X069/13/01

PHYSICS
ADVANCED HIGHER

Reference may be made to the Physics Data Booklet.

Answer **all** questions.

Any necessary data may be found in the Data Sheet on *Page two*.

Care should be taken to give an appropriate number of significant figures in the final answers to calculations.

Square-ruled paper (if used) should be placed inside the front cover of the answer book for return to the Scottish Qualifications Authority.

SQA
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DATA SHEET
COMMON PHYSICAL QUANTITIES

Quantity	Symbol	Value	Quantity	Symbol	Value
Gravitational acceleration on Earth	g	$9 \cdot 8 \, \text{m s}^{-2}$	Mass of electron	m_e	$9 \cdot 11 \times 10^{-31} \, \text{kg}$
Radius of Earth	R_E	$6 \cdot 4 \times 10^6 \, \text{m}$	Charge on electron	e	$-1 \cdot 60 \times 10^{-19} \, \text{C}$
Mass of Earth	M_E	$6 \cdot 0 \times 10^{24} \, \text{kg}$	Mass of neutron	m_n	$1 \cdot 675 \times 10^{-27} \, \text{kg}$
Mass of Moon	M_M	$7 \cdot 3 \times 10^{22} \, \text{kg}$	Mass of proton	m_p	$1 \cdot 673 \times 10^{-27} \, \text{kg}$
Radius of Moon	R_M	$1 \cdot 7 \times 10^6 \, \text{m}$	Mass of alpha particle	m_α	$6 \cdot 645 \times 10^{-27} \, \text{kg}$
Mean Radius of Moon Orbit		$3 \cdot 84 \times 10^8 \, \text{m}$	Charge on alpha particle		$3 \cdot 20 \times 10^{-19} \, \text{C}$
Universal constant of gravitation	G	$6 \cdot 67 \times 10^{-11} \, \text{m}^3 \, \text{kg}^{-1} \, \text{s}^{-2}$	Planck's constant	h	$6 \cdot 63 \times 10^{-34} \, \text{J s}$
Speed of light in vacuum	c	$3 \cdot 0 \times 10^8 \, \text{m s}^{-1}$	Permittivity of free space	ε_0	$8 \cdot 85 \times 10^{-12} \, \text{F m}^{-1}$
Speed of sound in air	v	$3 \cdot 4 \times 10^2 \, \text{m s}^{-1}$	Permeability of free space	μ_0	$4\pi \times 10^{-7} \, \text{H m}^{-1}$

REFRACTIVE INDICES
The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	Refractive index	Substance	Refractive index
Diamond	2·42	Glycerol	1·47
Glass	1·51	Water	1·33
Ice	1·31	Air	1·00
Perspex	1·49	Magnesium Fluoride	1·38

SPECTRAL LINES

Element	Wavelength/nm	Colour	Element	Wavelength/nm	Colour
Hydrogen	656	Red	Cadmium	644	Red
	486	Blue-green		509	Green
	434	Blue-violet		480	Blue
	410	Violet			
	397	Ultraviolet			
	389	Ultraviolet			

Lasers

Element	Wavelength/nm	Colour
Carbon dioxide	9550 } 10590 }	Infrared
Helium-neon	633	Red

Sodium 589 Yellow

PROPERTIES OF SELECTED MATERIALS

Substance	Density/ kg m^{-3}	Melting Point/ K	Boiling Point/K	Specific Heat Capacity/ $\text{J kg}^{-1} \, \text{K}^{-1}$	Specific Latent Heat of Fusion/ J kg^{-1}	Specific Latent Heat of Vaporisation/ J kg^{-1}
Aluminium	$2 \cdot 70 \times 10^3$	933	2623	$9 \cdot 02 \times 10^2$	$3 \cdot 95 \times 10^5$	. . . .
Copper	$8 \cdot 96 \times 10^3$	1357	2853	$3 \cdot 86 \times 10^2$	$2 \cdot 05 \times 10^5$	. . . .
Glass	$2 \cdot 60 \times 10^3$	1400	. . . .	$6 \cdot 70 \times 10^2$	. . . .	. . . .
Ice	$9 \cdot 20 \times 10^2$	273	. . . .	$2 \cdot 10 \times 10^3$	$3 \cdot 34 \times 10^5$	. . . .
Glycerol	$1 \cdot 26 \times 10^3$	291	563	$2 \cdot 43 \times 10^3$	$1 \cdot 81 \times 10^5$	$8 \cdot 30 \times 10^5$
Methanol	$7 \cdot 91 \times 10^2$	175	338	$2 \cdot 52 \times 10^3$	$9 \cdot 9 \times 10^4$	$1 \cdot 12 \times 10^6$
Sea Water	$1 \cdot 02 \times 10^3$	264	377	$3 \cdot 93 \times 10^3$	. . . .	. . . .
Water	$1 \cdot 00 \times 10^3$	273	373	$4 \cdot 19 \times 10^3$	$3 \cdot 34 \times 10^5$	$2 \cdot 26 \times 10^6$
Air	1·29	. . . .	. . . .	. . . .	. . . .	. . . .
Hydrogen	$9 \cdot 0 \times 10^{-2}$	14	20	$1 \cdot 43 \times 10^4$	. . . .	$4 \cdot 50 \times 10^5$
Nitrogen	1·25	63	77	$1 \cdot 04 \times 10^3$	. . . .	$2 \cdot 00 \times 10^5$
Oxygen	1·43	55	90	$9 \cdot 18 \times 10^2$	. . . .	$2 \cdot 40 \times 10^4$

The gas densities refer to a temperature of 273 K and a pressure of $1 \cdot 01 \times 10^5 \, \text{Pa}$.

1. The Large Hadron Collider (LHC) at CERN is a ring around which charged particles are accelerated in order to conduct experiments into the nature of matter. The ring, as shown in Figure 1, has a circumference of 27 km.

Figure 1

When the LHC is operating at full capacity, protons travel around the ring at $2 \cdot 99 \times 10^8 \, \text{m s}^{-1}$.

