Paper Reference(s)

6736/01

Edexcel GCE

Physics

Advanced Level

Unit Test PHY6: Synoptic Paper

Friday 20 June 2003 – Afternoon

Time: 2 hours

Materials required for examination	Items included with question papers
Answer Book (AB12)	Nil

Instructions to Candidates

In the boxes on the answer book provided, write the name of the examining body (Edexcel), your centre number, candidate number, the subject title, the paper reference, your surname, initials and signature.
The paper reference is shown above.
Answer ALL questions in the answer book.
In calculations you should show all the steps in your working, giving your answer at each stage.
Calculators may be used.
Include diagrams in your answers where these are helpful.

Information for Candidates

This question paper is designed to give you the opportunity to make connections between different areas of physics and to use skills and ideas developed throughout the course in new contexts. You should include in your answers relevant information from the whole of your course, where appropriate.
The mark for individual questions and the parts of questions are shown in round brackets. There are four questions in this question paper. The total mark for this paper is 80.
The list of data, formulae and relationships is printed at the end of this booklet.

Advice to Candidates

You must ensure that your answers to parts of questions are clearly numbered.
You will be assessed on your ability to organise and present information, ideas, descriptions and arguments clearly and logically, taking account of your use of grammar, punctuation and spelling.

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SECTION I

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

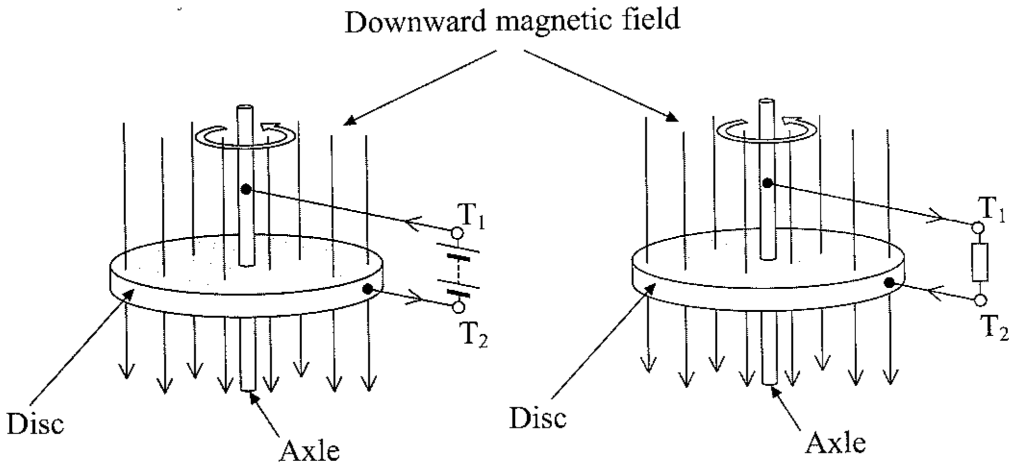
The homopolar generator

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

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

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.

[The passage is adapted from *The homopolar generator* by G Newstead in *Physics and the engineer*, Penguin 1973.]

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

(2)

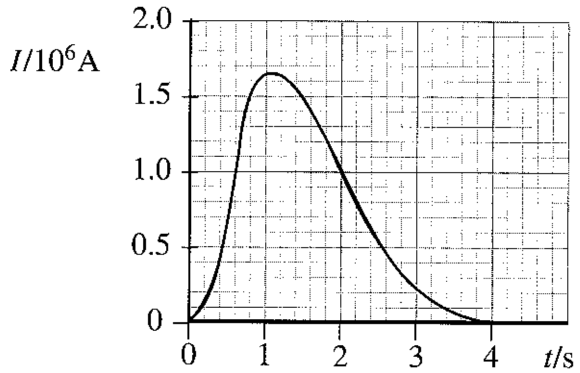
(b) (i) Is the output of a homopolar generator a.c. or d.c.?

(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.

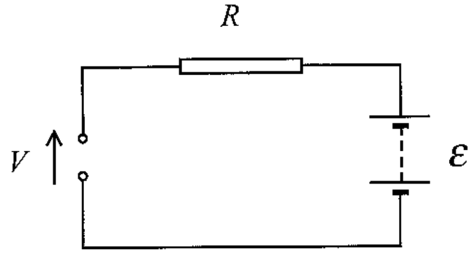
(i) State the main energy change involved.

