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Thursday 18 June 2015 – 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 (Advance Notice for this Question Paper) (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 (Advance Notice) 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 additional 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.
- The values of standard physical constants are given in the Data, Formulae and Relationships Booklet. Any additional data required are given in the appropriate question.
- 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 **28** 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 Look at the list of particle names and properties.

lepton **negative** **neutral** **hadron** **nucleon** **quark**

(a) Choose **two** words from the list that describe neutrinos.

..... and ..... **[1]**

(b) Choose **two** words from the list that describe protons.

..... and ..... **[1]**

2 Fig. 2.1 shows the path of an alpha particle as it passes a nucleus.

Fig. 2.1

Draw a second line on the diagram representing the path of an alpha particle with **lower** energy taking the same initial path. Give a reason why the paths are different.

[3]

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3 Fig. 3.1 shows two metal plates. There is a potential difference between the plates.

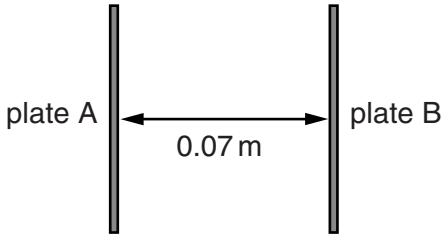

Fig. 3.1

Fig. 3.2 shows the variation in potential between the plates.

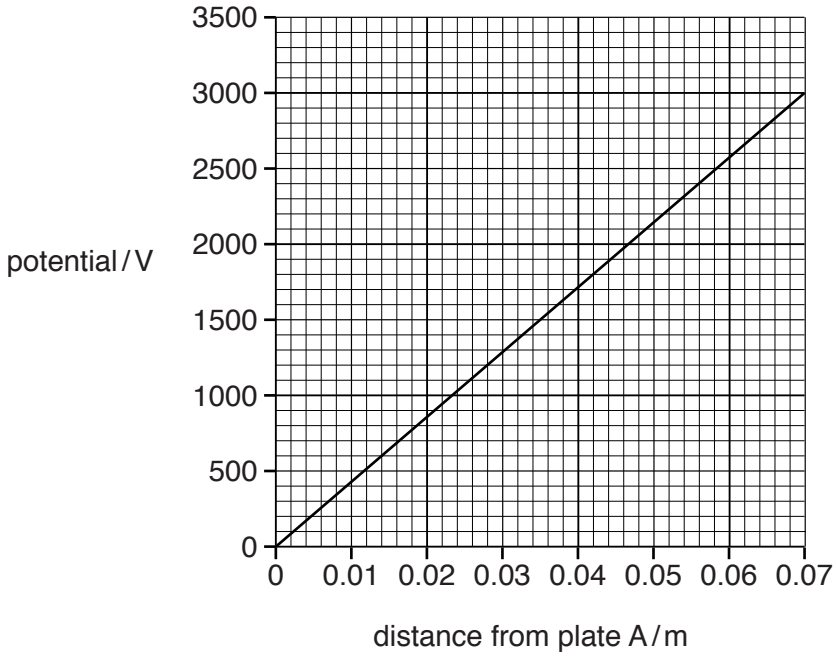

Fig. 3.2

Use the graph to describe the electric field between the plates. Explain your reasoning.

You may use data from the graph for calculations in your answer.

[3]

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4 The radium isotope $^{224}_{88}Ra$ decays into radon through alpha decay as shown:

$$^{224}_{88}Ra \rightarrow ^{220}_{86}Rn + ^{4}_{2}He$$

(a) Here is a list of quantities.

nucleon number **charge** **mass** **quark number**

Choose the **one** quantity which is **not** conserved in this decay process.

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

(b) A student makes this statement about alpha decay:

"Isotopes which emit alpha radiation mainly cause serious damage to body tissue only when they are swallowed or breathed in."

Explain why you agree or disagree with the statement, making reference to the properties of alpha particles.

[2]

5 An ideal transformer has 1500 turns on its primary coil and 750 turns on its secondary coil. The alternating voltage across the primary is 12 V and the primary current is 0.18 A.

Choose which pair of data correctly shows the values for the secondary coil.

A 24 V 0.09 A
B 24 V 0.36 A
C 6 V 0.36 A
D 6 V 0.09 A

The correct pair of values for the secondary coil is ..... . **[1]**

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6 Fig. 6.1 shows an iron core. There is a magnetic flux in the core produced by the current-carrying coil. The shaded region **Z** has half the cross-sectional area of the rest of the core.

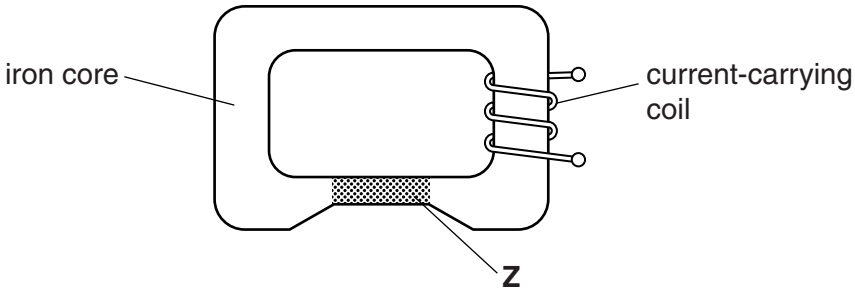

Fig. 6.1

(a) State how the values of the flux and flux density in the shaded region **Z** compare with those in the rest of the core.

flux:

flux density:

[2]

(b) A crack forms across the core at **X** as shown in Fig. 6.2.

