



UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS  
 Cambridge International Level 3 Pre-U Certificate  
 Principal Subject

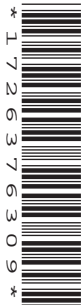
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**PHYSICS**

**9792/03**

Paper 3 Part B Written Paper

**May/June 2010**

**3 hours**

Candidates answer on the Question Paper.

No Additional Materials are required.

**READ THESE INSTRUCTIONS FIRST**

Write your Centre number, candidate number and name on all the work you hand in.  
 Write in dark blue or black pen.  
 You may use a soft pencil for any diagrams, graphs or rough working.  
 Do not use staples, paper clips, highlighters, glue or correction fluid.

**Section A**

Answer **all** questions.  
 You are advised to spend about 1 hour 30 minutes on this section.

**Section B**

Answer any **three** questions. All six questions carry equal marks.  
 You are advised to spend about 1 hour 30 minutes on this section.

You may lose marks if you do not show your working or if you do not use appropriate units.

At the end of the examination, fasten all your work securely together.  
 The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
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7	
8	
9	
10	
11	
12	
<b>Total</b>	

This document consists of **39** printed pages and **1** blank page.



**Data**

gravitational field strength close to Earth's surface	$g = 9.81 \text{ N kg}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
speed of light in vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
electron mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$
proton mass	$m_p = 1.67 \times 10^{-27} \text{ kg}$
unified atomic mass constant	$u = 1.66 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

## Formulae

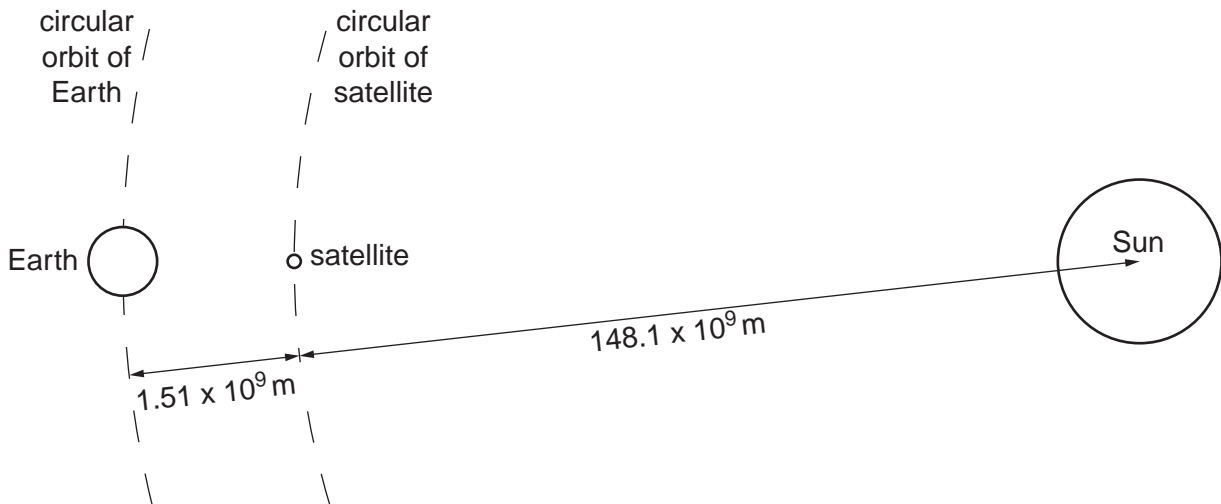
uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$	magnetic force	$F = BIl \sin\theta$
	$v^2 = u^2 + 2as$		$F = BQv \sin\theta$
	$s = \left(\frac{u+v}{2}\right)t$	electromagnetic induction	$E = \frac{-d(N\Phi)}{dt}$
heating	$\Delta E = mc\Delta\theta$	Hall effect	$V = Bvd$
change of state	$\Delta E = mL$	time dilation	$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$
refraction	$n = \frac{\sin\theta_1}{\sin\theta_2}$	kinetic theory	$\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$
	$n = \frac{v_1}{v_2}$	work done on/by a gas	$W = p\Delta V$
photon energy	$E = hf$	radioactive decay	$\frac{dN}{dt} = -\lambda N$
de Broglie wavelength	$\lambda = \frac{h}{p}$		$N = N_0 e^{-\lambda t}$
simple harmonic motion	$x = A \cos \omega t$		$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
	$v = -A\omega \sin \omega t$	attenuation losses	$I = I_0 e^{-\mu x}$
	$a = -A\omega^2 \cos \omega t$	mass-energy equivalence	$\Delta E = c^2 \Delta m$
	$F = -m\omega^2 x$	hydrogen energy levels	$E_n = \frac{-13.6 \text{ eV}}{n^2}$
	$E = \frac{1}{2}mA^2\omega^2$	Heisenberg uncertainty principle	$\Delta p \Delta x \geq \frac{h}{2\pi}$
energy stored in a capacitor	$W = \frac{1}{2}QV$		$\Delta E \Delta t \geq \frac{h}{2\pi}$
electric force	$F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2}$	Wien's law	$\lambda_{\max} \propto \frac{1}{T}$
electrostatic potential energy	$W = \frac{Q_1 Q_2}{4\pi\epsilon_0 r}$	Stefan's law	$L = 4\pi\sigma r^2 T^4$
gravitational force	$F = \frac{-Gm_1 m_2}{r^2}$	electromagnetic radiation from a moving source	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$
gravitational potential energy	$E = \frac{-Gm_1 m_2}{r}$		

## Section A

Answer **all** questions in this section.

