Rewarding Learning

ADVANCED
General Certificate of Education
2023

Centre Number

Candidate Number

Physics

Assessment Unit A2 2
assessing

Fields, Capacitors and Particle Physics

[APH21]

APH21

FRIDAY 9 JUNE, MORNING

TIME

2 hours.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.
You must answer the questions in the spaces provided.
Do not write outside the boxed area on each page or on blank pages.
Complete in black ink only. **Do not write with a gel pen.**
Answer **all eight** questions.

INFORMATION FOR CANDIDATES

The total mark for this paper is 100.
Quality of written communication will be assessed in question **7(a)**.
Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part question.
Your attention is drawn to the Data and Formulae Sheet which is inside this question paper.
You may use an electronic calculator.

1 (a) In any interaction between sub-atomic particles, lepton number must be conserved. State **two** other conservation laws that must be obeyed.

____

____ [2]

(b) In **Table 1.1**, indicate with a tick (✓) which of the statements are correct for each particle listed.

Table 1.1

Particle	Is fundamental	Is a lepton	Is acted on by the strong nuclear force	Is a gauge boson
Electron				
Neutron				
Kaon (a meson)				
Neutrino				

[4]

(c) In 2012 scientists at CERN claimed to have discovered the Higgs boson. Its rest energy was measured to be 126 GeV.

Calculate the rest mass of the Higgs boson.

Mass = ________________ kg [4]

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(Questions continue overleaf)

2 A satellite in a polar orbit of the Earth passes from North to South over the poles. A polar orbit is widely used for monitoring the Earth because each day, as the Earth rotates below it, the entire surface of the Earth is observed.

The period of a satellite in a polar orbit is 1.68 hours.

(a) (i) Calculate the angular velocity of the satellite in this polar orbit.

Angular velocity = _______________ rad s^{-1} [3]

(ii) The mass of the Earth is 5.97×10^{24} kg and it has a radius 6378 km. Calculate the height of the satellite's polar orbit above the Earth's surface. Give your answer in kilometres.

Height of orbit = _______________ km [6]

(b) State **two** differences between the orbit of a satellite in a polar orbit and that of a satellite in a geostationary orbit.

1. ____

____

2. ____

____ [2]

3 Spiders sometimes travel great distances by “ballooning”, where they are carried high in the air on silk threads. The silk threads become charged and the interaction of the charged silk threads with the electric field of the Earth provides the force needed to lift the spiders.

At one point on the surface of the Earth the electric field strength is $110\,V\,m^{-1}$. The direction of the electric field is towards the centre of the Earth.

(a) Explain why the charge on the silk strands must be negative.

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____ [1]

(b) (i) A spider of mass $2.0 \times 10^{-5}\,kg$ initially moves vertically upwards with an acceleration of $8.0\,m\,s^{-2}$. Calculate the magnitude of the charge on the silk threads.

Charge = ________________ C [6]

(ii) How many electrons were gained by the silk threads during the charging process?

Number of electrons = ________________ [1]

(c) At the end of the acceleration due to the electric field, the spider is moving with a vertical velocity of 35 m s^{-1}.

There is a breeze causing the spider to move horizontally with a velocity of 3.2 m s^{-1}.

Calculate the horizontal distance the spider moves between the end of the acceleration due to the electric field and the time the spider reaches its maximum height.

Distance = _______________ m [6]

[Turn over

4 In a hydrogen atom, when an electron is in the ground state, the distance between the electron and the proton is 5.29×10^{-11} m.

(a) (i) Determine the electrostatic force between the proton and the electron in the ground state. State the direction of the force on the electron.

Force = ________________ N

Direction = ____ [4]

(ii) Describe and explain what happens to the magnitude of the force as the distance between the electron and the proton is increased.

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____

____ [2]

(b) The de Broglie wavelength λ of the electron in the ground state is given by **Equation 4.1** where r is the distance between the electron and the proton.

$$\lambda = 2\pi r \qquad \textbf{Equation 4.1}$$

(i) Calculate the velocity of the electron in the ground state.

Velocity = _______________ m s^{-1} [3]

(ii) Determine the kinetic energy of the electron in the ground state.

Give your answer in electron volts.

Energy = _______________ eV [3]

5 (a) An uncharged capacitor is connected to a battery. Describe what happens to the charge carriers from the instant that the battery is connected until the capacitor is fully charged.

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____ [5]

(b) (i) An uncharged, 200 μF capacitor is charged by connecting it to a 12 V battery.

On the grid of **Fig. 5.1**, draw a graph showing how the charge Q on the capacitor plates varies with the potential difference V across the capacitor plates.

Calculate and insert an appropriate Q value and draw the line showing how Q varies with V.

