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Tuesday 28 June 2016 – Morning

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

Candidates answer on the Question Paper.

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

Other materials required:
- Electronic calculator
- Ruler (cm/mm)

Duration: 2 hours

Candidate forename		Candidate surname	

Centre number						Candidate number				

INSTRUCTIONS TO CANDIDATES

- The Insert will be found inside this document.
- 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 page(s) 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.
- 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.

Answer **all** the questions.

SECTION A

1 Here is a list of particles:

proton **quark** **neutron** **neutrino**

Here are four statements about the particles in the list.

A All the particles in the list are hadrons.

B The quark is the only fundamental particle in the list.

C The neutrino is the only lepton in the list.

D The proton is the only nucleon in the list.

Choose the correct statement.

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

2 Fig. 2.1 shows a graph of electrical field strength *E* against distance *r* from a point source.

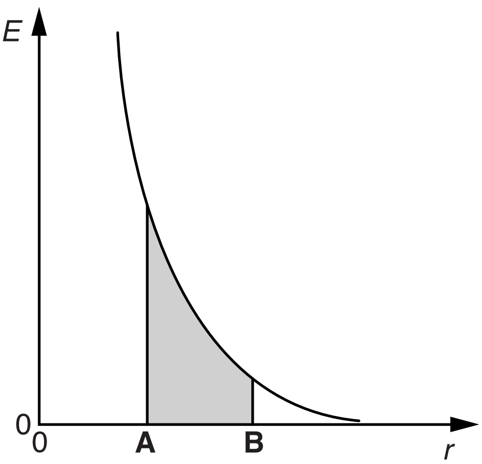

Fig. 2.1

State what is represented by the shaded area of the graph.

[2]

3 The biggest contributor to annual radiation dose in the UK is the gas radon. This is an alpha emitter with a half-life of a few days.

A typical dose equivalent to the lungs in one year from radon and its products is 500 μSv.

(a) Calculate the energy absorbed by the lungs in one year to give a dose equivalent of 500 μSv.

mass of lungs = 0.8 kg
quality factor of alpha radiation = 20

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

(b) Calculate an estimate of the number of cases of cancer developed in a population of 50 million for an average radon dose equivalent of 500 μSv. Assume a risk factor of 3% per sievert.

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

4 Fig. 4.1 shows a positively charged sphere above an earthed metal plate. Three field lines from the sphere are partially drawn.

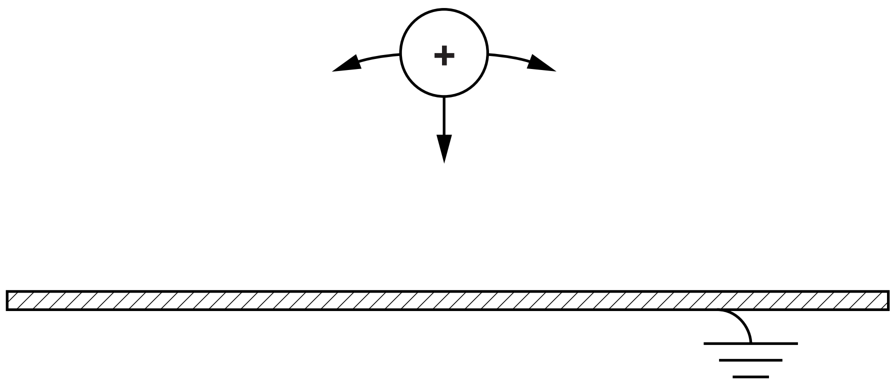

Fig. 4.1

(a) Complete the paths of the field lines to the metal plate. **[1]**

(b) Compare the strength of the field close to the plate with the strength close to the sphere. Explain your reasoning.

[2]

5 Transformers are not 100% efficient. Some of the energy loss is due to **eddy currents**.

Describe how eddy currents form in the iron core of a transformer.
Suggest and explain how such currents can be reduced.

