OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE

PHYSICS B (ADVANCING PHYSICS) G495

Field and Particle Pictures

Candidates answer on the question paper.

OCR Supplied Materials:
- Data, Formulae and Relationships Booklet
- Insert (inserted)

Other Materials Required:
- Electronic calculator

Wednesday 2 February 2011
Afternoon

Duration: 2 hours

Candidate Forename		Candidate Surname	

Centre Number						Candidate Number				

INSTRUCTIONS TO CANDIDATES

- The insert will be found in the centre of this document.
- Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.
- Use black ink. Pencil may be used for graphs and diagrams only.
- 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. Additional paper may be used if necessary but you must clearly show your candidate number, centre number and question number(s).
- Answer **all** the questions.
- 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.
- 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 the meaning is clear;
  - organise information clearly and coherently, using specialist vocabulary when appropriate.
- You are advised to show all the steps in any calculations.
- This document consists of **24** pages. Any blank pages are indicated.
- The questions in Section C are based on the material in the Insert.

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Answer **all** the questions.

Section A

1 A charging unit for a laptop computer uses a transformer to convert a 230 V, 50 Hz mains supply to a 15 V alternating supply.

The primary coil has 3800 turns of wire. Assume the transformer is ideal.

(a) Calculate the number of turns on the secondary coil.

number of turns = ... **[2]**

(b) Put a ring around the **one** quantity which will **not** be the same for both coils of this transformer.

magnetic flux

magnetic flux density

magnetic flux linkage **[1]**

2 Fig. 2.1 shows the electric field lines at the tip of a positively charged needle.

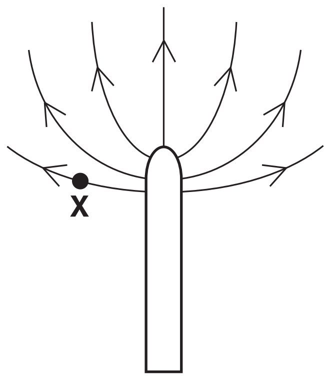

Fig. 2.1

(a) Draw an equipotential line passing through **X**, in the field region shown. **[1]**

(b) State the feature of the diagram that shows that the electrical field strength is **not** uniform near the tip of the needle.

[1]

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3 Americium-241 emits alpha particles.

$$^{241}_{95}\text{Am} \longrightarrow {}^{237}_{93}\text{Np} + {}^{4}_{2}\text{He}$$

Here are the masses of the nuclei involved in the decay:

$^{241}_{95}\text{Am} = 4.0031 \times 10^{-25}\,\text{kg}$

$^{237}_{93}\text{Np} = 3.9365 \times 10^{-25}\,\text{kg}$

$^{4}_{2}\text{He} = 0.0665 \times 10^{-25}\,\text{kg}$

Calculate the energy released in the decay.

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

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

4 Fig. 4.1 shows how the electric field strength of a positive point charge varies with distance from the charge.

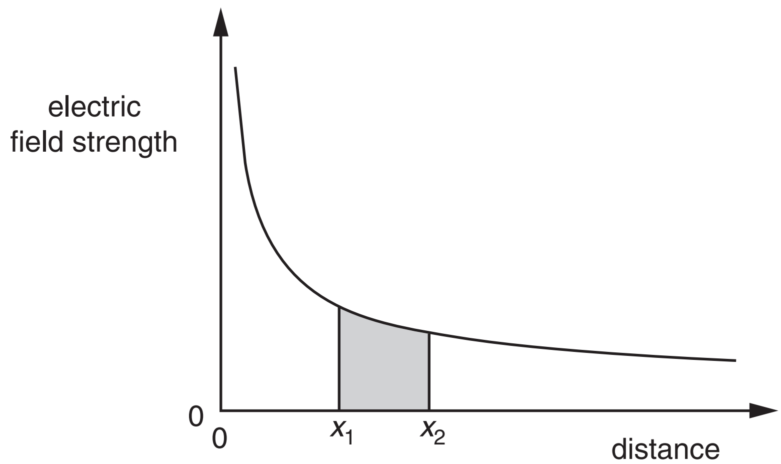

Fig. 4.1

State the quantity represented by the shaded area.

.... **[2]**

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5 An electron in a hydrogen atom can be crudely modelled as a standing wave in a box of length about 1.5×10^{-10} m.

Fig. 5.1 shows the standing wave pattern for the lowest, $n = 1$, energy state.

