OCR
RECOGNISING ACHIEVEMENT

Friday 27 January 2012 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495 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 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. 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. Additional paper may be used if necessary but you must clearly show your candidate number, centre number and question number(s).
- 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 Here is a list of five units:

$Wb\,m^{-2}$ $C\,s^{-1}$ $J\,C^{-1}$ $J\,s^{-1}$ $Wb\,s^{-1}$

(a) Which unit is equivalent to the tesla (T)?

unit .... **[1]**

(b) Which two units are equivalent to the volt (V)?

unit .... and ....**[2]**

2 Use the equations $p = mv = \frac{h}{\lambda}$ and $E_k = \frac{1}{2}mv^2$ to show that

(a) $E_k = \frac{p^2}{2m}$

(b) $\lambda = \frac{h}{\sqrt{2mE_k}}$.

[2]

(c) Calculate the wavelength of an electron with a kinetic energy $E_k = 2.0 \times 10^{-18}$ J.

$h = 6.6 \times 10^{-34}$ J s
$m = 9.1 \times 10^{-31}$ kg

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

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3 Two coils are wrapped around a laminated iron core as shown in Fig. 3.1.

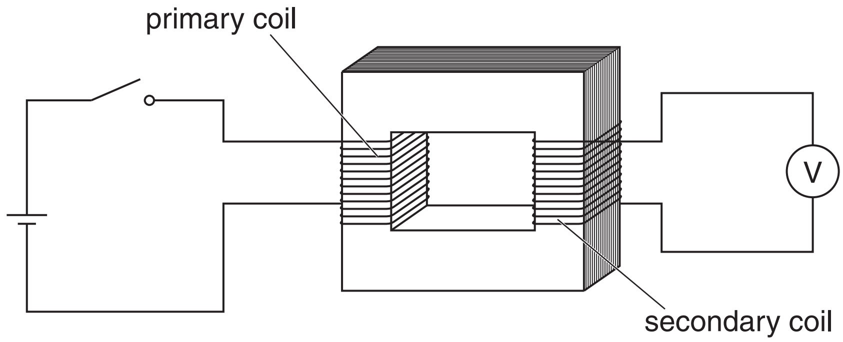


Fig. 3.1

The switch is closed at time t_1. The current in the primary coil rises as shown in the graph in Fig. 3.2.

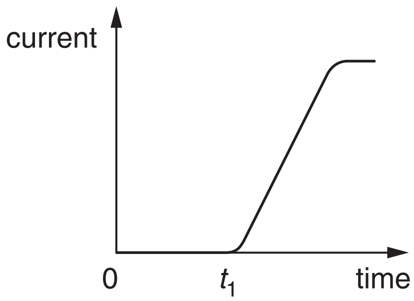
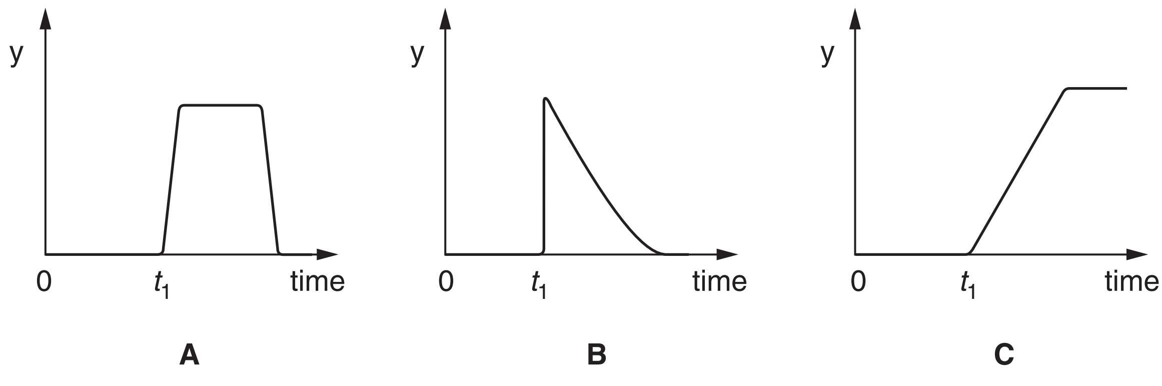


Fig. 3.2

Here are three graphs showing variation of y-value against time. Time t_1 is shown on the graphs.



(a) Which graph shows the relationship between flux in the secondary coil (y-value) and time?

graph .... **[1]**

(b) Which graph shows the relationship between the magnitude of the emf across the secondary coil (y-value) and time?

graph .... **[1]**

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4 A spark plug ionises the air between two plates separated by 0.4 mm.
A p.d. of 3 kV is required for the air to ionise. Calculate the magnitude of the electric field strength between the plates.