(*a*) Calculate the relativistic mass of a proton when the LHC is operating at full capacity. **2**

(*b*) Calculate the relativistic energy of this proton. **2**

(4)

[Turn over

2. A flywheel consisting of a solid, uniform disc is free to rotate about a fixed axis as shown in Figure 2A. The disc has a mass of 16 kg and a radius of 0·30 m.
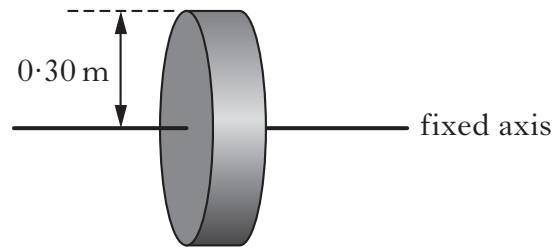
Figure 2A

(*a*) Calculate the moment of inertia of the flywheel. **2**

(*b*) A mass is attached to the flywheel by a light string as shown in Figure 2B.
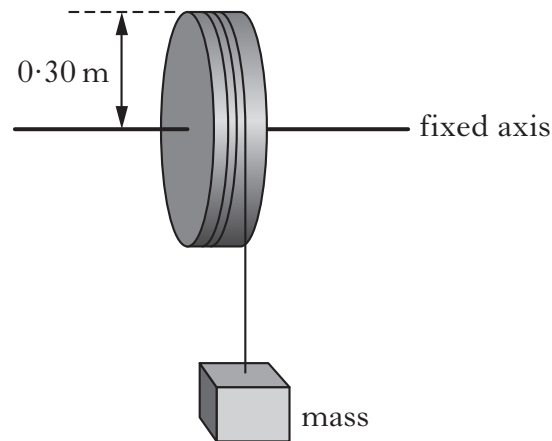
Figure 2B

The mass is allowed to fall and is found to be travelling at $3·0 \, \mathrm{m\,s^{-1}}$ when the string leaves the flywheel. The flywheel makes 5 further revolutions before it comes to rest.

(i) Calculate the angular acceleration of the flywheel after the string leaves the flywheel. **3**

(ii) Calculate the frictional torque acting on the flywheel. **2**

(*c*) The experiment is repeated with a flywheel made from a more dense material with the same physical dimensions. The string, falling mass and all frictional forces are the same as in part (*b*).

As the string detaches from the flywheel, is the speed of the falling mass greater than, the same as or less than $3·0 \, \mathrm{m\,s^{-1}}$?

You must justify your answer. **2**

2. (continued)

(*d*) A Kinetic Energy Recovery System (KERS) is used in racing cars to store energy that is usually lost when braking.

One of these systems uses a flywheel, as shown in Figure 2C, to store the energy.
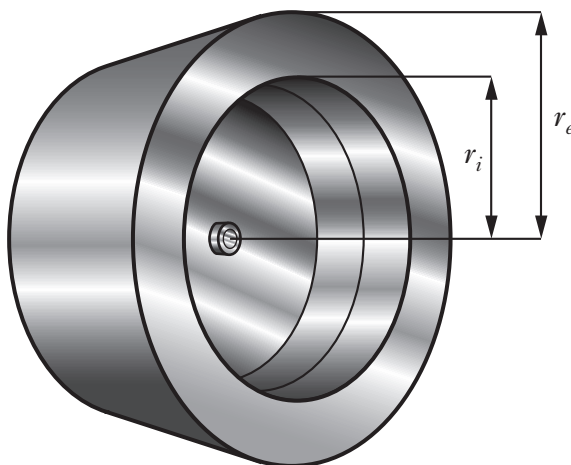
Figure 2C

Data for this KERS flywheel is given below.

Internal radius r_i $= 0.15$ m

External radius r_e $= 0.20$ m

Mass of flywheel M $= 6.0$ kg

Maximum rate of revolution $= 6.0 \times 10^4$ revolutions per minute

(i) Using the expression

$$I = \tfrac{1}{2} M(r_i^2 + r_e^2)$$

determine the moment of inertia of the flywheel.   **1**

(ii) Calculate the maximum rotational kinetic energy that can be stored in the flywheel.   **3**

(13)

[Turn over

3. (*a*) Many planets outside the Solar System have been discovered in recent years. These planets are known as exoplanets.

One exoplanet is Gliese 785C. Data relating to the circular orbit of Gliese 785C around its parent star is shown in Figure 3A.
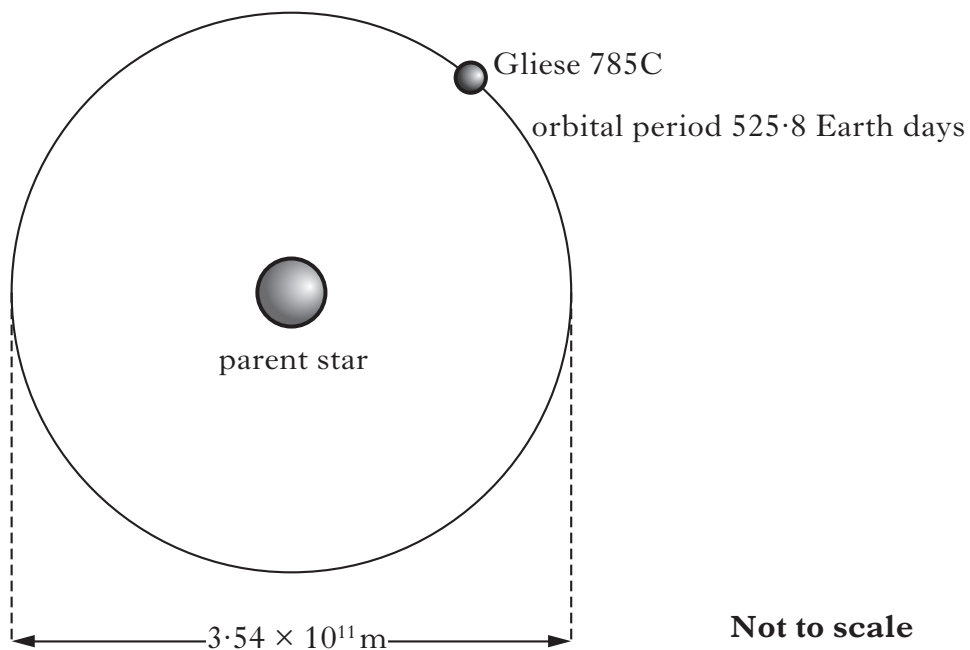
Figure 3A

(i) Show that the mass *M* of the parent star can be written as

$$M = \frac{4\pi^2 r^3}{GT^2}$$

where the other symbols have their usual meanings. **2**

(ii) Determine the mass of the parent star. **2**

3. (continued)

(*b*) Consider the Earth and Moon as an isolated system.