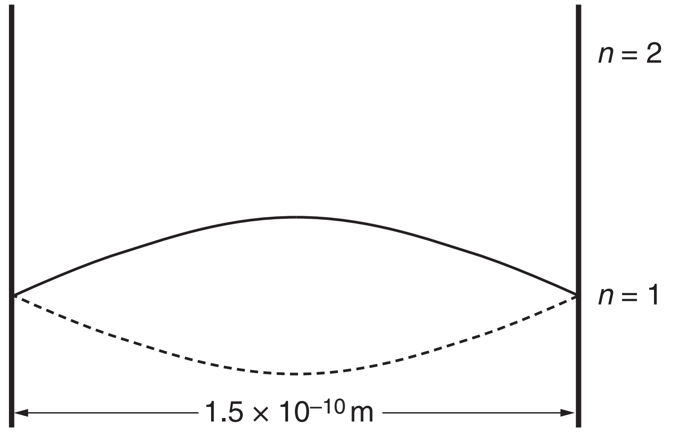

Fig. 5.1

(a) State the wavelength of the standing wave.

wavelength = ... m **[1]**

(b) On Fig. 5.1 sketch the standing wave pattern for the $n = 2$ energy level. **[1]**

6 Here is a list of particles.

electron

neutron

photon

positron

(a) Which particle has zero rest energy? ....

(b) Which particle has positive charge? ....

(c) Which particle is a hadron ? ....

[3]

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7 Fig. 7.1 represents the scattering of a high-energy electron by a quark within a particle. The electron loses energy in the scattering process.

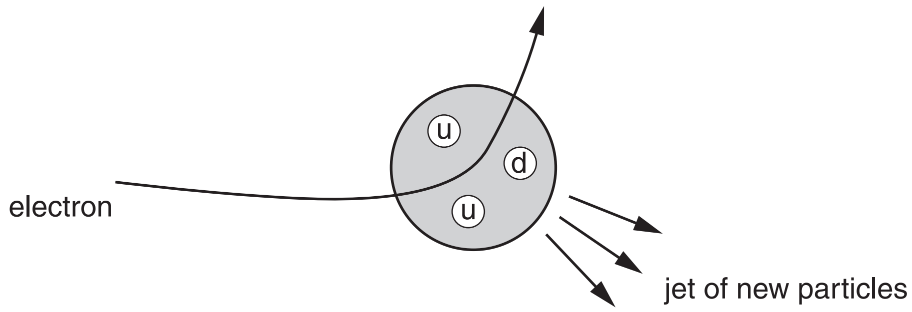

Fig. 7.1

charge on u quark = +2/3 e
charge on d quark = –1/3 e

(a) State the name of the shaded particle containing three quarks.

particle name .... **[1]**

(b) Explain why the electron loses energy in the scattering process.

[2]

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8 Fig. 8.1 shows a simple d.c. motor.

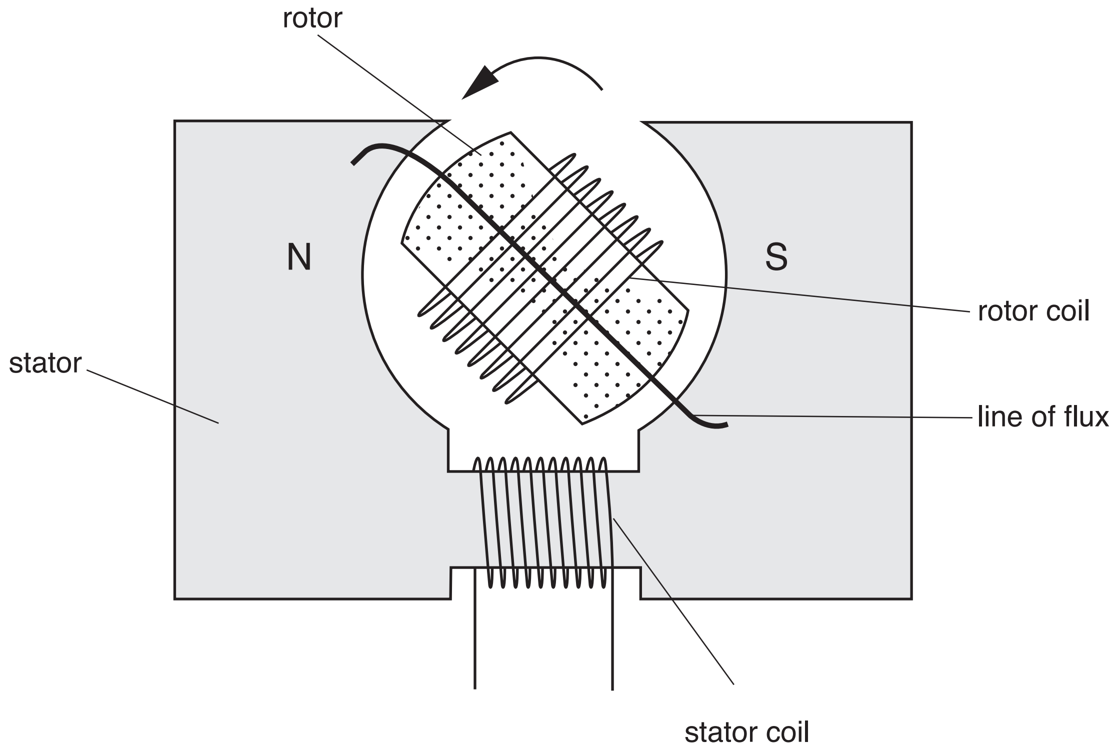

Fig. 8.1

(a) There is a current in the stator coil and the rotor coils. Complete the line of flux drawn in the diagram. **[1]**