Use the space below **Fig. 5.1** for any calculations needed.

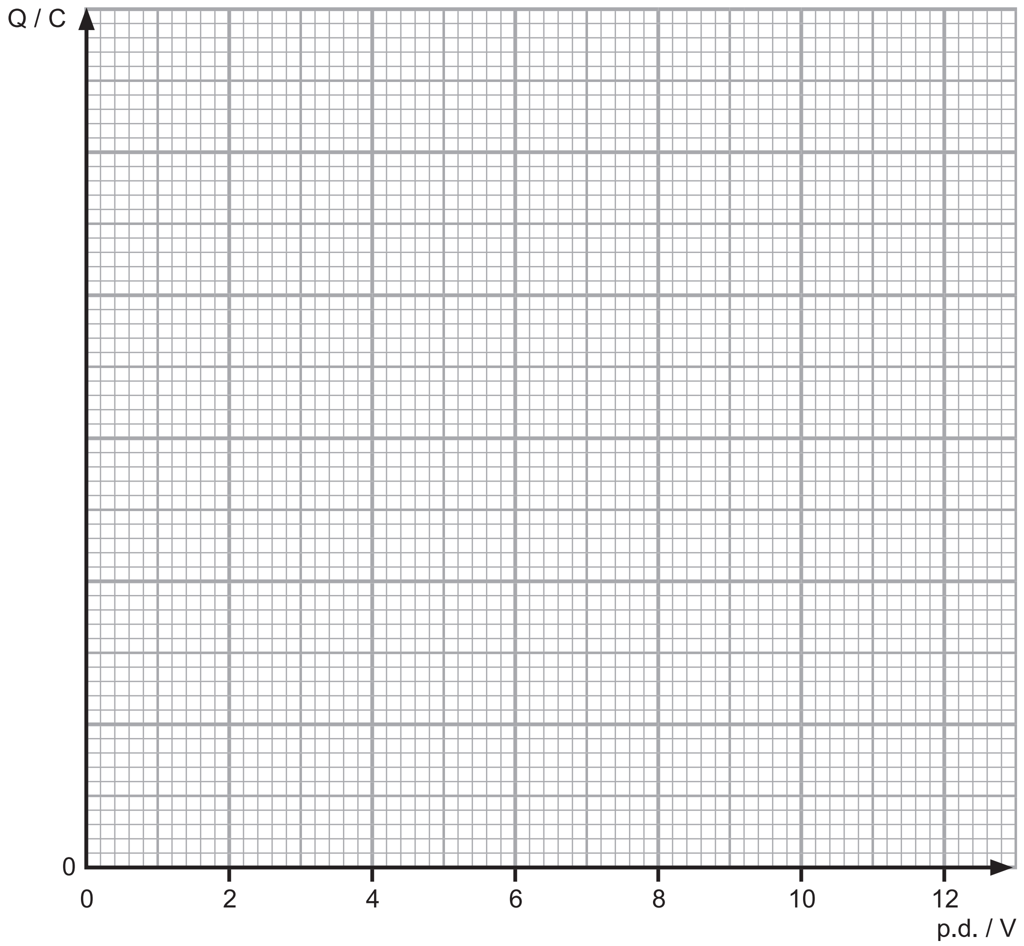

Fig. 5.1

[4]

(ii) Calculate the energy stored by the capacitor when it is fully charged.

Energy stored = _______________ J [3]

(c) After being charged to 12 V, the 200 μF capacitor is then discharged through a 570 Ω resistor.

(i) Calculate the initial current that flows through the resistor. Give your answer in milliamps.

Current = _______________ mA [4]

(ii) Calculate the reduction in current after a time of 0.16 s.

Reduction in current = _______________ mA [4]

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(Questions continue overleaf)

6 A magnet is suspended from a spring above a coil of wire as shown in **Fig. 6.1**. When the magnet is displaced vertically and released it oscillates. The coil is connected to a centre zero ammeter.

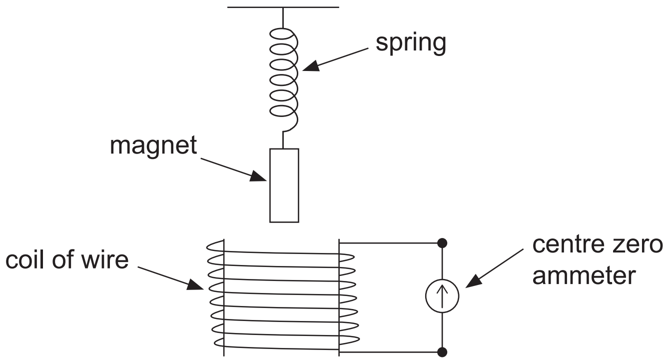

Fig. 6.1

(a) Describe what will happen to the needle on the ammeter as the magnet oscillates.