Point X is $3{\cdot}00 \times 10^8$ m from the centre of the Earth as shown in Figure 3B.

Not to scale
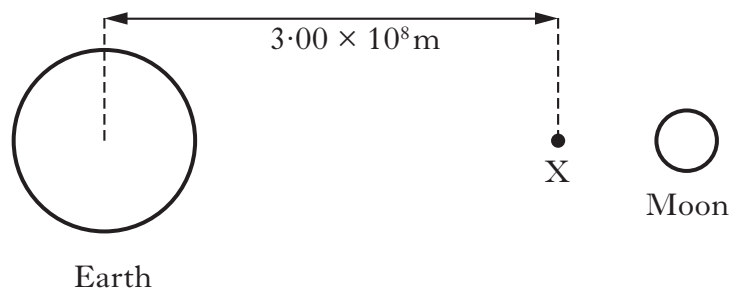
Figure 3B

  (i) Calculate the magnitude of the resultant force acting on a $2{\cdot}0$ kg mass at point X. **3**

 (ii) Calculate the gravitational potential at point X due to the Earth. **2**

(iii) By considering its definition, explain why the gravitational potential at any point has a negative value. **2**

(11)

[Turn over

4. (*a*) (i) State what is meant by *simple harmonic motion*. **1**

(ii) The displacement of an oscillating mass can be described by the expression

$$y = A\sin\omega t$$

where the symbols have their usual meanings.

Show that this mass exhibits simple harmonic motion (SHM). **2**

(iii) The displacement of an object exhibiting SHM can also be written as

$$y = A\cos\omega t$$

Identify the initial condition for which this equation would be used. **1**

(*b*) A mass attached to a spring is displaced from its equilibrium position and allowed to oscillate vertically. A motion sensor, connected to a computer, is placed below the mass as shown in Figure 4A.

motion sensor
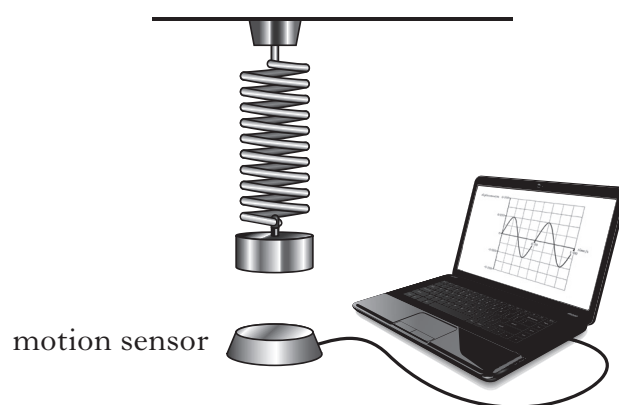
Figure 4A

Figure 4B shows the graph of the displacement from equilibrium position against time for the mass.
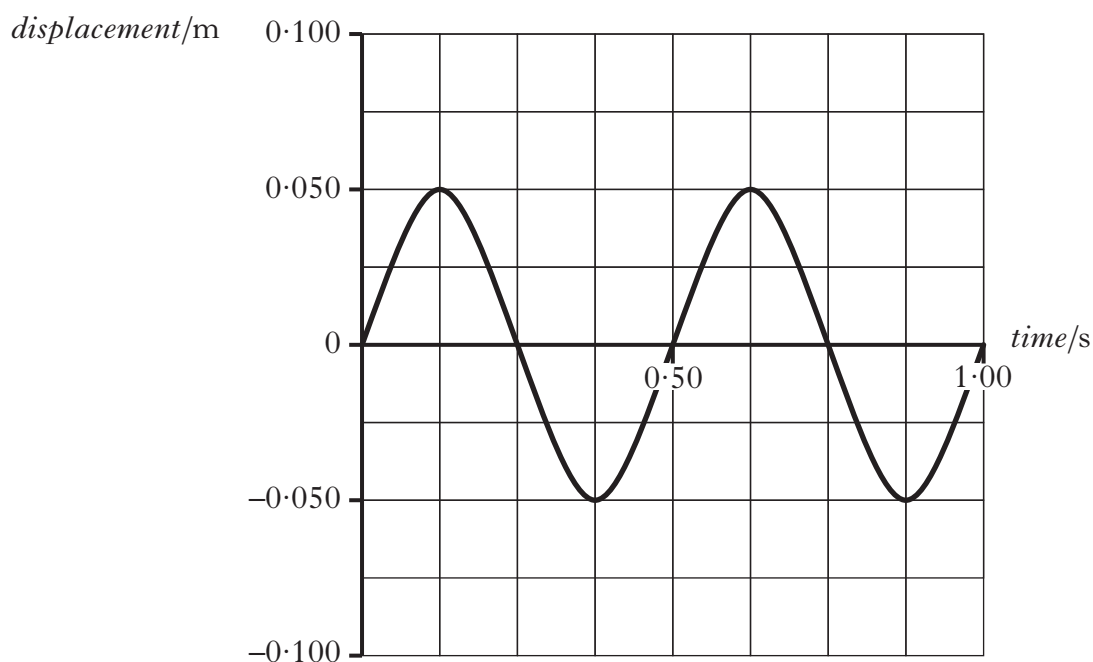
Figure 4B

4. (*b*) (continued)

      (i) Using data from the graph, determine the velocity of the mass at 0·50 s.   **3**

