A2 PHYSICS PAST PAPER QUESTIONS

UNIT 6 – Synoptic Papers (Sorted by Year)

(Time Allowed: 120 minutes)

1. Read the passage and then answer the questions at the end.

What is lightning?

Lightning has been a source of wonder to all generations. Its origins, in the processes of the electrification of thunderstorms, are being studied by means of laboratory experiments, together with observational and theoretical studies.

Summer airmass storms and winter-time cold frontal storms can become electrified and produce lightning and thunder. The high currents in the lightning strokes (typically 20 000 A) heat the air sufficiently to cause rapid expansion; the resulting shock wave is heard as thunder. Travelling at the speed of sound, 340 m s^{-1}, the noise arrives after the flash is seen and so the distance to the storm may be estimated. The flash is seen as a result of the effect of the electrical discharge on the gases through which the discharge travels. The lightning may occur completely within the cloud as a cloud stroke, often called sheet lightning, or it may reach the Earth as a ground stroke.

In the production of a ground stroke, the lightning channel first makes its way towards the ground as a weakly luminous negative leader which attracts positive charge from sharp objects on the ground. This leader is a column of negatively charged ions which flow from the charged lower regions of the cloud in a stepwise fashion to form a conducting channel between the cloud and the ground. When a conducting channel is completed the negative charge flows to the ground. The brightest part of the channel appears to move upwards at about 30% of the speed of light. Often there is sufficient charge available to allow several strokes to occur along the same lightning channel within a very short time. The resulting flickering can be observed by the eye and the whole series of strokes is called a flash. The peak electrical power is typically 1×10^8 W per metre of channel, most of which is dissipated in heating the channel to around 30 000ºC.

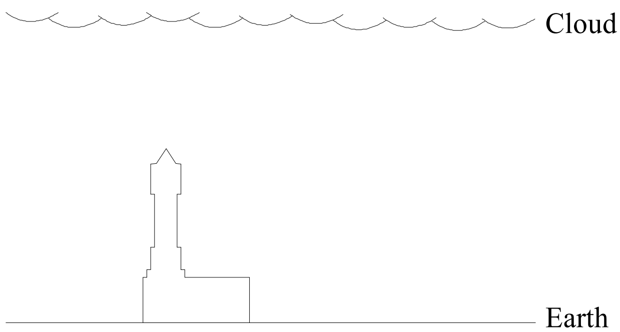
In London the average number of days per year on which thunder is heard is 17, the peak thunderstorm activity being in the late afternoon and evening during summer. When a person is struck by lightning, heart action and breathing stop immediately. Heart action usually starts again spontaneously but breathing may not and, on average, four people are killed by lightning each year in Britain.

(a) (i) Explain how the distance from an observer to a lightning flash may be estimated. Illustrate this for the case where the distance is 1.5 km.

(ii) Explain the meaning of the phrase *sheet lightning* (paragraph 2).

(5)

(b) The diagram represents a storm cloud over a building with a high clock tower.



Copy the diagram. Explain, with the aid of additions to your diagram, what is meant by a *negative leader* (paragraph 3).

(5)

(c) Suppose lightning strikes from a cloud to the Earth along a channel 400 m long.

Calculate:

(i) a typical potential difference between cloud and Earth,

(ii) the average electric field strength along such a lightning channel.

(5)

(d) (i) Use the passage to explain how thunder is produced.

(ii) Estimate the pressure of the air within a lightning channel immediately after a lightning flash. Take the atmospheric pressure to be 100 kPa. State any assumptions you make.

(7)

(e) Suggest why those who are killed each year by lightning are usually alone.

(2)

(f) *The flash is seen as a result of the electrical discharge on the gases through which the discharge travels* (paragraph 2).

Rewrite this sentence using the phrases "ionises or excites" and "visible photons". You may be awarded a mark for the clarity of your answer.

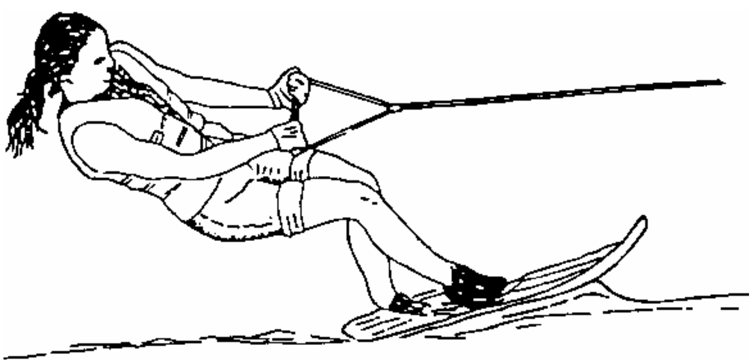
(4)

(g) Describe how you would attempt to demonstrate in the laboratory that the electric field strength needed to produce a spark in air is about 3000 V mm^{-1} (3×10^6 V m^{-1}).

Suggest why this value differs from that which you calculated in (c)(ii).

(4)
(Total 32 marks)

2. The diagram shows a water skier being pulled at a steady speed in a straight line. Her mass plus the mass of the ski is 65 kg. The pull of the tow-rope on her is 520 N.



(a) (i) What are the horizontal and vertical components *X* and *Y* of the push of the water on the ski? (Ignore air resistance.)

(ii) Her weight and the 520 N towing force exert moments around the point on the ski through which the resultant of *X* and *Y* act.

Explain how she can remain in equilibrium as she is towed along if the size of the towing force varies.

(4)

(b) Later, while still being towed, she moves in a curved path from behind the boat to approach a ramp from which she makes a jump, remaining in the air for over two seconds.

Describe the force which enables her to accelerate centripetally as she moves in a curved path.

Why does she feel "weightless" while in the air during her jump?

(3)

(c) After her jump she again moves with her original velocity, experiencing a towing force of 520 N. Suddenly, she lets go of the tow-rope. Calculate her initial deceleration. Why does her deceleration reduce as she slows down?

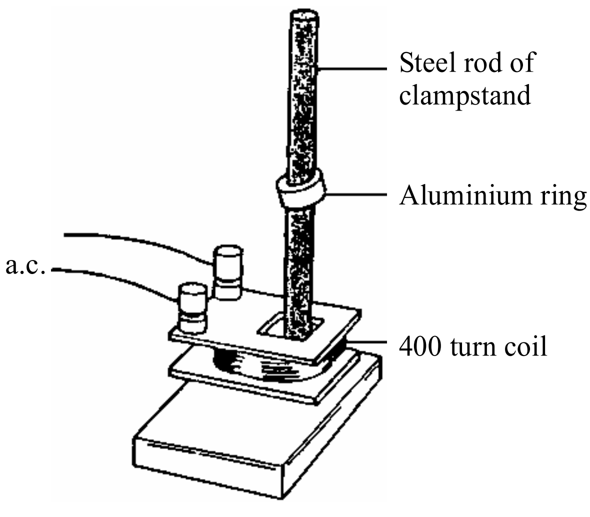
(3)

(d) An observer notices that the waves she produces approaching the shore diffract as they pass through a gap leading to a boatyard. The diffraction of electro-magnetic waves is involved when we collect information about stars and galaxies.