You are advised to spend about 1 hour 30 minutes on this section.

- 1 A satellite of mass 200 kg is placed between the Earth and the Sun. The satellite is at a distance of  $1.51 \times 10^9$  m from the centre of the Earth and a distance of  $148.1 \times 10^9$  m from the centre of the Sun, as shown in Fig 1.1.



**Fig. 1.1** (not to scale)

The speed of the satellite is adjusted so that it orbits the Sun with a period of 1 year ( $3.1526 \times 10^7$  s). The rocket motor is then switched off. The satellite then travels round the Sun in a circle, keeping constant the distances between the satellite, the Earth and the Sun.

(a) Calculate

- (i) the speed of the satellite,

speed = .....  $\text{ms}^{-1}$  [1]

- (ii) the centripetal acceleration of the satellite.

centripetal acceleration = .....  $\text{ms}^{-2}$  [2]

(b) The mass of the Sun is  $1.99 \times 10^{30}$  kg and the mass of the Earth is  $5.98 \times 10^{24}$  kg.

(i) Calculate the gravitational force exerted on the satellite by

1. the Earth,

force = ..... N [2]

2. the Sun.

force = ..... N [1]

(ii) Calculate the resultant force on the satellite.

resultant force = ..... N [1]

(c) Show that the centripetal acceleration of the satellite is caused by this resultant force.

[2]

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(d) For such a satellite, suggest why

(i) the satellite has an advantage over a geostationary satellite for observing the Sun,

.....  
.....  
.....[2]

(ii) the satellite requires frequent small corrections of position and/or speed,

.....  
.....  
.....[2]

(iii) the satellite is considerably more expensive to put into orbit than a geostationary satellite circling the Earth.

.....  
.....  
.....[2]

- 2 (a) State the conditions necessary for an object to have *simple harmonic motion*.

.....

.....

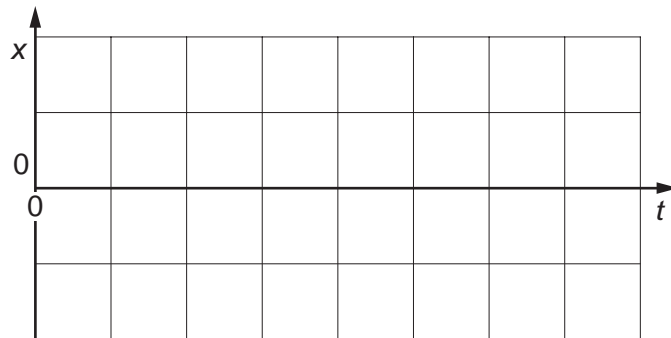
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..... [2]

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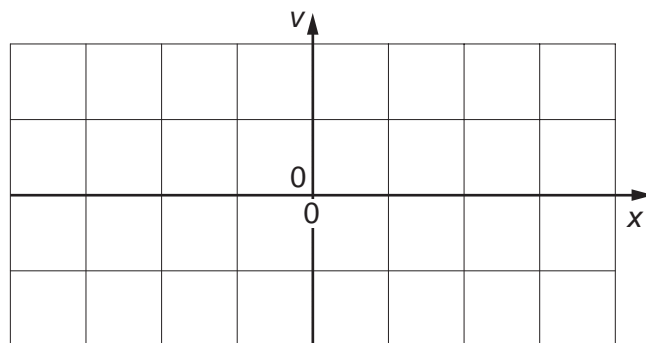
- (b) Draw sketch graphs to show how, for a single time period of simple harmonic motion,

- (i) the displacement  $x$  varies with time  $t$ ,



[2]

- (ii) the velocity  $v$  varies with displacement  $x$ .



[3]

- (c) A mass  $m = 2.3\text{kg}$  is oscillating vertically with simple harmonic motion on a spring. The spring has a spring constant  $k$  of  $63\text{Nm}^{-1}$ . The amplitude  $A$  of the oscillation is  $0.28\text{m}$  and the period  $T$  of the oscillation is given by the equation

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$$T = 2\pi\sqrt{\frac{m}{k}}.$$

- (i) Calculate the angular frequency  $\omega$  of the oscillation.

$$\omega = \dots\dots\dots \text{rads}^{-1} \text{ [2]}$$

- (ii) Use the expression  $E = \frac{1}{2}mA^2\omega^2$  to find the maximum kinetic energy  $E$  of the oscillating mass.

$$E = \dots\dots\dots \text{J [2]}$$

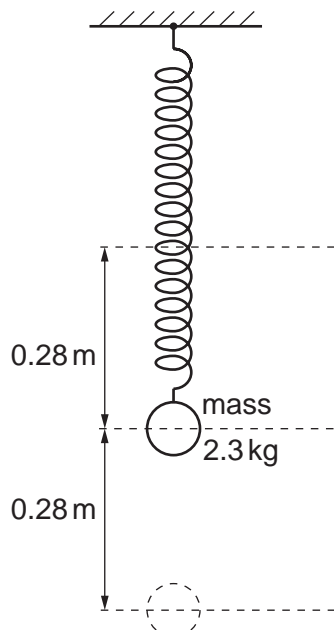
- (iii) Deduce the maximum speed of the oscillating mass.

$$\text{maximum speed} = \dots\dots\dots \text{ms}^{-1} \text{ [1]}$$



- (d) The potential energy of the oscillating system in (c) is partly gravitational potential energy and partly elastic potential energy. Complete the following table to show the values of the various different forms of energy at the top, the middle and the bottom of the oscillation of the mass.

