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
- Ruler (cm/mm)

**Tuesday 21 June 2011**
**Morning**

**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.

Answer **all** the questions.

## Section A

**1** Here is a list of some particles emitted in radioactive decays.

**alpha particle** **neutrino** **gamma ray** **positron** **beta particle**

Choose from the list

**(a)** the particle with negative charge

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

**(b)** the two particles with positive charge

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

**(c)** the three particles that are leptons.

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

**2** Fig. 2.1 shows the variation of electrical potential *V* with distance *r* from a charged particle.

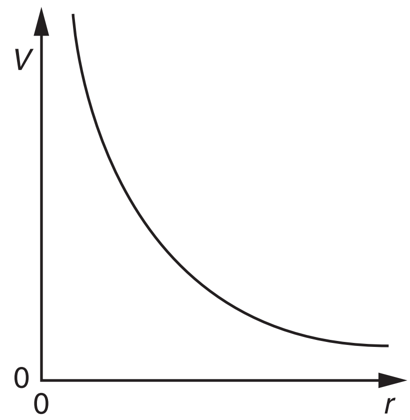



**Fig. 2.1**

**(a)** State what is represented by the gradient of the graph.

**[1]**

**(b)** State the feature of the graph that shows that the charge on the particle is **positive**.

**[1]**

**3** A fast-moving electron enters a container of low pressure gas. There is a uniform magnetic field in the container. Fig. 3.1 shows the path of the electron. The region of the magnetic field is shown by the crosses on Fig. 3.1.

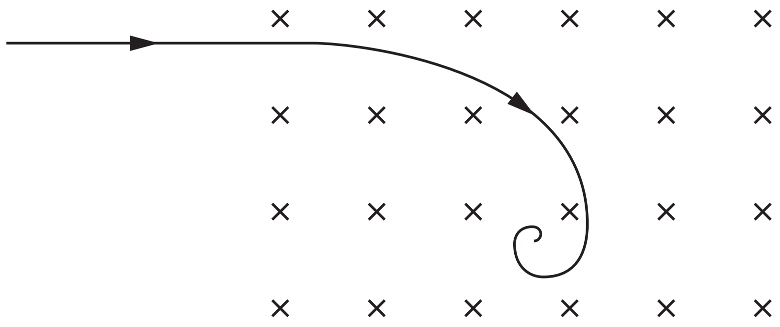


**Fig. 3.1**

**(a)** State why the electron path is curved.

**[1]**

**(b)** State why the path is a spiral.

**[1]**

**4** Fig. 4.1 shows an electron and a proton separated by $5.0 \times 10^{-11}$ m.

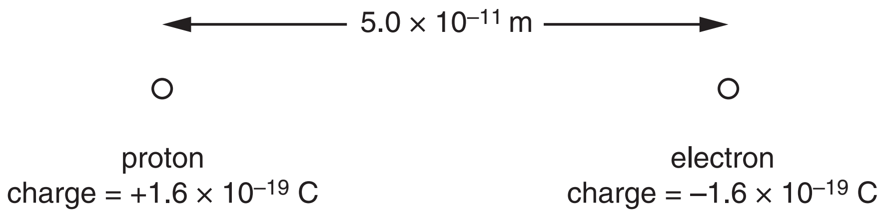



**Fig. 4.1**

Use information from Fig. 4.1 to calculate the electric force between the two particles.

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

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

**5** In the second half of the twentieth century many people were given chest X-rays to look for early stages of tuberculosis, a serious disease.

**(a)** Use the data below to estimate the likely number of cancer cases expected from an X-ray programme over a 25 year period.

risk of developing cancer = 3% per Sv in a lifetime
number of people X-rayed per year = 290 000
equivalent dose of a chest X-ray = 20 μSv

number = .......................................................... **[1]**

**(b)** Suggest why the X-ray programme was stopped when the number of cases of tuberculosis fell.

**[1]**

**6** Fig. 6.1 shows the three lowest energy levels of hydrogen.

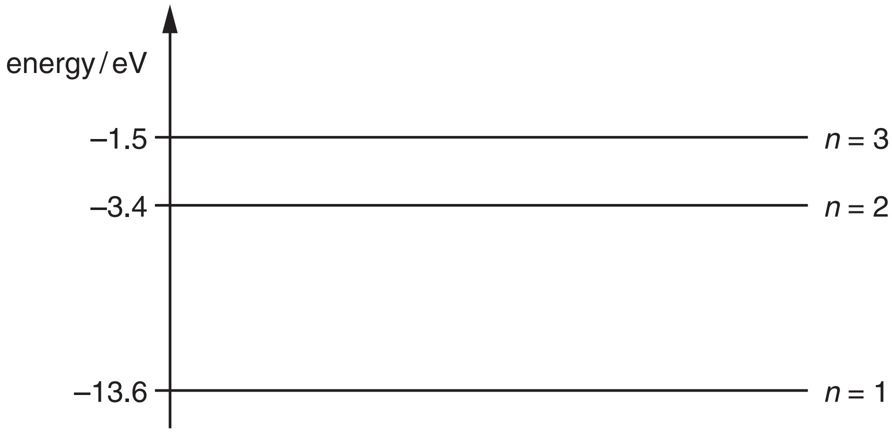



**Fig. 6.1**

**(a)** Explain why electron transitions between the energy levels shown can give three different frequencies of radiation. You may add to the diagram in your explanation.