Assume the field is uniform.

electric field strength = ... $V\,m^{-1}$ **[1]**

5 The fusion of hydrogen into helium is the source of the Sun's energy. The first stage of the process is shown below.

$$ {}^{1}_{1}\text{H} + {}^{1}_{1}\text{H} \longrightarrow {}^{2}_{1}\text{H} + {}^{\dots\dots}_{\dots\dots}\text{X} + {}^{0}_{0}\nu $$

Complete the equation and identify particle **X**.

particle **X** is .... **[2]**

6 Fig. 6.1 shows a beam of electrons entering the space between two metal plates in a vacuum. The upper plate is at a positive potential and the lower plate is earthed.

On leaving the plates the beam strikes a screen.
Complete the path of the beam to the screen.

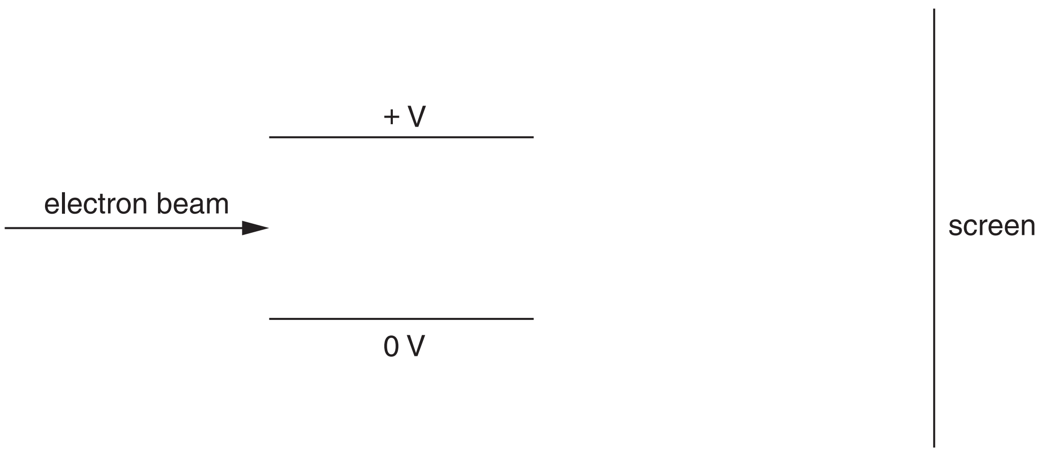

Fig. 6.1

[2]

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7 An iron core is shaped as shown in Fig. 7.1. Current in the coil produces flux Φ in the iron. The cross-sectional area of the core at **X** is twice the cross-sectional area at **Y**.

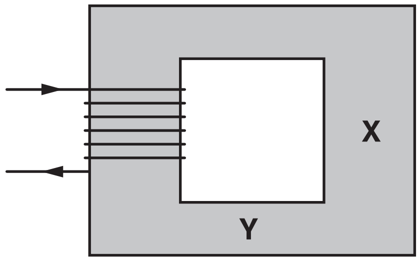

Fig. 7.1

The core behaves ideally and there is no flux leakage.

(a) State how the flux through **X** compares with the flux through **Y**.

[1]

(b) State how the flux density through **X** compares with the flux density through **Y**.

[1]

8 A school cobalt-60 source has an activity of 125 kBq.
The source will be replaced when the activity falls to 35 kBq.
The decay constant of cobalt-60 = $4.1 \times 10^{-9}\,s^{-1}$.

Show that the school will need to replace the source after about 10 years.

1 year = $3.2 \times 10^{7}\,s$

[2]

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9 Experiments show that the radius r of a nucleus is given by the relationship

$$r = r_0 A^{\frac{1}{3}}$$

where A is the nucleon (mass) number of the nucleus
r_0 is a constant.

(a) Choose the statement below which gives the relationship between the volume V of the nucleus and A.

A V is proportional to A^3

B V is proportional to A^2

C V is proportional to A

D V is proportional to $A^{\frac{1}{2}}$

The relationship is given by statement .... **[1]**

(b) The radius of a gold nucleus $^{197}_{79}\text{Au}$ is 7.0×10^{-15} m.

Use this value to show that the radius of an alpha particle, $^{4}_{2}\text{He}$ is about 2×10^{-15} m.