[4]

6 Protons in an accelerator beam have a relativistic gamma factor of 2.5.

Calculate the kinetic energy in MeV of a proton in the beam.

rest energy of proton = 938 MeV

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

7 Fig. 7.1 shows an iron rod with 200 turns of wire around it. The current in the coil produces a magnetic field in the rod. The flux density in the iron is 0.070 T. The cross-sectional area of the rod is $2.4 \times 10^{-5}\,m^2$.

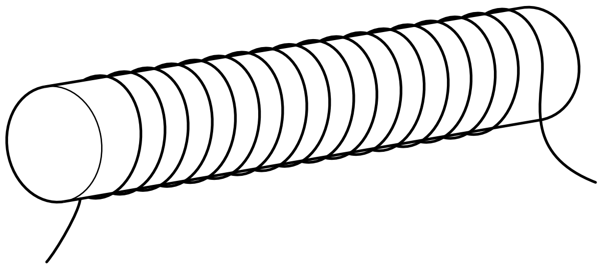

Fig. 7.1

Calculate the flux linkage of the coil. State the units.

flux linkage = ... units .... **[3]**

8 A high energy beam of protons is fired at a thin sheet of aluminium. A small proportion of the protons are scattered through large angles. The proportion of protons scattered through large angles increases when the aluminium sheet is replaced with a gold sheet of the same thickness.

Gold has a higher proton number than aluminium. State why the proportion of protons scattered through large angles is greater for gold than for aluminium.

[1]

SECTION B

9 This question is about an estimate of the size of a hydrogen atom.

(a) An electron in a hydrogen atom can be modelled as a standing wave confined in a box as shown in Fig. 9.1 where d is the diameter of the atom.

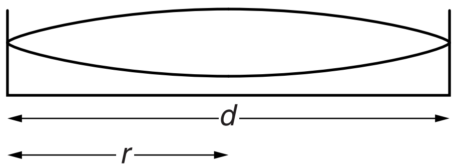

Fig. 9. 1

(i) State the relationship between the wavelength λ of the standing wave shown and r, the radius of the atom.

[1]

(ii) Use the two equations below with your answer to **(i)** to show that the kinetic energy of the electron of mass m is given by $E_k = \dfrac{h^2}{32\,m\,r^2}$.

momentum $p = \dfrac{h}{\lambda}$

kinetic energy $E_k = \dfrac{p^2}{2m}$

[2]

(iii) State the factor by which the kinetic energy of the electron increases when the radius of the atom halves.

[1]

(b) The potential energy E_p of the electron at a radius r away from the hydrogen nucleus is given by

$$E_p = -\frac{e^2}{4\pi\varepsilon_0 r}$$

where e is the charge on an electron.

State the factor by which the magnitude of the potential energy of the electron increases when the radius of the atom halves.

[1]

(c) A simple model of the hydrogen atom suggests that its radius will be a minimum value when

$$E_k + E_p = 0.$$

(i) Use the equations for E_k and E_p to show that in this model the minimum radius r of a hydrogen atom is given by

$$r = \frac{h^2 \pi \varepsilon_0}{8e^2 m}.$$

[2]

(ii) Calculate the minimum radius of a hydrogen atom using the data below:

$e = 1.6 \times 10^{-19}\,\mathrm{C}$
$h = 6.6 \times 10^{-34}\,\mathrm{J\,s}$
$\varepsilon_0 = 8.9 \times 10^{-12}\,\mathrm{C^2\,N^{-1}\,m^{-2}}$
$m = 9.1 \times 10^{-31}\,\mathrm{kg}$

minimum radius = ... m **[2]**

(d) A hydrogen atom in a bound state cannot have a total energy greater than zero. Explain why a hydrogen atom with smaller than the minimum radius cannot be in a bound state.

[2]

10 This question is about pions.

Pions are particles made of up, *u*, and down, *d*, quarks combined in quark anti-quark pairs. Charged pions are represented by the symbols π^+ and π^-.

Anti-quarks have opposite charge to their quark partners. $\bar{u}$ is an anti-up quark and $\bar{d}$ is an anti-down quark.

The up quark has charge = $+\frac{2}{3}$ e . The down quark has charge = $-\frac{1}{3}$ e .

(a) Complete the table below.