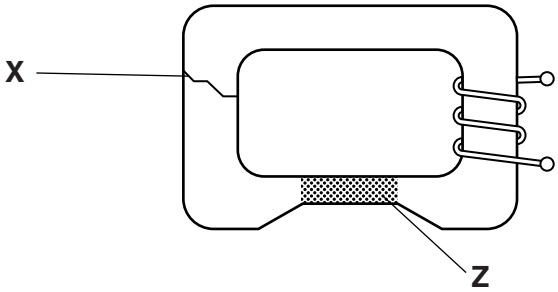

Fig. 6.2

State and explain the effect the crack will have on the values of flux and flux density in region **Z**.

[2]

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7 Fig. 7.1 shows the lowest three energy levels of a hydrogen atom.

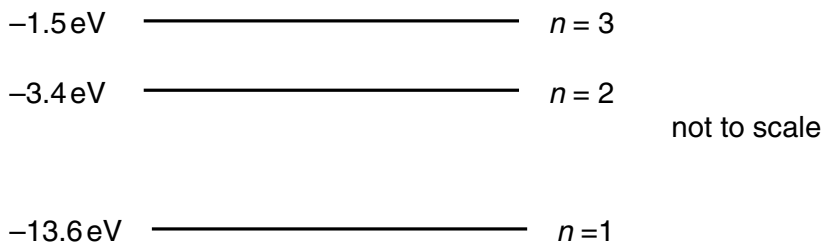

Fig. 7.1

Calculate the frequency of the photon emitted when an electron falls from the $n = 3$ energy level to the $n = 2$ energy level.

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

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

frequency = ... Hz **[2]**

8 Physicists are investigating the possibility of using nuclear fusion as an energy source. One possible reaction is given below:

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

The mass of the products of the reaction is 3.1×10^{-29} kg less than the mass of the original nuclei.

(a) Calculate the energy released in the reaction.

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

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

(b) State why high temperatures are needed for this reaction to take place.

[1]

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SECTION B

9 This question is about the electric field near point charges.

The field near a charge is represented by the field lines shown in Fig. 9.1.

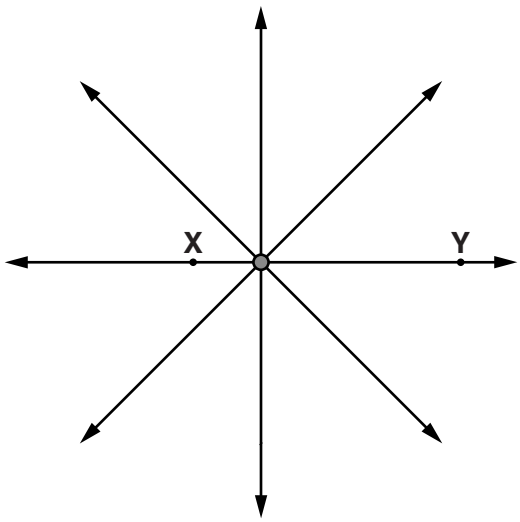

Fig. 9.1

(a) **(i)** State the feature of the diagram in Fig. 9.1 that shows that the field is stronger at point **X** than at point **Y**.

[1]

(ii) Draw a complete equipotential line through point **X**. **[1]**

(b) As shown in Fig. 9.2, point **Y** is four times the distance of point **X** from the charge.

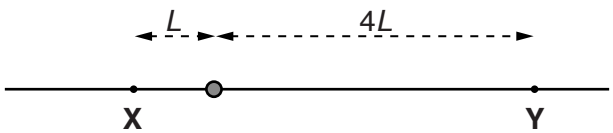

Fig. 9.2

(i) The potential at **X** is +1800 V. Calculate the potential at **Y**.

potential = ... V **[1]**

(ii) The electric field strength at **X** is $9.7 \times 10^4\,\mathrm{N\,C^{-1}}$. Calculate the field strength at **Y**.

field strength = ... $\mathrm{N\,C^{-1}}$ **[1]**

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(c) Fig. 9.3a shows two positive charges of the same magnitude. Fig. 9.3b shows two charges also of the same magnitude but of the opposite sign.

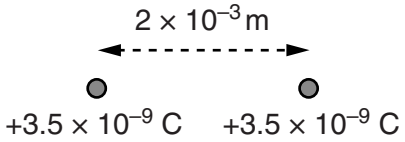

Fig. 9.3a

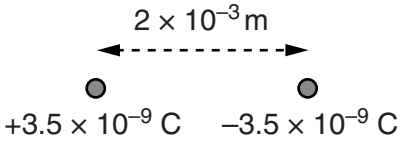

Fig. 9.3b

(i) Explain using calculations why the field strength at the midpoint between the charges in Fig. 9.3a is zero but is $6.3 \times 10^7\,\mathrm{N\,C^{-1}}$ at the midpoint between the charges in Fig. 9.3b.

electric force constant $k = 9.0 \times 10^9\,\mathrm{N\,m^2\,C^{-2}}$

[3]

(ii) Explain why the **potential** at the midpoint between the charges in Fig. 9.3b is zero.