Explain how light diffracted through gratings can yield information about distant stars and galaxies. You may be awarded a mark for the clarity of your answer.

(5)
(Total 15 marks)

3. Apparatus to demonstrate electromagnetic levitation is shown in the diagram.



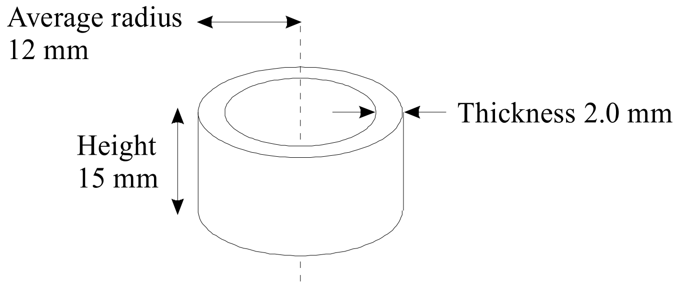
When there is an alternating current in the 400-turn coil, the aluminium ring rises to a few centimetres above the coil. Changes in the size of the alternating current make the ring rise to different heights.

(a) (i) Explain why, when there is a varying current in the coil, there is an induced current in the aluminium ring. Suggest why the ring then experiences an upward force. You may be awarded a mark for the clarity of your answer.

(6)

(ii) In one experiment the power transfer to the aluminium ring is 1.6 W. The induced current is then 140 A. Calculate the resistance of the aluminium ring.

The dimensions of the aluminium ring are given on the diagram below. Use your value for this resistance to find a value for the resistivity of aluminium.



(5)

(b) The aluminium ring becomes hot if the alternating current is left on for a few minutes. In order to try to measure its temperature it is removed from the steel rod and then dropped into a small plastic cup containing cold water.

(i) State what measurements you would take and what physical properties of water and aluminium you would need to look up in order to calculate the initial temperature of the hot aluminium ring.

(3)

(ii) Explain whether experimental errors would make your value for the initial temperature of the aluminium ring too big or too small.

(2)
(Total 16 marks)

4. (a) (i) Particle accelerators are used to increase the energy of charged particles. Circular accelerators can accelerate charged particles to higher energies than can be achieved in linear accelerators. Discuss the principles of physics used in a circular accelerator. You should refer to principles from more than one unit. You may be awarded a mark for the clarity of your answer.

(6)

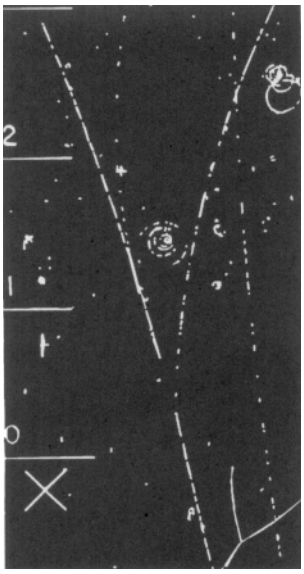
(ii) Show that, if the speed of a charged particle in a circular accelerator is increased, the radius of the circular path increases.

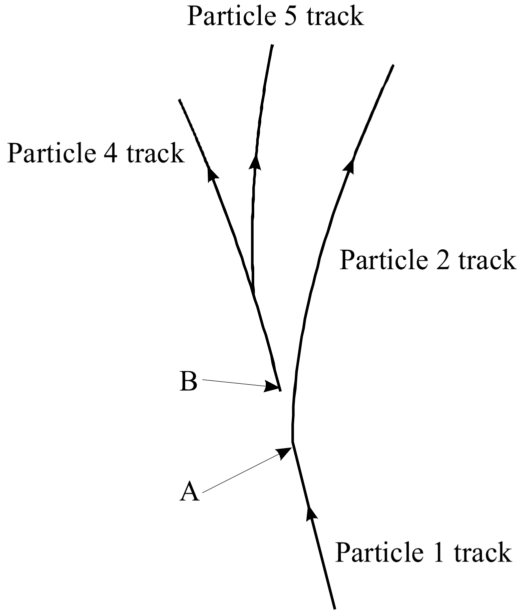
(3)

(b) (i) A bubble chamber contains liquid hydrogen at high pressure. When the high pressure is suddenly released, visible tracks of particles moving through the chamber are produced. Describe the processes which lead to these tracks being made visible.

(3)

(ii) The photograph shows tracks in a hydrogen bubble chamber. The tracks associated with one particular interaction are reproduced as a diagram alongside. There is a magnetic field into the page.





The tracks in the diagram show particle 1 decaying at A into two particles 2 and 3, with particle 3 leaving no track. What can you deduce about particle 2?

Suggest why particle 3 leaves no track.

(3)

(iii) Particle 3 subsequently decays at B into another pair of particles, 4 and 5. The sum of the masses of particles 4 and 5 is less than the mass of particle 3. Explain how this can be the case.

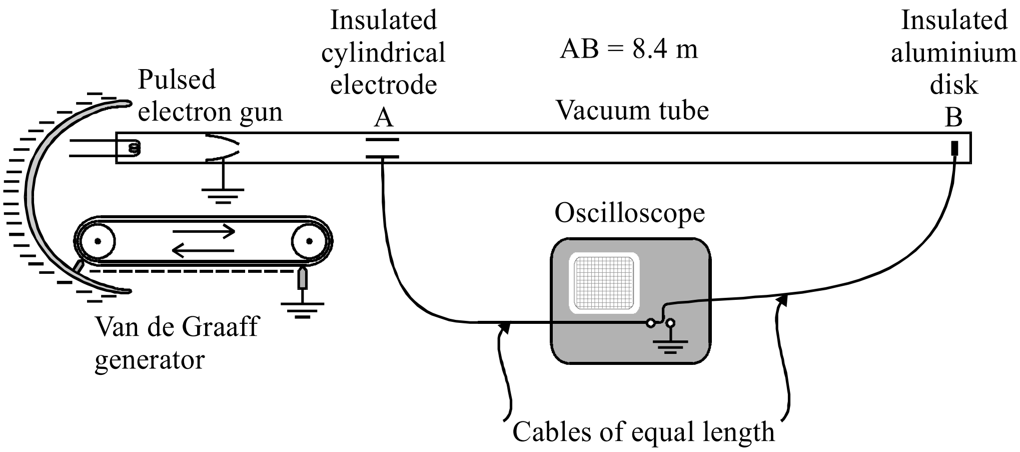
(2)
(Total 17 marks)