For  
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Use

		kinetic energy/J	gravitational potential energy/J	elastic potential energy/J	total energy/J
top				-3.85	
middle			reference zero	reference zero	
bottom					

[5]

3 (a) Define *electric field strength* at a point in an electric field.

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

(b) The magnitude of the potential gradient in an electric field is always equal to that of the electric field strength. Show that this is true for a uniform electric field  $E$  between two parallel plates a distance  $d$  apart when the potential difference between the plates is  $V$ .

.....  
.....  
.....  
..... [2]

(c) Fig. 3.1 shows a full-scale cross-section of the electric field in the region of a charged circular metal rod and a U-shaped metal frame. The potential difference between the rod and the frame is 600V with the metal frame earthed at 0V. The dotted lines on the diagram are equipotential lines at labelled potentials.

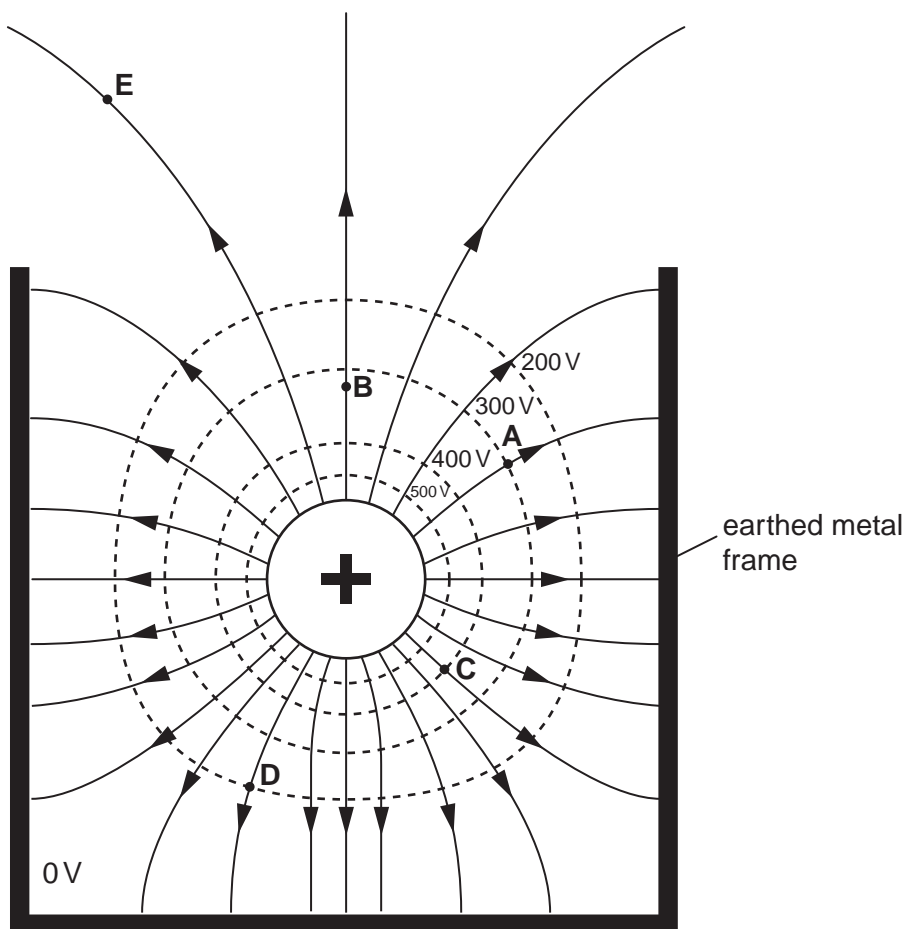


Fig. 3.1 (actual scale)

By taking measurements from the diagram, determine approximate values of

For  
Examiner's  
Use

- (i) the magnitude of the electric field strength at point A, giving the unit of electric field strength,

electric field strength = ..... [2]

- (ii) the electric potential at point B,

electric potential = ..... V [1]

- (iii) the work done in moving a charge of  $3.0\ \mu\text{C}$  from point D to point C.

work = ..... J [2]

- (d) Draw on Fig. 3.1

- (i) an arrow showing the direction of the force on an electron at point E, [1]

- (ii) an equipotential line at 50V. [2]

4 (a) State three assumptions made in deriving the equation  $pV = \frac{1}{3}Nm\langle c^2 \rangle$  from the kinetic theory model of a gas.

1. ....

.....

2. ....

.....

3. ....

.....

[3]

(b) Give the meaning of each symbol in the equation given in (a).

$p$  .....  $V$  .....

$N$  .....  $m$  .....

$\langle c^2 \rangle$  .....

[3]

(c) Determine the internal energy of 0.36 mol of an ideal gas at a temperature of 350 °C.

internal energy = ..... J [4]

- 5 A spacecraft to be sent to explore the outer planets could be provided with a radioactive source of polonium-210 as a source of energy. Alpha particles of average energy 5.2 MeV are emitted and cause the temperature of the polonium to rise.

(a) The proton number of polonium is 84. Write a nuclear equation for the decay of a polonium (Po) nucleus into a lead (Pb) nucleus.

