



Rewarding Learning

ADVANCED
General Certificate of Education
2023

Centre Number

--	--	--	--	--

Candidate Number

--	--	--	--	--

Physics

StemUp Model Solution

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.

13550



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

Conservation of charge.

Conservation of baryon number.

[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.

$$E = 126 \text{ GeV} = 126 \times 10^9 \text{ eV}$$

$$E = 126 \times 10^9 \times 1.60 \times 10^{-19} = 2.016 \times 10^{-8} \text{ J}$$

$$E = mc^2 \text{ so } m = E / c^2$$

$$m = 2.016 \times 10^{-8} / (3.00 \times 10^8)^2$$

$$m = 2.24 \times 10^{-25} \text{ kg}$$

Mass = 2.24×10^{-25} kg

[4]





BLANK PAGE

DO NOT WRITE ON THIS PAGE

(Questions continue overleaf)

13550

[Turn over



- 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.

$$T = 1.68 \times 3600 = 6048 \text{ s}$$

$$\omega = 2\pi / T$$

$$\omega = 2\pi / 6048$$

$$\omega = 1.04 \times 10^{-3} \text{ rad s}^{-1}$$

Angular velocity = 1.04×10^{-3} 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.

Gravitational force provides the centripetal force:

$$GMm / r^2 = m\omega^2 r \quad \text{so} \quad \omega^2 = GM / r^3$$

$$r^3 = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (1.039 \times 10^{-3})^2$$

$$r^3 = 3.69 \times 10^{20} \text{ m}^3 \quad \text{so} \quad r = 7.17 \times 10^6 \text{ m}$$

$$h = r - R = 7.17 \times 10^6 - 6.378 \times 10^6 = 7.94 \times 10^5 \text{ m}$$

$$h = 794 \text{ km}$$

Height of orbit = 794 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. *A geostationary satellite orbits above the equator, whereas a polar orbit passes over the poles.*
2. *A geostationary orbit has a period of 24 hours, whereas the polar orbit has a much shorter period (1.68 hours) and a lower height.* [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.

The field direction is the direction of the force on a positive charge, which is downwards. The force on the threads is upwards (opposite to the field), so the charge must be negative.

[1]

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

$$\text{Resultant force} = ma = 2.0 \times 10^{-5} \times 8.0 = 1.6 \times 10^{-4} \text{ N}$$

$$\text{Weight} = mg = 2.0 \times 10^{-5} \times 9.81 = 1.96 \times 10^{-4} \text{ N}$$

$$\text{Upward electric force } F = 1.6 \times 10^{-4} + 1.96 \times 10^{-4} = 3.6 \times 10^{-4} \text{ N}$$

$$F = Eq \text{ so } q = F / E = 3.56 \times 10^{-4} / 110$$

$$q = 3.2 \times 10^{-6} \text{ C}$$

$$\text{Charge} = 3.2 \times 10^{-6} \text{ C}$$

[6]

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

$$n = q / e = 3.24 \times 10^{-6} / 1.60 \times 10^{-19} = 2.0 \times 10^{13}$$

$$\text{Number of electrons} = 2.0 \times 10^{13}$$

[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.

Vertically, the spider decelerates at g until $v = 0$ at maximum height:

$$v = u + at$$

$$0 = 35 - 9.81t$$

$$t = 35 / 9.81 = 3.57 \text{ s}$$

Horizontal velocity is constant:

$$s = ut = 3.2 \times 3.57$$

$$s = 11.4 \text{ m}$$

Distance = 11.4 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 $5.29 \times 10^{-11} \text{ m}$.

- (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.

$$F = q_1 q_2 / 4\pi\epsilon_0 r^2$$

$$F = 8.99 \times 10^9 \times (1.60 \times 10^{-19})^2 / (5.29 \times 10^{-11})^2$$

$$F = 8.22 \times 10^{-8} \text{ N}$$

Force = 8.22×10^{-8} N

Direction = towards the proton (attractive) [4]

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

The force decreases, because it is inversely proportional to the
square of the separation ($F \propto 1/r^2$): doubling r reduces F to a
quarter. [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.

$$\lambda = 2\pi r \quad \text{Equation 4.1}$$

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

$$\lambda = 2\pi r = 2\pi \times 5.29 \times 10^{-11} = 3.32 \times 10^{-10} \text{ m}$$

$$\lambda = h / mv \quad \text{so} \quad v = h / m\lambda$$

$$v = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 3.32 \times 10^{-10})$$

$$v = 2.19 \times 10^6 \text{ m s}^{-1}$$

Velocity = 2.19 × 10⁶ m s⁻¹ [3]

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

Give your answer in electron volts.

$$E_k = \frac{1}{2}mv^2$$

$$E_k = \frac{1}{2} \times 9.11 \times 10^{-31} \times (2.19 \times 10^6)^2$$

$$E_k = 2.18 \times 10^{-18} \text{ J}$$

$$E_k = 2.18 \times 10^{-18} / 1.60 \times 10^{-19} = 13.6 \text{ eV}$$

Energy = 13.6 eV [3]

[Turn over]



- 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.