**[1]**

**(b)** Show that the highest of these frequencies is about $3 \times 10^{15}$ Hz.

$h = 6.6 \times 10^{-34}$ J s
$e = 1.6 \times 10^{-19}$ C

**[2]**

**7** Fig. 7.1 shows a simple magnetic circuit and a simple electric circuit.

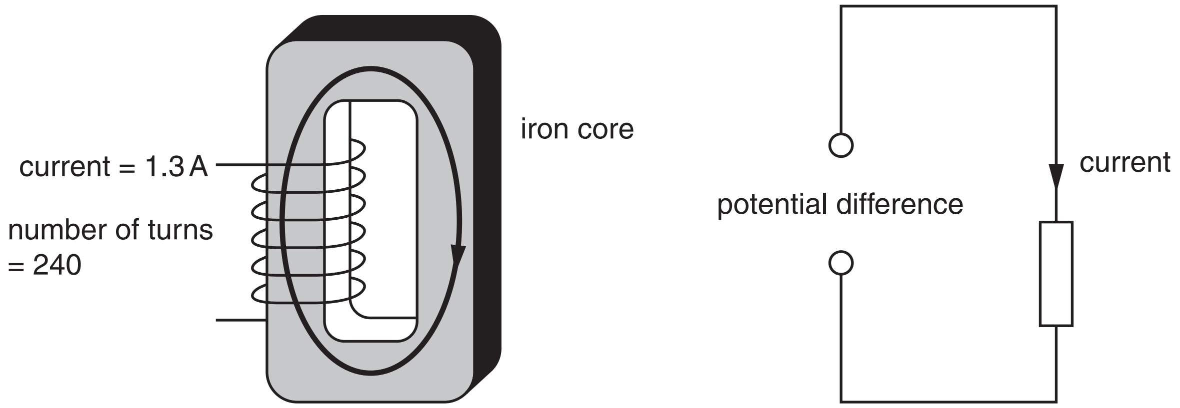



**Fig. 7.1**

In the magnetic circuit, current turns = 1.3 × 240 = 312 A turns.

The current produces a magnetic flux in the iron core, where flux = permeance × current turns.

**(a)** A magnetic circuit with greater permeance will produce a larger flux for the same current turns. Suggest **two** ways in which the permeance of the magnetic circuit could be increased.

**[2]**

**(b)** The magnetic circuit is analogous to the electric circuit. Complete the table below.

| magnetic circuit | electric circuit |
|---|---|
| current turns | potential difference |
| flux | current |
| permeance of circuit | |

**[1]**

**8** Fig. 8.1 shows a simple transformer.

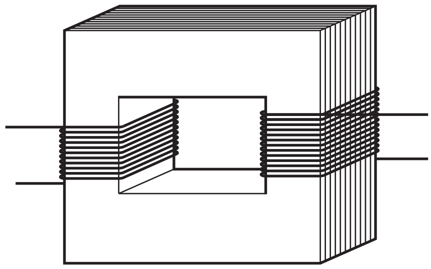


**Fig. 8.1**

Explain how an alternating current in the primary coil produces an alternating emf in the secondary coil.

Consider the behaviour of the flux in the core in your answer

**[3]**

**[Section A Total: 20]**

## Section B

**9** This question is about the force on an object in an electric field.

A small ball with a metallic coating is hung from an insulating spring between two metal plates as shown in Fig. 9.1. The ball is initially uncharged.

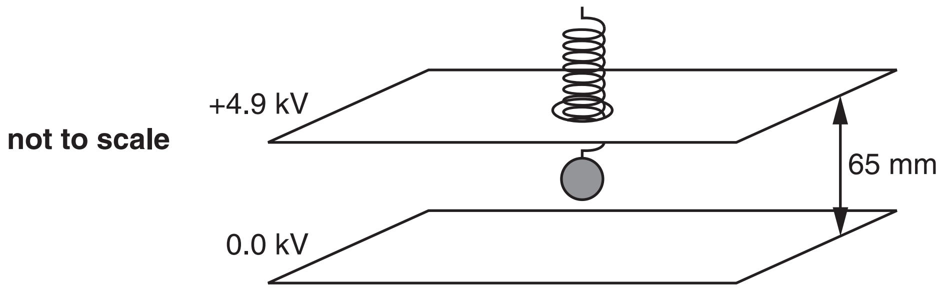



**Fig. 9.1**

The separation of the plates is 65 mm. There is a potential difference of 4.9 kV between the plates. This produces a uniform electric field.