[2]

(b) Convert an energy of 5.2 MeV into joules.

energy = ..... J [2]

(c) Calculate the decay rate required for a power of 2500 W.

rate = .....  $\text{s}^{-1}$  [2]

(d) The half-life of polonium-210 is 138 days. Calculate

(i) its decay constant  $\lambda$ ,

$\lambda = \dots\dots\dots \text{ s}^{-1}$  [2]

(ii) the mass of polonium required to provide 2500W.

mass =  $\dots\dots\dots$  kg [3]

(e) Suggest and explain why it is an advantage, for this application, that this source produces alpha particles rather than beta particles or gamma rays.

.....  
.....  
.....  
.....  
.....  
.....  
..... [2]

- (f) Polonium-209 is a different isotope, which could be used instead of polonium-210. It emits alpha particles of approximately the same energy but its half-life is 200 years. Compare the advantage and disadvantage of the two isotopes in relation to the mass required, the half-life, and safety.

For  
Examiner's  
Use

mass .....

.....

.....

half-life .....

.....

.....

safety .....

.....

.....

[4]

- 6 (a) The line spectrum of light from a distant galaxy has a known line in the hydrogen spectrum of wavelength 623.7 nm. The wavelength of the same line, when measured in the laboratory, has wavelength 486.1 nm. Calculate the speed of recession of the galaxy using the equation

$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$$

speed of recession  $\approx$  .....  $\text{ms}^{-1}$  [2]

- (b) State Hubble's law.

.....  
 .....  
 ..... [2]

- (c) Explain how redshift leads to the ideas of the expanding Universe and to the Big Bang theory.

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 .....  
 ..... [4]



- (d) The Hubble constant has a value estimated to be  $2.3 \times 10^{-18} \text{ s}^{-1}$ . Estimate the age of the Universe.

*For  
Examiner's  
Use*

time = ..... s [2]

## Section B

Answer any **three** questions in this section.  
You are advised to spend about 1 hour 30 minutes on this section.

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- 7 Diamonds sparkle because light entering the diamond undergoes numerous internal reflections before emerging.

Fig. 7.1 shows the path of a ray of light through a diamond.

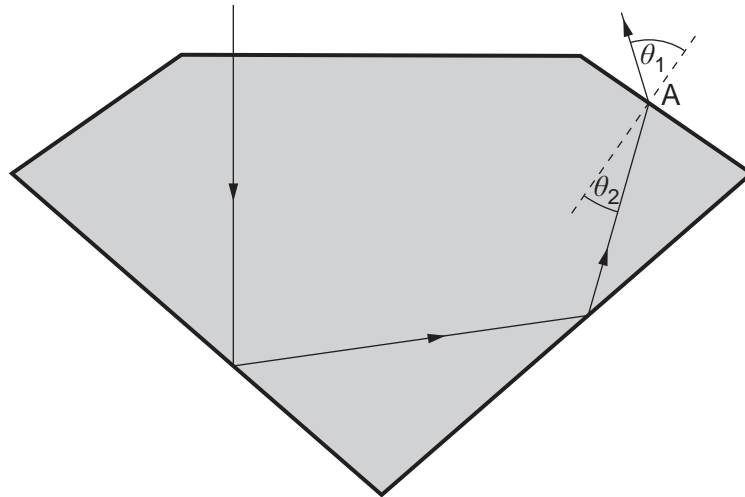


Fig. 7.1 (not to scale)

- (a) The critical angle of light in diamond is  $24^\circ$ . Calculate the refractive index  $n$  of diamond to 2 decimal places.

$$n = \dots\dots\dots [2]$$

- (b) The ray finally emerges at the point labelled A. The angle of incidence  $\theta_2$  within the diamond is  $19.0^\circ$ .

- (i) Calculate the angle of refraction  $\theta_1$  in air.

$$\theta_1 = \dots\dots\dots [1]$$

- (ii) Place ticks in the table below to identify the effect on waves of light as they refract from diamond into air at A.

wave property of the light	effect		
	increase	unchanged	decrease
speed			
wavelength			
frequency			

[3]

- (c) A very thin phosphor-bronze disc is used to saw through rough uncut diamonds. The disc rotates about a horizontal axis at 4000 revolutions each minute.

- (i) Calculate the angular speed  $\omega$  of the disc.

$$\omega = \dots\dots\dots \text{ rad s}^{-1} \quad [2]$$

- (ii) The rim of the disc is initially impregnated with diamond dust, which is replenished as the diamond is cut. Without this dust, the disc would fail to cut through the diamond. What does this tell us about the relative hardness of diamond and phosphor-bronze?

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

- (d) Laws of rotational motion can be deduced by comparison with Newton's laws of linear motion. Complete the table below by stating the equivalent formulae, in words, for rotational motion.

linear motion	rotational motion
work = force $\times$ displacement	
momentum = mass $\times$ velocity	

[2]

- (e) Fig. 7.2a and Fig. 7.2b show a phosphor-bronze cutting disc of mass  $M$  and thickness  $t$  with radius  $R$ . The uniform density of the disc is  $\rho$ .

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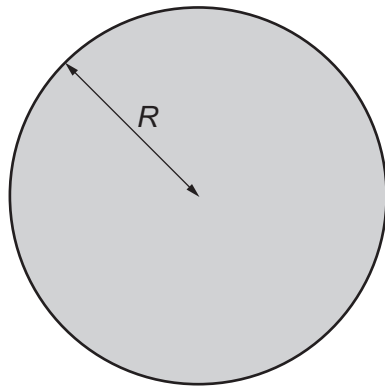


Fig. 7.2a (front view)

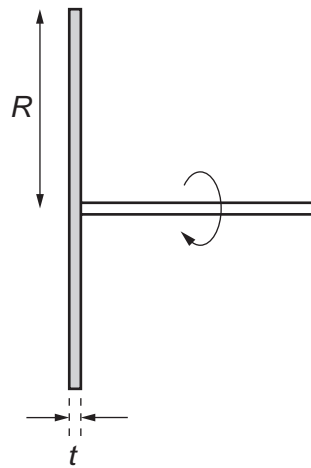


Fig. 7.2b (side view)

- (i) Use integration to derive an expression for the moment of inertia  $I$  of the disc. You may draw on Fig. 7.2a to help illustrate your working.