The charge carriers are electrons. On connection, electrons flow from the negative terminal onto the plate connected to it, which becomes negatively charged.

At the same time electrons are repelled from the other plate to the positive terminal, so it becomes equally positively charged. No electrons cross the gap.

As charge builds up the capacitor p.d. rises, so the rate of flow of electrons (current) decreases. When the capacitor p.d. equals the battery p.d., electrons stop moving: current is zero.

[5]



- (b) (i) An uncharged, $200\ \mu\text{F}$ 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.

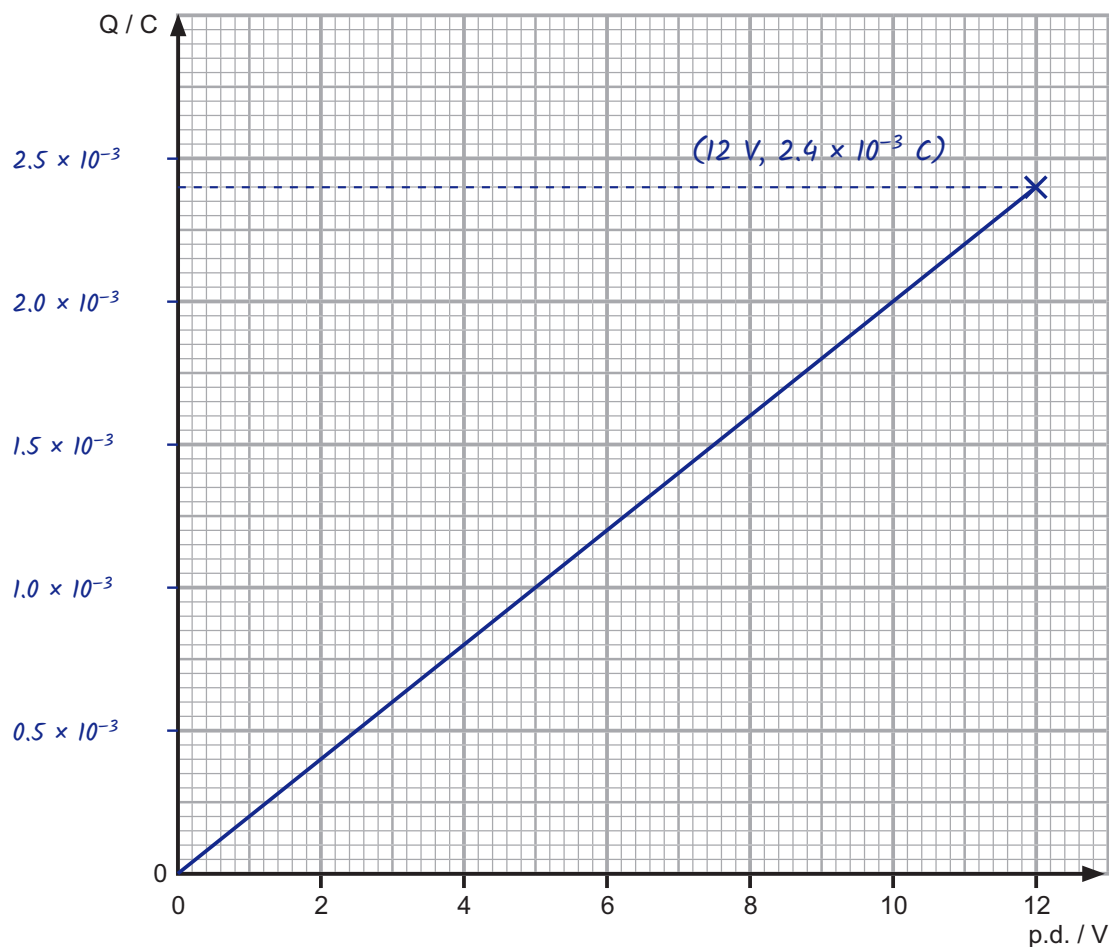


Fig. 5.1

$$Q = CV = 200 \times 10^{-6} \times 12$$

$$Q = 2.4 \times 10^{-3} \text{ C at } 12 \text{ V}$$

[4]

[Turn over]



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

$$E = \frac{1}{2} CV^2 \text{ (area under the } Q \text{ against } V \text{ graph)}$$

$$E = \frac{1}{2} \times 200 \times 10^{-6} \times 12^2$$

$$E = 0.0144 \text{ J}$$

$$\text{Energy stored} = \underline{0.0144} \text{ J}$$

[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.