      (ii) Calculate the maximum acceleration of the mass.   **2**

    (*c*) The system is modified by attaching a rigid card of negligible mass as shown in Figure 4C.
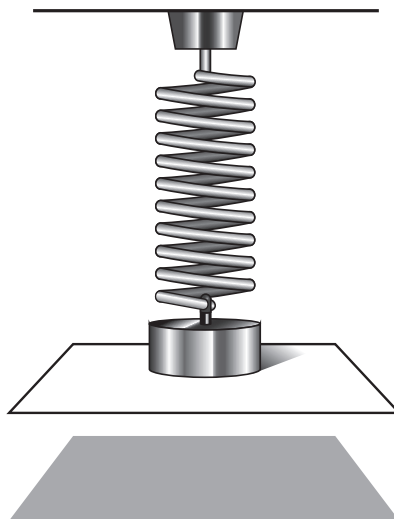

Figure 4C

The mass is displaced from its equilibrium position and allowed to oscillate vertically.

Sketch a displacement time graph of this motion.   **1**

    (10)

[Turn over

5. (*a*) Two small identical conducting spheres P and Q are placed on insulating stands 0·30 m apart as shown in Figure 5.
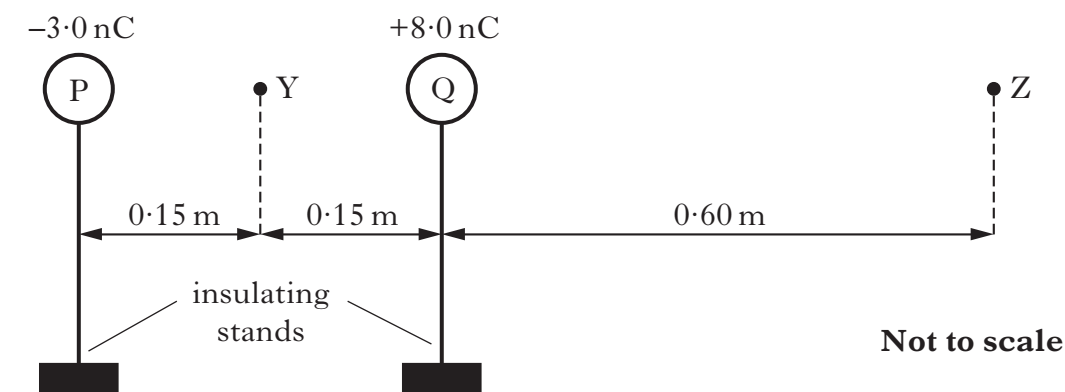
Figure 5

Point Y is equidistant from spheres P and Q. Point Z is 0·60 m to the right of sphere Q.

Sphere P carries a charge of −3·0 nC and sphere Q carries a charge of + 8·0 nC. The spheres can be considered as point charges.

(i) Show that the electrostatic potential at point Y is +300 V.

2

(ii) Sphere Q is now moved towards point Z.

Describe the changes to the potential at point Y as sphere Q is moved to point Z.

2

(*b*) The following equation represents the decay of a radioactive isotope by beta emission.

$$^{210}_{83}\text{Bi} \rightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}\text{e} + \bar{\nu}$$
$$\text{(antineutrino)}$$
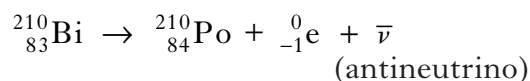
The process involves a neutron from the parent element $^{210}_{83}\text{Bi}$ decaying into a proton, electron and antineutrino. The antineutrino is a neutral particle with negligible mass.

Protons and neutrons are composed of combinations of up and down quarks. Up quarks have a charge of $+\frac{2}{3}\text{e}$ while down quarks have a charge of $-\frac{1}{3}\text{e}$.

How do the number of up quarks and the number of down quarks in the daughter element $^{210}_{84}\text{Po}$ compare with those in the parent element?

2

(6)

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6. (*a*) A teacher investigates the electric field between two parallel metal plates X and Y using the apparatus shown in Figure 6A.

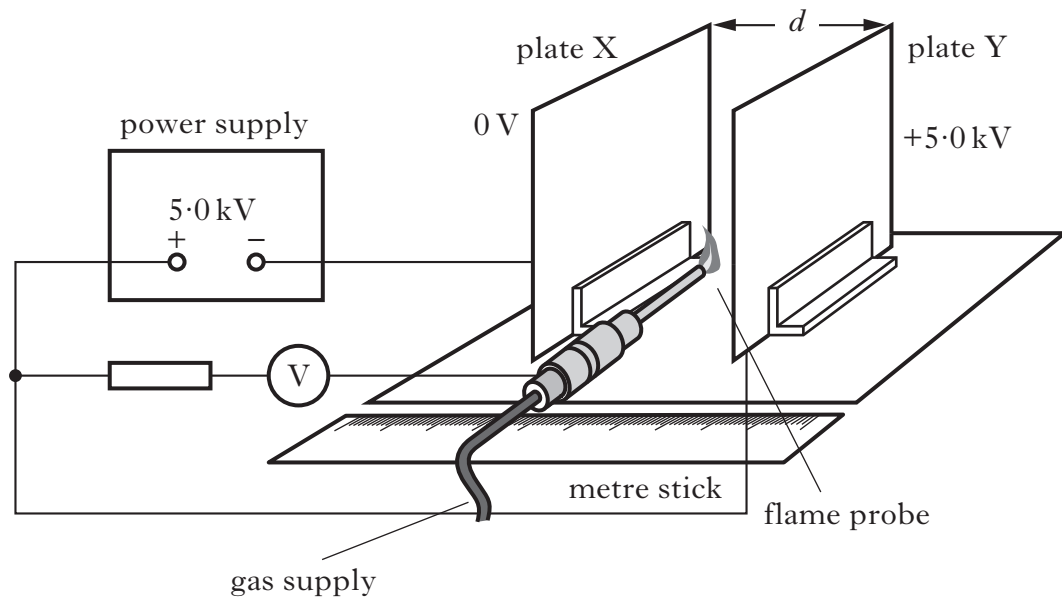

Figure 6A

The plates are connected to a 5·0 kV supply and are separated by a distance *d*.

