Duration: 2 hours

Candidate forename		Candidate surname	

Centre number						Candidate number				

INSTRUCTIONS TO CANDIDATES

- Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.
- Use black ink. HB pencil may be used for graphs and diagrams only.
- Answer **all** the questions.
- Read each question carefully. Make sure you know what you have to do before starting your answer.
- Write your answer to each question in the space provided. If additional space is required, you should use the lined pages at the end of this booklet. The question number(s) must be clearly shown.
- Do **not** write in the bar codes.

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 **100**.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- Where you see this icon you will be awarded marks for the quality of written communication in your answer.
  This means for example you should:
  - ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear;
  - organise information clearly and coherently, using specialist vocabulary when appropriate.
- This document consists of **24** pages. Any blank pages are indicated.

Turn over

Answer **all** the questions.

1 **(a)** Fig. 1.1 shows a negatively charged metal sphere close to a positively charged metal plate.

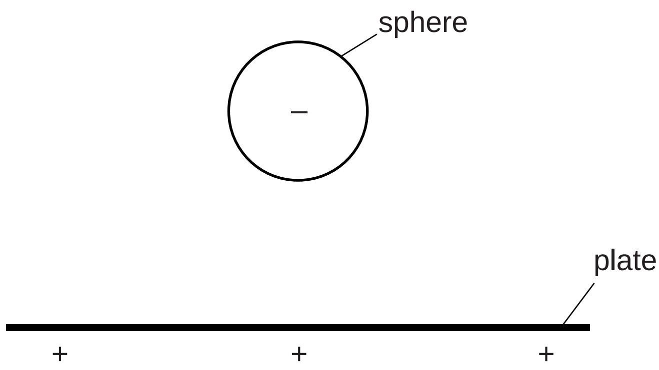

Fig. 1.1

On Fig. 1.1, draw a minimum of five field lines to show the electric field pattern between the plate and the sphere. **[2]**

(b) Fig. 1.2 shows two positively charged particles **A** and **B**.

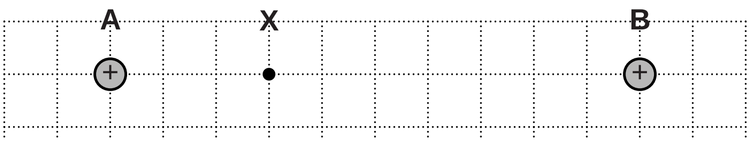

Fig. 1.2

Fig. 1.3

At point **X**, the magnitude of the **resultant** electric field strength due to the particles **A** and **B** is zero.

(i) State, with a reason, which of the two particles has a charge of greater magnitude.

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.... **[1]**

(ii) On Fig. 1.3 sketch the variation of the resultant electric field strength E with distance d from the particle **A**. **[3]**

(c) Fig. 1.4 shows a stationary positively charged particle.

Fig. 1.4

This particle creates both electric and gravitational fields in the space around it. Explain why the **ratio** of the electric field strength E to the gravitational field strength g at any point around this charge is independent of its distance from the particle.

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.... **[1]**

[Total: 7]

2 Fig. 2.1 shows the circular path described by a helium nucleus in a region of uniform magnetic field in a vacuum.

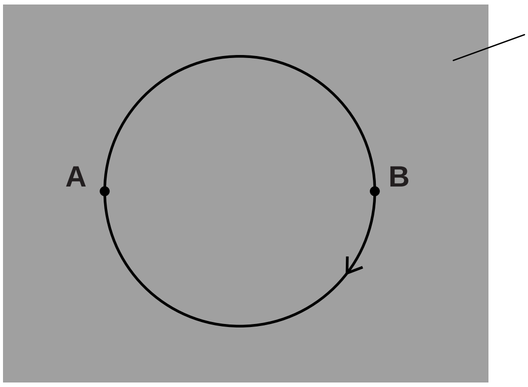

Fig. 2.1

The direction of the magnetic field is perpendicular to the plane of the paper. The magnetic flux density of the magnetic field is 0.20 mT. The radius of the circular path is 15 cm. The helium nucleus has charge $+ 3.2 \times 10^{-19}$ C and mass 6.6×10^{-27} kg.