**(a)** Show that the strength of the field is about $8 \times 10^4\,\mathrm{V\,m^{-1}}$.

**[2]**

**(b)** Show that the units $\mathrm{V\,m^{-1}}$ are equivalent to the units $\mathrm{N\,C^{-1}}$.

**[2]**

**(c)** The ball is now given a positive charge. The ball moves towards the lower plate, extending the spring by 2.5 mm.

**(i)** Show that the force on the ball due to the electric field is about 1μN.

stiffness constant of spring $k = 4.2 \times 10^{-4}\,\text{N m}^{-1}$

**[2]**

**(ii)** Use your answers to **(a)** and **(c)(i)** to estimate to one significant figure the number of electrons removed from the ball when it is given the positive charge.

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

number of electrons = ........................................................... **[3]**

**(d)** A radioactive beta source is placed near the apparatus as shown in Fig. 9.2. Nothing else is changed.

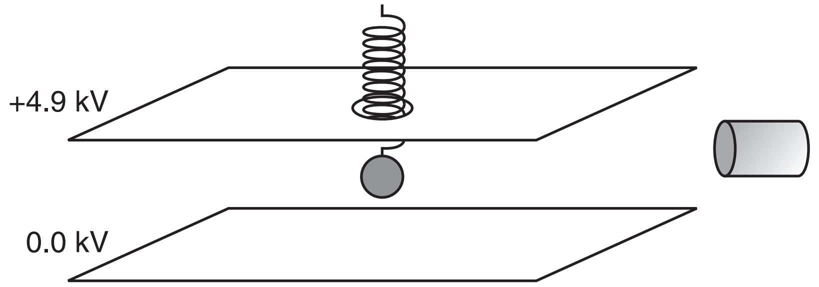
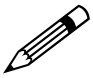



**Fig. 9.2**

Suggest and explain how this might affect the position of the ball between the plates.

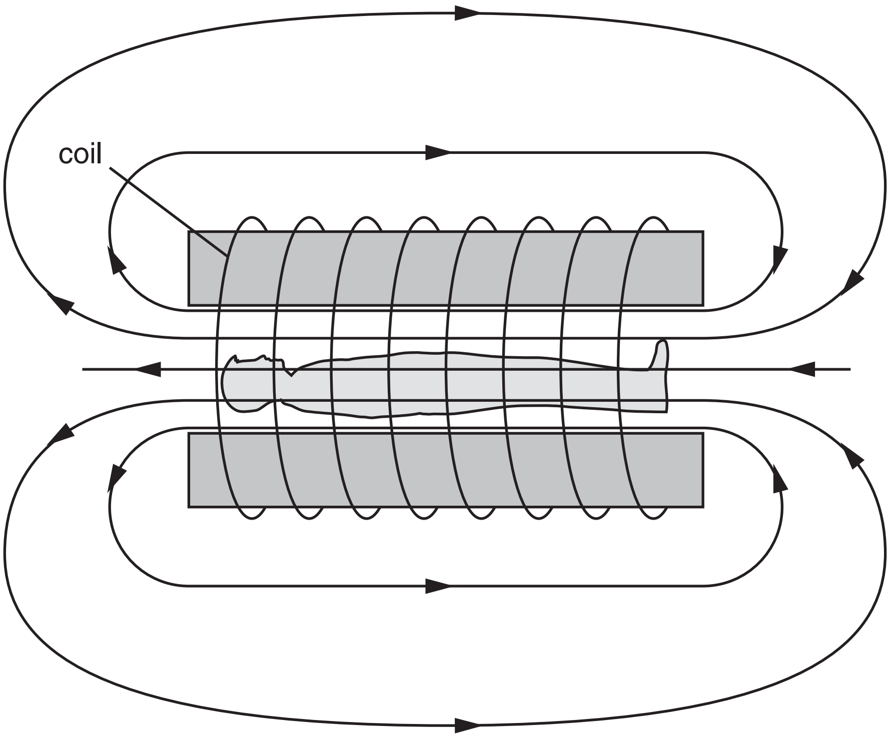


*Your answer should use the correct terms in a logical order.*

**[4]**

**[Total: 13]**

**10** This question is about the magnetic field inside a magnetic resonance imaging (MRI) scanner.




**not to scale**

**Fig. 10.1**

Fig. 10.1 shows a simplified diagram of an MRI scanner. A direct current in the coil produces a uniform magnetic field inside the scanner.

**(a)** State how Fig. 10.1 shows that

**(i)** the field is uniform inside the scanner

**(ii)** the field is weaker outside the scanner than inside.

**[2]**

Patients with metal implants must inform the operator of the scanner. However, wearing a ring on the hand is acceptable.

**(b)** Fig. 10.2a shows a diagram of a ring in the magnetic field of the scanner. The plane of the ring is at right angles to the field.