A calibrated flame probe and voltmeter measure the potential relative to plate X. The probe is placed at different points between the plates. The distance from plate X and the potential at each point are measured.

The results are used to plot the graph shown in Figure 6B.

6. (a) (continued)
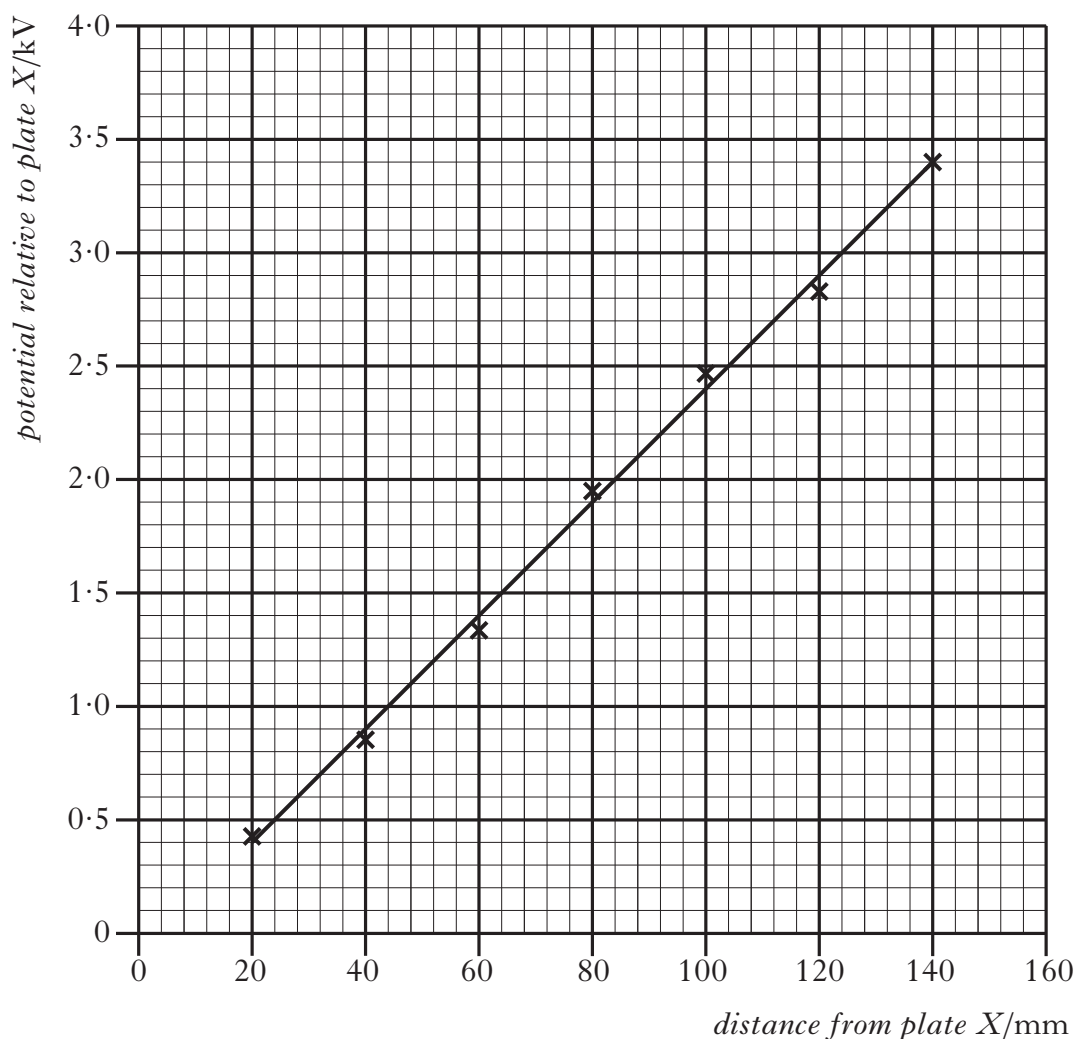
Figure 6B

  (i) The electric field strength in the region between the plates is considered to be uniform. Explain the meaning of the term *uniform electric field*. **1**

 (ii) Using information from the graph, determine the electric field strength between the plates. **2**

(iii) Calculate the separation *d* of the plates. **2**

(iv) In theory the best fit line for this graph should pass through the origin. Suggest why the line on the graph in Figure 6B does not pass through the origin. **1**

[Turn over

6. (continued)

(*b*) In an experiment to investigate the deflection of alpha particles in an electric field a potential difference of 2·0 kV is applied across two parallel metal plates.

An alpha particle moving horizontally at $1·6 \times 10^7 \, \text{m s}^{-1}$ enters the region between the plates. The alpha particle is deflected vertically by a distance s_v as shown in Figure 6C.
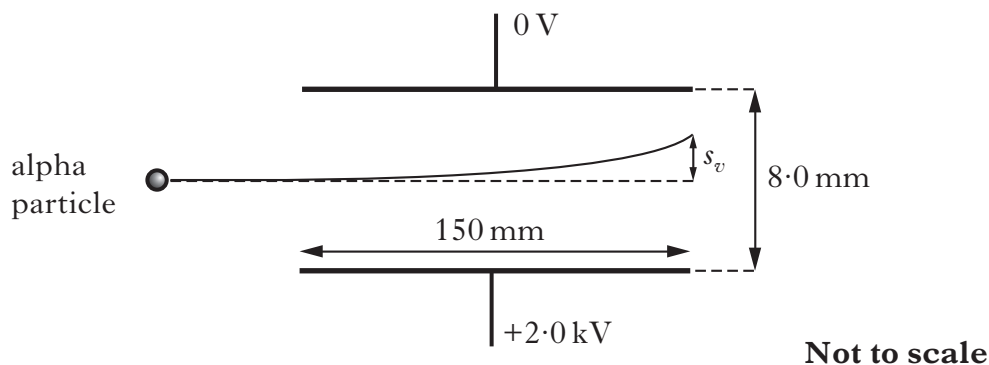