(a) Explain why the helium nucleus

(i) travels in a circular path

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.... **[1]**

(ii) has the same kinetic energy at **A** and **B**.

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.... **[1]**

(b) Calculate the magnitude of the momentum of the helium nucleus.

momentum = ... kg m s^{-1} **[3]**

(c) Calculate the kinetic energy of the helium nucleus.

kinetic energy = ... J **[2]**

(d) A uniform electric field is now also applied in the region shaded in Fig. 2.1. The direction of this electric field is from **left** to **right**. Describe the path now followed by the helium nucleus in the electric and magnetic fields.

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.... **[2]**

[Total: 9]

3 **(a)** Deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) are isotopes of hydrogen.

(i) State **two** features common to all isotopes of hydrogen.

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.... **[1]**

(ii) Explain why the total mass of the individual nucleons of a deuterium nucleus is different from the mass of the deuterium nucleus.

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.... **[3]**

(b) A fusion reaction between two nuclei is shown below.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

A neutron inside a nucleus is stable. However, a 'free' neutron, when outside the nucleus, undergoes beta decay with a half-life of about 11 minutes.

(i) Complete the decay equation below for a free neutron.

$^{1}_{0}n \rightarrow$ .... + $^{0}_{-1}e$ + ... **[2]**

(ii) Explain what is meant by the *half-life* of a free neutron.

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.... **[1]**

(c) For the fusion reaction to occur the separation between the deuterium and tritium nuclei must be less than 10^{-14} m. This means that the average kinetic energy of these hydrogen nuclei needs to be about 70 keV. The energy released by the fusion reaction is 18 MeV.

(i) Calculate the repulsive electrical force between the deuterium and tritium nuclei at a separation of 10^{-14} m.

force = ... N **[2]**

(ii) Assume that a mixture of these hydrogen nuclei behaves as an ideal gas.

Estimate the temperature of the mixture of nuclei required for this fusion reaction.

temperature = ... K **[3]**

(iii) In practice, fusion occurs at a much lower temperature. Suggest a reason why.

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.... **[1]**

(iv) Calculate the change in mass in a single fusion reaction.

change in mass = ... kg **[2]**

(v) Fig. 3.1 shows the variation of probability of fusion reaction with temperature *T* for deuterium and tritium and for deuterium and helium.

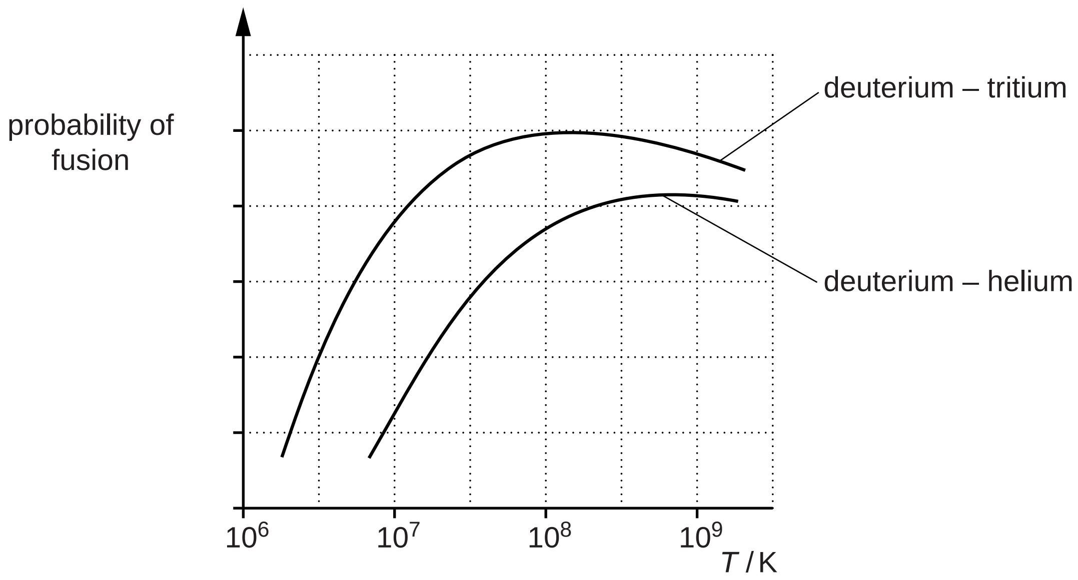

Fig. 3.1

Suggest why the probability of reaction at a given temperature is smaller for deuterium and helium.