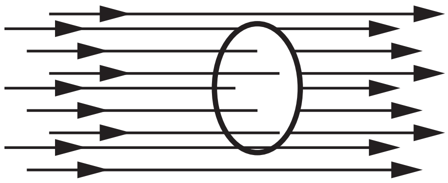


**Fig. 10.2a**

**(i)** Calculate the flux through the ring.

diameter of ring = $1.8 \times 10^{-2}$ m
magnetic flux density $B = 0.70$ T

flux = .................................................... Wb **[2]**

**(ii)** Explain why no emf is generated when the ring moves from left to right as shown in Fig. 10.2b.

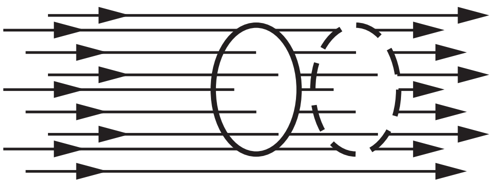


**Fig. 10.2b**

**[2]**

**(c)** The ring is turned through 90° in the field as shown in Fig. 10.3. The plane of the ring is now parallel to the field. This rotation takes 0.4 s.

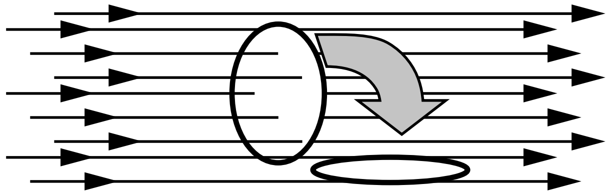


**Fig. 10.3**

Estimate the average emf generated during this rotation and explain why your calculation only gives an average value of emf.

emf = ........................................................ V **[3]**

**[Total: 9]**

**11** This question is about the decay of strontium-90, a beta-emitter commonly used in schools.

A school source has an activity of $7.0 \times 10^4$ Bq.

**(a) (i)** Show that the minimum number of strontium-90 nuclei in the source is about $9 \times 10^{13}$.

half-life of strontium = $9.2 \times 10^8$ s

**[2]**

**(ii)** Suggest why this is a minimum figure.

**[1]**

Strontium-90 decays into yttrium-90 by releasing an electron and an anti-neutrino. Fig. 11.1 shows the energy spectrum of electrons released in this decay.

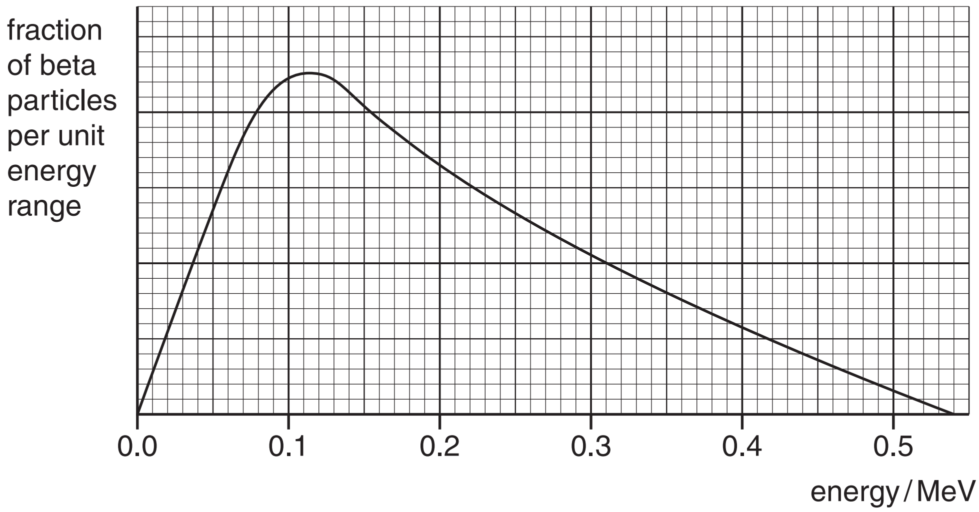



**Fig. 11.1**

**(b) (i)** Use the graph to estimate the most common energy of a beta particle released in the decay.

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

**(ii)** Each strontium-90 nucleus releases just over 0.5 MeV energy when it decays. Explain how the graph suggests that particles other than beta particles are also emitted in the decay.

**[3]**

**(c)** A beta particle released from strontium-90 has a kinetic energy of 0.45 MeV.

Calculate the relativistic factor $\gamma$ for a beta particle with this kinetic energy and use this value to find the speed of a 0.45 MeV beta particle.

rest energy of electron = 0.511 MeV.
$c = 3.0 \times 10^8\,\mathrm{m\,s^{-1}}$

speed = ................................................ $\mathrm{m\,s^{-1}}$ **[4]**

**[Total: 11]**

**12** This question is about neutron-induced nuclear fission. This is the process that is the ultimate source of energy in nuclear power plants.

A uranium-235 (U-235) nucleus can 'capture' a neutron to form U-236. This nucleus is unstable.