[2]

[Total: 9]

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10 This question is about a simple d.c. motor. Fig. 10.1 shows a square current-carrying coil between two permanent magnets.

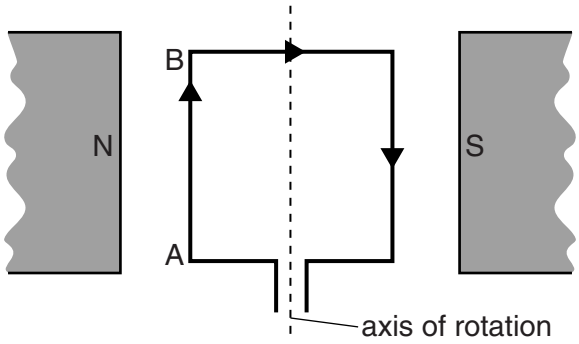

Fig. 10.1

(a) **(i)** Use the data below to calculate the force on side AB of the coil.

length of AB = 6.0×10^{-2} m
current in coil I = 0.57 A
magnetic field strength B = 90 mT
number of turns N = 75

force = ... N **[1]**

(ii) The force on the coil makes the coil rotate. Suggest and explain how you expect the rate of rotation to change if all the sides of the square coil are reduced to 3.0×10^{-2} m. The current in the coil is not changed.

[2]

(b) An emf is generated in the coil in Fig. 10.1 when it rotates in the magnetic field. Fig. 10.2 shows the coil in positions of zero flux linkage and maximum flux linkage viewed along the axis of rotation.

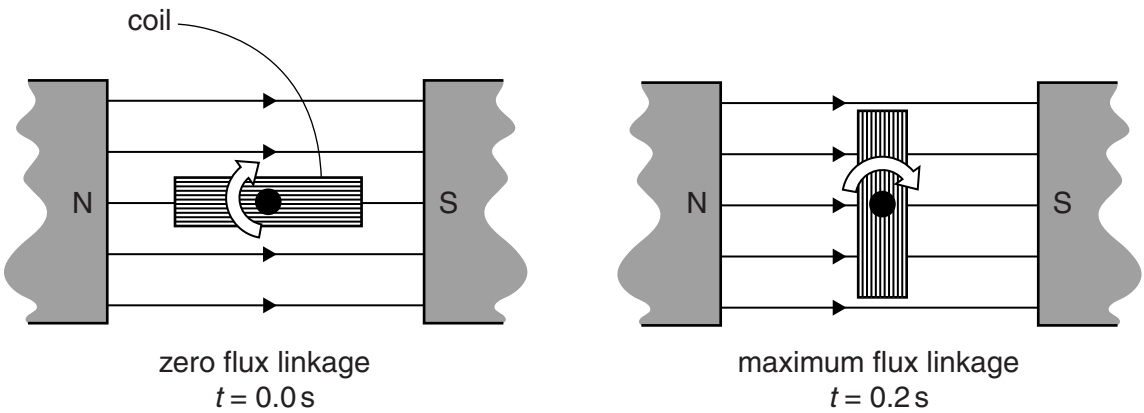

Fig. 10.2

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(i) Use data from **(a)(i)** to calculate the maximum flux linkage of the **square** coil.

maximum flux linkage = ... Wb-turns **[1]**

(ii) The coil moves through one quarter turn in 0.2 s as shown in Fig. 10.2. Calculate the average emf induced during this time.

average emf induced = ... V **[1]**

(iii) If the motor is jammed so that it stops turning, the current in the coil increases. Explain why.

In your answer you should use ideas about electromagnetic induction to explain why the current is higher when the motor turns more slowly.

[4]

[Total: 9]

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11 This question is about the deflection of particles in a magnetic field.

(a) Fig. 11.1 shows the path of an alpha particle in a uniform magnetic field.