[4]

- (ii) The disc has mass  $35.4\text{ g}$  and a moment of inertia of  $1.13 \times 10^{-4}\text{ kg m}^2$ . Calculate the radius  $R$  of the disc.

$R = \dots\dots\dots\text{ m}$  [2]

- (iii) Determine the rotational kinetic energy  $E$  of the disc.

*For  
Examiner's  
Use*

$E = \dots\dots\dots$  J [3]

- 8 A nucleus of  ${}^{207}_{81}\text{Tl}$ , an isotope of thallium, decays to a nucleus of lead by beta-minus emission.

(a) Complete the nuclear equation for this decay.



(b) The activity  $-\frac{dN}{dt}$  of a radioactive source is proportional to the number  $N$  of nuclei present. Hence,

$$\frac{dN}{dt} = -\lambda N$$

where  $\lambda$  is the decay constant.

Show by integration that  $N = N_0 e^{-\lambda t}$  is a solution to this equation when  $N = N_0$  at time  $t = 0$ s.

[3]

(c) Fig. 8.1 shows the activity of  ${}^{207}_{81}\text{Tl}$  over a period of about 120 days.

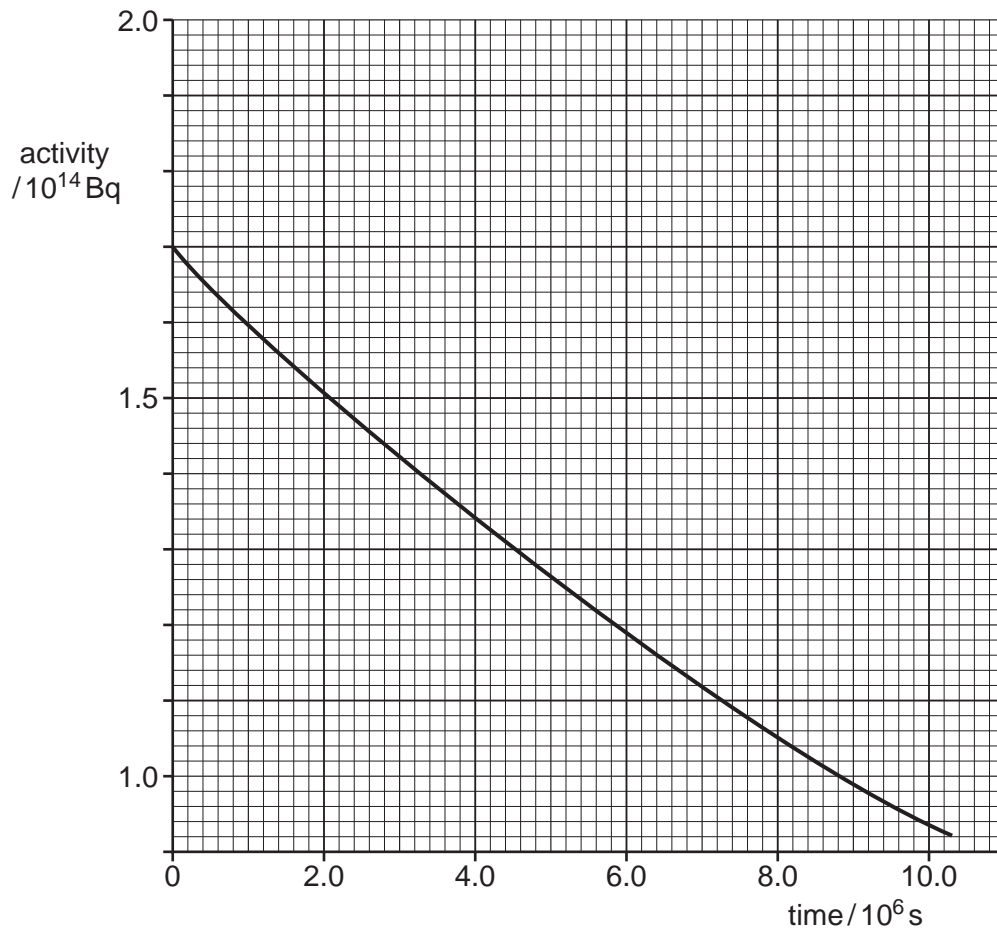


Fig. 8.1

- (i) Show that the graph is an exponential decay curve.

For  
Examiner's  
Use

[3]

- (ii) The decay constant of  ${}_{81}^{207}\text{Tl}$  is  $5.94 \times 10^{-8} \text{ s}^{-1}$ . Determine the activity of  ${}_{81}^{207}\text{Tl}$  after 270 days.

activity = ..... Bq [3]

- (d) Fig. 8.2 shows two horizontal parallel metal plates. A voltage is applied across them to produce a uniform electric field between them.