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

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \longrightarrow ^{236}_{92}\text{U} \longrightarrow ^{90}_{\dots\dots\dots}\text{Kr} + ^{144}_{56}\text{Ba} + 2^{1}_{0}\text{n}$$

**[1]**

**(ii)** Suggest why the rate of formation of krypton (Kr) and barium (Ba) may increase in an uncontrolled fission reaction of this type.

**[1]**

**(b)** Show that the energy released when a U-236 nucleus decays in the manner shown in **(a)** is about $3 \times 10^{-11}$ J. Make each step in your calculation clear.

Data:

U-236 binding energy per nucleon = –7.6 MeV
Kr-90 binding energy per nucleon = –8.7 MeV
Ba-144 binding energy per nucleon = –8.3 MeV

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

**[3]**

**(c)** In a typical fission reactor, energy is released at a rate of about $2.8 \times 10^9$ W.

Use the value of energy released in one fission event from **(b)** to calculate the mass of U-235 used in one year of operating the reactor.

1 atomic mass unit = $1.66 \times 10^{-27}$ kg
1 year = $3.2 \times 10^7$ s

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

**[Total: 8]**

**[Section B Total: 41]**

## Section C

These questions are based on the Advance Notice.

**13 (a) (i)** Assuming that the Earth is a perfect sphere show that its circumference (the length of a meridian line) is about 40 000 km.

radius of Earth = 6 400 km

**[1]**

**(ii)** Using the value calculated in **(i)** for the length of a meridian show that a milliare (line 23 in the article) is about 2 km.

**[1]**

**(b) (i)** The article states (lines 28–29) that a pendulum of length 0.1 virga would "change direction 3959.2 times in exactly half an hour". Show that this is equivalent to a frequency of about 1.0 Hz.

**[2]**

**(ii)** The Earth is not a perfect sphere: its radius at the Equator is greater than at the poles.

Use the expression for gravitational field strength $g = -\frac{GM}{r^2}$ to calculate the ratio

$$\frac{g \text{ at the poles}}{g \text{ at the Equator}}.$$

Earth's radius at poles = 6 360 km
Earth's radius at Equator = 6 380 km

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

**(iii)** Use the expression $T = 2\pi \sqrt{\frac{l}{g}}$ to explain why pendulums constructed to have a frequency of 1.0 Hz would have to be longer at the Earth's poles than at the Equator.

**[2]**

**(iv)** Suggest advantages and disadvantages of using the pendulum in this way to define a standard length (lines 33–34 in the article).

**[4]**

**[Total: 12]**

**14 (a)** When producing a prototype standard metre bar, it is important to be very specific about its structure and the conditions under which it is kept. Suggest and explain what is likely to happen to the length of the supported bar with the following changes:

**(i)** too high a temperature

**[1]**

**(ii)** too high an atmospheric pressure

**[1]**

**(iii)** too great a distance between the cylindrical supports (Fig. 2 in the article).

**[2]**

**(b)** Suggest and explain an advantage of making the bar from platinum-iridium rather than from pure platinum.

**[2]**

**(c)** Describe how the definition of the metre was used to define the kilogramme (lines 45–48 in the article).

**[2]**

**[Total: 8]**

**15** In the twentieth century, the wavelengths of certain specific colours of light were determined very accurately and used as the basis for a standard length.

**(a)** State **two** advantages of using the wavelength of light as a standard for length.

1.

2.

**[2]**

**(b)** In 1960, the metre was defined as the distance in a vacuum occupied by 1 650 763.73 wavelengths of the orange-red light emitted by krypton-86 (lines 81–87 in the article). Show that this implies that the wavelength of this light is about 600 nm.

**[1]**

**(c)** Using the value of the wavelength from **(b)**, calculate the energy difference between the electron levels in the krypton atom giving rise to the emitted orange-red light.

Planck constant, $h = 6.6 \times 10^{-34}\,\text{J s}$
speed of light, $c = 3.0 \times 10^{8}\,\text{m s}^{-1}$

energy difference = ...................................................... J **[3]**

**[Total: 6]**

**16** The development of interferometers provided a new, accurate method of measuring the wavelength of light, allowing an improved way of defining the metre to be used. Fig. 16.1 is a diagram of a Michelson interferometer (Fig. 3 in the article).