(b) The rotor is turning anticlockwise. Mark the north and south poles of the rotor. **[1]**

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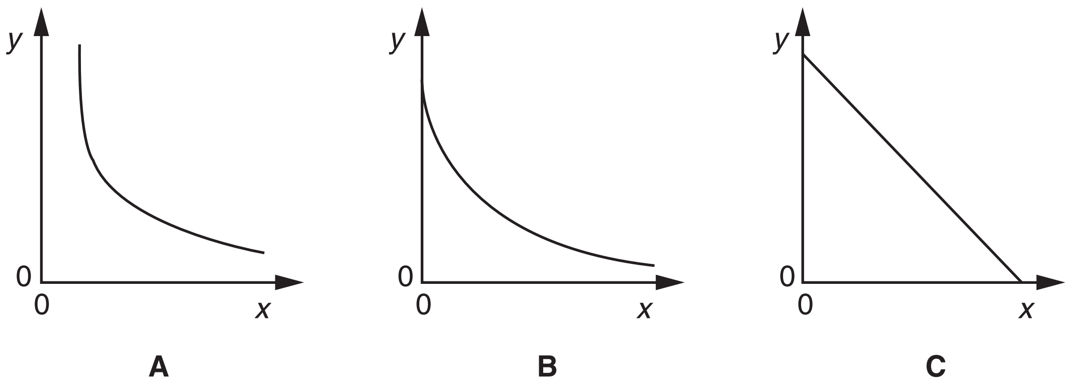
9 Here are three graphs:



Each row of the table shows possible pairs of *x* and *y* variables.

y variable	*x* variable	graph
activity of a sample of radioactive material	time	
natural log of activity of a sample of radioactive material	time	

Complete the third column with the most appropriate graph (**A**, **B** or **C**) for each row. **[2]**

[Section A Total: 21]

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Section B

10 This question is about the scattering of alpha particles by nuclei as shown in Fig. 10.1.

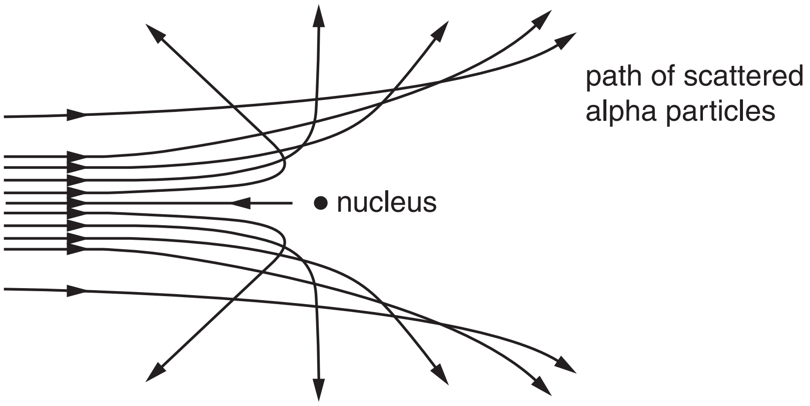

Fig. 10.1

Alpha particles of energy 5.0 MeV are fired at a thin gold foil. It is observed that 4 in every 100 000 alpha particles are scattered through large angles and 'bounce back' from the foil. It is assumed that these particles have made collisions with individual, stationary gold nuclei.

(a) State and explain any changes in the proportion of alpha particles which bounce back when the following changes are made to the experiment.

(i) A **thicker** gold foil is irradiated with 5 MeV alpha particles.

[2]

(ii) The original gold foil is irradiated with alpha particles of **higher** energy than 5 MeV.

[2]

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(b) When a 5 MeV alpha particle makes a direct collision with a nucleus, the alpha particle is momentarily stationary.

(i) State the electrical potential energy of such an alpha particle when it is at its closest to the gold nucleus.

electrical potential energy = ... MeV **[1]**

(ii) Convert the value in **(i)** into joules.

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

electrical potential energy = ... J **[1]**

(iii) Use the value in **(ii)** to calculate the distance of closest approach of the particle to the nucleus.

charge on alpha particle = +2 e
charge on gold nucleus = +79 e

$k = \frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9\,N\,m^{-2}\,C^{-2}$

distance = ... m **[2]**

(c) Assuming that the distance calculated in **b(iii)** equals the radius of the nucleus, the experiment suggests that the ratio $\frac{\text{nuclear radius}}{\text{atomic radius}}$ is about 6×10^{-5}.

Use the value of the ratio to estimate the density of a gold nucleus. State one other assumption that you make.

density of gold = $1.9 \times 10^4\,kg\,m^{-3}$

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

[Total: 11]

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11 This question is about an isotope used in medicine.

Iodine-131 undergoes beta decay.