1. Read the passage and then answer the questions at the end.

The ultimate speed

According to Newtonian mechanics, there is no upper limit to the speed that may be given to an object. Imagine, for example, that a body is acted on continually by a constant resultant force equal to its weight at the Earth's surface. After six months, starting from rest, its speed would be more than half the speed of light! For an electron, forces very much greater than its weight can be applied, and so it can easily be accelerated to speeds which Newton's laws predict to be greater than the speed of light. As little as 100 V between two electrodes in a vacuum tube would accelerate an electron from rest to about 6×10^6 m s^{-1}. Indeed, if the electrodes were only a few millimetres apart, the electrons' acceleration would be about 10^{15} g. If the acceleration is through millions of volts, the need for a revised non-Newtonian dynamics becomes glaringly obvious.

An experiment was performed in 1962 by W. Bertozzi to measure the speeds of electrons accelerated by a Van de Graaff generator up to measured energies of 1.5 MeV. The experimental arrangement is shown in the diagram.



The idea is to make direct measurements of the time of flight of electrons travelling in a vacuum over a distance AB of 8.4 m. The electrons are released in short bursts of about 3×10^{-9} s duration from the electron gun system. The accelerating voltage is produced by the Van de Graaff generator. A cylindrical electrode at A and an aluminium disk at B pick up signals as a burst passes through A and arrives at B. These signals are carried to an oscilloscope with a calibrated time-base by cables of equal length, giving rise to the following results:

Kinetic energy	T/MeV	0.25	0.50	1.00	1.50
Flight time	$t/10^{-8}$ s	3.85	3.28	3.03	2.92

A direct calorimetric measurement of the kinetic energy of each electron burst is made by monitoring the rate of rise of temperature of the aluminium disk. The number of electrons arriving at B in each burst is found by measuring the rate of rise of the total charge on it. In this way, they were able to confirm that the kinetic energy acquired by an electron accelerated through a potential difference V is eV.

[The passage is adapted from *Special Relativity,* A. P. French, Nelson 1968.]

(a) Calculate the final speed of an object accelerated from rest at 9.81 m s^{-2} for 182.5 days.

(3)

(b) (i) Calculate the electric field strength between two flat electrodes placed 4.0 mm apart when there is a potential difference of 100 V between them.

(ii) What is the force on an electron in this field?

(iii) What is the acceleration of an electron in this field?

(6)

(c) Outline briefly how a Van de Graaff generator can accelerate electrons to very high energies.

(3)

(d) The oscilloscope time-base was set at 10 ns div^{-1}, i.e. 10^{-8} s div^{-1}.

Draw carefully what is seen on the oscilloscope screen when a burst of 1.00 MeV electrons passes down the vacuum tube. Show the time-base scale on the screen.

(4)

(e) When N electrons hit the aluminium disk B, its temperature rises by $\Delta\theta$, where N and $\Delta\theta$ are related by the equation $mc\Delta\theta = NeV$.

(i) What do m and c represent in the product $mc\Delta\theta$?

(ii) Explain what is meant by a potential difference of 1 volt. Hence show that the unit of the product NeV is the joule.

(4)

(f) (i) Calculate the speed υ of the electrons for each value of the flight time given in the table.

(ii) Draw a graph of υ^2 against T, the kinetic energy of the electrons in MeV.

(iii) Does your graph support the prediction of Newtonian mechanics that $\upsilon^2 \propto T$? Justify your answer.

(iv) What would you expect the best fit graph line to do as T rises to 10 MeV and beyond?

(8)

(g) Explain why, in the Bertozzi experiment,

(i) the cables from A and B to the oscilloscope are of equal length,

(ii) a direct calorimetric measurement of the energy of each electron is made.

(3)
(Total 31 marks)

2. (a) The equations $F = kx$ and $V = \dfrac{Q}{C}$ are sometimes referred to as analogous mathematical models for a spring and a capacitor respectively.

(i) State what physical quantities are represented by F, x, V and Q in the equations above.

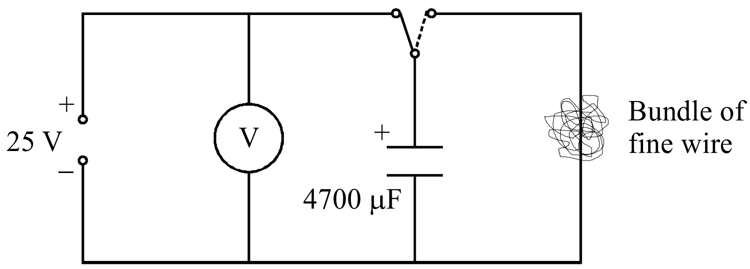
(ii) The energy stored in a capacitor is given by $W_c = \frac{1}{2}QV$ and also by $W_c = \frac{1}{2}CV^2$.

Write down, by analogy, the two equivalent expressions for the energy W_s stored in a spring.

Show that W_s can also be expressed as $\frac{1}{2}kx^2$.

(5)

(b) (i) A 4700 μF capacitor is charged to 25 V and discharged through a tightly wound bundle of fine insulated wire.

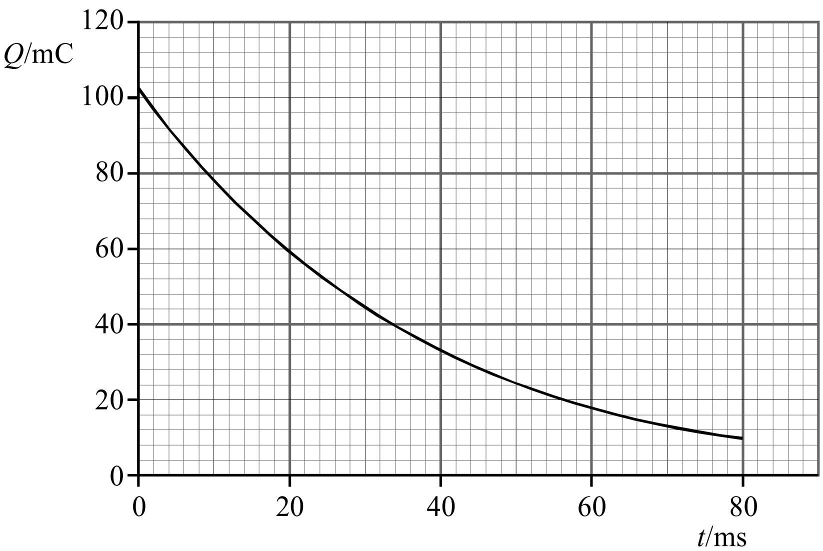


Calculate the energy dissipated in the wire.