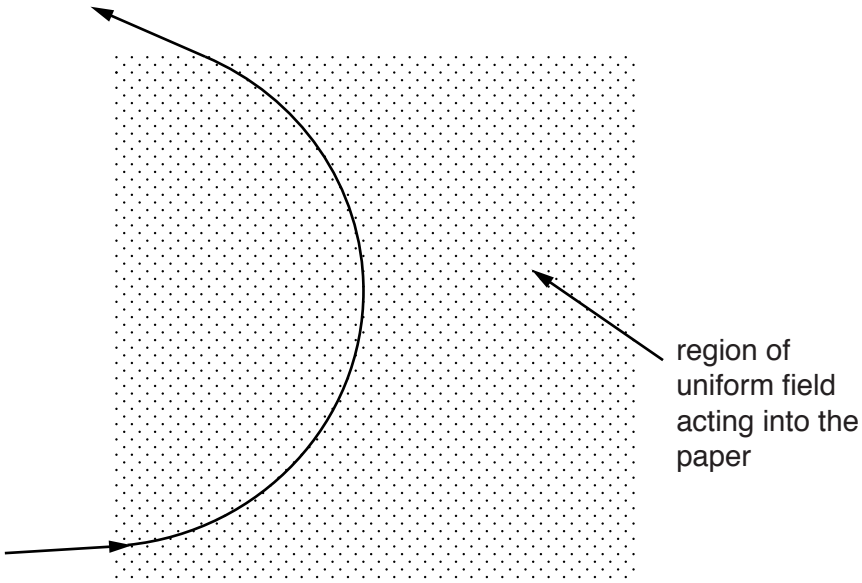

Fig. 11.1

The magnetic field produces a force on the alpha particle which travels in a circular path.

(i) State why the force on the alpha particle deflects the particle in a circular path.

[1]

(ii) Use equations for the force on a moving charge in a magnetic field and for the force on a mass moving in a circle to show that the radius r of the path taken by a particle moving at speed v at right angles to a magnetic field of flux density B is given by

$$r = \frac{mv}{Bq}$$

where m is the mass of the particle and q is the charge on the particle.

[1]

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(b) Fig. 11.2 shows a diagram that often appears in physics textbooks. It gives a misleading impression of how much alpha and beta particles are typically deflected by a magnetic field. The diagram is not to scale.

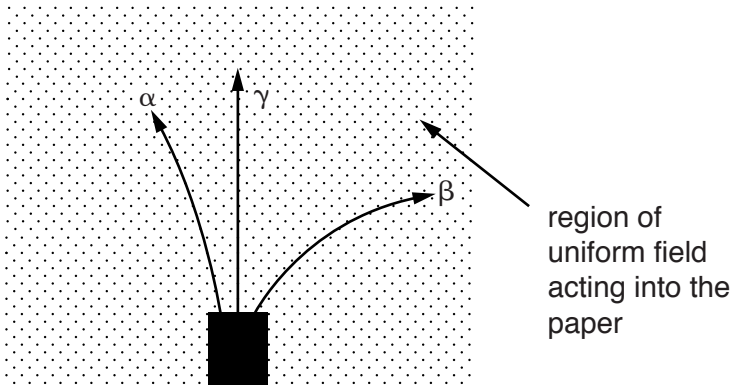

Fig. 11.2

Suggest why the diagram is correct to show that an alpha particle is deflected less than a beta particle, and that a gamma ray is not deflected.

[2]

(c) Here are some typical data about alpha and beta particles released in radioactive decays.

Particle	**Mass / kg**	**Typical velocity on release / m s^{-1}**	**Charge / C**
alpha	6.6×10^{-27}	1.0×10^{7}	$+3.2 \times 10^{-19}$
beta	9.1×10^{-31}	2.0×10^{8}	-1.6×10^{-19}

Use these data and the equation given in **(a)(ii)** to explain why Fig. 11.2 does not accurately compare the paths of the alpha and beta particles.

In your answer you should link the results of any calculations to the paths shown on Fig. 11.2.

[4]

[Total:8]

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12 This question is about a radioisotope used in medicine.

Iodine-131 is a beta emitter. It decays to xenon as shown.

$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\bar{\upsilon}$$

Each xenon nucleus produced in the decay immediately emits a gamma ray photon of energy 364 keV.

(a) Describe how the decay equation shows that lepton number is conserved in this process.

[2]

(b) In a medical procedure, 1.20×10^{-13} kg of iodine-131 is absorbed into the thyroid gland in the neck.

(i) The initial activity of the iodine is stated to be about 5×10^{5} Bq.

Confirm this value of the activity, showing each step of your calculation.

mass of iodine-131 atom = 2.18×10^{-25} kg
half life of iodine-131 = 6.95×10^{5} s (8 days)

[3]

(ii) It is said that a person treated with iodine-131 may still emit enough gamma rays to set off airport alarms twelve weeks after the treatment. Calculate the activity of the iodine sample in **(i)** after twelve weeks.

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

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(c) Calculate the maximum dose in gray delivered to the thyroid gland from the beta emission, assuming all the iodine-131 decays in the gland. State why your answer is a maximum value.

average energy of beta particle = 2.9×10^{-14} J
mass of thyroid gland = 1.8×10^{-2} kg

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

(d) Iodine-131 has been used as a 'tracer'. The movement of the iodine through the body is detected by gamma sensors around the body.

Explain why isotopes that emit gamma rays are required for use as tracers, and suggest why iodine-131 is now rarely used for this purpose.

[3]

[Total: 13]

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SECTION C

The questions in this section are based on the insert.

13 Optical microscopes use combinations of glass lenses to produce magnified images (line 10). The objective lens is a short focal length converging lens as shown in Fig. 13.1.