[2]

[Section A Total: 20]

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Section B

10 This question is about the design of a simple d.c. motor as shown in Fig. 10.1.

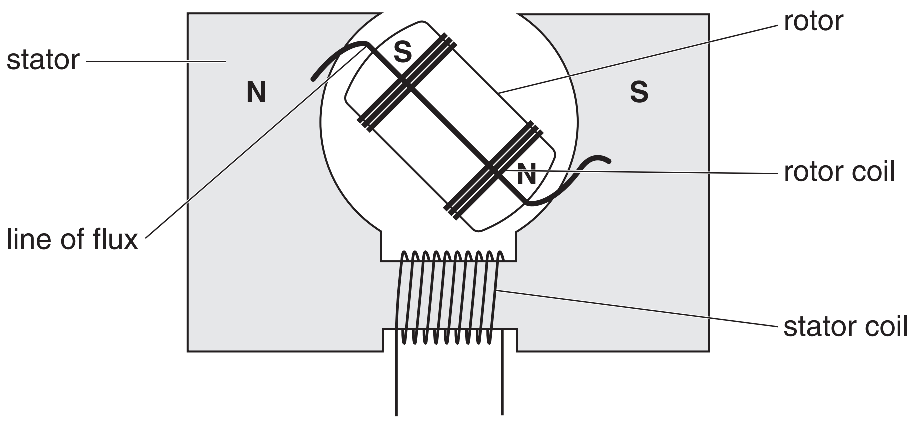

Fig. 10.1

Current in the stator coil produces a magnetic flux in the stator. There is also a current in the rotor coils. The rotor is turning anticlockwise.

(a) Part of a flux line is shown. Complete the flux line and explain how the shape of the line suggests that the rotor will experience an anti-clockwise force.

[2]

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(b) The rotor is laminated; it is made of layers of iron separated by thin layers of insulator.

(i) Explain how the choice of an **iron** rotor together with **curved** poles on the stator help improve the performance of the motor.

[3]

(ii) Explain why **laminating** the iron rotor increases the flux in the magnetic circuit.

[2]

(c) When the motor is first switched on there is a large current in the rotor coil, but as the rotor speeds up the current decreases. Use ideas about electromagnetic induction to explain why the current decreases.

[3]

[Total: 10]

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11 This question is about the electric field near a positively-charged sphere.

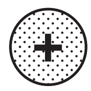

Fig. 11.1

Fig. 11.1 shows an isolated, positively-charged metal sphere.

(a) On Fig. 11.1 draw four field lines from the surface of the sphere. **[2]**

(b) The radius of the sphere is 4.0 mm and the charge on it is $+2.5 \times 10^{-9}$ C.
Show that the potential at the surface of the sphere is about +5.6 kV.

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

[2]

(c) The graph in Fig. 11.2 gives the potential at increasing distance from the sphere.

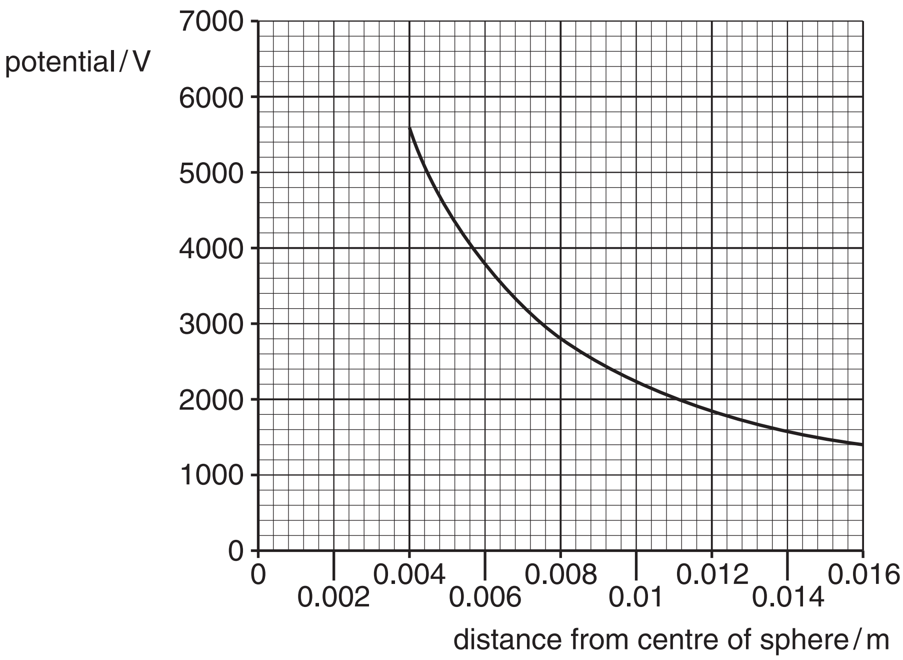

Fig. 11.2

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(i) Explain how the graph could be used to show that the potential is inversely proportional to the distance from the centre of the sphere.