Explain why it would be difficult to use this arrangement to demonstrate that $W_c \propto V^2$ for a range of potential differences up to about 50 V. You may be awarded a mark for the clarity of your answer.

(6)

(ii) The graph shows how the charge on the capacitor varies with time as it discharges.

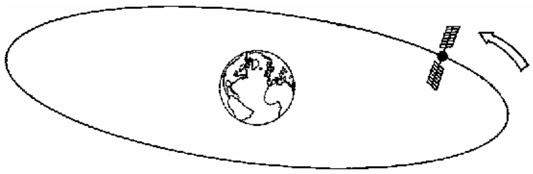


State what name is given to this shape of graph and name another physical phenomenon which gives rise to graphs of this shape.

Showing your working, determine a value for the resistance of the bundle of wire.

(6)
(Total 17 marks)

3. A communications satellite is in geosynchronous orbit around the Earth, i.e. it orbits the Earth once every 24 hours. The radius of the orbit is 4.2×10^4 km.



(a) (i) Show that the acceleration of the satellite is about 0.2 m s^{-2}. In what direction is the acceleration?

(ii) This acceleration is equal to the gravitational field strength g of the Earth at the satellite orbit.

Explain how a knowledge of g at 4.2×10^4 km from the centre of the Earth enables the mass of the Earth to be calculated.

(6)

(b) The satellite's electrical system is powered by an array of 18 000 photovoltaic cells, each of area 12 cm^2.

(i) When fully illuminated in space by sunlight of intensity 1.4 kW m^{-2}, the array produces 4.5 kW of electrical power.

Calculate the efficiency of transfer of solar to electrical energy.

(3)

(ii) In laboratory tests, the internal resistance of a single cell was found to be 40 Ω.

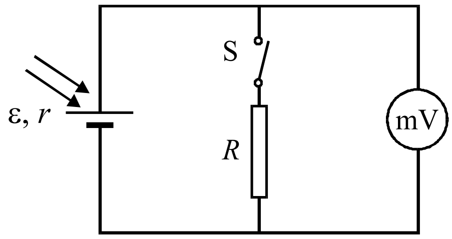
In the satellite the 18 000 cells are arranged in 300 rows of 60 by connecting 60 of them in series and joining 300 such rows in parallel.

Show that the combined resistance of the 18 000 cells in this arrangement is less than 10 Ω.

What e.m.f. will this arrangement produce if the e.m.f. of one cell is $\mathcal{E}$?

(4)

(iii) To measure the internal resistance *r* of one cell, a student uses the circuit shown.

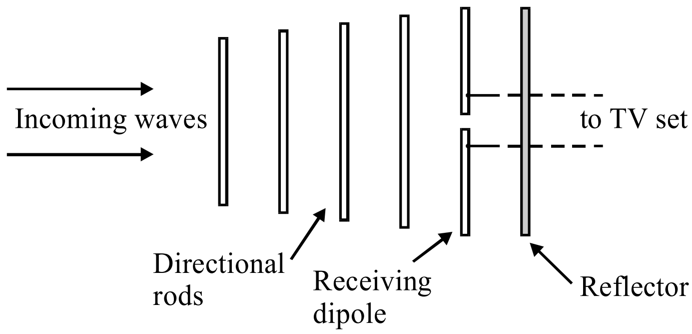


Explain how, by taking readings with the switch S first open and then closed, the student can find the value of *r*.

Suggest a value for the fixed resistor *R* when r is 40 Ω.

(4)
(Total 17 marks)

4. (a) The diagram shows the main features of a rooftop TV aerial. The supporting structure is omitted. The receiving section is the unshaded dipole.



(i) The incoming signal is a plane polarised electromagnetic wave of frequency 1.07 GHz.

Calculate the wavelength of the incoming wave.

Outline how you could demonstrate experimentally, using the aerial and a TV set, that the incoming wave was plane polarised.

(5)

(ii) Two waves, the incoming wave and its reflection from the reflector, are superposed at the receiving dipole.

Explain what is meant by the phrase 'two waves are superposed'.

Suggest, with a reason, how far the reflector should be placed from the receiving dipole to get the strongest signal for the TV set.

(4)

(b) A plane electromagnetic wave consists of oscillating electric and magnetic fields. The intensity or energy flux I, measured in W m^{-2}, can be expressed as

$$I = \frac{cB_0^2}{2\mu_0}$$

where B_0 is the maximum value of the magnetic flux density and the other symbols have their usual meaning.

(i) Show that the expression for I is homogeneous with respect to units.

(ii) Describe how a coil, together with any other apparatus you require, could be used to detect the presence of a steady magnetic field in the region of a bar magnet.

(6)
(Total 15 marks)

1. Read the passage and then answer the questions at the end.

Light can exert a force

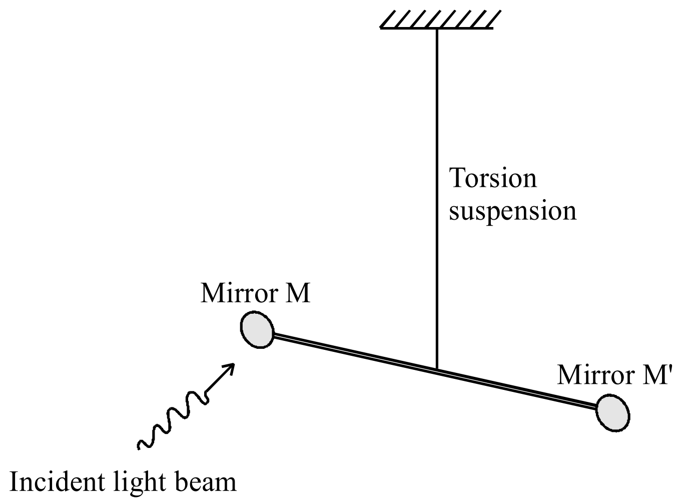
Energy is carried from the Sun to the Earth or from an open fire to a hand by electromagnetic waves. More surprising is the fact that electromagnetic waves also transport linear momentum. This means that it is possible for electromagnetic waves to exert a force, and hence a radiation pressure, on an object, e.g. by shining light on it. Such forces must be small as we do not, after all, get pushed backwards when we raise a window blind and let in the sunlight. Radiation pressure is partly responsible for the way the tails of comets stream away from the Sun. Its use has even been proposed to propel space vehicles, by using reflecting sails that would open when the vehicle is going "down wind".