(a) **(i)** Complete the decay equation below.

$$^{131}_{53}\text{I} \longrightarrow \,^{\cdots\cdots}_{\cdots\cdots}\text{Xe} + \,^{0}_{-1}\text{e} + \,^{0}_{0}\bar{\nu}$$

[1]

(ii) Here are four types of fundamental particle:

lepton   anti-lepton   quark   anti-quark

Circle the type of fundamental particle represented by $^{0}_{0}\bar{\nu}$ in the decay equation. **[1]**

(b) Iodine-131 has a half-life of 8 days. In a thyroid gland investigation, 4.0×10^{-11} gram of iodine is absorbed by the gland.

(i) Calculate the initial activity of the iodine-131 in the gland.

decay constant, λ, of iodine-131 = $1.00 \times 10^{-6}\,\text{s}^{-1}$
molar mass of iodine-131 = 131 gram
$N_A = 6.02 \times 10^{23}\,\text{mol}^{-1}$

initial activity = ... Bq **[2]**

(ii) Show that it will take about 50 days for the activity of the sample to fall to 1% of its original value.

[2]

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(iii) The mass of the thyroid gland is about 50 gram. Estimate the maximum dose in gray that the gland receives from 4.0×10^{-11} gram of iodine-131.

average energy of a β particle released in the decay of iodine-131 = 1×10^{-13} J

maximum dose = ... Gy **[2]**

(iv) Suggest **two** reasons why your estimate gives a maximum dose.

[2]

[Total: 10]

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12 This question is about charges accelerated to high speeds. Fig. 12.1 shows a beam of electrons which are accelerated as they pass between two parallel charged electrodes.

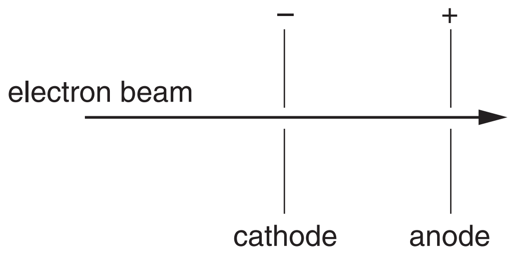

Fig. 12.1

(a) **(i)** Which of the graphs in Fig. 12.2 correctly shows the relationship between the acceleration of an electron (y-axis) and the distance from the cathode (x-axis) assuming that relativistic effects are not important?

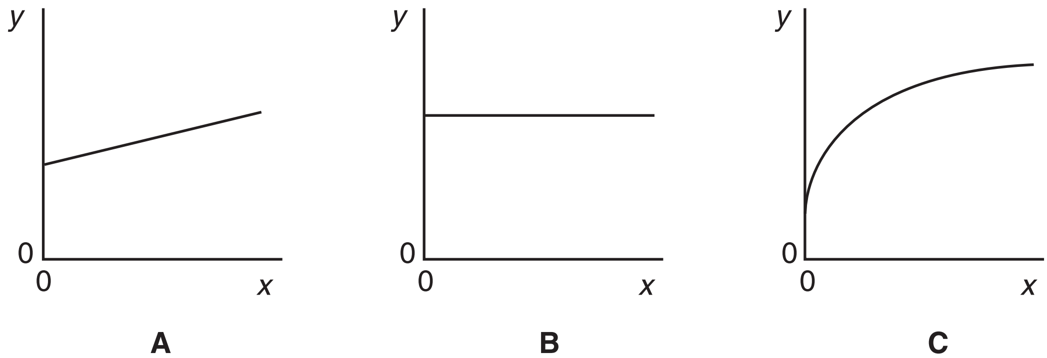

Fig. 12.2

The correct relationship is shown in graph .... **[1]**

(ii) The distance between the anode and cathode is 0.20 m. Calculate the strength of the uniform electric field between the anode and cathode when the p.d. is 70 kV.

field strength = ... V m^{-1} **[1]**

(b) The mass of an electron at rest is 9.1×10^{-31} kg. Show that the rest energy, E_{rest}, of the electron is about 8×10^{-14} J.

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

[1]

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(c) The relativistic factor, γ, is given by

$$\gamma = \frac{E_{total}}{E_{rest}} = \frac{E_{rest} + E_{kinetic}}{E_{rest}}.$$

(i) When an electron is accelerated through a p.d. of 70 kV it gains a kinetic energy of 1.1×10^{-14} J. Calculate γ for the electron.

γ = ... **[1]**

(ii) The accelerating p.d. is doubled to 140 kV.
Choose which of the statements below correctly describes how γ changes.

A γ increases by a factor of two when the p.d. doubles

B γ increases by a factor of less than two when the p.d. doubles

C γ increases by a factor of more than two when the p.d. doubles

the correct statement is .... **[1]**

(d) According to classical physics the momentum of a particle of mass *m* and velocity *v* is given by

$$p = mv.$$

At very high speeds, relativistic physics shows that the momentum of the particle is given by

$$p = \gamma\, mv.$$

In an X-ray tube an electron is accelerated to a kinetic energy of 60 keV (about 1×10^{-14} J). Explain whether the classical equation will give an accurate value of the momentum of the particle or whether relativistic effects are important.

[3]

[Total: 8]

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13 This question is about a simple a.c. generator as shown in Fig. 13.1.