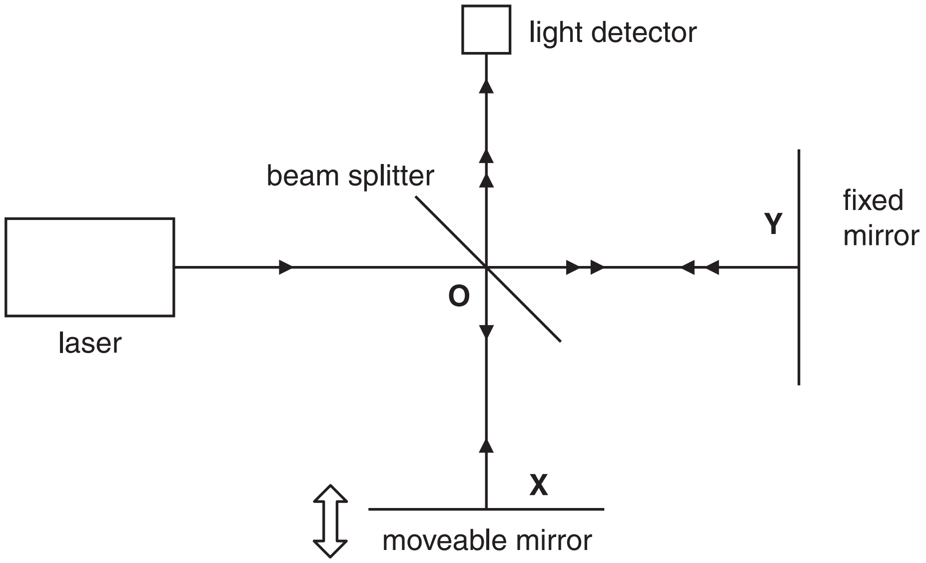



**Fig. 16.1**

**(a)** Draw a phasor representing photons taking the path **OXO** when the intensity of light at the detector is **zero**. The phasor for those photons travelling the path **OYO** has been drawn.

phasor via **OYO**

phasor via **OXO**

**[2]**

**(b)** In a typical experiment, the moveable mirror is moved along the line **OX** a distance of 0.21 mm. During that movement the intensity of light at the detector falls to zero 800 times.
Calculate the wavelength of the laser light.

wavelength = ...................................................... m **[3]**

**(c)** A glass tube is placed in the beam **OX** and the air is slowly pumped out of the tube. The refractive index of air is proportional to its density.
Describe what changes will occur to the two phasors as the air is removed. State how the detector signal will vary.

**[3]**

**[Total: 8]**

**17** In 1983, the definition of the metre was changed to that which we use today (lines 99–100) along with three recommended methods of using it to measure distances.

**(a)** Explain why method 1 (line 103 in the article) is not used in practice except for very long distances.

**[2]**

**(b)** Describe how method 2 (line 104 in the article) can be used to make precise measurements of length.

*Your explanation should be carefully ordered and clear.*

**[3]**

**[Total: 5]**

**[Section C Total: 39]**

**END OF QUESTION PAPER**

**PLEASE DO NOT WRITE ON THIS PAGE**

OCR
RECOGNISING ACHIEVEMENT

**ADVANCED GCE**

**PHYSICS B (ADVANCING PHYSICS)** **G495**

Unit G495: Field and Particle Pictures

**INSERT**

**Tuesday 21 June 2011**
**Morning**

**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**

- Do not send this insert for marking; it should be retained in the centre or destroyed.

# How the metre measures up

For as long as human beings have been measuring things, there has been a need for the standardisation of units, to enable agreement amongst and between communities. Very often, the chosen starting point for deciding on basic units has been the human body itself – for example, the heartbeat as a unit of time.

A very early example of a distance unit is the Egyptian *cubit*, which was first defined and used over 5000 years ago. It was based on the length of a human arm (from the elbow to extended finger tip). Such definitions, though useful, are unsatisfactory for accurate measurements for the simple reason that humans come in a variety of shapes and sizes, so one Egyptian's cubit is likely to be different from another's. The idea of a standard unit was necessary and a famous example of this is the English *yard*, still used today in the UK and North America. It was defined in 1120 by the English king Henry the First, as the exact length of his own arm. Since the king could not be transported to wherever a length of cloth needed to be measured, iron bars were made to the same length and stored around the country. From them, wooden rulers could be made for everyday use. Thus arose the custom of having a single primary standard (the king's arm), and secondary standards made from it. Some of the original, now rusty, iron bars still exist in museums.

**A truly global solution**

It was not until the 17th century that the unit of distance known to us today as the *metre* began to emerge as the standard unit of length. As part of his attempt to create a language system in which scholars could communicate more effectively, John Wilkins, the Secretary of the Royal Society in London, proposed a standard system of measurement based on units of ten, i.e. a decimal system. Two years later, in 1670, the French scientist and priest Gabriel Mouton proposed a similar system, but with more detail, in which it was suggested that the standard unit of length should be the *milliare*, defined as the distance covered by one minute of arc along a meridian on the surface of the Earth (see Fig. 1). This corresponds today to a distance known as a Nautical Mile.

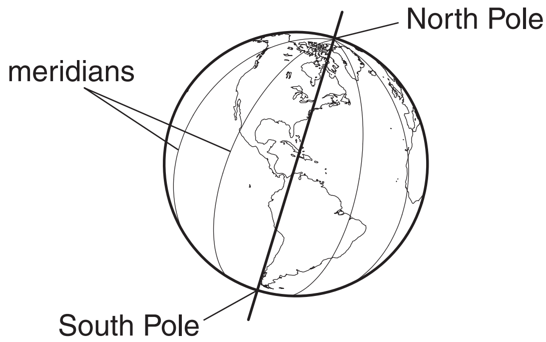



**Fig. 1** A meridian is an imaginary circle drawn on the surface of the Earth, passing through both poles and meeting the Equator at right angles. It is a line of longitude.