When a parallel beam of light, of intensity or energy flux I, falls perpendicularly on an absorbing surface of area A, the energy E incident in a time t is equal to IAt. The momentum p transferred to the surface is given by

$$p = \frac{E}{c} = \frac{IAt}{c}$$

where c is the speed of light. When the light is entirely reflected from the surface the momentum transfer will be twice this amount, just as a perfectly elastic ball transfers twice its initial momentum when it bounces from the Earth.

The first measurement of radiation pressure was made more than a hundred years ago by Nichols and Hull using a torsion balance technique.



They allowed light to fall on mirror M in the diagram, causing the balance arm MM' to turn through a measured angle θ. By switching the beam on and off, they were able to find the resonant frequency f_0 of the torsion balance. A knowledge of θ and f_0, together with details of the suspended mirror system, enabled them to calculate the force, and hence the radiation pressure, exerted by the light. The intensity of their light beam was measured by allowing it to fall on a blackened metal disc and measuring the rise in temperature of the disc. Their experiments measured a radiation pressure of 7.01 μPa compared to the predicted value of 7.06 μPa.

[Adapted from D Halliday and R Resnick: *Phvsics* parts I and 11 Combined, third edition, 1978]

(a) Explain the meaning of the following phrases as used in the passage:

(i) radiation pressure (paragraph 1),

(ii) down wind (paragraph 1),

(iii) perfectly elastic (paragraph 2).

(5)

(b) (i) Show that p = Iat / c is homogeneous with respect to units.

(ii) Light of intensity 12 W cm^{-2} falls for 30 minutes on a mirror of area 460 cm^2 which reflects 80% of the incident light. Calculate the energy reflected from the mirror in this time.

(7)

(c) Consider the following argument:

The momentum transferred to the surface $= IAt / c$ (paragraph 2)
Hence the force exerted on the surface $= IA / c$ (step 1)
Hence the pressure on the surface $= I / c$ (step 2)

(i) State the physical principle used in step 1.

State the physical principle used in step 2.

(ii) In sunlight the force on two sails, each of area 2 km^2, is of the order of 10 N each at a distance from the Sun equal to the Earth's orbital radius.

Discuss the viability of using such sails to propel space vehicles, already in orbit, to reach the outer planets of the solar system.

(5)

(d) Refer to the experiment performed by Nichols and Hull (paragraph 3).

(i) Describe how the balance arm was set into resonant oscillations and sketch a graph of the amplitude of oscillation against the forcing frequency.

(ii) Suggest two ways of modifying the apparatus to increase the angle θ through which the balance arm MM' rotated when M was illuminated.

(5)

(iii) State what data and what measurements, in addition to the rise in temperature of the disc, would be needed in order to establish the intensity of the light beam used.

(iv) The calculated uncertainty in their measured value, 7.01 μPa, of the pressure of light was 1.5%. Discuss briefly whether or not the result of their experiment confirms the theory of radiation pressure.

(5)

(e) (i) Why is the fact that light can transport linear momentum surprising? (paragraph 1).

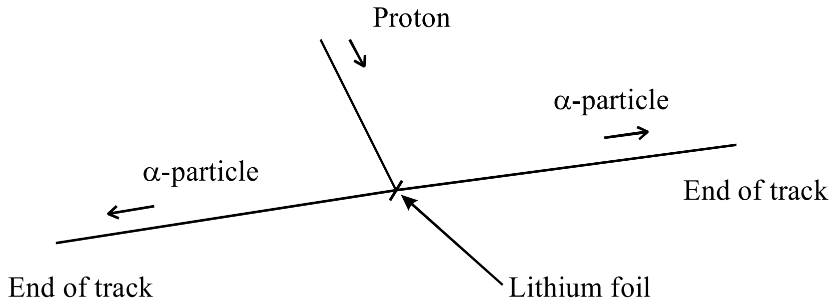
(ii) By considering the equation $p = E/c$, show that the momentum of a single photon of yellow light of energy E, for which $\lambda = 560$ nm, is about 10^{-27} N s.

(4)

(f) Draw a sketch to illustrate “the way the tails of comets stream away from the Sun” (paragraph 1). Your sketch should show the direction in which the comet is moving as well as the direction of the tail.

(2)
(Total 33 marks)

2. In 1932 Cockroft and Walton accelerated protons through a few hundred kilovolts and directed them at a lithium-7 target placed in a cloud chamber. The diagram illustrates the outcome of the experiment.



(a) (i) What evidence is there in the diagram that the two α-particles have the same initial energy?

(ii) Write a nuclear equation for this event.

(4)

(iii) Calculate the kinetic energy of the pair of α-particles in joules, given

mass of proton = 1.007 28 u
mass of lithium nucleus = 7.014 37 u
mass of α-particle = 4.001 50 u

State any assumption you make.

(4)

(b) Describe how the tracks of the protons and α-particles are produced in **either** a cloud chamber **or** a bubble chamber. You may be awarded a mark for the clarity of your answer.

(4)

(c) As the proton approaches the lithium-7 nucleus, it is attracted gravitationally and repelled electrostatically.

Show that the ratio of the electrostatic force between these two particles to the gravitational force between them is independent of their distance *r* apart.

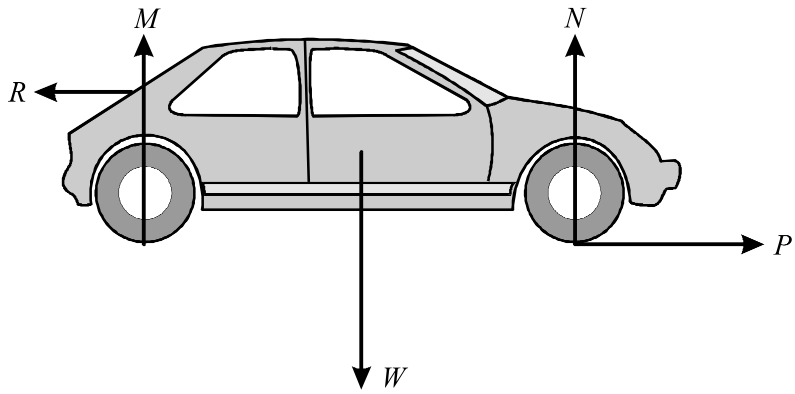
Hence show that this ratio is a very large number. (Refer to the data on the data sheet)

(4)
(Total 16 marks)

3. (a) A car is advertised as being able to accelerate from 0 to 60 miles per hour in 4.5 s.