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.... **[2]**

[Total: 17]

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Question 4 begins on page 10

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4 **(a)** Define the *time constant* of a capacitor-resistor discharge circuit.

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.... **[1]**

(b) A student designs a circuit with a time constant of 5.0 s. State suitable values for resistance *R* and capacitance *C* for this circuit.

R = ... *C* = ... **[1]**

(c) Fig. 4.1 shows a circuit with a capacitor of capacitance 0.010 F.

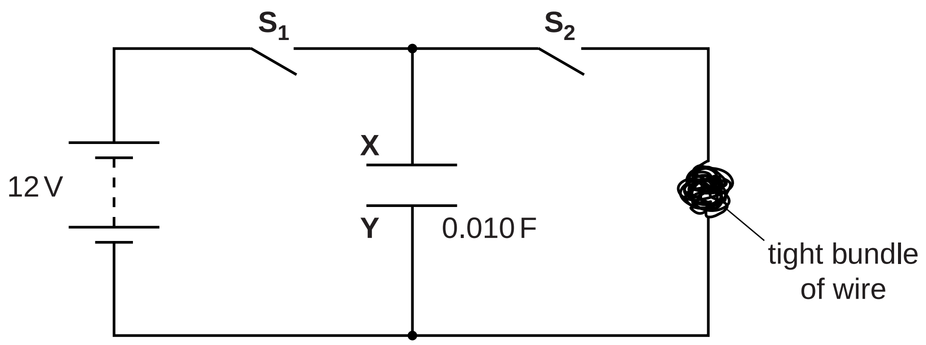

Fig. 4.1

A tight bundle of wire is made from 5.0 m of insulated wire of diameter 0.12 mm and resistivity $4.9 \times 10^{-7}\,\Omega\,m$. The material of the wire has density $8900\,kg\,m^{-3}$ and specific heat capacity $420\,J\,kg^{-1}\,K^{-1}$.

(i) Calculate the time constant of the circuit.

time constant = ... s **[3]**

(ii) Switch $\mathbf{S_2}$ is open. Switch $\mathbf{S_1}$ is closed. Explain in terms of the movement of electrons how **X** and **Y** acquire equal but opposite charge.

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.... **[3]**

(iii) Switch $\mathbf{S_1}$ is opened. The potential difference across the capacitor is 12 V. Switch $\mathbf{S_2}$ is now closed. Assume that all the energy stored by the capacitor is used to heat up the bundle of wire. Calculate the increase in the temperature of the bundle of wire.

increase in temperature = ... °C **[4]**

(iv) State and explain how your answer to **(iii)** would change when a 24 V power supply is used to carry out the experiment.

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.... **[2]**

[Total: 14]

5 **(a)** State Faraday's law of electromagnetic induction.

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.... **[1]**

(b) Fig. 5.1 shows a magnet being moved towards the centre of a flat coil.

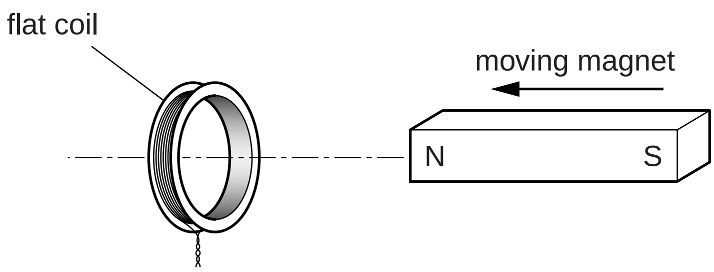

Fig. 5.1

A current is induced in the coil. Use ideas about energy conservation to state and explain the polarity of the face of the coil nearer the magnet.