[2]

(ii) Use data from the graph to calculate the magnitude of the electric field strength at a distance of 0.0080 m from the centre of the sphere. Explain your method clearly.

field strength = ... NC^{-1} **[2]**

(d) The sphere is brought near an identically charged metal sphere as shown in Fig. 11.3.

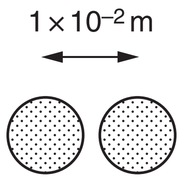

Fig. 11.3

Using the equation $F = \frac{kq_1q_2}{r^2}$ gives a value for the force between the spheres of 5.6×10^{-4} N.

Explain why the actual force between the metal spheres at this separation is less than 5.6×10^{-4} N.

[2]

[Total: 10]

12 This question is about the unstable isotope potassium-40.
Potassium-40 undergoes beta decay. This decay is represented in the equation:

$$^{40}_{19}\text{K} \longrightarrow {}^{40}_{20}\text{Ca} + {}^{0}_{-1}e + \bar{\nu}$$

(a) Name the particle represented by $\bar{\nu}$. .... **[1]**

(b) **(i)** Calculate the total energy released in the beta decay of a potassium-40 nucleus.

mass of $^{40}_{19}\text{K}$ = 39.953579 u

mass of $^{40}_{20}\text{Ca}$ = 39.951610 u

electron mass = 0.000549 u

electronic charge = 1.60×10^{-19} C

atomic mass unit, u = 1.66×10^{-27} kg

speed of light, $c = 3.00 \times 10^{8}\,\text{m s}^{-1}$

In your working include the values indicated below.

change in mass = ... u = ... kg

total energy released = ... J = ... MeV
[4]

(ii) The kinetic energy of the beta particle is generally less than the total energy released. State where the remaining energy goes.

[1]

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(c) The decay of potassium in the human body contributes the largest proportion of radiation produced inside the body.

The amount of potassium-40 in an adult body is about 1.5×10^{-5} kg. This represents about 2.2×10^{20} atoms.

(i) The half-life of potassium-40 is 4.2×10^{16} seconds. Show that the activity of the potassium-40 in the adult body is about 4000 Bq.

[2]

(ii) The great majority of the decays release beta particles as above. The mean energy of these particles is about 7×10^{-14} J.

Estimate the dose from beta emission for a 60 kg person in one year.
State any assumptions you make.

1 year = 3.2×10^{7} s

dose = ... Gy **[3]**

(iii) The lifetime risk of developing a cancer is about 3% per sievert. Estimate the number of cancers developed due to potassium decay in a population of 40 million people over a period of 50 years.

quality factor of beta radiation = 1

number of cancers in population of 40 million = ... **[2]**

[Total: 13]

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13 This question is about a cyclotron, an early form of particle accelerator. It consists of two hollow semi-circular metal 'dees' in a uniform magnetic field of 0.80 T in a vacuum. The dees are separated by a gap as shown in Fig. 13.1.