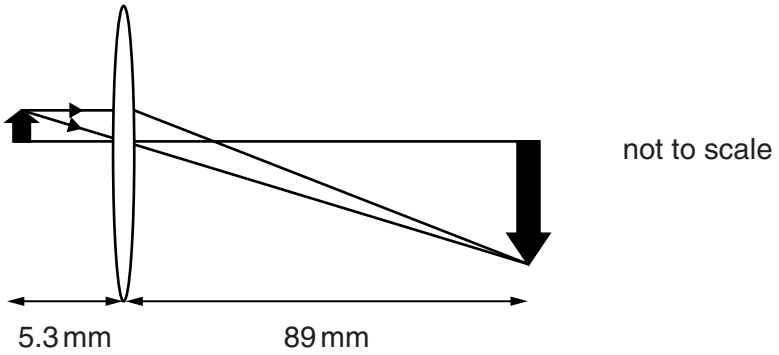

Fig. 13.1

(a) Calculate the magnification of the image.

magnification = ... **[1]**

(b) Calculate the power of the lens.

power = ... dioptre **[2]**

[Total: 3]

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14 The image shown in Fig. 14.1 is that of part of a fly's eye, obtained with an electron microscope. The eye consists of a large array of lenses (line 75).

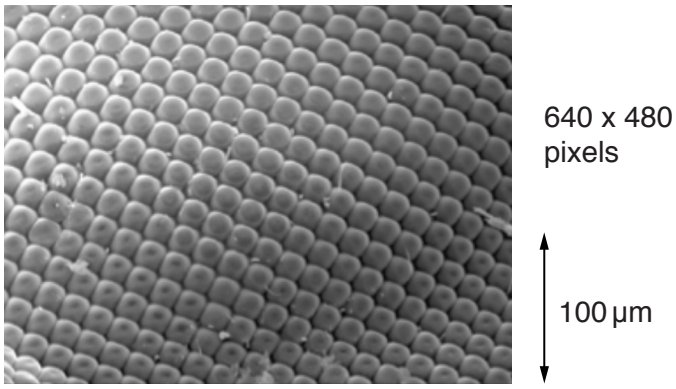

Fig. 14.1

(a) From the information given in Fig. 14.1, calculate the resolution of the image.

resolution = ... metres per pixel **[2]**

(b) The surface area of the fly's eye covered by the lenses is about $6.2 \times 10^{-6}\,m^2$. Calculate the approximate number of lenses covering one eye.

approximate number of lenses covering one eye = ... **[2]**

[Total: 4]

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15 While in operation, an electron microscope produces a continuous beam of electrons travelling along an evacuated tube (line 50).

(a) The beam of electrons carries a current of 2.0×10^{-12} A.

Calculate the number of electrons leaving the electron gun each second.

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

number of electrons per second = ... **[1]**

(b) The pressure in the tube is 1.0×10^{-5} Pa.
The device is operating at 300 K (room temperature).
Calculate the number of gas particles per cubic centimetre in the chamber.

Boltzmann constant $k = 1.4 \times 10^{-23}$ J K^{-1}

number of gas particles per cubic centimetre = ... **[3]**

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(c) The source of the electrons is a small coil of tungsten wire (the filament). A current is passed through the coil and electrons boil off the hot surface of the wire. The electrons receive the energy to do this from the thermal vibrations of the metal lattice. The energy, E, required to remove an electron in this way is about 7×10^{-19} J (just over 4 eV, line 42).

(i) The beam current I_B will depend upon the Boltzmann factor:

$$I_B \propto e^{-E/kT}$$

Explain why it is reasonable to expect the beam current to be proportional to the Boltzmann factor.

[3]

(ii) When the filament is at a temperature of 2200 K, N electrons are emitted per second.

Use the Boltzmann factor to calculate an estimate of the temperature the wire must reach to emit $3N$ electrons per second.

$k = 1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$

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

[Total: 10]

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16 In a typical scanning electron microscope, the electrons are accelerated from rest through a potential difference of 40 kV.

(a) **(i)** Show that the kinetic energy gained by each electron is about 6×10^{-15} J.

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

[1]

(ii) Calculate the momentum gained by each electron. Ignore relativistic effects.

mass of an electron $m_e = 9.1 \times 10^{-31}$ kg

momentum gained = ...kg m s^{-1} **[2]**

(b) Calculate the maximum theoretical resolution of an instrument using 40 keV electrons. Assume this resolution is given by half the de Broglie wavelength of the electrons.

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

resolution = ... m **[2]**

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(c) When the electrons strike the sample most of their energy is converted to thermal energy (line 56). Excessive heating could damage the sample.

Calculate the minimum number of electrons required to strike a small sample in order to raise its temperature by 1 K.

electron energy $E = 6.0 \times 10^{-15}$ J
mass of sample $m = 0.25 \times 10^{-6}$ kg
specific thermal capacity of sample $c = 3000\,\text{J kg}^{-1}\,\text{K}^{-1}$

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

(d) Some of the electrons' energy is carried away as x-rays (line 56). The maximum energy of an emitted x-ray photon is equal to that of the incident electron.