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.... **[1]**

(c) Fig. 5.2 shows the magnetic field from the north pole of a vertically held bar magnet.

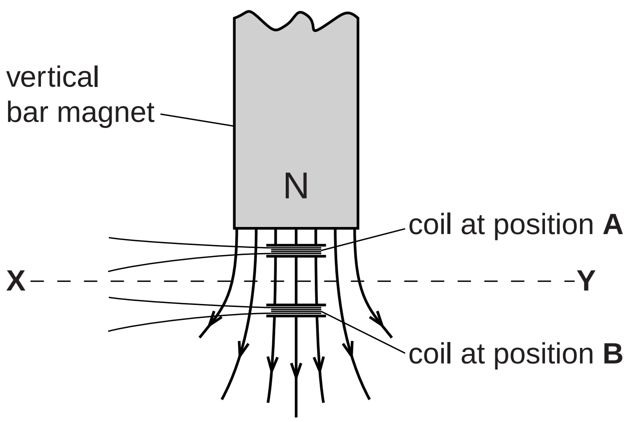

Fig. 5.2

(i) A small flat coil is placed at **A**. The coil is moved downwards from position **A** to position **B**. The plane of the coil remains horizontal between these two positions. Explain why there is no induced e.m.f. across the ends of the coil.

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.... **[1]**

(ii) Fig. 5.3 is a graph showing how the magnetic flux density *B* varies along the horizontal line **XY** in Fig. 5.2.

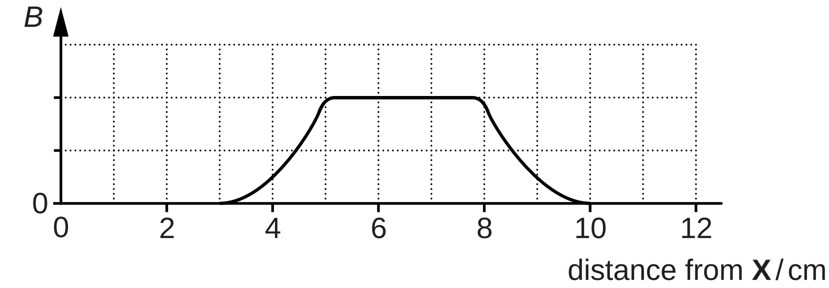

Fig. 5.3

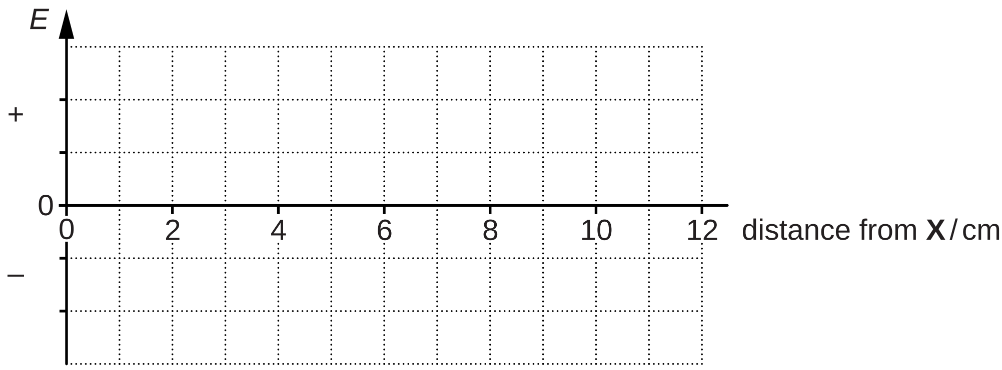

Fig. 5.4

The same small flat coil from **(i)** is moved at a constant speed from **X** to **Y**. The plane of the coil remains horizontal between **X** and **Y**.

On the axis provided in Fig. 5.4, sketch a graph to show the variation of the induced e.m.f. *E* across the ends of the coil with distance from **X**. **[3]**

[Total: 6]

Question 6 begins on page 14

6 **(a)** Fig. 6.1 shows the quark composition of some particles.