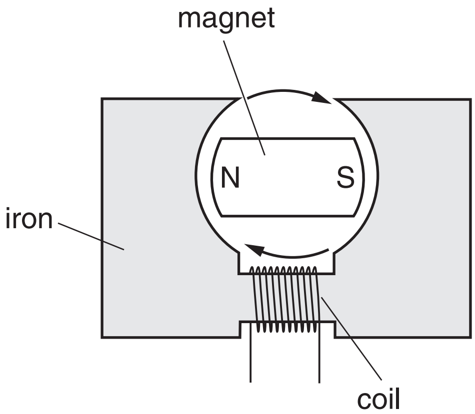

Fig. 13.1

Fig. 13.2 shows how the emf induced in the coil varies over time.

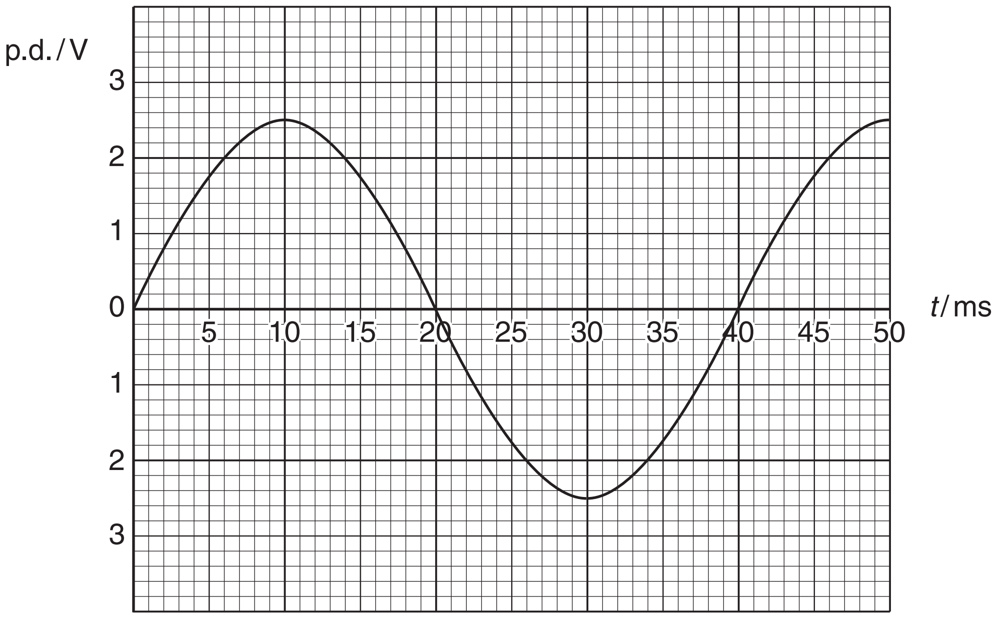

Fig. 13.2

(a) Use Fig. 13.2 to find the frequency f of the emf induced in the coil.

f = ... Hz **[1]**

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(b) The coil has 700 turns. Using data from the graph, explain by doing suitable calculations why the maximum rate of change of flux in the coil is 0.0036 Wb s^{-1}.

[3]

(c) Assuming that the emf and flux are changing sinusoidally with frequency *f*, the rate of change of flux at time *t* is given by the equation

$$\text{rate of change of flux} = 2\pi f \times \text{maximum flux} \times \cos(2\pi f t).$$

The core has a cross section of 25 mm × 25 mm.

Calculate the **maximum** flux density in the core.

maximum flux density = ... T **[3]**

(d) Suggest **two** modifications to the generator that would increase the emf induced without changing the speed of the rotor.

[2]

[Total: 9]

[Section B Total: 38]

Section C

The questions in this section are based on the Advance Notice.

14 Using Sir Fred Hoyle's comment (lines 1 to 2 in the article) calculate the distance from the surface of the Earth to space. Assume the car travels at 70 miles per hour

1 mile = 1.6 km

distance = ... km **[1]**

[Total: 1]

15 This question is about temperature control in a space suit (lines 26 to 31 in the article).

A human, when working hard, can dissipate about 1 MJ of energy in an hour, warming the temperature of the body and its surroundings.

(a) Show that this rate of energy transfer is about 280 watts.

[1]

(b) Explain how the rate of pumping of the water around the liquid cooling and ventilation garment (LCVG) would need to change in order to maintain the same temperature if the astronaut moved from a sunlit, warm area to an unlit, colder one.

The steps of your explanation should be clear and in a logical order.

[3]

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(c) One problem that would arise if the LCVG water pump failed would be that the gas inside the suit would heat up, resulting in an increase in the pressure.

(i) Show that the mass of gas in the space suit is about 80 gram. Assume that all the gas is oxygen.

volume of gas in the suit = 0.058 m^3

density of oxygen gas in the suit = 1.4 kg m^{-3}

[1]

(ii) Calculate the temperature reached by the oxygen in the space suit after five seconds. Assume that all the energy dissipated by the astronaut is transferred to the gas.

initial temperature of gas = 18 °C

rate of energy transfer = 280 W

specific thermal capacity of oxygen = 900 J kg^{-1} $°C^{-1}$

temperature = ... °C **[3]**

(iii) As the temperature of the oxygen increases the pressure in the suit will rise. Calculate the factor that the pressure will rise by when the temperature rises to the value calculated in **(ii)**.