$$I = V / R$$

$$I = 12 / 570$$

$$I = 0.021 \text{ A} = 21 \text{ mA}$$

$$\text{Current} = \underline{21} \text{ mA}$$

[4]

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

$$\tau = RC = 570 \times 200 \times 10^{-6} = 0.114 \text{ s}$$

$$I = I_0 e^{-t/CR}$$

$$I = 21 \times \exp(-0.16 / 0.114)$$

$$I = 5.2 \text{ mA}$$

$$\text{Reduction} = 21 - 5.2 = 15.8 \text{ mA}$$

$$\text{Reduction in current} = \underline{15.8} \text{ mA}$$

[4]





BLANK PAGE

DO NOT WRITE ON THIS PAGE

(Questions continue overleaf)

13550

[Turn over



- 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.

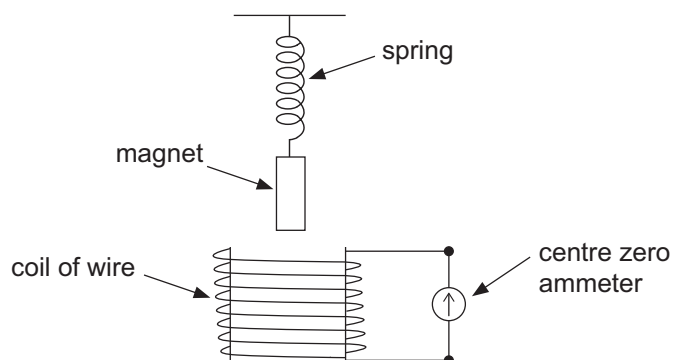


Fig. 6.1

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

The needle oscillates from side to side (left and right of zero), at the same frequency as the magnet.

[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**.

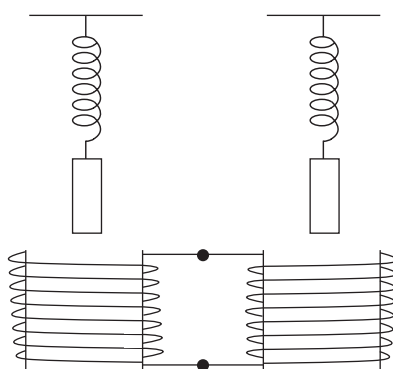


Fig. 6.2



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

The moving magnet changes the flux linkage of coil 1, inducing an alternating e.m.f. that drives an alternating current through both coils. This causes a changing magnetic flux in the second coil, which exerts a periodic force on the second magnet so it oscillates.

[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.

Then the second system has the same natural frequency as the first. The driving (forcing) frequency equals its natural frequency, so resonance occurs and the amplitude is a maximum.

[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.

$$A = 3.0 \text{ cm}^2 = 3.0 \times 10^{-4} \text{ m}^2$$

$$\omega = 2\pi f = 2\pi \times 18 = 113 \text{ rad s}^{-1}$$

$$E_{\text{max}} = BAN\omega$$

$$E_{\text{max}} = 0.05 \times 3.0 \times 10^{-4} \times 90 \times 113$$

$$E_{\text{max}} = 0.15 \text{ V}$$

e.m.f. = 0.15 V

[4]

[Turn over]



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.

At the power station a step-up transformer is used between the generator and the transmission lines. It increases the voltage to a very high value (for example 400 kV).

For the same power transmitted ($P = IV$), a higher voltage means a much lower current in the cables. Since the power loss in the cables is $P = I^2R$, the lower current greatly reduces the energy lost as heat in the cables, so transmission is more efficient.

Near where the electricity is needed, step-down transformers (at substations) reduce the voltage in stages to a safe value (230 V) before it is used in homes.

[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 $1.2 \times 10^{-5} \text{ T}$. 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**.

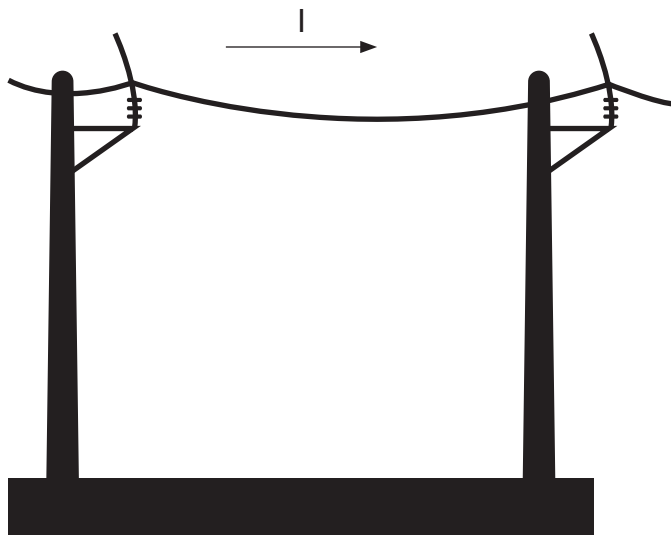


Fig. 7.1

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.