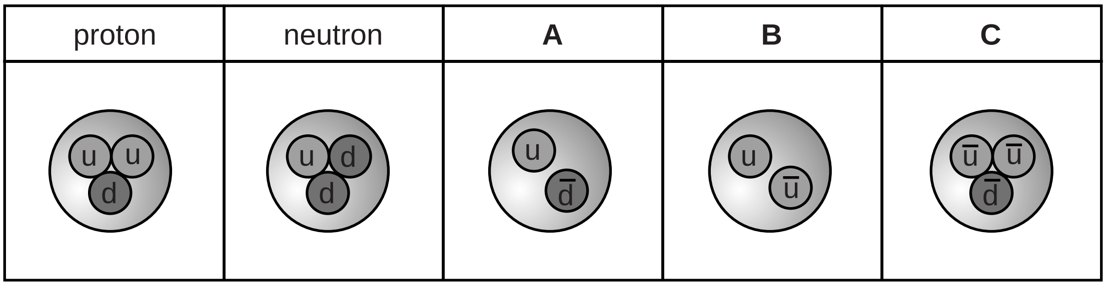

Fig. 6.1

(i) Identify the anti-proton from the table of particles shown in Fig. 6.1.

.... **[1]**

(ii) State the value of the charge of particle **B**.

.... **[1]**

(b) The nuclei of carbon-14 are produced naturally in the upper atmosphere from the reactions of slow-moving neutrons with nitrogen nuclei.

(i) The reaction below shows a nuclear reaction between a neutron and a nitrogen nucleus.

$$^{1}_{0}\text{n} \; + \; ^{14}_{7}\text{N} \; \rightarrow \; ^{14}_{6}\text{C} \; + \; \mathbf{X}$$

Identify the particle **X**.

.... **[1]**

(ii) Carbon-14 has a half-life of 5700 years. The molar mass of carbon-14 is 0.014 kg mol^{-1}. The total activity from all the carbon-14 nuclei found on the Earth is estimated to be 1.1×10^{19} Bq. Estimate the total mass of carbon-14 on the Earth.

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

(c) Energy in the core of a nuclear reactor is produced by induced nuclear fission of uranium-235 nuclei. Explain what is meant by *induced nuclear fission*.

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.... **[2]**

(d) Many nuclear reactors use uranium-235 as fuel. Some of these reactors use water as both coolant and moderator. The control rods contain boron-10. Fig. 6.2 shows part of the inside of the core of a nuclear reactor.