Figure 6C

An extract from the notes on the experiment is shown in Figure 6D.

$$s_h = v_h t \qquad\qquad s_h = 150 \, \text{mm} = 0·15 \, \text{m}$$
$$0·15 = 1·6 \times 10^7 \times t \qquad v_h = 1·6 \times 10^7 \, \text{m s}^{-1}$$
$$t = 9·4 \times 10^{-9} \, \text{s}$$

$$E = \frac{V}{d} = \frac{2000}{8 \times 10^{-3}} = 2·5 \times 10^5 \, \text{V m}^{-1} \quad V = 2 \, \text{kV} = 2 \times 10^3 \, \text{V}$$
$$d = 8 \, \text{mm} = 8 \times 10^{-3} \, \text{m}$$

Figure 6D

(i) Calculate the vertical deflection s_v of the alpha particle. **4**

(ii) The separation of the parallel plates is now increased. An alpha particle enters the electric field at the same point and with the same velocity as before. How does the magnitude of the vertical deflection s_v compare with the value calculated in part (*b*)(i)?

You must justify your answer. **2**

(12)

DO NOT WRITE ON THIS PAGE

7. (*a*) A proton moving at constant speed *v* enters a uniform magnetic field of induction *B* as shown in Figure 7A.
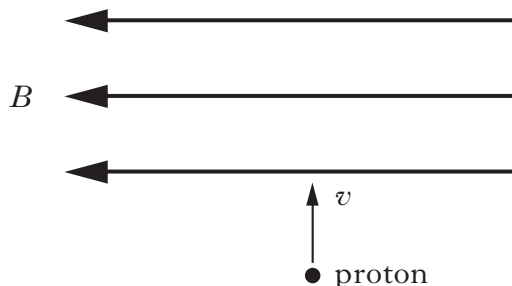

Figure 7A

Within the field the proton follows a circular path of radius *r*.

(i) Explain why the proton follows a circular path. **1**

(ii) Show that the radius of the path *r* is given by

$$r = \frac{1 \cdot 05 \times 10^{-8} v}{B}.$$

2

(*b*) Another proton moving at the same speed *v* enters the magnetic field at an angle *θ* to the magnetic field lines as shown in Figure 7B.
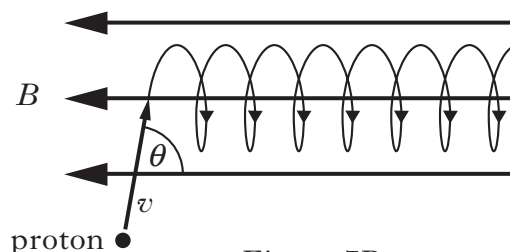
Figure 7B

Explain the shape of the path followed by this proton in the magnetic field. **2**

7. **(continued)**

(*c*) The solar wind is a stream of charged particles, mainly protons and electrons, released from the atmosphere of the Sun. Many of these particles become trapped by the magnetic field of the Earth.

Some of the trapped particles move back and forth in helical paths between two **_magnetic mirror points_**. The path followed by one particular proton is shown in Figure 7C.
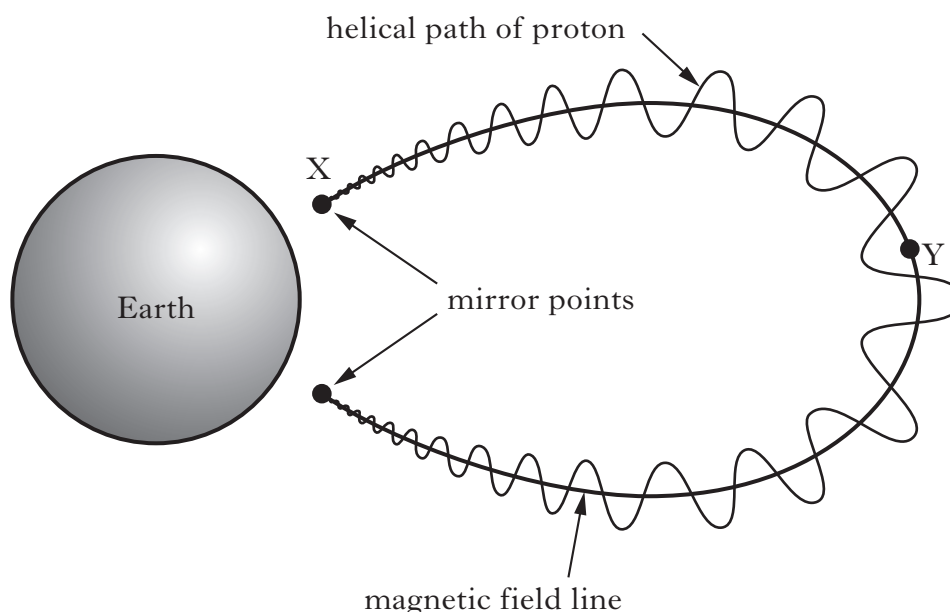
helical path of proton

X

Y

Earth

mirror points

magnetic field line

Figure 7C

The speed of the proton remains constant at $1 \cdot 2 \times 10^{7}\,\mathrm{m\,s^{-1}}$ as it travels along its helical path from one magnetic mirror point to the other.

  (i) The proton oscillates between the two mirror points with a frequency of $4 \cdot 0$ Hz. Calculate the distance that the proton travels in moving from one mirror point to the other.   **3**

 (ii) Explain why the radius of the helical path followed by the proton increases as it moves from point X to point Y as shown in Figure 7C.   **1**

(iii) At point X the radius of curvature of the helix for this proton is $1 \cdot 0 \times 10^{4}\,\mathrm{m}$. Calculate the strength of the Earth's magnetic field at this point.   **2**

(11)

[Turn over

8. (*a*) A student investigates how the current in an inductor varies with the frequency of a voltage supply.

   (i) Draw a suitable labelled circuit diagram of the apparatus required to carry out the investigation.

   (ii) The student collects the following data.