____

____ [1]

(b) The first coil is connected to a second coil. A spring and magnet, identical to the first are suspended above the second coil, as shown in **Fig. 6.2**.

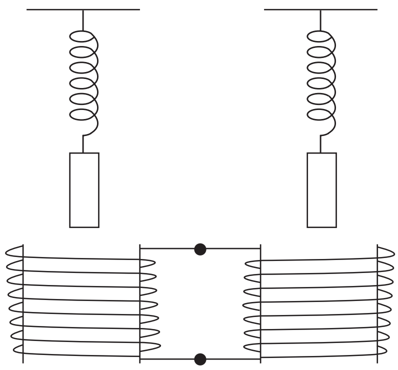

Fig. 6.2

(i) If the first magnet is set into oscillation, explain why the second magnet will start to oscillate.

____

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____ [3]

(ii) Explain why the second spring and magnet must be identical to the first spring and magnet for the oscillation of the second magnet to be as large as possible.

____

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____ [2]

(c) The coil of an a.c. generator completes 18 revolutions every second. It rotates in a uniform magnetic field of strength 0.05 T. The coil has an area of 3.0 cm^2 and 90 turns. Calculate the maximum induced e.m.f. across the coil.

e.m.f. = ________________ V [4]

Quality of written communication will be assessed in part (a) of this question.

7 **(a)** The National Grid transfers electricity from the power station to where it is needed. Explain why transformers are used in the National Grid system and state the type and position of the different transformers that are used.

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____ [6]

(b) The current flowing through a 175 m long power line is 85 A. The component of the Earth's magnetic field that is perpendicular to the power line has a magnetic flux density of 1.2×10^{-5} T. The direction of the magnetic field is into the page and at this instant, the current is in the direction shown in **Fig. 7.1**.

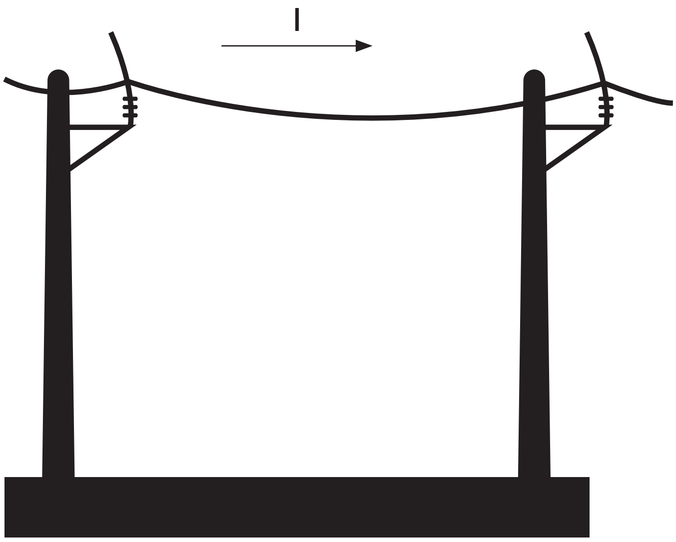

Fig. 7.1

Calculate the magnitude of the force on the power line due to the magnetic field of the Earth. State the direction of the force at this instant.

Force = _______________ N

Direction = _______________ [4]

[Turn over

8 **Fig. 8.1** shows the path of protons before and after entering a synchrotron.

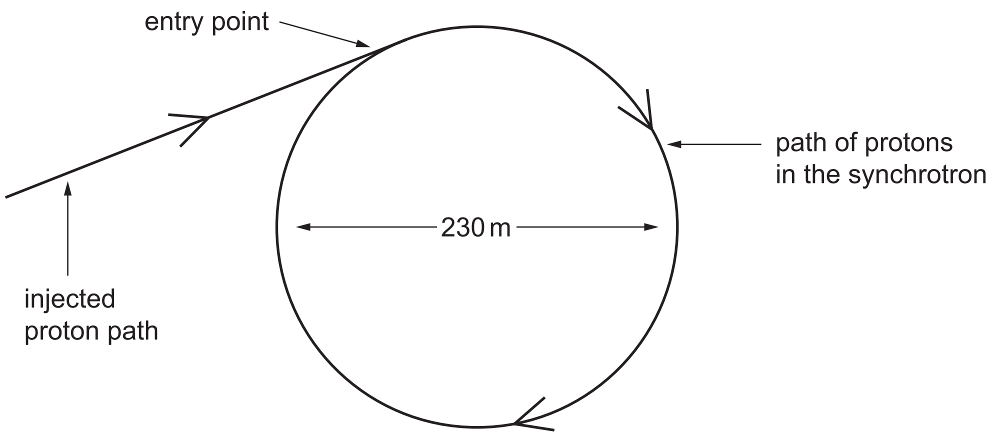

Fig. 8.1

(a) Electric and magnetic fields cause the proton to accelerate. State the effect of the acceleration caused by each type of field.