(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 to 7 km s^{-1}?

(4)

TOTAL FOR SECTION I: 31 MARKS

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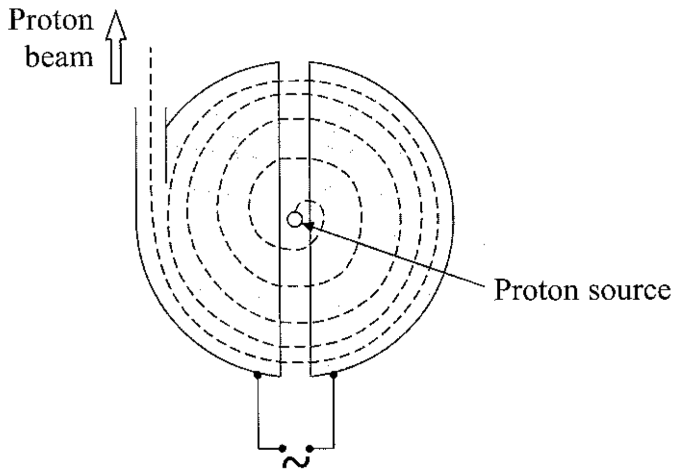
SECTION II

(Answer ALL questions)

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.

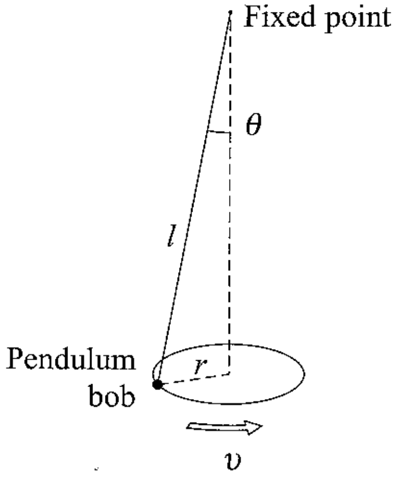
(v) The kinetic energy of a proton circling at a radius r can be expressed as

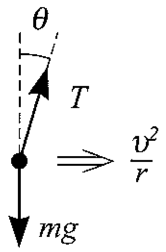
$$\text{k.e.} = \frac{B^2 e^2 r^2}{2m}$$

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 v, 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:

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

$$mg = T\cos\theta$$

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

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

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

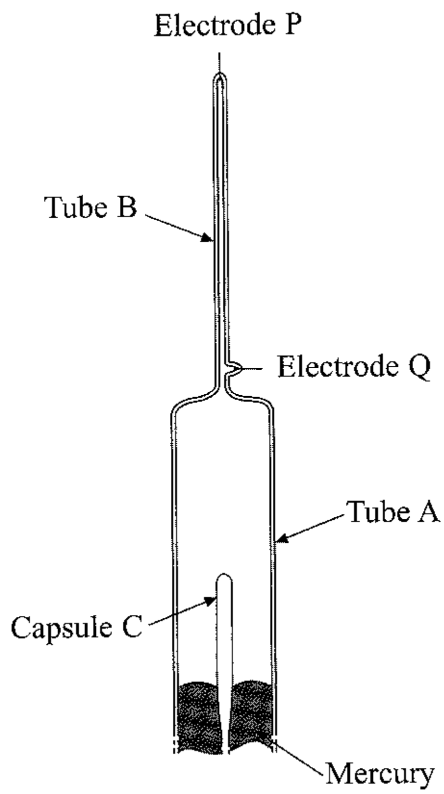
(ii) What assumption is needed in order to show that the expression for t deduced above is independent of the radius of the circle in which the pendulum bob is moving?

(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, $^{222}_{86}Rn$, 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

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

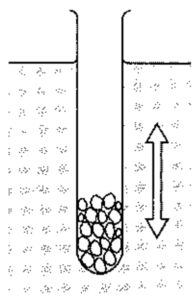
State what a, f and x represent in this equation and explain the significance of the minus sign.