Assume that the volume of the suit does not change.

factor = ... **[2]**

[Total: 10]

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16 Fig. 16.1 shows how the Earth's atmospheric pressure varies with altitude.

(a) Explain what is meant by an *exponential relationship* and use data from Fig.16.1 (Fig. 3 in the article) to show that the relationship between pressure and altitude is exponential.

In your answer you should use appropriate technical terms spelled correctly.

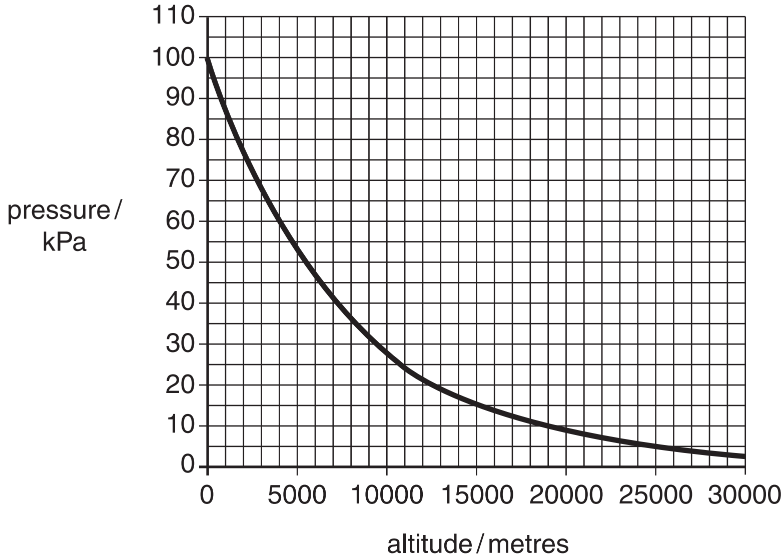

Fig. 16. 1

[5]

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(b) The gas pressure within the suit is much less than atmospheric pressure at sea level. Explain how the gas in the suit being almost 100% oxygen (line 40 in the article) allows the astronaut to breathe at this reduced pressure.

[2]

[Total: 7]

17 This question is about the Thermal Micrometeoroid Garment (TMG) (lines 41 to 53 in the article). This comprises several layers, some of which are composite materials.

Explain what is meant by a *composite material* and explain a benefit of using a composite material in the TMG. Refer to one of the materials mentioned in the article in your answer.

[4]

[Total: 4]

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18 Spacewalking astronauts are in constant danger of being struck by fast-moving tiny fragments of dust, called micrometeoroids (lines 58 to 62 in the article).

(a) Show that the kinetic energy of a typical micrometeoroid is about 1 kJ.

speed of micrometeoroid = $50\,km\,s^{-1}$

mass of micrometeoroid = $1.0 \times 10^{-6}\,kg$

[2]

(b) Assume that 90% of this energy is used on impact to melt and then vaporise some of the aluminium in the outer layer of the helmet.

(i) By neglecting the energy used to melt the metal, calculate the mass of aluminium that can be vaporised by this amount of energy.

energy required to vaporise 1 kg of aluminium = 10.5 MJ

mass vaporised = ... kg **[2]**

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(ii) Assuming the vaporised shape is a hemisphere, calculate the penetration depth, r (the radius of the hemisphere) of the micrometeoroid (Fig. 18.1).

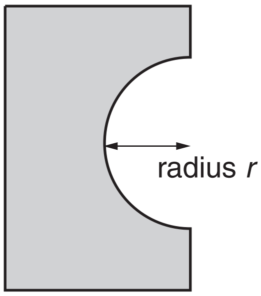

Fig. 18.1

density of aluminium = 2400 kg m^{-3}

volume of a sphere of radius $r = \frac{4}{3}\pi r^3$

penetration distance = ... m **[3]**

[Total: 7]

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19 Astronauts face the danger of the solar wind. This accounts for 10^6 tonnes (10^9 kg) of mass streaming from the Sun each second (lines 63 to 66 in the article).

(a) (i) Show that the Sun emits about 6×10^{35} particles per second.
Assume that each particle has mass equal to that of a proton.

mass of proton = 1.7×10^{-27} kg

[2]

(ii) The solar wind flux is the number of particles per m^2 per second.

Use your answer to **(i)** to show that the solar wind flux at the Earth's distance from the Sun is about $2 \times 10^{12}\ m^{-2}\ s^{-1}$. Assume the solar wind is emitted evenly in all directions.

mean Earth-Sun distance = 1.5×10^{11} m

surface area of a sphere = $4\pi r^2$

[2]

(b) The protons in the solar wind have energies of about 1 keV (1.6×10^{-16} J).