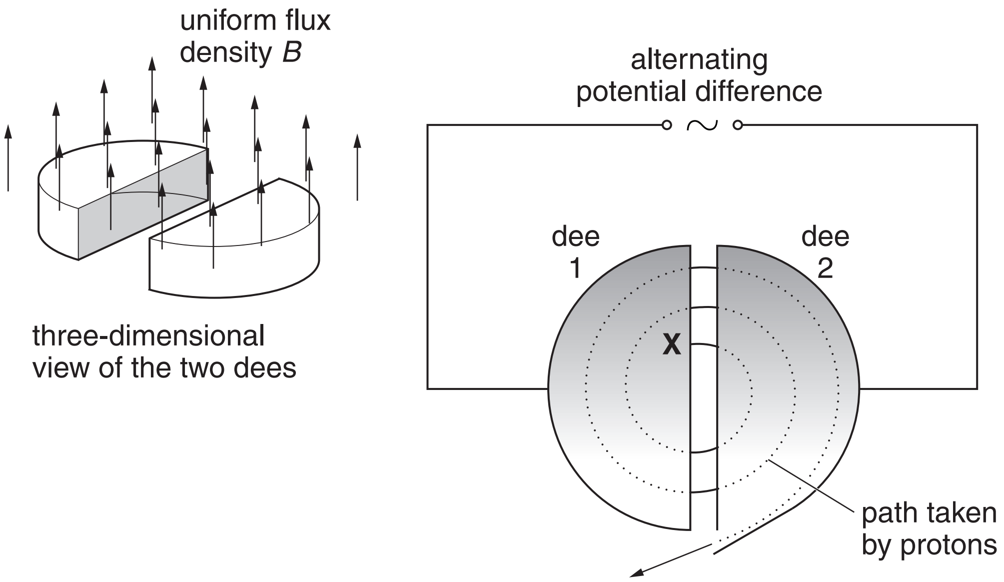

Fig. 13.1

Protons are injected into the gap between the dees at **X** and are accelerated by the potential difference between the dees. The magnetic field is directed out of the paper in Fig. 13.1 and the protons move in a circular path through the dees. There is no electric field inside the dees.

(a) **(i)** State why it is necessary to have a vacuum inside the cyclotron.

[1]

(ii) Explain why the protons move in a circular path with constant speed inside a dee.

[2]

(b) The protons are accelerated through a p.d. of 400 V each time they cross the gap between the dees.

Show that a proton will have gained an energy of 9.6×10^{-15} J after crossing the gap between the dees 150 times.

electronic charge = 1.6×10^{-19} C

[1]

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(c) The radius r of the path of a particle of mass m and kinetic energy E_k in a dee is given by the equation

$$r = \frac{\sqrt{2mE_k}}{Bq}$$

where B is the magnetic field strength and q is the charge on the particle.

Calculate the radius of the path of a proton of kinetic energy 9.6×10^{-15} J in a magnetic field of strength 0.80 T.

mass of proton = 1.7×10^{-27} kg
electronic charge = 1.60×10^{-19} C

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

(d) Cyclotrons are not used to accelerate electrons because electrons show relativistic behaviour at the energies reached.

Use the relativistic factor γ to explain why an electron of kinetic energy 9.6×10^{-15} J shows relativistic behaviour to a greater extent than a proton of the same kinetic energy.

rest energy of electron = 0.511 MeV
rest energy of proton = 938 MeV

[3]

[Total: 9]

[Section B Total: 42]

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Section C

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

14 Ceiling balloons are used to determine the altitudes of cloud bases (lines 2 and 3 in the article). When released, they ascend and quickly reach a vertical speed of 150 metres per minute.

(a) Show that the height of a cloud into which a ceiling balloon disappears 400 s after being released is about 1000 m.

[1]

(b) Suggest and explain one reason for this method of determining cloud height gives only approximate results.

[2]

(c) The volume of gas used to fill the balloon at launch is 0.030 m^3. As the altitude increases, both the temperature and the pressure of the gas change, as given in the table, Fig. 14.1.

altitude / m	temperature / K	pressure / kPa	volume / m^3
0	293	101.3	0.030
1000	280	89.1	

Fig. 14.1

Complete the table by calculating the volume that the same mass of gas would occupy at an altitude of 1000 m. Assume ideal gas behaviour.

[2]

[Total: 5]

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15 Weather balloons carry scientific instruments high into the atmosphere to make a range of meteorological measurements (lines 6 and 7 in the article).

(a) State two physical properties it would be important for the material of the weather balloon to possess. Give a reason why each property is important.

(i) property:

reason:

(ii) property:

reason:

[4]

(b) The diameter of the balloon when launched is 2.0 m and at this size the balloon fabric is **unstrained**. The diameter increases to 8.0 m when the balloon reaches an altitude of 35 km.

By considering the circumference of the spherical balloon, calculate the strain in the balloon fabric at an altitude of 35 km.

strain = ... **[2]**

(c) Box 1 in the article shows that the buoyancy force, *B*, on the balloon, when launched, is given by

$$B = \text{weight of air displaced.}$$

Show that at launch, *B* is approximately 50 N.

radius of balloon = 1.0 m
density of air at launch = 1.2 kg m^{-3}
g = 9.8 N kg^{-1}

[3]

(d) Hence show that the initial upwards acceleration of the balloon is about 30 m s^{-2}.

total mass of inflated balloon + load = 1.25 kg

[2]

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(e) Suggest why the acceleration changes as the balloon rises.

Your explanation should be carefully ordered and clear.

[3]

[Total: 14]

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16 In 2009, some impressive photographs of the Earth were taken by relatively cheap cameras from high-altitude weather balloons. In one such image (Fig. 16.1, Fig. 3 in the article), the width of the photograph spans a distance on the ground of 1100 m.