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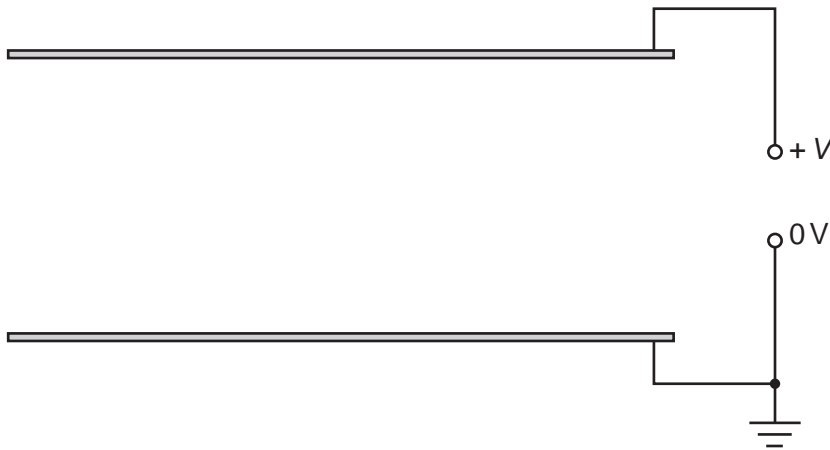


Fig. 8.2

- (i) Explain what is meant by a *uniform electric field*.

.....  
..... [2]

- (ii) On Fig. 8.2, draw lines to represent the uniform field between the plates. [2]

- (e) A very small droplet of oil is introduced between plates that are 20 mm apart. The droplet is given a charge  $Q$  using a beta radioactive source. It is held stationary when the voltage is adjusted to 746 volts. Fig. 8.3 shows the main forces acting on the droplet.

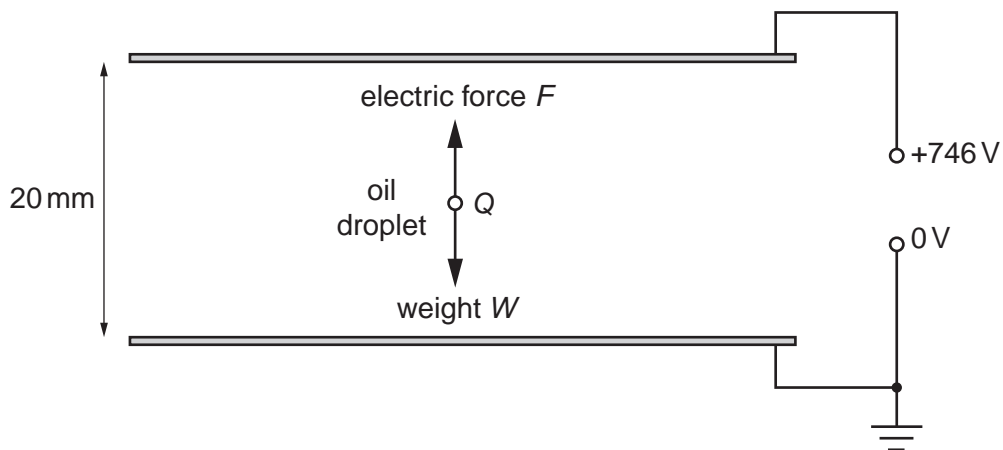


Fig. 8.3

The density of the oil is  $920 \text{ kg m}^{-3}$ . The average radius of the droplet is  $7.8 \times 10^{-7} \text{ m}$ .



- (i) The volume of a sphere  $V$  is given by  $V = \frac{4\pi r^3}{3}$ . Use this expression to calculate the weight  $W$  of the droplet.

For  
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$W = \dots\dots\dots$  N [2]

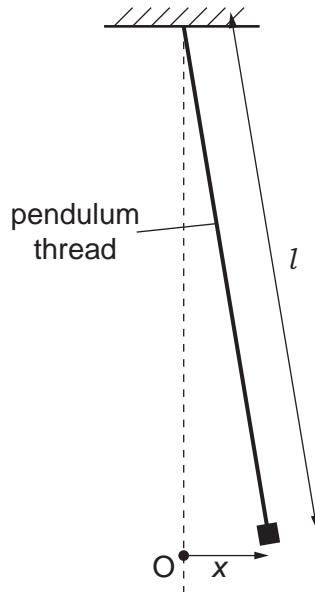
- (ii) Hence, show that  $Q$  is approximately  $5.0 \times 10^{-19}$  C.

[3]

- (iii) Using your knowledge of the electron, state what can be deduced from the value of  $Q$ .

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

- 9 Fig. 9.1 shows a simple pendulum, which consists of a small mass suspended by a thread. The equilibrium position of the small mass is O. When the mass is given a displacement  $x$  and released, the pendulum oscillates with simple harmonic motion (s.h.m.).



**Fig. 9.1** (not to scale)

- (a) The period  $T$  of the pendulum is related to its length  $l$  by the equation

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where  $g$  is the acceleration of free fall.

- (i) State an assumption made for this equation to be valid.

..... [1]

- (ii) Show that a pendulum of length 54 cm has a period of approximately 1.5 s.

[1]

- (b) Write an expression for the instantaneous acceleration  $\frac{d^2x}{dt^2}$  of the pendulum from O in terms of  $x$ ,  $l$  and  $g$ .

[2]

(c) Fig. 9.2 is a graph of  $\ln T$  against  $\ln l$  for different lengths of the pendulum.