Frequency/Hz	40	60	80	100	120
Current/mA	148	101	76·0	58·2	50·0

Determine the relationship between the supply frequency and current for this inductor.

(*b*) An inductor of inductance 3·0 H and negligible resistance is connected in a circuit with a 12 Ω resistor and supply voltage V_s as shown in Figure 8A.
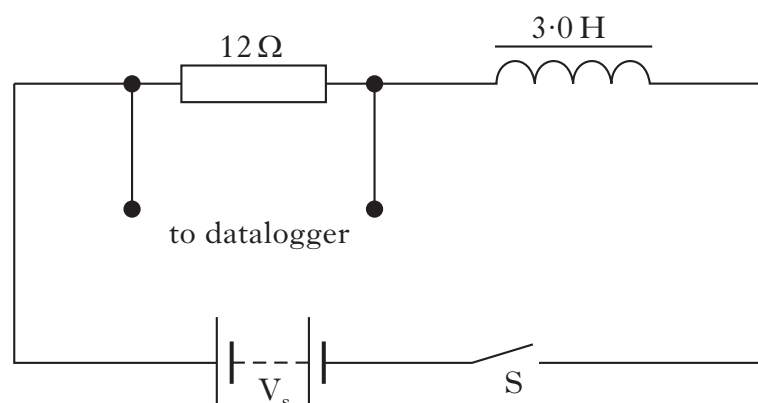
Figure 8A

The datalogger is set to calculate the back emf across the inductor.

Switch S is initially open.

Switch S is now closed. Figure 8B shows how the back emf across the inductor varies from the instant the switch is closed.

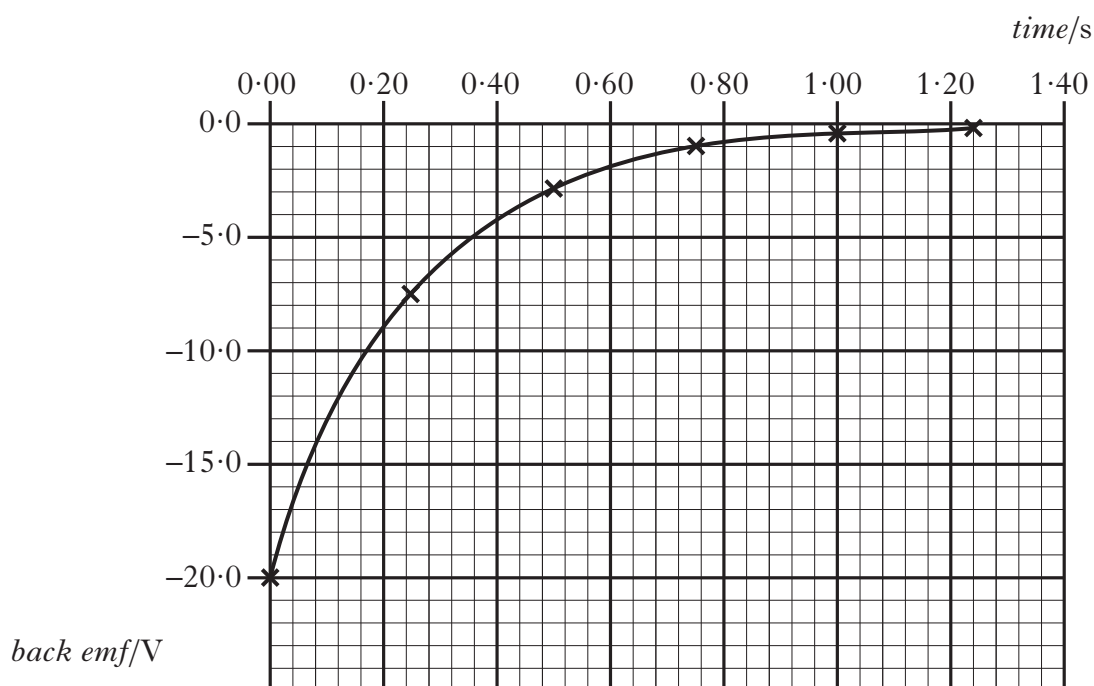**8.** **(b)** **(continued)**

Figure 8B

    (i) Determine the voltage across the resistor at $t = 0.20$ s.   **2**

    (ii) Calculate the rate of change of current in the circuit at $t = 0.40$ s.   **2**

    (iii) State why the magnitude of the back emf is greatest at $t = 0$.   **1**

  (*c*) The switch is opened and the 3.0 H inductor is replaced by an inductor of greater inductance.
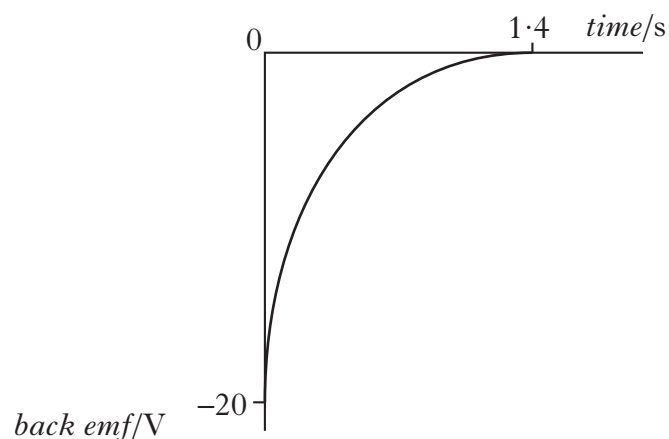
    The sketch in Figure 8C represents the graph shown in Figure 8B.