Calculate the minimum wavelength of the emitted x-rays.

electron energy $E = 6.0 \times 10^{-15}$ J
Planck constant $h = 6.6 \times 10^{-34}$ J s
speed of light $c = 3.0 \times 10^{8}\,\text{ms}^{-1}$

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

[Total: 9]

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17 In electron microscopes, beams of electrons are focused using circular solenoids producing strong magnetic fields (line 46), typically about 1 tesla in TEMs.

(a) Show that the number of turns required to produce this field strength in a circular solenoid of mean diameter 0.010 m which carries a current of 2.0 A is about 4000.

$$\text{field strength in solenoid } B = \mu_o \frac{IN}{d}$$

where

B is magnetic field strength in tesla
μ_o is permeability of free space = $1.3 \times 10^{-6}\,\text{N A}^{-2}$
I is current in amps
N is number of turns
d is diameter of solenoid in metres

[2]

(b) Estimate the potential difference needed across this coil to produce the required field strength.

resistance per unit length of the wire used = $1.6\,\Omega\,\text{m}^{-1}$

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

[Total: 4]

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Question 18 is printed on page 24

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18 In some SEM systems, sideways deflection of the beam (for scanning) can be obtained using a uniform electric field (line 70) between two parallel plates (Fig. 18.1).

Fig. 18.1

(a) Show that the electric field between a pair of plates 1.8 mm apart with a potential difference across them of 200 volts is more than 10^5 V m^{-1}.

[1]

(b) The electrons move through the field at a speed of 40% of the speed of light so relativistic effects can be ignored.

Calculate the length of plates required to produce a deflection of 5×10^{-4} m at the end of the plates.

electronic charge $e = 1.6 \times 10^{-19}$ C
electron mass $m_e = 9.1 \times 10^{-31}$ kg

length of plates = ... m **[4]**

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(c) Explain why the size of the deflection of an electron passing through the middle of the gap between the plates would be unchanged if it entered the gap closer to the negative plate.

[2]

[Total: 7]

19 Transmission electron microscopes use electrons of high energy, at which relativistic effects ($\gamma > 1$) are significant.

Calculate the velocity of an electron accelerated through a potential difference of 200 kV, taking relativistic effects into account.

rest energy of the electron = 0.511 MeV
speed of light $c = 3.0 \times 10^8\,\text{ms}^{-1}$

velocity = ... ms^{-1} **[3]**

[Total: 3]

END OF QUESTION PAPER

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Thursday 18 June 2015 – Morning

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

INSERT

Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

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

INFORMATION FOR CANDIDATES

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Seeing with electrons

Given the role it has played in scientific and technological revelation and development over the centuries, it is fair to describe the microscope as one of the most important inventions in history. Although it is not known for certain who actually invented it, the optical microscope was in use from the end of the 16th century and led to rapid developments in our knowledge of what became known as the microscopic world. For hundreds of years it remained based upon a standard design. That same design provided the template for the invention that would eventually supersede it as the main tool to be used for the study of some of the smallest objects in the natural world: the electron microscope.

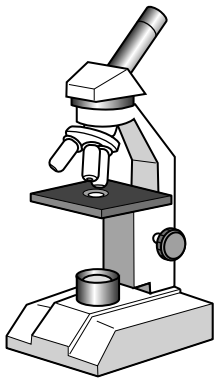


Fig. 1: a compound optical microscope

The compound optical microscope

Although it is possible to use a single convex lens as a simple magnifying glass, substantial magnifications (more than 30×) only become possible by using combinations of lenses to produce what is called a compound microscope; a simple version is drawn in Fig. 2 with rays included.

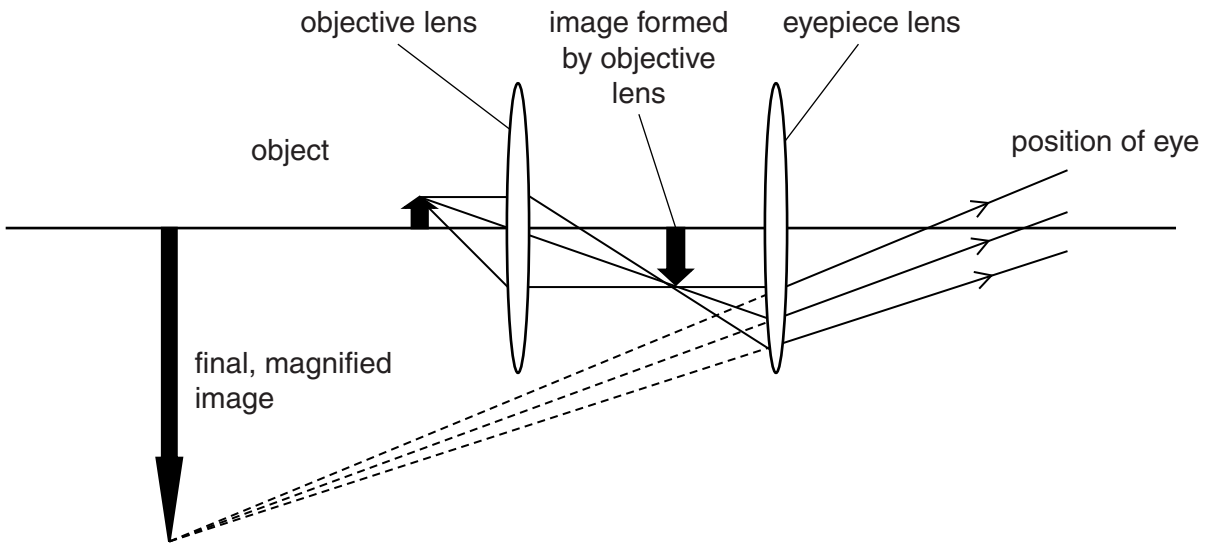


Fig. 2: compound microscope, schematic

The lens closest to the object is called the *objective lens*; it forms an inverted and magnified image of the object. This image is viewed through the *eyepiece lens*, which acts as a magnifying glass to produce a final highly-magnified image of the object.