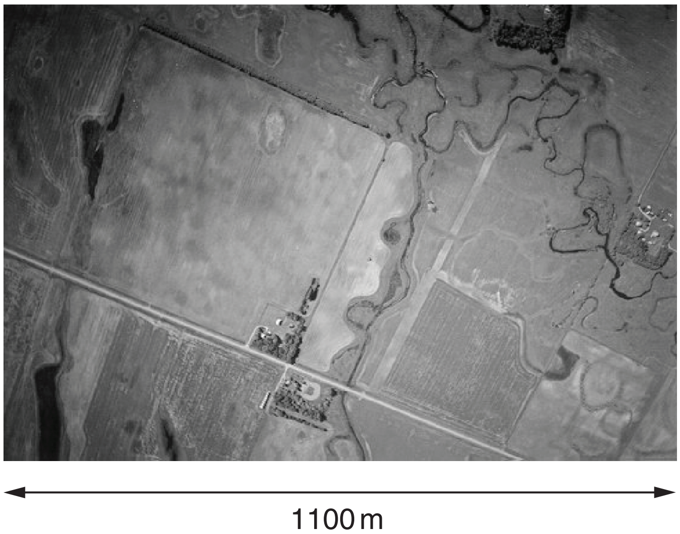

Fig. 16.1

The camera screen was made up of an array of 4352 × 3264 pixels.

(a) Calculate the resolution of the image.

resolution = ... m pixel^{-1} **[1]**

(b) **(i)** In the original image, each pixel has three colour segments. Each segment has 256 intensity levels. Calculate the number of bits required to store one image.

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

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(ii) Calculate the number of images that could be stored on an 8 Gbyte memory card.

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

[Total: 5]

17 Interactions between high energy cosmic rays (mostly protons) and atoms and molecules in the upper atmosphere can create other particles such as mesons, which travel at very high speed down to the Earth's surface (lines 64–66 in the article).

(a) Ignoring relativistic effects, calculate the speed of a 10 MeV proton.

$1\,\text{eV} = 1.6 \times 10^{-19}\,\text{J}$
mass of proton $= 1.7 \times 10^{-27}\,\text{kg}$

speed = ... m s^{-1} **[2]**

(b) (i) A meson takes 0.13 ms to travel 35 km to the Earth's surface.

Show that the speed with which it travels to the Earth's surface is about 90% of the speed of light, c.

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

[2]

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(ii) The half-life of these mesons travelling at 90% of the speed of light is 0.13 ms. Calculate the half-life of these mesons at rest.

half-life = ... s **[3]**

[Total: 7]

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18 The BOOMERANG study resulted in a picture showing temperature fluctuations in the early universe (Fig. 5 in the article, reproduced as Fig. 18.1 below).

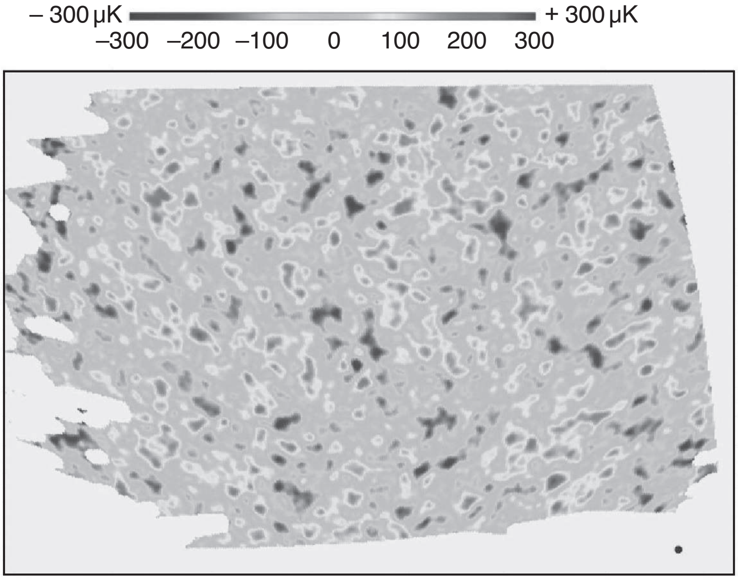

Fig. 18.1

(a) Estimate the wavelength of the cosmic background radiation photons corresponding to a temperature of 2.7 K.

Boltzmann constant, $k = 1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
speed of light, $c = 3 \times 10^{8}\,\mathrm{m\,s^{-1}}$
$h = 6.6 \times 10^{-34}\,\mathrm{J\,s}$

wavelength = ... m **[2]**

QUESTION 18 CONTINUES OVER THE PAGE

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(b) The temperature variation scale in Fig. 18.1 runs from 300 μK below the mean temperature to 300 μK above it. Assuming a mean temperature of 2.7 K, show that this range is only about 0.02% of 2.7 K.