Electric field:

____

Magnetic field:

____ [2]

(b) **(i)** The protons are injected into the synchrotron at a speed of 1.3×10^5 m s^{-1}. If the protons follow the path shown in **Fig. 8.1**, calculate the magnetic flux density of the field in the synchrotron at the time of injection.

Magnetic flux density = ________________ T [4]

(ii) Describe how and explain why the magnetic flux density must be changed as the protons gain energy.

____

____

____ [3]

(c) The accurate value for the speed of light c is 2.99792458×10^{8} m s^{-1}. A proton in a synchrotron can be accelerated to a speed v which is 3 m s^{-1} less than c.

The relativistic mass m of an object travelling at a speed v is given by **Equation 8.1**.

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$ **Equation 8.1**

The rest mass m_0 of a proton is $1.67262189 \times 10^{-27}$ kg. Calculate the relativistic mass of the proton when it is travelling at the speed v in the synchrotron. Give your answer to an appropriate number of significant figures.

Relativistic mass = _______________ kg [4]

THIS IS THE END OF THE QUESTION PAPER

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For Examiner's use only	
Question Number	Marks
1	
2	
3	
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8	
Total Marks	

Examiner Number

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General Certificate of Education

Physics

Assessment Units A2 1 and A2 2

[APH11/APH21]

DATA AND FORMULAE SHEET

Data and Formulae Sheet for A2 1 and A2 2

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^{8}$ m s^{-1}
permittivity of a vacuum	$\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
	$\left(\dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \text{F}^{-1}\ \text{m}\right)$
elementary charge	$e = 1.60 \times 10^{-19}$ C
the Planck constant	$h = 6.63 \times 10^{-34}$ J s
(unified) atomic mass unit	1 u = 1.66×10^{-27} kg
mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
mass of proton	$m_p = 1.67 \times 10^{-27}$ kg
molar gas constant	$R = 8.31$ J K^{-1} mol^{-1}
the Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant	$k = 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant	$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall on the Earth's surface	$g = 9.81$ m s^{-2}
electron volt	1 e$V = 1.60 \times 10^{-19}$ J
the Hubble constant	$H_0 \approx 2.4 \times 10^{-18}$ s^{-1}

Useful formulae

The following equations may be useful in answering some of the questions in the examination:

Mechanics

conservation of energy	$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$ for a constant force
Hooke's Law	$F = kx$ (spring constant k)
strain energy	$E = \frac{1}{2}\mathrm{Fx} = \frac{1}{2}kx^2$

Uniform circular motion

centripetal Force	$F = \frac{mv^2}{r}$

Simple harmonic motion

displacement	$x = A\cos\omega t$
simple pendulum	$T = 2\pi\sqrt{\frac{l}{g}}$
loaded spiral spring	$T = 2\pi\sqrt{\frac{m}{k}}$

Waves

two-source interference	$\lambda = \frac{ay}{d}$
diffraction grating	$d\sin\theta = n\lambda$

Thermal physics

average kinetic energy of a molecule $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$

kinetic theory $pV = \frac{1}{3} Nm \langle c^2 \rangle$

thermal energy $Q = mc\Delta\theta$

Capacitors

capacitors in series $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

capacitors in parallel $C = C_1 + C_2 + C_3$

time constant $\tau = RC$

capacitor discharge $Q = Q_0 e^{\frac{-t}{CR}}$

or $V = V_0 e^{\frac{-t}{CR}}$

or $I = I_0 e^{\frac{-t}{CR}}$

Light

lens formula $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

Electricity

terminal potential difference $V = E - Ir$

(e.m.f., E; Internal Resistance, r)

potential divider $V_{out} = \frac{R_1 V_{in}}{R_1 + R_2}$

a.c. generator $E = BAN\omega \sin\omega t$

Nuclear Physics

nuclear radius	$r = r_0 A^{\frac{1}{3}}$
radioactive decay	$A = -\lambda N, \quad A = A_0 e^{-\lambda t}$
half-life	$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$

Particles and photons

Einstein's equation	$\frac{1}{2} m v_{max}^2 = hf - hf_0$
de Broglie equation	$\lambda = \frac{h}{p}$

Astronomy

red shift	$z = \frac{\Delta\lambda}{\lambda}$
recession speed	$z = \frac{v}{c}$
Hubble's law	$v = H_0 d$