As with all imaging systems, the performance of a microscope can be described in terms of *magnification* and *resolution*. Typically, laboratory microscopes have a maximum magnification of about 2000×. The resolution of an image is defined in terms of the size of the smallest distinct object visible on the image. When considering modern digitised images this is usually quantified as the actual distance represented by each pixel. However, the production of the image is itself limited by the diffraction caused when the incident light interacts with the tiny structures of the specimen. This leads to a diffraction limit dependent upon the wavelength of the light being used. Laboratory microscopes using visible light are limited to a resolution which makes it impossible to identify objects that are smaller than approximately half the wavelength of the light being used i.e. about 250 nm for visible light.

Improving the view

Developments in lens design and production, along with the use of a variety of lens combinations and arrangements, led to significant improvements on the early instruments over a period of about 300 years. It was not until the end of the 19th century that the limits of the performance of an optical (light) microscope were fully understood. Progression now only became possible with a radical change of approach which was prompted by a series of important discoveries: the suggestion by Hertz that cathode rays were wavelike (1891), Thomson's discovery of the electron (1897), de Broglie's formula for calculating the wavelength of an electron from its momentum (1924) and Busch's success with the focusing of electron beams using magnetic fields (1926). Using all of these ideas, Ernst Ruska suggested the construction of a microscope that used high-speed electrons instead of light waves, and he built such a device in 1933. This revolutionary instrument, the first electron microscope, was a type known as a transmission electron microscope (TEM). For producing it Ruska was awarded the Nobel Prize for Physics over half a century later, in 1986. Fig. 3 shows a modern version of the instrument.

Fig. 3: a modern electron microscope

Fig. 4 is a schematic diagram comparing the structure of a TEM with that of an optical microscope.