[2]

(c) Explain the significance of the observed fluctuations in the temperature when considering the evolution of the universe.

Your explanation should be carefully ordered and clear.

[3]

[Total: 7]

[Section C Total: 38]

END OF QUESTION PAPER

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RECOGNISING ACHIEVEMENT

Friday 27 January 2012 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495 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 **8** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER/INVIGILATOR

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Floating an idea or two

Every day, across the world, hundreds of balloons are released into the air to enable scientists to make a range of studies of our atmosphere. Some of these balloons are used in a simple way to measure the altitude of the bases of clouds. These so-called ‘ceiling balloons’ are boldly coloured (usually red) and small. After being released, they are observed continuously (the use of binoculars is usually sufficient) and the time taken for them to disappear into the cloud is measured.

Many other much larger balloons carry atmospheric monitoring equipment (typically of mass 0.25 kg) to very high altitudes. These can measure a range of parameters including temperature, humidity and pressure. The measurements are transmitted to ground-based detectors across the world and Global Positioning Systems (GPS) can be used to track the positions of the balloons, enabling wind speeds and directions to be determined as well. Data collected in this way are brought together in a global collaborative project to enable a detailed analysis of the Earth’s atmosphere to be made on a daily basis.

Fig. 1: a helium-filled weather balloon shortly after being released

Weather balloons are made of a very flexible rubber-based material and have a mass of about a kilogram before being inflated. They are usually filled with hydrogen, though sometimes helium is used. The roughly spherical balloons are typically about 2 m in diameter. Upthrust (see Box 1) causes them to rise and as they do so they expand; at altitudes of around 35 km, their diameters have increased to about 8 m. When they exceed this size, they burst and the small package of measuring instrumentation (called a ‘radiosonde’) falls to the Earth’s surface. A small parachute automatically deploys to reduce the risk of harm when it lands and to preserve the instruments so that they can be re-used.

Box 1 – The Upthrust Force

When an object is immersed in a fluid, it will displace its own volume of that fluid. As a result, it will experience an upwards force (the buoyancy or upthrust) equal to the weight of the amount of fluid displaced. For example, a 1 cm × 1 cm × 1 cm cube of iron will displace one cubic centimetre of water when placed in a beaker of that water. The weight of 1 cm^3 of water is about 0.01 N, so that the upthrust force on the iron cube is 0.01 N. Since the weight of the iron cube itself is about 0.08 N, it will sink when placed in the water. Weather balloons, however, have a weight less than that of the volume of fluid they displace (air). The net force, and thus acceleration, is upwards so they rise.

Balloons have not just led to studies of the Earth’s atmosphere. Similar balloons have been used to enable other scientific measurements to be taken at high altitudes, of other features of the Earth and of the universe beyond.

Pictures from the edge of Space

In February 2009, four Spanish schoolboys (of the Meteotek project) astounded scientists when they took pictures of the Earth's atmosphere using a simple digital camera that had been carried over 30 km into the sky by a helium-filled weather balloon. This type of low-budget experiment was undertaken by several other groups across the world shortly after.

Fig. 2: photograph taken by the Meteotek Team using a digital camera in their high-altitude balloon

The sample photograph in Fig. 2 shows cloud formations in the stratosphere and the curvature of the Earth is clearly visible. This picture was taken just a few weeks after NASA had announced details of a prototype balloon that could carry up to a tonne of equipment to great heights (over 35 km) and for sustained periods of time (11 days or more). There are long term plans for such balloons to replace satellites for certain functions as they are cheaper and more accessible. Mapping and monitoring the surface of the Earth would be a principal function and relatively easily carried out at a range of altitudes. The image in Fig. 3 was taken with a similar camera to that used for Fig. 2, with a screen resolution of 4352 × 3264 pixels.

Fig. 3: digital camera image from a balloon at an altitude of just over 1000 m

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Cosmic ray studies

Cosmic rays were discovered using measurements taken in a balloon by the scientist Victor Hess in 1912. He discovered that their incidence increased with altitude and proposed that they were of a cosmic origin. He was awarded the Nobel Prize for Physics in 1936 for this discovery.

Cosmic rays are high energy ionised particles, mostly ions of hydrogen (i.e. protons) which comprise about 90% of those detected. Helium ions make up about 9% whilst the remainder is a mixture of other familiar ions (including carbon and oxygen). Some cosmic ray particles originate from the Sun and these have relatively low energy (no more than about 10 MeV) but the majority are much higher energy (hundreds of GeV) and are believed to originate largely in exploding stars (supernovae).