(i) Estimate the energy transferred to the suit and astronaut in one second assuming that the solar wind strikes an area of $1.5\,m^2$.

energy = ... J **[1]**

(ii) Discuss whether the solar wind protons are likely to be a significant health hazard for the astronaut.
The quality factor for protons is 20.

[3]

[Total: 8]

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20 For space walks and other extra-vehicular activity, the astronauts wear a Mobile Manoeuvring Unit (MMU) which is fitted with a number of nitrogen gas thruster jets. The MMU itself has a mass of 100 kg.

(a) Show that the momentum of an astronaut wearing an MMU and moving forwards at 5 m s^{-1} is about 1 × 10^3 kg m s^{-1}.

total mass of astronaut, space suit and MMU = 225 kg

[1]

(b) Using the information in **(a)**, calculate the rate at which nitrogen gas would need to be expelled from the jet thrusters in order for the astronaut to increase his speed by 4 m s^{-1} in 20 seconds.

velocity of nitrogen gas expelled = 600 m s^{-1}

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

[Total: 4]

[Section C Total: 41]

END OF QUESTION PAPER

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ADVANCED GCE

PHYSICS B (ADVANCING PHYSICS) G495

Unit G495: Field and Particle Pictures

INSERT

Wednesday 2 February 2011
Afternoon

Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

- This insert contains the article required to answer the questions in Section C.

INFORMATION FOR CANDIDATES

- This document consists of **8** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER/INVIGILATOR

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Suited for Space

The astronomer Sir Fred Hoyle once remarked “Space isn’t remote at all. It’s only an hour’s drive away if your car could go straight upwards”. However one might get there, survival in space is not easy, for it is a hostile environment. Astronauts that have been for a “space walk” have done so dressed in carefully-designed suits that have developed over decades as mankind’s adventures have become increasingly daring. With hazards in mind, what are the important things to consider when designing a space suit?

To work in space, outside a spacecraft, astronauts must take their Earth-like environment with them in their suits. The suits must also protect the astronauts and allow them to move around as freely as possible to enable them to perform jobs.

Fig. 1: astronaut on a space walk

The Space Environment – a hazardous place

In space humans are deprived of essential things they have on Earth but they also have to cope with additional issues, largely based on the fact that space is a near-vacuum. Principal problems are:

- lack of air
- extreme temperatures (from +120 °C to –100 °C)
- micrometeoroids (fast-moving fragments of rock and dust)
- ionising radiation (primarily cosmic rays and the solar wind)
- working in a “weightless” environment

A successful space suit will cope with all of these problems; so, what does one consist of and how are these problems addressed?

The Structure of the Suit

The suit itself (known collectively as a Pressure Garment Assembly, PGA) has several basic components. There are many attachments added to enable things like radio communication and drinking (replacing fluids) to take place; the exact number of components will depend upon the nature of the mission, but some are common to all. The main components are:

The Liquid Cooling and Ventilation Garment (LCVG)

This is the first layer the astronaut puts on. It is tight-fitting and, among other things, keeps the astronaut cool. Water is circulated through a network of tubes in contact with the skin; the heated water flows to a back-pack (the Primary Life Support System) where it cools by radiating heat into space, before being circulated through the LCVG again. The system can typically lose heat at a rate of up to 600 W.

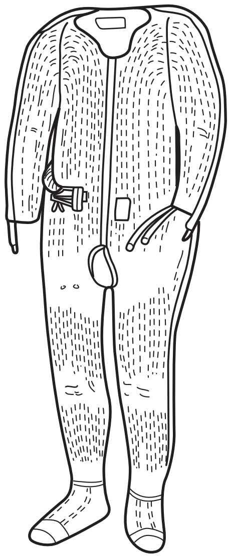

Fig. 2: the Liquid Cooling and Ventilation Garment

Nylon Bladder

This is a rubbery, airtight layer which covers the LCVG. Its function is primarily to contain the breathing air, rather like a balloon. It, in turn, is covered by an outer Nylon Restraint garment, a net-like structure which helps maintain the shape of the Nylon Bladder. Atmospheric pressure decreases roughly exponentially with altitude, as shown in Fig. 3. At altitudes greater than about 19 km, spacesuits with a contained atmosphere are required for breathing. These suits are maintained at a pressure which prevents body fluids from boiling. The pressure inside the suit is typically around 30 kPa, significantly less than atmospheric pressure. However, the gas in the suit is almost 100% oxygen, which allows the astronaut to breathe at this reduced pressure.