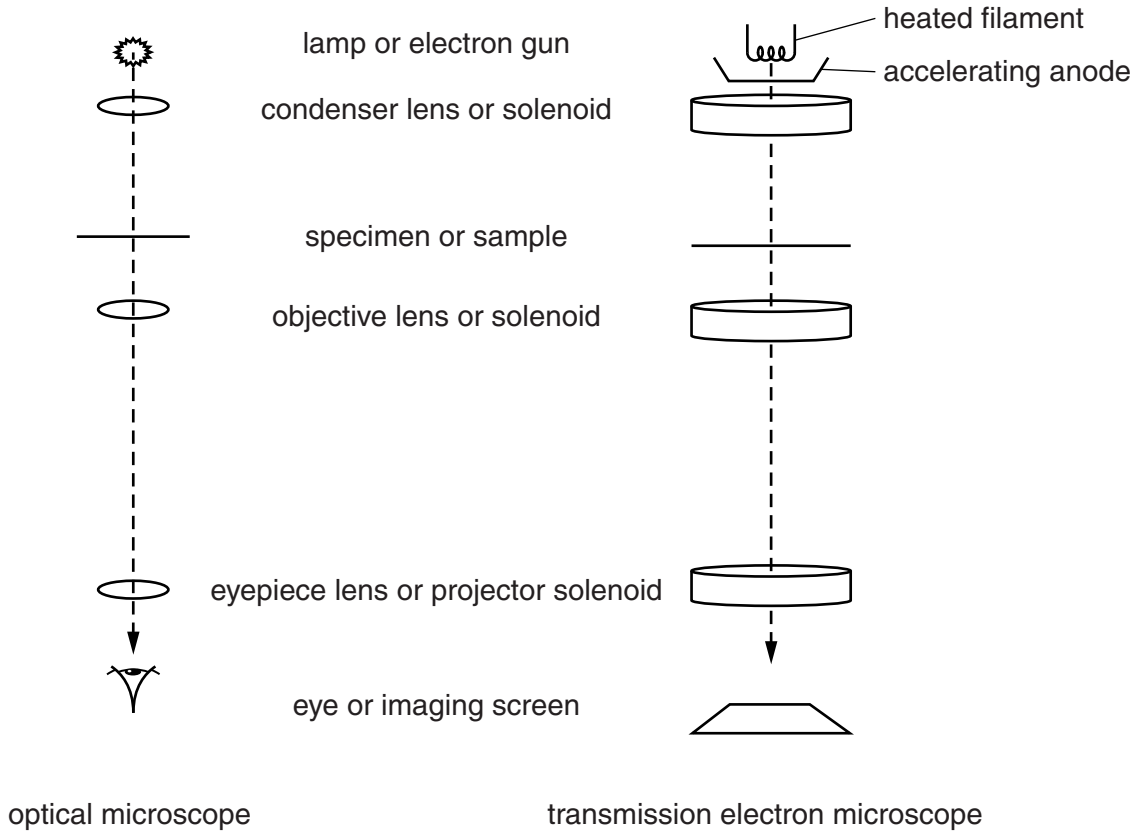


Fig. 4: comparison of the structure of an optical and an electron microscope

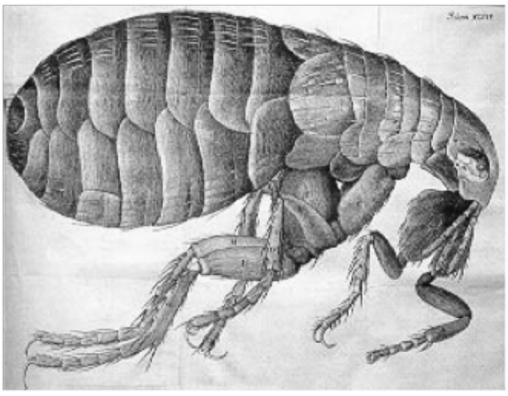
In the electron microscope, the source of the electrons is an electron gun. When a current is passed through the filament coil, it heats up and electrons boil off the surface. Individual electrons require about 4 eV of energy to escape the surface and the number of electrons emitted depends on the temperature of the filament. The electrons are emitted into a gap, across which there is a large potential difference creating an electric field. This causes them to accelerate through the accelerating anode and at high speed they pass through the first of a series of short circular solenoids and are focused onto the sample being imaged. The magnetic field strength inside a solenoid depends upon the number of turns for the coil and the current it carries. Complicated combinations of solenoids are used and these are equivalent to the illumination system in an optical microscope which produces and focuses the light onto the sample.

The flow of electrons from filament to sample produces a beam current along the tube of the microscope and into the sample chamber. The tube and chamber need to be evacuated and so efficient pumps are an integral part of electron microscope assemblies. The vacuum environment, while essential for the operation of the instrument, does limit the usefulness of the instrument and often samples need to be carefully prepared before being imaged.

When the high-speed electrons meet the sample, a number of different interactions can occur resulting in heating and sometimes including the production of x-rays. If the sample is thin, however, and the electrons are of very high energy then most will pass through the sample, being scattered and diffracted as they do so. The amount of interaction will depend upon the types of atoms in the sample, the sample density and other similar factors so that a transmission image can be obtained. It is because the wavelength of the electrons is much smaller than that of visible light that superior performance is possible. For example, electrons accelerated from rest through a potential difference of 50 kV will gain sufficient momentum to give them a de Broglie wavelength of about 5 picometres which, theoretically, would produce a much better resolution than an optical microscope.

A later development of the instrument was the scanning electron microscope (SEM). For thicker samples and lower energy electrons, many *secondary electrons* will be emitted. These are produced when an incident electron excites an electron below the surface of the sample. The excited electron moves towards the surface and can escape if it has not lost too much energy in the process. The secondary electrons emitted at each beam position are detected, giving a signal that varies as the beam moves across the sample. Electric fields are sometimes used to deflect the electrons, scanning the beam across the sample in a raster pattern. This allows an image of the surface to be built up on a display screen. Modern instruments use photomultiplier tubes and CCDs to produce high-quality images.

Fig. 5a shows an image of a flea drawn by Robert Hooke in 1665. Fig. 5b is a view of a fly's eye obtained by a 21st century SEM. At this magnification (about 1000×) it can be seen that the eye consists of an array of small lenses.



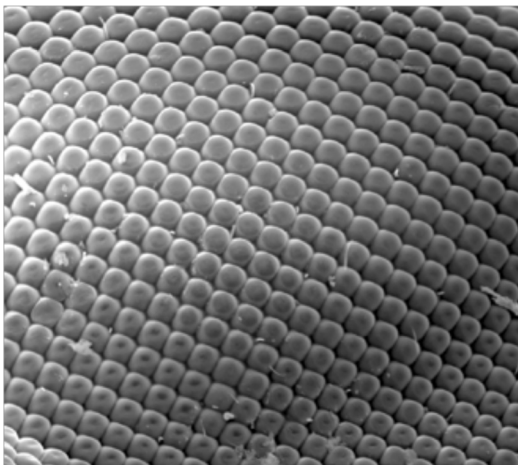


Fig. 5a (left) and 5b (right): images of a flea from Robert Hooke's *Micrographia* (1665) and a fly's eye from a modern SEM, respectively.

Scrutinising the future

Magnification and resolution continue to be improved as technology develops. Electron microscopes have progressed significantly, though they remain based on Ruska's original ideas. Additional challenges being met include real-time imaging and the ability to image living organisms. Meanwhile, microscopes based on other ideas and principles have emerged, including scanning tunnelling microscopes and atomic force microscopes, but we shall be forever indebted to those early pioneers of electron microscopy for paving the way to a smaller world.

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