(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

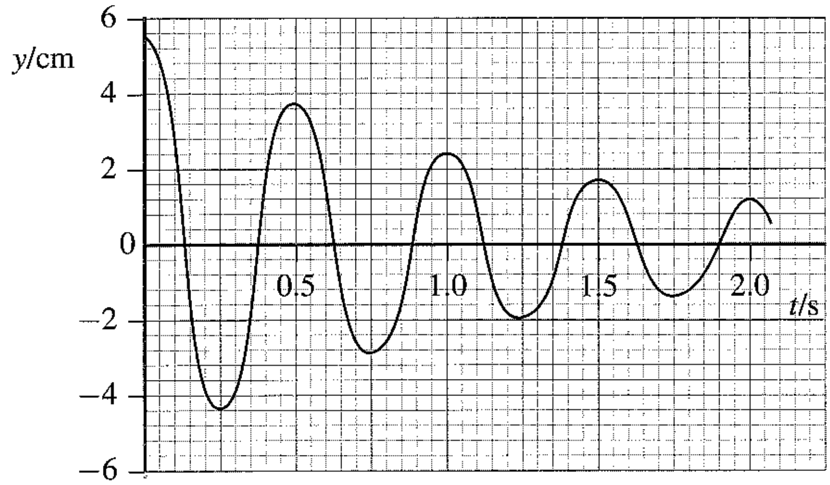
$$2\pi f = \sqrt{\frac{A\rho g}{m}}$$

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)

TOTAL FOR SECTION II: 49 MARKS

TOTAL FOR PAPER: 80 MARKS

END

List of data, formulae and relationships

Data

Speed of light in vacuum	$c = 3.00 \times 10^8\ \text{m s}^{-1}$	
Gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	
Acceleration of free fall	$g = 9.81\ \text{m s}^{-2}$	(close to the Earth)
Gravitational field strength	$g = 9.81\ \text{N kg}^{-1}$	(close to the Earth)
Elementary (proton) charge	$e = 1.60 \times 10^{-19}\ \text{C}$	
Electronic mass	$m_e = 9.11 \times 10^{-31}\ \text{kg}$	
Electronvolt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$	
Planck constant	$h = 6.63 \times 10^{-34}\ \text{J s}$	
Unified atomic mass unit	$\text{u} = 1.66 \times 10^{-27}\ \text{kg}$	
Molar gas constant	$R = 8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$	
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$	
Coulomb law constant	$k = 1/4\pi\varepsilon_0$	
	$= 8.99 \times 10^9\ \text{N m}^2\ \text{C}^{-2}$	
Permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\ \text{N A}^{-2}$	

Rectilinear motion

For uniformly accelerated motion:

$$v = u + at$$

$$x = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2ax$$

Forces and moments

Moment of F about O $= F \times$ (Perpendicular distance from F to O)

Sum of clockwise moments about any point in a plane = Sum of anticlockwise moments about that point

Dynamics

Force $\quad F = m\dfrac{\Delta v}{\Delta t} = \dfrac{\Delta p}{\Delta t}$

Impulse $\quad F\Delta t = \Delta p$

Mechanical energy

Power $\quad P = Fv$

Radioactive decay and the nuclear atom

Activity $\quad A = \lambda N \quad$ (Decay constant λ)

Half-life $\quad \lambda t_{\frac{1}{2}} = 0.69$

Electrical current and potential difference

Electric current $I = nAQv$

Electric power $P = I^2R$

Electrical circuits

Terminal potential difference $V = \mathcal{E} - Ir$ (E.m.f. $\mathcal{E}$; Internal resistance r)

Circuit e.m.f. $\Sigma\mathcal{E} = \Sigma IR$

Resistors in series $R = R_1 + R_2 + R_3$

Resistors in parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Heating matter

Change of state energy transfer $= l\Delta m$ (Specific latent heat or specific enthalpy change l)

Heating and cooling energy transfer $= mc\Delta T$ (Specific heat capacity c; Temperature change ΔT)