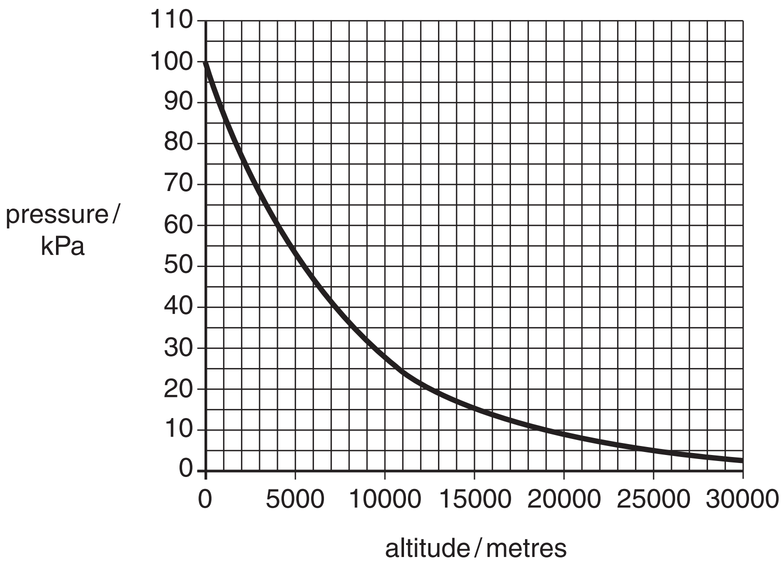

Fig. 3: variation of atmospheric pressure with altitude

The Thermal Micrometeoroid Garment (TMG)

This is the outer garment, the main part of the suit, put on in two sections (upper and lower torso), along with the arms and gloves. It acts as armour against impacting dust and micrometeoroids. It also provides thermal and cosmic ray protection. The TMG comprises several layers, some of which are composite materials. The three main layers, starting with the innermost, are:

- a synthetic rubber – a thermally-insulating, flexible and tear-resistant material of the sort used in wet suits
- PTFE-coated silica fibre – rather like a thin layer of fibre glass. It is fireproof and coated with extremely non-abrasive PTFE, which is used on non-stick cooking equipment.
- a polymer, thinly coated with aluminium – very high tensile strength, chemically very un-reactive and with a high reflectivity and very resistant to puncture. (This is the outermost layer of the garment.)

The suit is coloured white, maximising reflectivity to enable effective temperature control.

Fig. 4: the Thermal Micrometeoroid Garment

The Helmet and Sun Visor

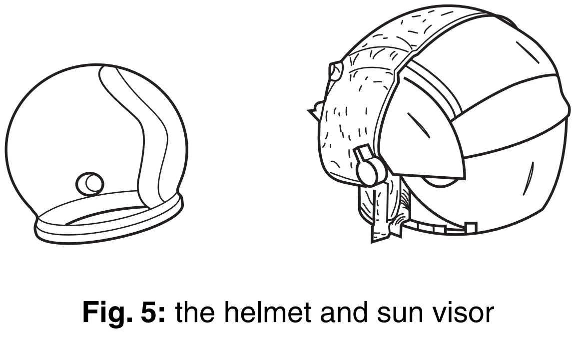

Fig. 5: the helmet and sun visor

These are the final parts of the suit to be put on. The helmet has similar layers to the TMG, whilst the visor is needed to protect the eyes from sunlight.

Protection

The space in which the Earth orbits is littered with tiny fragments of ancient dust (often from comets). Although such particles may be low in mass (less than 10^{-6} kg), their velocity relative to an astronaut on a space walk could be several tens of $km\,s^{-1}$ and impact can potentially cause a great deal of damage. Some could penetrate the outer layers of the suit, but even if they don't, they can cause severe degradation of the suit as they vaporize on impact.
The solar wind is another hazard to protect against. This is the stream of charged particles moving at high speed, continuously emitted by the Sun at a typical rate of a million tonnes per second. At Earth's distance, this amounts to a solar wind flux (the number of particles passing perpendicularly through unit area every second) of more than $10^{12}\,m^{-2}\,s^{-1}$.
There are also galactic cosmic rays to worry about, streams of sub-atomic particles from beyond the solar system, 90% of which are protons. The energies of these particles typically range from about 100 MeV to about 10 GeV, but some with energies as high as 10^{11} GeV have been detected, against which present suits offer little protection.

Mobility

Moving around dressed in a space suit is difficult, especially when in a state of constant freefall, with no planetary surface providing a reaction force. The suits have a mass of around 50 kg. An astronaut of 75 kg would therefore have a total mass of 125 kg. A Mobile Manoeuvring Unit (MMU) attached to the suit enables the astronaut to move by firing jets of gas in different directions. MMU thrusters can enable delicate movements to be made, but can also propel the astronaut to speeds of up to $20\,m\,s^{-1}$.
The arm and leg joints of the suit are designed to allow the astronaut as much limb mobility as possible. Another problem which needs to be overcome with these joint designs is the change in internal volume of the suit produced when a joint is flexed. If the pressure inside the suit is increased by decreasing the volume, the astronaut would need to work harder in order to move. The design of "constant volume" joints helps to remove this problem.

Future Considerations

The most sophisticated space suits of the current generation have been largely designed to be worn in "zero-gravity" conditions, for missions involving space walks to repair satellites. Future missions might well involve a return to the Moon, or even venture to Mars for the first time. The suits worn by the first Moon-walkers were very different from those of today and new suits to be worn on the Moon today would be much improved. Mars, meanwhile, will present even greater challenges.

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