Pion	π^+	π^-
Pion Charge		−e
Quarks	$u\bar{d}$	

[2]

(b) When π^+ and a π^- with the same energy meet head-on they annihilate. Their total energy is carried away by photons.

(i) Explain why a minimum of two photons must be produced in this process.

[2]

(ii) Two photons produced in such an annihilation have equal energy. Calculate the minimum frequency of the photons.

mass of a pion = 2.5×10^{-28} kg

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

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

minimum frequency = ... Hz **[3]**

(c) A π^- is accelerated through a potential difference of 50 V.

(i) Show that the kinetic energy of the π^- would increase by approximately 1×10^{-17} J.

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

[1]

(ii) Before the acceleration the π^- has a velocity of 1.0×10^5 m s^{-1}.

The acceleration is in the same direction as the initial velocity.

Calculate the final velocity.

Ignore relativistic effects.

final velocity = ... m s^{-1} **[3]**

11 This question is about the fission of uranium-235 ($^{235}_{92}U$).

The binding energy per nucleon of uranium-235 is about –7.6 MeV.

(a) Explain the term 'binding energy per nucleon'. Describe how you would calculate the binding energy per nucleon of a uranium-235 nucleus from the values of the masses listed below.

- mass of uranium-235 nucleus
- mass of a proton
- mass of a neutron

You should make each step of your explanation clear.

[4]

(b) One uranium-235 fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{141}_{\dots\dots}Ba + 3^{1}_{0}n.$$

Complete the equation above. **[1]**

(c) Show that the energy released when one uranium-235 nucleus splits into barium-141 and krypton-92 is about 170 MeV. Show all your working clearly.

binding energy per nucleon of uranium-235 = –7.6 MeV
binding energy per nucleon of barium-141 = –8.3 MeV
binding energy per nucleon of krypton-92 = –8.5 MeV

[3]

(d) A typical uranium fission reactor produces a power of 1500 MW.

Assume each uranium fission reaction releases about 170 MeV.

(i) Calculate the number of fission reactions required per second.

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

number of fission reactions per second = ... s^{-1} **[2]**

(ii) Calculate the mass of uranium-235 fuel that must undergo fission in order to produce a power of 1500 MW for one year.

mass of uranium-235 atom = 4.0×10^{-25} kg

1 year = 3.2×10^{7} s

[2]

12 This question is about moving charges in a magnetic field.

Electrons are flowing in the semiconducting strip shown in Fig. 12.1.

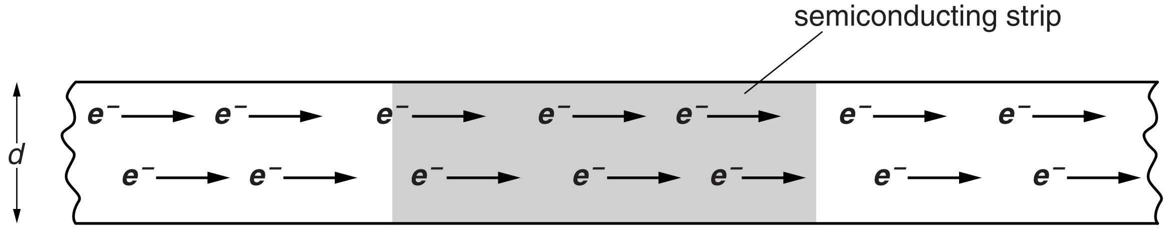

Fig. 12.1

A uniform magnetic field of strength 0.18 T acts perpendicularly up out of the paper in the shaded region of the strip.

(a) Show that an electron, travelling at the average (drift) speed in the direction shown, will experience a force due to the magnetic field of about 3.5×10^{-20} N.

average speed of electrons = $1.2\,\mathrm{m\,s^{-1}}$
electronic charge, e = 1.6×10^{-19} C

[1]

(b) The force on the electrons from the magnetic field makes them drift towards the top edge of the strip which gains a negative charge. The lower edge has a positive charge of equal magnitude. See Fig. 12.2.