Figure 8C

    Copy this sketch and add a line to show how the back emf across the new inductor varies with time from the instant the switch is closed.   **2**

                                                                          (11)

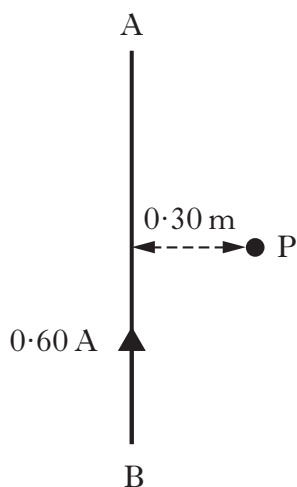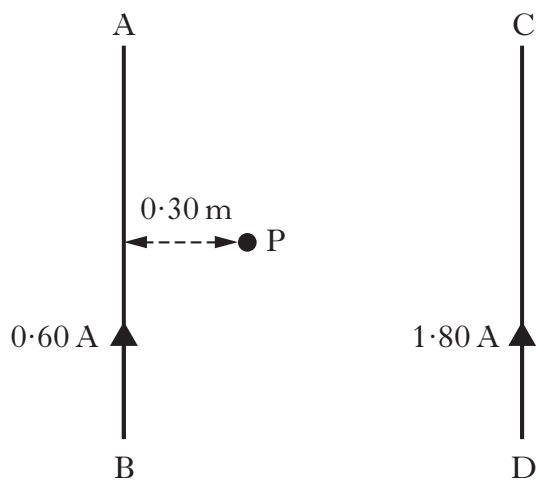**9.** (*a*) A long straight conductor AB carries a current of 0·60 A from B to A as shown in Figure 9A.

Figure 9A

Calculate the magnitude of the magnetic induction at point P, a distance of 0·30 m from the conductor.

2

(*b*) A second conductor CD, carrying a current of 1·80 A, is placed parallel to AB as shown in Figure 9B.

Figure 9B

At this separation the magnetic induction at point P is zero.

(i) Explain why the magnetic induction at point P is zero.

1

(ii) Calculate the distance of conductor CD from conductor AB.

2

(5)

10. A police officer is conducting vehicle speed checks using a radar based monitoring device as shown in Figure 10. A car emitting sound of frequency 500 Hz drives past the officer at constant velocity.

Figure 10

(*a*) (i) Describe how the frequency of the sound heard changes as the car passes the officer. **1**

    (ii) At one instant the frequency heard by the officer is 480 Hz.

        Calculate the speed of the car at this instant. **2**

    (iii) Describe the difference in the frequency heard by the officer if the car had been:

        (A) decelerating on its approach to the officer; **1**

        (B) accelerating away from the officer. **1**

(*b*) The radar based speed monitoring equipment uses microwaves to determine the speed v of a vehicle. The microwaves are transmitted towards the vehicle, and the reflected waves are detected by the equipment.

The expression for the frequency change Δf between the transmitted and received frequencies is given as

$$\Delta f \;=\; \frac{2vf_T}{(c-v)}.$$

The transmitted frequency, f_T, of the microwaves is 10·5 GHz.

  (i) Explain why this expression can be approximated by

$$\Delta f \;=\; \frac{2vf_T}{c}.$$ **1**

  (ii) The frequency change is 880 Hz for an approaching vehicle.

     Calculate the speed of the vehicle. **2**

(8)

11. A student carries out a Young's double slit experiment in order to determine the wavelength of monochromatic red light.

The student uses the apparatus shown in Figure 11 to produce an interference pattern on the screen.
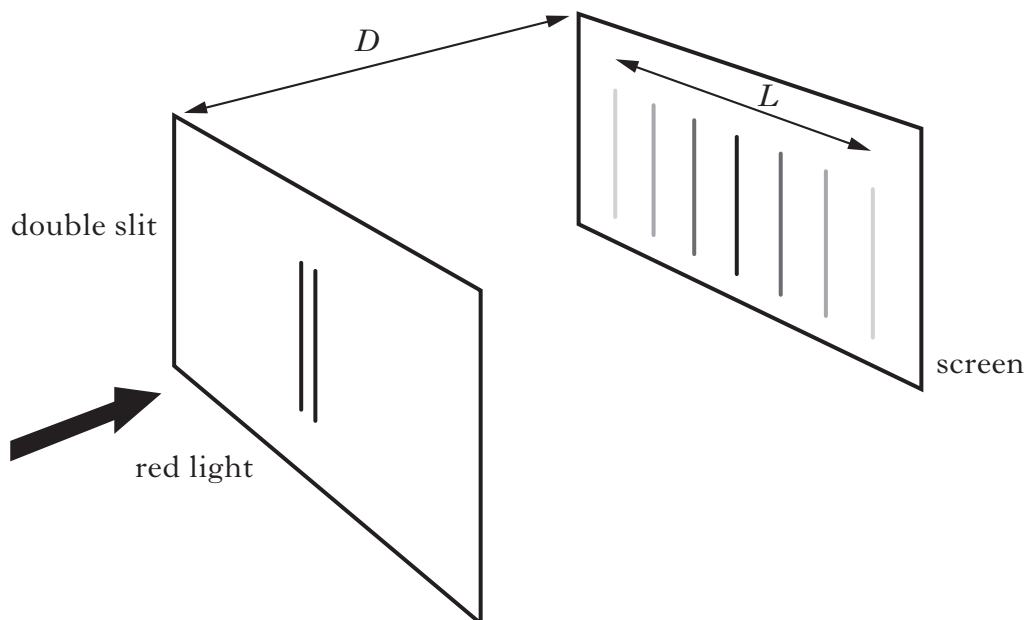

Figure 11

The double slit separation d is measured using a travelling microscope. The distance D between the double slit and the screen is measured using a steel measuring tape. The length L of the interference pattern is measured using a plastic ruler.

The student records the following data.

$D = (4 \cdot 250 \pm 0 \cdot 005)\,\text{m}$
$L = (67 \pm 2)\,\text{mm}$
$d = (0 \cdot 25 \pm 0 \cdot 01)\,\text{mm}$

(*a*) (i) State why it is possible to produce an interference pattern using only a single light source. **1**

   (ii) Calculate the wavelength of the light from the source. **3**

   (iii) Calculate the absolute uncertainty in the wavelength. **3**

(*b*) The student repeats the experiment with the same apparatus but uses a monochromatic blue light source. *D* remains fixed.

State the effect this will have on the percentage uncertainty in the calculated value for the wavelength of the blue light.

You must justify your answer. **2**

(9)

[*END OF QUESTION PAPER*]