$$F = BIl$$

$$F = 1.2 \times 10^{-5} \times 85 \times 175$$

$$F = 0.18 \text{ N}$$

Force = 0.18 N

Direction = upwards

[4]

[Turn over]



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

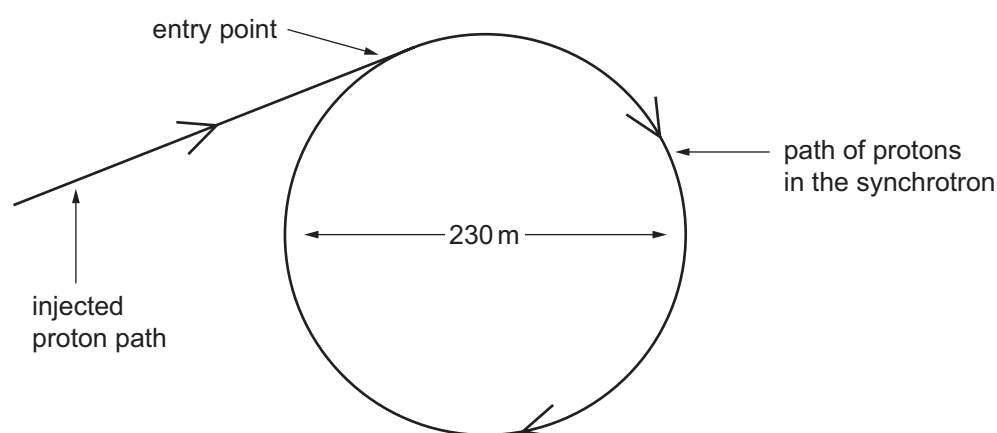


Fig. 8.1

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

Electric field:

It increases the energy (speed) of the protons.

Magnetic field:

It changes their direction, keeping them on a circular path.

[2]

- (b) (i) The protons are injected into the synchrotron at a speed of $1.3 \times 10^5 \text{ m s}^{-1}$. 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.

$$Bqv = mv^2 / r \quad \text{so} \quad B = mv / qr, \quad \text{with } r = 230 / 2 = 115 \text{ m}$$

$$B = 1.67 \times 10^{-27} \times 1.3 \times 10^5 / (1.60 \times 10^{-19} \times 115)$$

$$B = 1.2 \times 10^{-5} \text{ T}$$

Magnetic flux density = 1.2×10^{-5} T

[4]



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

B must be increased. Faster protons need a bigger centripetal force

($F = mv^2/r$) to keep the radius of the circle constant, and since r

$= mv/Bq$, B must rise as the momentum rises. [3]

- (c) The accurate value for the speed of light c is $2.99792458 \times 10^8 \text{ m s}^{-1}$. 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**.

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

The rest mass m_0 of a proton is $1.67262189 \times 10^{-27} \text{ kg}$. 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.

$$v = 2.99792458 \times 10^8 - 3 = 2.99792455 \times 10^8 \text{ m s}^{-1}$$

$$m = m_0 / \sqrt{1 - v^2/c^2}$$

$$1 - v^2/c^2 = 1 - (2.99792455 / 2.99792458)^2 = 2.0014 \times 10^{-8}$$

$$m = 1.67262189 \times 10^{-27} / \sqrt{2.0014 \times 10^{-8}}$$

$$m = 1.18231 \times 10^{-23} \text{ kg} = 1.18 \times 10^{-23} \text{ kg (3 s.f.)}$$

Relativistic mass = 1.18×10^{-23} kg [4]

THIS IS THE END OF THE QUESTION PAPER



DO NOT WRITE ON THIS PAGE

For Examiner's use only	
Question Number	Marks
1	
2	
3	
4	
5	
6	
7	
8	

Total Marks	
-------------	--

Examiner Number

Permission to reproduce all copyright material has been applied for.
In some cases, efforts to contact copyright holders may have been unsuccessful and CCEA
will be happy to rectify any omissions of acknowledgement in future if notified.

APH21/6
276857





Rewarding Learning

ADVANCED
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	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permittivity of a vacuum	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ $\left(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ F}^{-1} \text{ m} \right)$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
(unified) atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall on the Earth's surface	$g = 9.81 \text{ m s}^{-2}$
electron volt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$
the Hubble constant	$H_0 \approx 2.4 \times 10^{-18} \text{ s}^{-1}$

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 $E = \frac{1}{2}Fx = \frac{1}{2}kx^2$

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

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

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

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

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

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

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

$$v = H_0 d$$