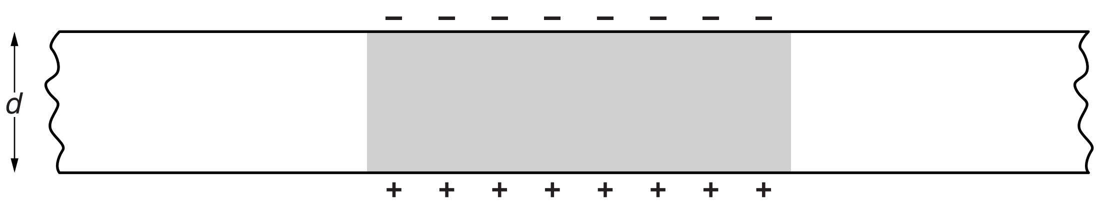

Fig. 12.2

The charges set up a uniform electric field in the shaded region.
Draw **four** electric field lines on Fig. 12.2 to represent the uniform electric field in the region.

[2]

(c) The charges on the edges of the strip create a potential difference V across the strip given by the equation

$V = B\,v\;d$

where B is the magnetic field strength, v the velocity of the electrons and d the distance between the charged edges.

Calculate the potential difference V when:

$d = 1.3\,\text{mm}$
$v = 1.2\,\text{m}\,\text{s}^{-1}$
$B = 0.18\,\text{T}$.

potential difference = ... V **[2]**

(d) The semiconducting strip is replaced by a metal strip of identical dimensions. The current and magnetic field are kept the same. The potential difference across the strip falls to about $\mathbf{10^{-4}}$ of its previous value.

Suggest and explain what this tells you about:

- the drift speed of the conduction electrons in the metal compared with the drift speed of the electrons in the semiconductor
- the number of conduction electrons per m^3 in the metal compared with the number per m^3 in the semiconductor.

[4]

SECTION C

These questions are based on the Advance Notice *Electricity for Spacecraft*.

13 The type of battery used to power the first satellite (Sputnik 1) has an energy density of 130 watt-hours per kilogram.

(a) The mass of the battery used in Sputnik 1 was 51 kg. Show that the total amount of energy available from this battery was less than 25 MJ.

[2]

(b) This battery lasted 22 days (line 8 in the article). Calculate the average power demand of the satellite in that time.

average power = ... W **[2]**

14 Here are some data concerning the solar panel arrays on the Hubble Space Telescope (HST).

Number of panels	2
Power per panel	2.8 kW
Dimensions of each panel	2.5 m × 7.6 m
Mass of each panel	9.0 kg
Solar radiation intensity received	$1.4 \times 10^3 \mathrm{W\,m^{-2}}$

(a) Use data from the table to calculate the power per unit mass of the Hubble solar panel. Compare the value with the value given in the article (line 17).

[2]

(b) Show that the **total** amount of solar radiation striking both panels is about 50 kJ per second.

[2]

(c) Calculate the percentage efficiency of the panels.

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

(d) Use data from lines 19–22 in the article to calculate the number of orbits for which the onboard battery could power the telescope if the solar panels stopped working completely.

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

(e) Jupiter is 5.2 astronomical units (AU) from the Sun. Show that at this distance, the maximum electrical power produced by a pair of panels like those on the HST is only about 0.2 kW.

Earth-Sun distance = 1.0 AU

[2]

15 At the start of a mission, a typical Radioisotope Thermoelectric Generator (RTG) (line 29 in the article) will generate 4.4 kW of thermal power from alpha particle emissions.

(a) Calculate the initial activity of the plutonium in the RTG.

energy emitted in each decay = 5.5 MeV
1 eV = 1.6×10^{-19} J

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

(b) The RTG will not be able to provide sufficient electrical power when the rate of thermal energy production falls below 2500 W.

Calculate the length of time for which the RTG will operate before the rate of thermal energy production falls below this value.

half-life of plutonium-238 = 88 years

time = ... years **[3]**

(c) Some people are concerned about the possibility of accidents during the launch of spacecraft carrying RTGs, which would result in widespread contamination by the alpha-emitting radioisotope. They have suggested that using an isotope with a much shorter half-life of just a few years would be preferable.