The cosmic rays can be detected at high altitude towards the very top of the atmosphere which can be accessed by some weather balloons. Early measurements were made using photographic plates. When the cosmic ray particles struck an atom in the photographic emulsion, new particles were created and from the tracks they produced in the film, the nature of the cosmic ray could be established.

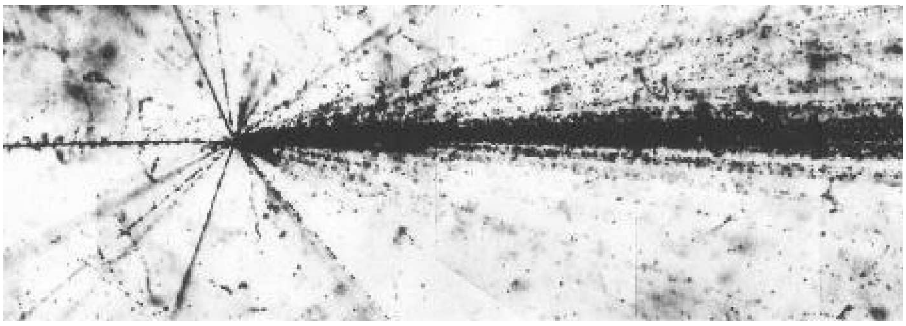

Fig. 4: a developed photographic film showing particle tracks

The atmosphere shields the surface of the Earth from the cosmic rays and is equivalent to a layer of concrete about 4 m thick in this respect. Thus, at ground level or in the lower atmosphere, only the products of the cosmic ray interactions with upper atmosphere particles can be detected. Such interactions produce a shower of new particles followed by a cascade of other particles down to the Earth's surface. These new particles are mostly unstable mesons with very short half-lives. However, because they travel at speeds near to the speed of light, relativistic time-dilation ensures that a significant number can still reach the surface of the Earth.

Cosmic Microwave Background Radiation

Perhaps one of the most high-profile and successful projects undertaken in a balloon was BOOMERANG (Balloon Observations of Millimetric Extragalactic Radiation and Geophysics). This comprised a pair of high-altitude balloon flights over Antarctica in 1998 and 2003. Very sensitive instruments mapped the sky to build up pictures showing the temperature distribution of the early universe (when it was only a few hundred thousand years old) (Fig. 5). This work supported that of NASA's famous COBE satellite (the Cosmic Background Explorer). Both found that the microwave background, as measured by its temperature, is extremely uniform. However, if the early universe were perfectly uniform in temperature and density, there is no way that the present non-uniform universe, clumped by gravity into stars and galaxies, could have formed. Very small fluctuations in temperature and density of the early universe are predicted by quantum theory. Surveys of the microwave background radiation looked to see if these fluctuations existed and whether they could account for the clumping of matter into galaxies. These and other results have also led to questions about what most of the universe is made of, one of the greatest puzzles in current cosmology.

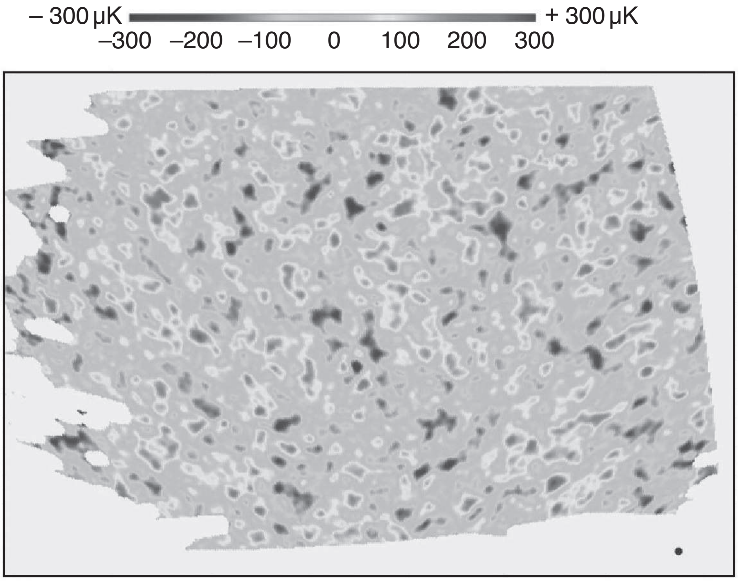

Fig. 5: map of the sky compiled by the BOOMERANG project showing temperature fluctuations in the early universe

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