(i) Given that 1 mile = 1.6 km, calculate the average acceleration of the car. Express this acceleration as a fraction of the acceleration of a freely falling body close to the Earth's surface.

(ii) The diagram shows a free-body force diagram for a front wheel drive car as the car accelerates from rest.



R is the backward push of the air on the car. Describe, in similar terms, each of the forces *P* and *W*.

(5)

(iii) The car's power unit may be considered as a heat engine. Draw a labelled energy flow diagram for this heat engine.

(4)

(b) The car is later travelling at a constant velocity υ of 29 m s^{-1}. A speed trap measures this velocity using microwaves of frequency 1.1×10^{10} Hz.

(i) When the microwaves are reflected from the receding car, a Doppler shift is detected.

What is meant by a **Doppler shift?**

In this case $\frac{\Delta f}{f} = \frac{2\upsilon}{c}$. Calculate the Doppler shift in this case.

(3)

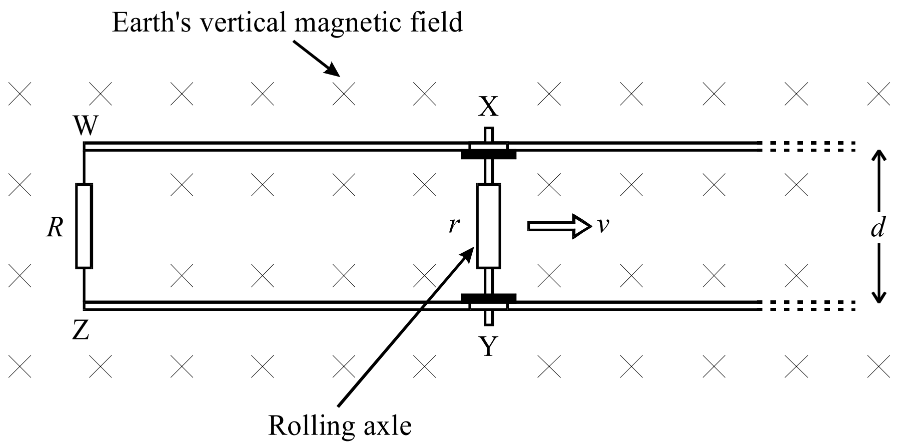
(ii) The wavelength of the microwaves used can be measured in the laboratory. Describe how this could be done.

(4)
(Total 16 marks)

4. The diagram shows a plan view of two horizontal parallel railway rails a distance d apart connected at one end by a conducting link WZ of resistance R. The rails have negligible electrical resistance.

An engineer rolls an axle XY, of resistance r, along the rails at a speed υ.

The vertical component of the Earth's magnetic flux density B_v acts downwards as indicated.



(a) As the axle moves along the rails an e.m.f. $\mathcal{E}$ is induced in the circuit WXYZ.

(i) Explain the origin of this induced e.m.f.

(ii) The size of the e.m.f. is given by $\mathcal{E} = B_v \upsilon d$. Suggest suitable values for d and v and hence estimate a value for $\mathcal{E}$. Take B_v to be 48 μT.

(5)

(iii) Show that the power P transferred to the conducting link of resistance R in the circuit WXYZ can be expressed as $P = \mathcal{E}^2 R / (R + r)^2$.

(3)

(b) (i) A small-scale model of this system is set up in a laboratory. State what additional apparatus is needed, how it is used and what readings need to be taken to determine the power transferred to the resistor forming the conducting link in the model.

(4)

(ii) It is suggested that in the laboratory the axle could be driven along the rails by replacing the conducting link WZ with a battery capable of delivering large currents.

Explain how the system would work.

Comment on the practicability of driving a train in this way.

(3)
(Total 15 marks)

1. Read the passage and then answer the questions at the end.

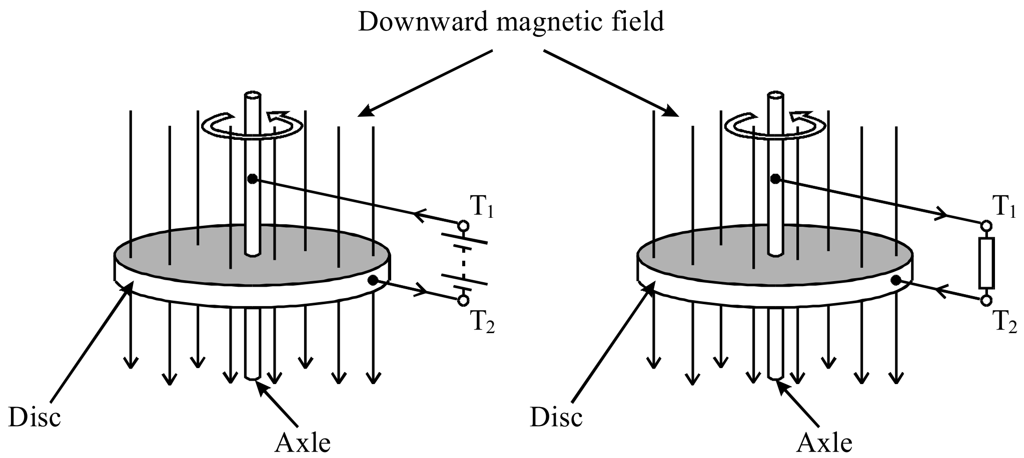
The homopolar generator

In principle a homopolar generator consists of a conducting disc spinning about an axis in a magnetic field parallel to this axis. When the spinning disc is stopped suddenly, all its kinetic energy can be used to generate large current surges.

In order to spin the disc up to speed, a d.c. power supply is connected as shown in Figure 1. The magnetic force on the current crossing from the axle to the rim of the conducting disc provides the necessary accelerating force. As the conducting disc speeds up, however, there is an increasing voltage generated between the terminals T_1 and T_2. When the power supply is disconnected this voltage can be used to drive a current through a resistor connected between them as shown in Figure 2.

Figure 1
Speeding up disc

Figure 2
Using generated voltage



The size of the voltage V generated can be calculated from the relationship

$$V = \pi\left(r_d^2 - r_a^2\right)fB$$

where r_d and r_a are the radii of the disc and axle, f is the frequency of rotation of the disc and B is the magnetic flux density assumed to be uniform over the surface of the disc.