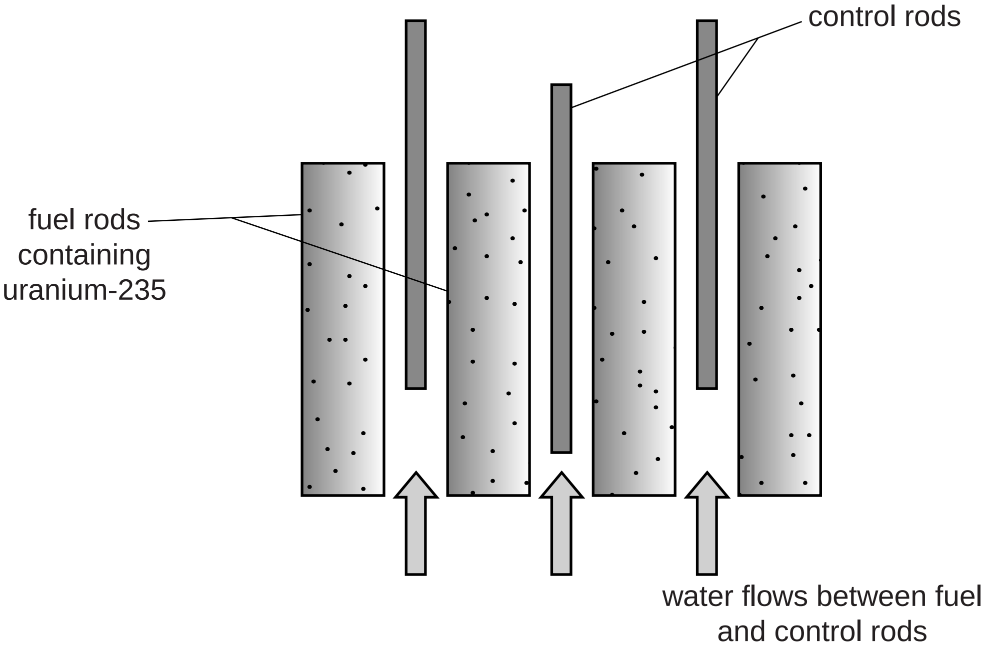

Fig. 6.2

Explain the purpose of using a moderator and control rods in the core of a nuclear reactor.

In your answer you should make clear how a moderator works at a microscopic level.

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.... **[4]**

[Total: 12]

7 **(a)** X-rays are produced in an X-ray tube when fast moving electrons hit a metal target.

Fig. 7.1 shows a typical graph of intensity I against wavelength λ of X-rays emitted by an X-ray tube.

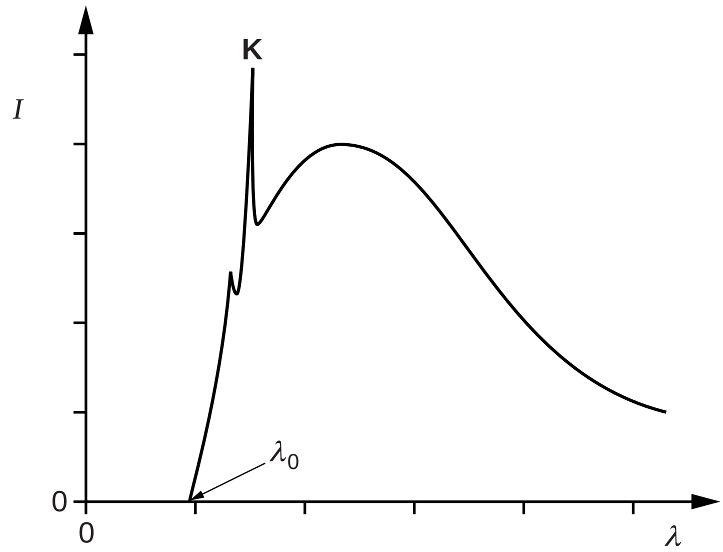

Fig. 7.1

High-speed electrons colliding with the atoms in the target metal can remove electrons from these atoms. The removal of such electrons creates 'gaps' in the lower energy levels of these atoms. These gaps are quickly filled by electrons in the higher energy levels making transitions to these lower energy levels. The electrons lose energy which is released as photons with particular wavelengths. These emission spectral lines are shown by the high intensity peaks such as **K** shown in Fig. 7.1.

Fig. 7.2 shows three of the energy levels, **A**, **B** and **C**, for the metal atoms of the target. The electron transition shown produces the peak **K**.

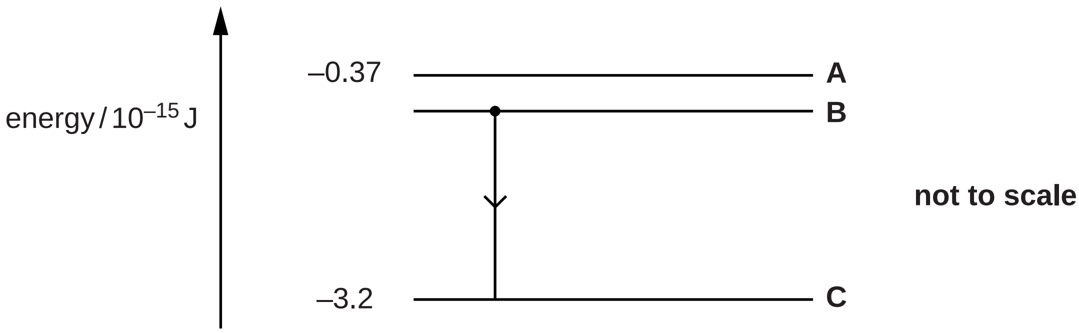

Fig. 7.2

(i) Explain what is meant by an *energy level* of an atom.