In this system, a sub-division of the *milliare* was the *virga*, corresponding to $10^{-3}$ of a *milliare* and roughly equal to a unit already in use in Europe, the *toise*, a similarity which helped Mouton's system gain some acceptance. Mouton added that a pendulum could be used to assist standardization in different places. He stated that pendulum of length precisely 0.1 virga would "change direction 3959.2 times in exactly half an hour".

Mouton's proposal to base the unit of length on the dimensions of the Earth was discussed, adopted and refined for well over a hundred years, whilst all over the world many other basic units of length were still being used. During that time, the only other main contender for a universal definition was the pendulum approach. A pendulum with a period of two seconds (i.e. a half-period of exactly one second) was indeed preferred by many as a definition of the metric unit of length. It had several appealing advantages: it was simple, portable and the principle enabled a standard to be constructed anywhere. However, it was ultimately rejected as a method since it was itself dependant upon standardized time, the second, and sufficiently accurate and reliable clocks did not exist. Moreover, the period of a pendulum depends upon the gravitational field strength, which varies across the surface of the Earth.

**Stating the rule**

With international trade increasing dramatically, the need for standard units of measurement was becoming ever more crucial and so, in 1790, the French Academy of Sciences formally recommended that a meridian-based definition for unit length be adopted. Their recommendation was that the length of the meridian at sea level passing through Paris be measured and that the distance along it from the North Pole to the Equator be determined. One ten-millionth ($10^{-7}$) of that distance would be called a *metre* and this would form the basic unit for length.

This led in turn to the definitions of area and volume and also, using water as a standard substance, to the density of water, when 1 $dm^3$ of water was defined as having a mass of 1 kilogram. When an accurate determination of the meridian distance from the North Pole to the Equator was finally made in 1799, the so-called metric system was officially declared. This length became the standard metre and metal bars were produced against which others could be tested. In fact, the very first prototype was too short, as the calculation of the quarter-meridian did not take account of the Earth's rotation, which alters its shape, flattening the poles and causing a bulge at the Equator.

It was also important to produce a standard prototype from a suitable material. In 1874, a metre length made of a platinum-iridium alloy was produced. In 1889, the composition of the alloy was carefully defined. The new standard alloy consisted of 10% iridium, to within 0.0001 of a percent and the length of the bar was to be measured at exactly the melting point of ice.

Later still, in 1927, account was taken of other conditions. The metre was now defined as the distance between two particular marks on the upper surface of a platinum-iridium bar at 0 °C and standard atmospheric pressure, when supported by two cylinders of at least one centimetre diameter, positioned symmetrically on the same horizontal plane a set distance apart – see Fig. 2. It was important to define such details since the bar supported in this way would naturally bend and stretch under its own weight.

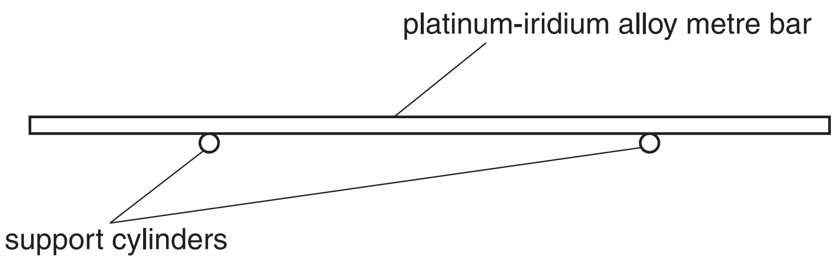
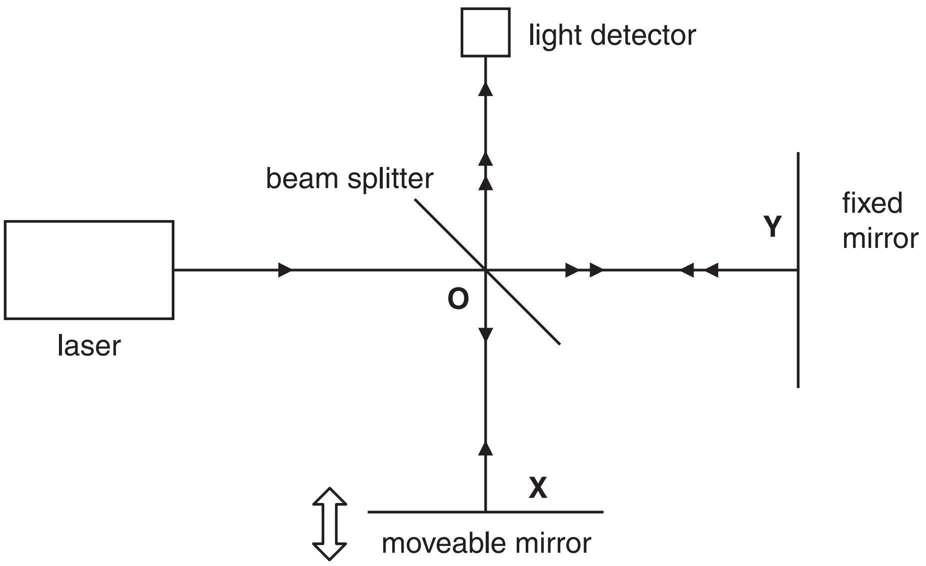