The main purpose of homopolar generators is as research tools to produce huge surges of current when their terminals are suddenly short-circuited. Apart from increasing the magnetic field, higher generated voltages can be obtained by increasing the speed of rotation or the diameter of the disc. The speed cannot be increased indefinitely as the speed of the edge of the disc is limited to a maximum of about 200 m s^{-1} by the mechanical properties of the material, usually steel, from which it is made.

One large homopolar generator in Australia, which is designed to produce huge current surges, measures 3.6 m in diameter, rotates at 15 Hz and is so massive that the kinetic energy it stores at this speed is 580 MJ. When it is short-circuited, the current surges are used to produce short-lived, but extremely high, magnetic fields in order to study the properties of matter under extreme conditions. Such fields, it is proposed, could be used in an electromagnetic gun to project a small mass at speeds of over 7 km s^{-1}. this speed is of the order of the speed of satellites in low orbit and hence the projected masses could be used to study the problems encountered by missiles re-entering the atmosphere.

(a) What is meant by the term 'short-circuited' used in the passage (paragraph 4)?

(2)

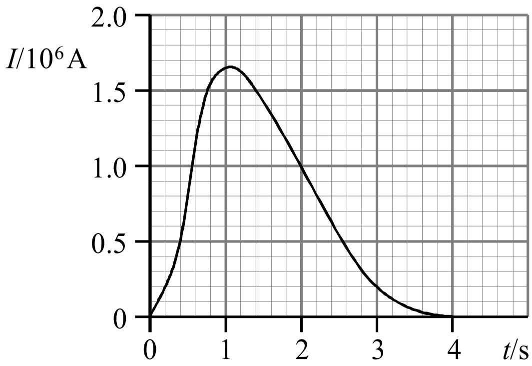
(b) (i) Is the output of a homopolar generator a.c. or d.c.?

(ii) List the quantities on which the voltage generated by a homopolar generator depends.

(iii) Give two uses which are suggested for the huge surges of current produced by a homopolar generator.

(6)

(c) The graph shows a current surge from a short-circuited homopolar generator.



(i) Estimate the charge flowing during this surge. Show each stage of your calculation.

(ii) Calculate the maximum power dissipated when the terminals T_1 and T_2 of the generator, which has an 'internal' resistance 0.12 mΩ (1.2×10^{-4} Ω), are connected together through a negligible external resistance.

(7)

(d) Show that the equation $V = \pi(r_d^2 - r_a^2)fB$ is homogeneous with respect to units.

(4)

(e) Figure 1 shows how the disc of a homopolar generator is spun up to speed.

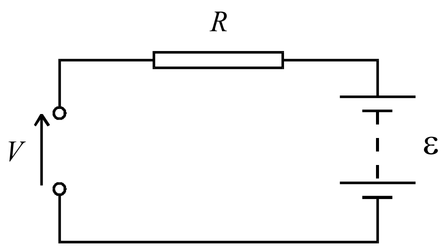
(i) State the main energy change involved.

(ii) What force speeds up the rotation of the disc?

(iii) Show that the speed of the edge of the disc described in the last paragraph is less than the maximum safe speed.

(5)

(f) In the circuit diagram below, the e.m.f of the d.c. power supply used to speed up the disc is $\mathcal{E}$ and the opposing voltage generated by the rotating disc is V. The total resistance of the circuit is R.



Write down an equation from which the current I in the circuit can be calculated and explain why I decreases as the speed of the disc increases.

(3)

(g) (i) Show that the speed v of a satellite in a circular orbit at a height h above the Earth's surface is given by

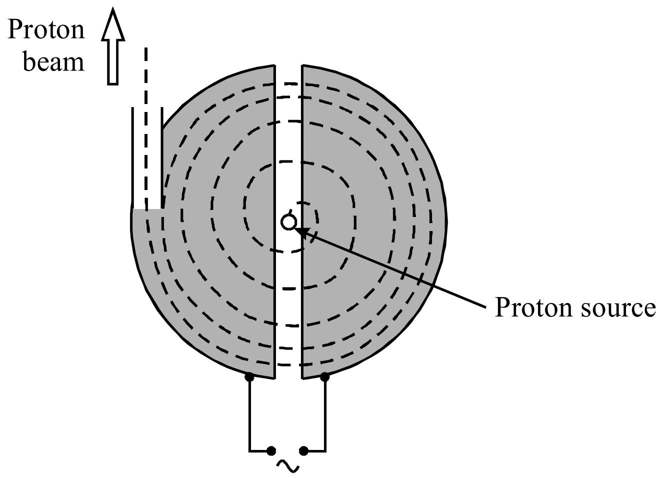
$$v = \sqrt{\frac{Gm_E}{(r_E + h)}}$$

where m_E is the mass of the Earth and r_E is its radius.

(ii) If $m_E = 6.0 \times 10^{24}$ kg and $r_E = 6.4 \times 10^6$ m**,** for what value of h is the orbital speed equal to7 km s^{-1}?

(4)
(Total 31 marks)

2. (a) The simplified diagram shows the 'dees' of a cyclotron connected to a high frequency alternating supply. The dashed line shows the path of an accelerated proton. In the shaded region a uniform magnetic field B of flux density 0.80 T acts upwards out of the paper.



(i) Explain why the magnetic field must be upwards out of the paper when accelerating protons.

(ii) By considering a proton of mass m and charge e (1.6×10^{-19} C) moving in a circle of radius r in the cyclotron, show that the time t taken to complete one semicircle is given by

$$t = \frac{\pi m}{Be}$$

(5)

(iii) Describe how the energy of the proton is increased in a cyclotron. Give one reason why the energy cannot be increased indefinitely. You may be awarded a mark for the clarity of your answer.

(4)

(iv) Show that the gain in energy of a proton accelerated through a potential difference of 12 kV is about 2×10^{-15} J.

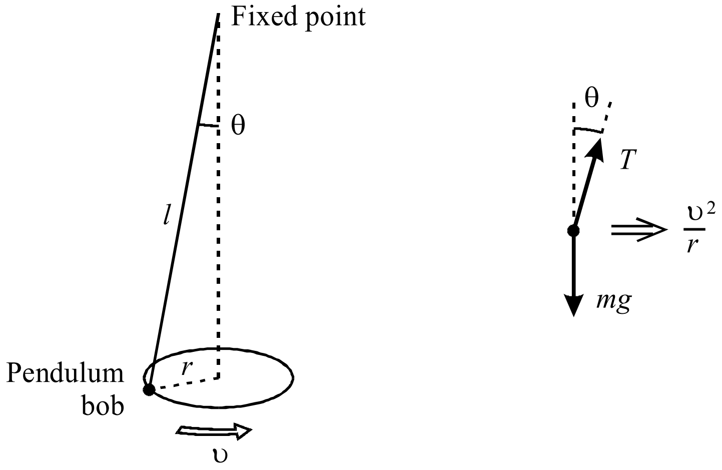
(v) The kinetic energy of a proton circling at a radius r can be expressed as

$$\text{k.e.} = \frac{B^2 e^2 r^2}{2m}$$

Calculate the radius of the circle in which a proton will be moving after being accelerated 850 times across a potential difference of 12 kV.