Celsius temperature $\theta/°\text{C} = T/\text{K} - 273$

Kinetic theory of matter

Temperature and energy $T \propto$ Average kinetic energy of molecules

Kinetic theory $p = \frac{1}{3}\rho\langle c^2\rangle$

Conservation of energy

Change of internal energy $\Delta U = \Delta Q + \Delta W$ (Energy transferred thermally ΔQ; Work done on body ΔW)

Efficiency of energy transfer $= \frac{\text{Useful output}}{\text{Input}}$

Heat engine maximum efficiency $= \frac{T_1 - T_2}{T_1}$

Circular motion and oscillations

Angular speed $\omega = \frac{\Delta\theta}{\Delta t} = \frac{v}{r}$ (Radius of circular path r)

Centripetal acceleration $a = \frac{v^2}{r}$

Period $T = \frac{1}{f} = \frac{2\pi}{\omega}$ (Frequency f)

Simple harmonic motion:

displacement $x = x_0 \cos 2\pi ft$

maximum speed $= 2\pi f x_0$

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

For a simple pendulum $T = 2\pi\sqrt{\frac{l}{g}}$

For a mass on a spring $T = 2\pi\sqrt{\frac{m}{k}}$ (Spring constant k)

Waves

Intensity	$I = \dfrac{P}{4\pi r^2}$	(Distance from point source r; Power of source P)

Superposition of waves

Two slit interference	$\lambda = \dfrac{xs}{D}$	(Wavelength λ; Slit separation s; Fringe width x; Slits to screen distance D)

Quantum phenomena

Photon model	$E = hf$	(Planck constant h)
Maximum energy of photoelectrons	$= hf - \varphi$	(Work function φ)
Energy levels	$hf = E_1 - E_2$	
de Broglie wavelength	$\lambda = \dfrac{h}{p}$	

Observing the Universe

Doppler shift	$\dfrac{\Delta f}{f} = \dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\upsilon}{c}$	
Hubble law	$\upsilon = Hd$	(Hubble constant H)

Gravitational fields

Gravitational field strength	$g = F/m$	
for radial field	$g = Gm/r^2$, numerically	(Gravitational constant G)

Electric fields

Electrical field strength	$E = F/Q$	
for radial field	$E = kQ/r^2$	(Coulomb law constant k)
for uniform field	$E = V/d$	
For an electron in a vacuum tube	$e\Delta V = \Delta(\frac{1}{2}m_e\upsilon^2)$	

Capacitance

Energy stored	$W = \frac{1}{2}CV^2$
Capacitors in parallel	$C = C_1 + C_2 + C_3$
Capacitors in series	$\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3}$
Time constant for capacitor discharge	$= RC$

Magnetic fields

Force on a wire	$F = BIl$	
Magnetic flux density (Magnetic field strength)		
in a long solenoid	$B = \mu_0 nI$	(Permeability of free space μ_0)
near a long wire	$B = \mu_0 I / 2\pi r$	
Magnetic flux	$\Phi = BA$	
E.m.f. induced in a coil	$\mathcal{E} = -\dfrac{N\Delta\Phi}{\Delta t}$	(Number of turns N)

Accelerators

Mass-energy	$\Delta E = c^2 \Delta m$
Force on a moving charge	$F = BQv$

Analogies in physics

Capacitor discharge	$Q = Q_0 e^{-t/RC}$
	$\dfrac{t_{\frac{1}{2}}}{RC} = \ln 2$
Radioactive decay	$N = N_0 e^{-\lambda t}$
	$\lambda t_{\frac{1}{2}} = \ln 2$

Experimental physics

$$\text{Percentage uncertainty} = \frac{\text{Estimated uncertainty} \times 100\%}{\text{Average value}}$$

Mathematics

$$\sin(90° - \theta) = \cos\theta$$

$$\ln(x^n) = n \ln x$$

$$\ln(e^{kx}) = kx$$

Equation of a straight line	$y = mx + c$	
Surface area	cylinder $= 2\pi rh + 2\pi r^2$	
	sphere $= 4\pi r^2$	
Volume	cylinder $= \pi r^2 h$	
	sphere $= \frac{4}{3}\pi r^3$	
For small angles:	$\sin\theta \approx \tan\theta \approx \theta$	(in radians)
	$\cos\theta \approx 1$	

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