Discuss the concerns and suggestions in detail.

Your answer should clearly link the concern and suggestion with the properties of the radioisotope involved and alpha radiation.

[5]

16 Long conducting cables ('tethers') hung from some satellites could be used to generate significant voltages (line 42 in the article).

(a) The choice of metal to be used in a tether depends upon a number of factors. State **two** factors and give a reason for the importance of each.

Factor 1:

....

Reason:

....

Factor 2:

....

Reason:

.... **[4]**

(b) Show that the speed that these satellites orbit the Earth is about $8 \times 10^3\,\mathrm{m\,s^{-1}}$.

radius of Earth = 6400 km
height of satellite above Earth's surface = 1000 km
orbital period = 100 minutes

[2]

(c) **(i)** Calculate the area swept out per second by a cable 20 km long moving at $8 \times 10^3\,m\,s^{-1}$ (Fig. 16.1).

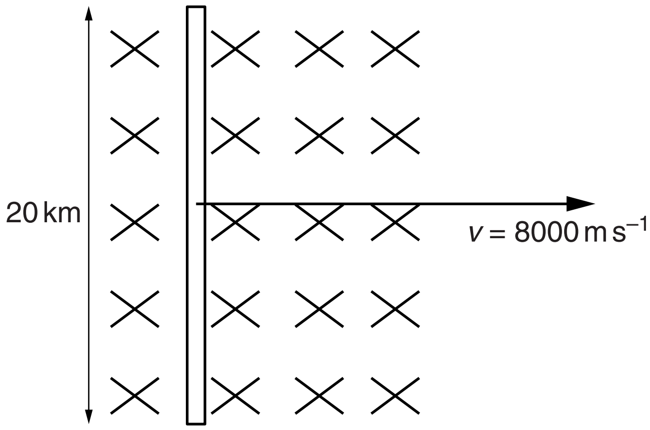

Fig. 16.1

area per second = ... m^2 **[1]**

(ii) The average flux density of Earth's magnetic field perpendicular to the cable is 2.1×10^{-5} T.

Show that the emf induced in this cable is about 3.5 kV. (line 47 in the article)

[2]

(d) Explain what effect the induced current in the cable will have on the satellite's motion.

[4]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

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

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A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

INSERT

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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 **4** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER/INVIGILATOR

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Electricity for Spacecraft

One of the biggest challenges to meet when designing an artificial satellite or spacecraft is that of the on-board electrical power supply. Two major considerations are mass and lifetime, both of which depend upon the function of the craft being constructed. Batteries are usefully described by the number of watt-hours they have per unit mass (a watt-hour being the energy transferred by a one watt device in one hour). Typically, these days, several kilowatts of power are required and the supply needs to function reliably in extremely hostile conditions.

The power supply for the very first artificial satellite, Sputnik 1, used batteries that lasted for twenty-two days. Modern craft have greater power demands and need to last for much longer. Therefore, rechargeable batteries are employed with solar panels being used for the re-charging process. For spacecraft travelling particularly large distances from the Sun, solar cells have limited use and another means of electrical generation is required. This uses the thermal energy produced from radioactive decay to generate electricity.

Catching the Sun

For satellites and space probes based in the inner Solar System, solar panels are the most common generators of electricity. They consist of large arrays of photovoltaic cells and are characterised by the amount of electrical power that can be generated per unit mass. A typical value for panels used on satellites in Earth orbit is $300\,\mathrm{W\,kg^{-1}}$. Perhaps the most familiar set of satellite panels belongs to the Hubble Space Telescope (Fig. 1) on which there are two large arrays.

Fig. 1: The Hubble Space Telescope

Each array can produce a maximum of 2.8 kW of electrical power. An orbit takes about 97 minutes but for 36 of those minutes the telescope is in the Earth's shadow and the panels do not generate electricity during these eclipse periods. For this reason, some of the electrical energy generated is stored in an on-board rechargeable battery, which can provide complete power for 7 hours.

Solar panels become less effective with increasing distance from the Sun, since light intensity obeys an inverse square law. Until recently the orbit of Mars was the greatest distance at which solar panels had been used. However, developments have led to them being included on probes journeying to the outer Solar System, such as the Rosetta probe to a distant comet (Fig. 2).