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.... **[1]**

(ii) The peak **K** occurs at a wavelength of 7.2×10^{-11} m. Calculate the value of the energy level **B**.

value of energy level = ... J **[3]**

(iii) In Fig. 7.1, the shortest wavelength λ_0 produced from an X-ray tube depends on the accelerating potential difference V. The maximum kinetic energy of a single accelerated electron is equal to the energy of a single X-ray photon of wavelength λ_0. Explain how λ_0 from the X-ray tube changes when the accelerating potential difference of the X-ray tube is **doubled**.

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.... **[2]**

(b) X-rays are used to scan the human body. A parallel beam of X-rays is incident on a muscle. The attenuation (absorption) coefficient μ for X-rays in muscle is $0.96\,\text{cm}^{-1}$.

(i) Calculate the fraction of X-ray intensity **absorbed** by 2.3 cm of muscle.

fraction = ... **[3]**

(ii) The attenuation coefficients for X-rays in bone and fat are $2.8\,\text{cm}^{-1}$ and $0.90\,\text{cm}^{-1}$ respectively. Two X-ray images are taken, one with bone and muscle and another with muscle and fat. State and explain which image will give better contrast.

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.... **[1]**

[Total: 10]

8 **(a)** Fig. 8.1 shows a B-scan image of an ultrasound scan of a 12 week foetus.

Fig. 8.1

The outline of the head of the foetus can be seen in Fig. 8.1. Describe and explain the principles of a B-scan.

In your answer you should make clear how it is possible to distinguish the boundaries between different materials.

.... **[3]**

(b) Fig. 8.2 shows an image of the brain using a positron emission tomography (PET) scanner.

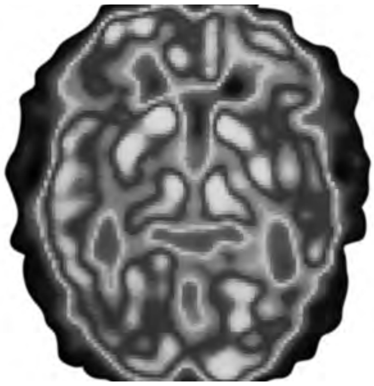

Fig. 8.2

The lighter regions in Fig. 8.2 show the active areas of the brain. Fluorine-18 is a common tracer injected into a patient before a PET scan.

Explain the basic principles of PET scanning, including how the image is formed.

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[Total: 7]

9 Sirius A and B are binary stars in our galaxy at a distance of 8.6 ly from the Sun. Sirius B is a white dwarf of diameter 12 km and mass 2.0×10^{30} kg.

(a) Calculate the density of Sirius B.

density = ... unit .... **[3]**

(b) The mass of the Sun is the same as Sirius B. The Sun has a diameter of 1.4×10^{9} m.

Calculate the ratio

$$\frac{\text{gravitational field strength on the surface of Sirius B}}{\text{gravitational field strength on the surface of the Sun}}.$$

ratio = ... **[2]**

(c) Calculate the parallax angle in arc seconds for Sirius B.

$1\,\text{pc} = 3.1 \times 10^{16}$ m

parallax angle = ... arc seconds **[2]**

(d) Sirius A is moving towards the Earth at a relative velocity of $7600\,\mathrm{m\,s^{-1}}$. Calculate the percentage change in the wavelength of a spectral line observed from this star compared with an identical spectral line observed in the laboratory.

percentage change = ... % **[2]**

(e) A student suggests that the distance of Sirius A can be calculated using Hubble's law and the speed given in **(d)**. Discuss whether this suggestion is correct or incorrect.

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.... **[1]**

[Total: 10]

Question 10 begins on page 22

10 **(a)** State the *cosmological principle*.

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.... **[2]**

(b) State some of the properties of the microwave background radiation observed from the Earth. Discuss how the background microwave radiation is linked to the big bang model of the universe.

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.... **[3]**

(c) Calculate the age of our universe in years based on a critical density of the universe of $9.7 \times 10^{-27}\,kg\,m^{-3}$.

age = ... y **[3]**

[Total: 8]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional answer space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margins.