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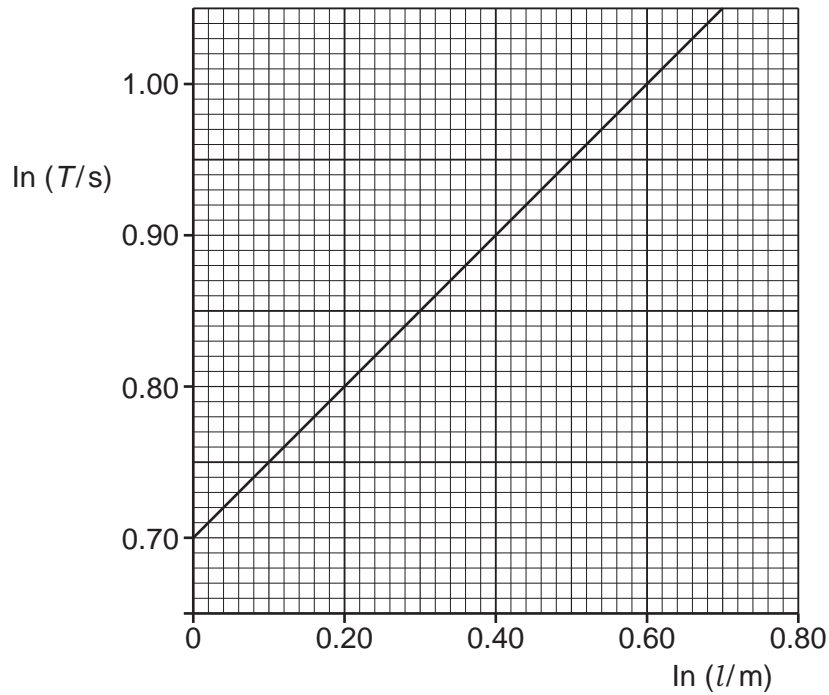


Fig. 9.2

Use the equation for the period of a pendulum and data from the graph in Fig. 9.2 to determine a value for  $g$ .

$g = \dots\dots\dots \text{ms}^{-2}$  [3]

(d) (i) Show that  $x = A \cos(\omega t)$  is a solution to the equation  $\frac{d^2x}{dt^2} = -\omega^2 x$  where  $A$  is the amplitude of oscillation and  $\omega$  is the angular frequency.

[3]

[Turn over

- (ii) At time  $t = 0$  the pendulum in (a)(ii) is released from an initial displacement of 3.0 cm.  
Calculate its displacement after 0.5 s.

For  
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Use

displacement = ..... cm [2]

- (e) Show that the total energy  $E$  of an undamped oscillating pendulum of mass  $m$  is given by  $E = \frac{1}{2}mAv^2$ .

[2]

- (f) The pendulum mass is a small magnet. It swings inside a horizontal coil, which is connected to a sensitive voltmeter, data-logger and computer, as shown in Fig. 9.3.

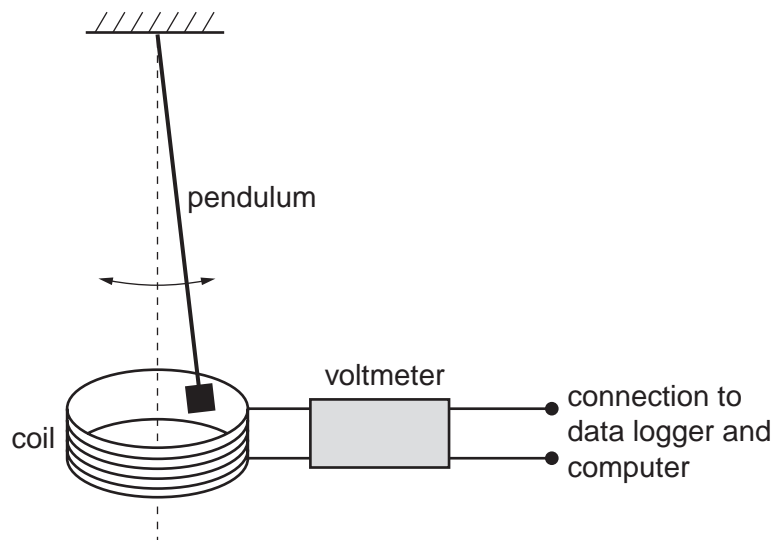


Fig. 9.3 (not to scale)

The maximum induced e.m.f. recorded by the data-logger is 25mV. The coil has 200 turns.

For  
Examiner's  
Use

- (i) Calculate the maximum rate of change of flux through the coil. Include units with your answer.

rate of change of flux = ..... [3]

- (ii) When the terminals of the coil are connected together, the oscillations of the pendulum are damped. The coil gains internal energy as the total mechanical energy of the pendulum gradually decreases with time. Explain how the energy transfer takes place.

.....

.....

.....

.....

.....

.....

.....[3]

10 A beam of electrons is directed along a normal towards a barrier, as shown in Fig. 10.1.

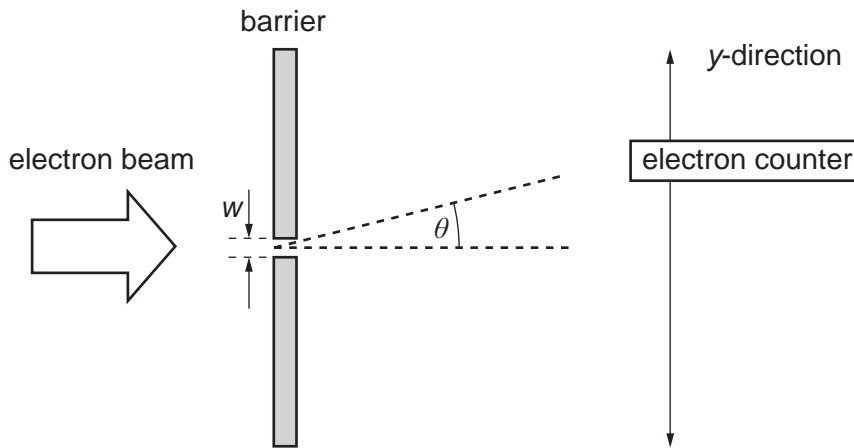


Fig. 10.1

The barrier contains a single slit of width  $w$ . Beyond the slit there is a detector that counts electrons. This can be moved in the  $y$ -direction to compare the rate of arrival of electrons at different values of the angle  $\theta$  from the original direction of the beam.