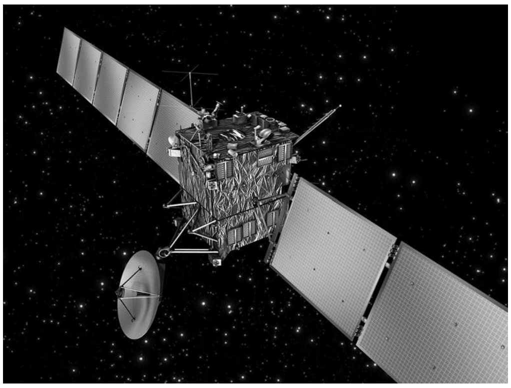

Fig. 2: The Rosetta probe, heading for a comet beyond the orbit of Jupiter

Nuclear-powered probes

For longer-lasting and more distant space missions, the principal devices used for generating electrical energy have been radioisotope thermoelectric generators (RTGs).

The first thing to note about RTGs is that they are not nuclear reactors – neither fission nor fusion plays a part. Nevertheless, there are concerns over the risks associated with such generators, especially during the launch.

Thermal energy is produced from the natural decay of the isotope, plutonium-238, which emits 5.5 MeV alpha particles. A voltage is then generated using a thermocouple. With the half-life of the isotope being 87.7 years, there is no danger of the energy "running out" and RTGs have proven to be extremely reliable. They have powered some of the most successful missions ever undertaken, such as the Voyagers of the 1980s (Fig. 3) and the more recent Cassini-Huygens probe to Saturn.

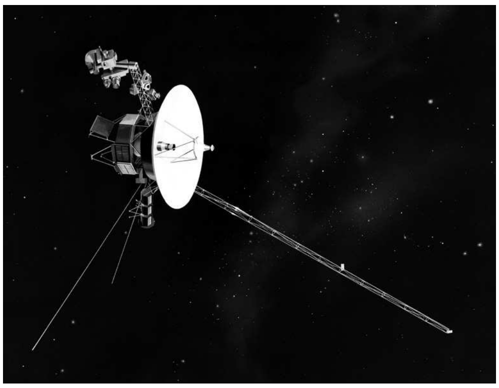

Fig. 3: Voyager 1 – one of the most successful space probes so far

A new line of enquiry

For the last two decades, serious studies have been made of the possibility of generating voltages using Faraday's principle of electromagnetic induction. In these experiments, an orbiting satellite drags a long electrically-conducting cable through the Earth's outer magnetic field (the magnetosphere). As these 'electrodynamic tethers' cut through the magnetic field lines, a voltage is generated (Fig. 4).

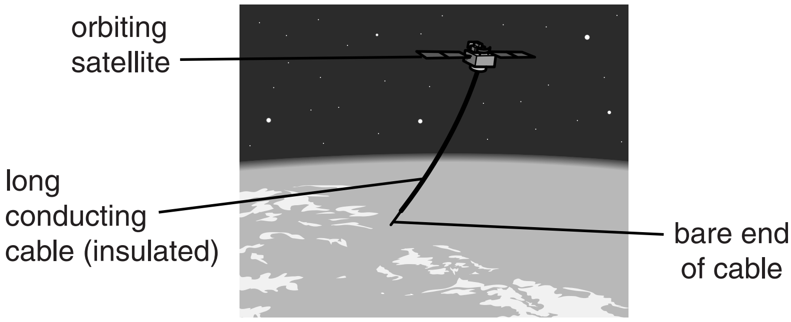

Fig. 4

Such tethers cannot be made into a complete circuit simply by adding another cable to complete the loop. However, the Earth's magnetosphere contains a large quantity of ions, created by solar radiation. There is a transfer of charge through the bare end of the cable which produces the required current. In one NASA investigation, a 20 km line was used generating a voltage of 3.5 kV. This is not a case of generating electrical energy from nothing, of course, but the method is relatively cheap and simple. This could certainly prove a lead worth following.

END OF ARTICLE