**Fig. 2** Arrangement for supporting the 1927 standard metre bar

**A new, enlightened approach**

The definition based on the metre bar remained the acknowledged standard well into the twentieth century. However, continual cross-comparisons between standard bars showed that they changed lengths in unpredictable ways. Throughout that time, therefore, another approach was being developed and the basis of the definition of the standard for length shifted from being an artefact (the bar) to a physical property: the wavelength of light. This alternative definition became possible because of newly-developed optical instruments called interferometers. These devices enable precise values of wavelengths to be made from interference patterns.

One particular type was developed by the physicist Albert Michelson. A modern version of this is shown in Fig. 3, together with an explanation of how it works. As early as 1893, Michelson used it to measure the wavelengths of specific frequencies of light and thereafter advocated this as an improved method of defining distance. One particular measurement, that of the wavelength of the red line in the emission spectrum of the element cadmium, was made with particular accuracy and proposed as the basis for a new definition of the metre, though it was not adopted by the scientific community. Further support for the argument for a definition based on the interferometer came when Michelson's measurement was used to determine the value of the angström ($10^{-10}$ m), thereafter accepted as the standard unit in the field of spectroscopy and atomic physics.




The beam splitter directs half of the light from the laser toward a fixed mirror (**OY**) and directs the other half toward a moveable mirror whose position forwards and backwards (along **OX**) can be changed very precisely. The light that travels the path from the fixed mirror to the beam splitter is then recombined with the light reflected from the moveable mirror. These beams will have different optical path lengths and the path difference between them will result in a phase difference between them when they arrive at the detector. An observer can bring the light in and out of phase by adjusting the position of the moveable mirror. As the mirror is moved forwards or backwards along the direction of **OX**, the intensity of light at the detector will alternate between bright and dark. Moving the mirror a distance $d$ changes the distance travelled by the beam of light reflecting off it by $2d$. The optical path length can also be affected by changes in the refractive index of the medium through which the light passes.

**Fig. 3** Schematic diagram of a modern version of a Michelson interferometer and (in text box) an explanation of how it works

Eventually, in 1960, at the 11th General Conference on Weights and Measures (CGPM), a new definition of the metre was adopted. It was defined in terms of the interferometer measurement, in a vacuum, of the wavelength of the light emitted due to an electron transition between two particular energy levels within a krypton-86 atom. Thus, one metre became precisely 1 650 763.73 wavelengths of the red-orange line in the krypton-86 spectrum and the metre was now something that could be universally reproduced and was no longer based on an artefact that could erode or be damaged.

**The laser points the way**

For the next twenty years, improvements to the value defined in this way were made by the production of increasingly accurate interferometers. However, although this new definition of the metre has a precision of nine significant figures, there were some problems using interferometry to measure distances to this precision. One problem is that atomic spectral lines are not completely monochromatic. A solution appeared in the shape of newly-developed highly-stabilised lasers producing monochromatic light. Another factor, though, was to influence the definition: the re-defining of the standard unit of time (the second) in terms of the frequency of a particular emission from a caesium-133 atom. This made the second an absolute quantity, i.e. independent of other physical variables. In view of these advances, in 1983, the 17th CGPM redefined the metre as

"The distance travelled by light in a vacuum during a time interval of 1/299 792 458 seconds". In effect, this defined the speed of light to be **exactly** $2.99792458 \times 10^8\,\mathrm{m\,s^{-1}}$.

In order to use this definition of the metre in practical ways of measuring distances, the International Office of Weights and Measures (BIPM) has recommended using one of the following methods:

1. Measure the time taken, $t$, for light to travel the required distance, $L$, and use $L = ct$.
2. Measure the frequency, $f$, of a stabilised laser in terms of the caesium time standard and find the wavelength from $\lambda = c/f$.
3. From a list of standard wavelengths issued by BIPM, use a suitable line which is known to a stated accuracy.

Methods 2 and 3 use interferometry, with method 2 being used when the highest possible accuracy is required. Method 3 would be used routinely for calibration purposes using 'off the shelf' lasers.

The metre can now be replicated to a high degree of accuracy across the world. The metre has been changed from being an empirical standard to being an absolute one. Clearly, when defining the standard unit of distance over the centuries, scientists have gone to great lengths to get it right.

**END OF ARTICLE**