(4)

(b) The diagram shows a pendulum bob of mass m which has been set moving in a horizontal circle at a speed υ, together with a free-body force diagram for the bob.



The time t taken by the pendulum bob to complete half a circle can be deduced as follows:

$$m\frac{\upsilon^2}{r} = T \sin\theta$$

$$mg = T\cos\theta$$

$$\Rightarrow \frac{v^2}{rg} = \tan\theta$$

$$\text{so } t = \frac{\pi r}{v} = \pi\sqrt{\frac{r}{g\tan\theta}}$$

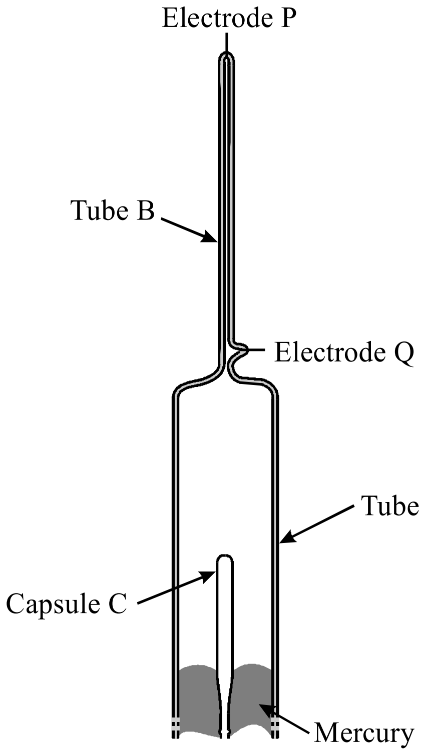
(i) State how Newton's laws of motion are applied in this deduction.

(ii) What assumption is needed in order to show that the expression for t deduced above is independent of the radius of the circle in which the pendulum bob is moving?

(iii) Suggest how you might use an arrangement like this as an analogy to demonstrate how protons are accelerated in a cyclotron.

(5)
(Total 18 marks)

3. In 1908 Rutherford and Royds, working at Manchester University, used the apparatus shown to study the nature of α-particles.



Radon gas, ${}^{222}_{86}\text{Rn}$, which decays by α-emission to an isotope of polonium, Po, is placed at atmospheric pressure in a capsule C made from very thin glass. Any α-particles passing through the glass from C become helium atoms in the evacuated tube A.

(a) (i) Write a nuclear equation for this α decay.

(ii) What must happen to an α-particle in order for it to become a helium atom?

(4)

(b) Even after several days, the helium gas that accumulates in tube A is only at a very low pressure *p*. By raising the level of the mercury, this gas is compressed into the narrow tube B.

(i) Take measurements from the diagram and use them to show that the ratio of the volumes of the tubes A and B is about 150.

(ii) If the pressure of the helium when compressed into tube B is 20 Pa, calculate a value for *p*.

(iii) Explain why the capsule C must have very thin walls.

(6)

(c) When a potential difference is applied across the electrodes P and Q, the helium atoms in tube B are excited and the resulting spectrum for helium can be studied.

(i) Outline how you could study the spectrum of helium in the laboratory. What would you observe in your experiment?

(ii) Explain, in terms of the frequencies of the emitted photons, why the spectrum of a gaseous element is unique to that element.

(iii) Discuss briefly whether the presence of mercury vapour in tube B would have been confusing in this experiment.

(6)
(Total 16 marks)

4. (a) (i) A body can be said to be moving with simple harmonic motion when

$$a = -(2\pi f)^2 x$$

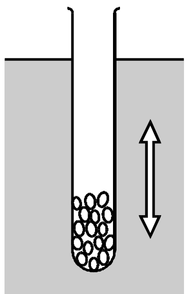
State what a, f and x represent in this equation and explain the significance of the minus sign.

(4)

(ii) Calculate the maximum speed of an electron which is oscillating with simple harmonic motion in a mains wire at 50 Hz with an amplitude of 8.0 μm.

(3)

(b) The diagram shows a weighted test tube of cross-sectional area A and mass m which is oscillating vertically in water.



The frequency f of the oscillations, which can be considered to be independent of their amplitude, is given by

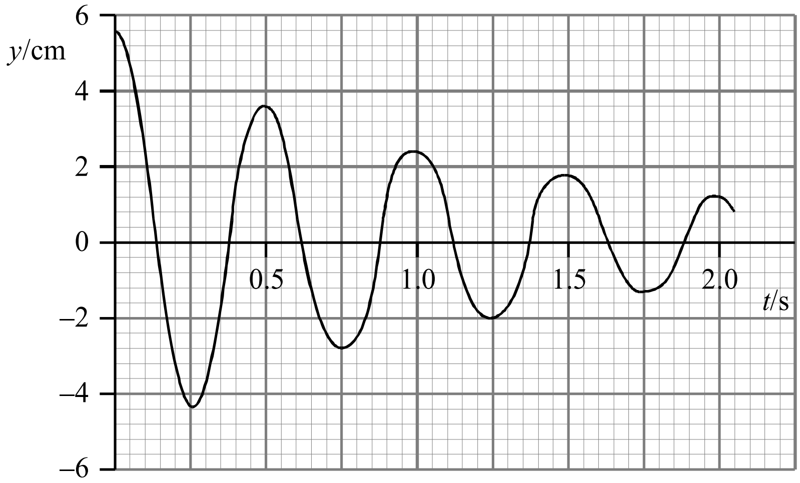
$$2\pi f = \sqrt{\frac{A\rho g}{m}}$$

where ρ is the density of the water and g is the acceleration of free fall.

(i) Show that this equation is homogeneous with respect to units.

(2)

(ii) The graph shows how the vertical displacement y of the test tube varies with time *t*. This shows that the oscillations of the test tube are damped. The damping is thought to be exponential.



By taking measurements from the graph, discuss whether the damping is exponential in this case.

(3)

(iii) Sketch a rough graph to show how the kinetic energy of the test tube varies from $t = 0$ to $t = 0.5$ s, i.e. during its first oscillation. Add a scale to the time axis.

(3)

(Total 15 marks)