(a) (i) Louis de Broglie suggested that some aspects of the behaviour of electrons can be explained using a wave model. Describe the main features of de Broglie's model of the electron.

.....  
 .....  
 .....  
 ..... [3]

(ii) Use the wave model to explain how the electron beam spreads out beyond the slit.

.....  
 .....  
 .....  
 ..... [2]

(b) State and explain one aspect of this experiment that cannot be explained using the wave model.

.....  
 .....  
 ..... [2]

- (c) Werner Heisenberg used a different approach involving what is now known as the uncertainty principle. This can also be used to explain why the electron beam spreads out after passing through the slit. One version of this involves the equation

$$\Delta p \Delta y \geq \frac{h}{2\pi}$$

Explain how the terms below apply to electrons **as they pass through** the slit.

- (i)  $\Delta y$

.....  
 ..... [2]

- (ii)  $\Delta p$

.....  
 ..... [2]

- (d) Hence use the uncertainty principle to explain why

- (i) the beam spreads out,

.....  
 .....  
 .....  
 ..... [2]

- (ii) the beam is spread out more when the slit is narrower (smaller  $w$ ),

.....  
 .....  
 ..... [3]

- (iii) the beam is spread out less when the incoming electrons have greater linear momentum. (You might find it helpful to include a vector diagram.)

.....  
 .....  
 .....  
 .....  
 .....  
 ..... [4]

- 11 The GPS (Global Positioning System) is used in satellite navigation systems in cars. The receivers pick up and compare time signals from orbiting satellites and use them to calculate positions relative to a particular satellite. For this system to work accurately, the time signals have to be corrected for two relativistic effects that affect the rate of the onboard atomic clocks.

The first of these effects is due to the satellite's relative velocity with respect to the receiver.

- (a) Explain why a 'moving' clock runs slow compared to a clock at rest beside the observer. Ignore the effects of gravity. (You may wish to use a diagram.)

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- (b) (i) The satellite's relative velocity is typically about  $3.5 \times 10^3 \text{ m s}^{-1}$ . Show that an atomic clock on a satellite moving at about  $3.5 \times 10^3 \text{ m s}^{-1}$  relative to the receiver loses about  $6.8 \times 10^{-11} \text{ s}$  every second.

You can use the approximation:  $\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \approx 1 + \frac{1}{2} \left( \frac{v^2}{c^2} \right)$  when  $\left( \frac{v^2}{c^2} \right)$  is small.

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- (ii) Show that this results in a time error of about 4 ns per minute.

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- (c) A GPS receiver is used to make two position measurements at different times from the same location.

Explain why these measurements will be different unless a correction for the motion of the satellite is made.

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(d) The second relativistic effect is due to gravitational time dilation. This makes the clock on a typical GPS satellite run **fast** by about 30 ns per minute relative to a clock at rest beside the receiver.

(i) Calculate the total time error due to both relativistic effects for two measurements of position made 10 minutes apart from the same point on Earth.

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(ii) Calculate the corresponding error in distance between the receiver and the satellite.

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(iii) Hence explain why it is important to correct for relativistic effects, and give a practical example of a navigation problem that might otherwise arise.

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(e) Explain the difference between Newton's concept of absolute time and the concept of time in Einstein's theory of relativity. State how this makes a practical difference in the case of GPS.

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12 Read the extract below, which is taken from Stephen Hawking's book, 'A Brief History of Time'.

*'The increase of disorder or entropy with time is one example of what is called an arrow of time, something that distinguishes the past from the future, giving a direction to time. There are at least three different arrows of time. First there is the thermodynamic arrow of time, the direction of time in which disorder or entropy increases. Then, there is the psychological arrow of time. This is the direction in which we feel time passes, the direction in which we remember the past but not the future. Finally, there is the cosmological arrow of time. This is the direction of time in which the universe is expanding rather than contracting.'*

Stephen Hawking, 'A Brief History of Time', Bantam Books 1988, p153.

(a) Explain in your own words, with a specific example, what is meant by 'an arrow of time'.

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(b) Imagine you could reverse time and watch everything running backwards from this moment to the start of the universe. For each of the following laws of physics, state the law and, using an example, explain whether the law would also apply in the reverse-time universe.

(i) Newton's first law of motion.

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**(ii)** The first law of thermodynamics.

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**(iii)** Newton's second law of motion.

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**(iv)** The second law of thermodynamics.

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(c) In the extract, Hawking uses 'disorder' as a loose description of entropy.

(i) Give a scientific description of the term *entropy*.

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(ii) Explain why 'disorder' and entropy are linked.

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(d) Explain a situation in which the cosmological and thermodynamic arrows of time point in different directions.

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(e) State what the second law of thermodynamics implies about the thermodynamic state of the universe immediately after the Big Bang.

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*Copyright Acknowledgements:*

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