



Rewarding Learning

ADVANCED
General Certificate of Education
2024

Centre Number

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Candidate Number

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Physics

StemUp Model Solution

Assessment Unit A2 2
assessing

Fields, Capacitors and
Particle Physics



[APH21]

APH21

THURSDAY 6 JUNE, AFTERNOON

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 and use a dark HB pencil for drawings and graphs.

Do not write with a gel pen.

Answer **all seven** questions.

INFORMATION FOR CANDIDATES

The total mark for this paper is 100.

Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part question.

You may use a scientific calculator.

A Data and Formulae Sheet is included in this question paper.

Quality of written communication will be assessed in Question **3(a)**.

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1 Fig. 1.1 shows a diagram of a step-up transformer.

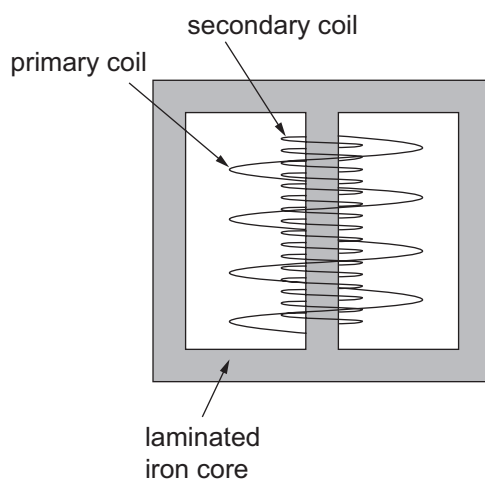


Fig. 1.1

- (a) State how you can determine from the diagram that the transformer is a step-up transformer.

The secondary coil has more turns than the primary coil ($N_s > N_p$).

[1]

- (b) The coils are wound on a common core that is laminated to reduce energy loss and improve efficiency.

- (i) State a reason for winding the primary and secondary coils on a common core as shown in Fig. 1.1.

So that all the magnetic flux produced by the primary links the secondary coil; it reduces flux leakage.

[1]

- (ii) Explain the reason for laminating the core and state the advantage of doing this.

Laminating reduces the eddy currents induced in the core, which reduces energy lost as heating within the core.

[2]

[Turn over]



- (c) The primary coil of a transformer is connected to an a.c. supply with a 40 V peak value. This induces an e.m.f. across the secondary coil as shown in Fig. 1.2.

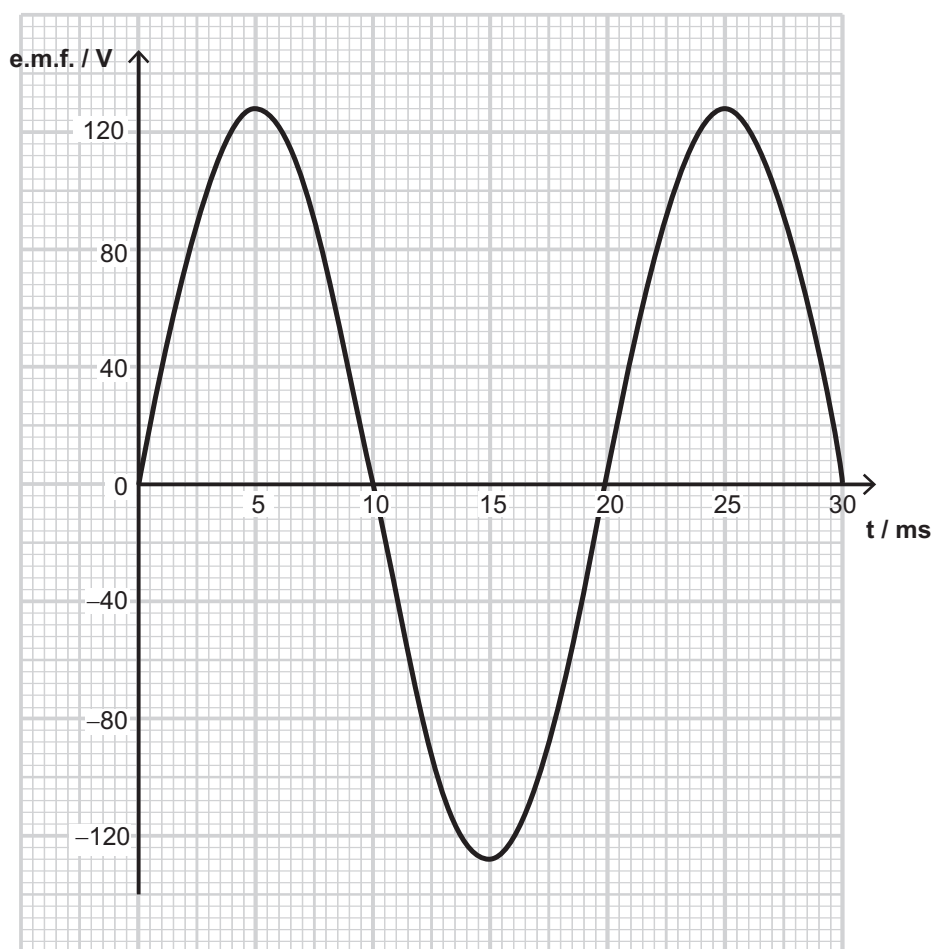


Fig. 1.2



- (i) Calculate the number of turns on the primary coil if the secondary coil has 800 turns.

Peak secondary e.m.f. from Fig. 1.2: $V_s = 128 \text{ V}$

$$V_s / V_p = N_s / N_p$$

$$128 / 40 = 800 / N_p$$

$$N_p = 800 \times 40 / 128 = 250$$

Number of turns on primary coil = 250 [4]

- (ii) Calculate the current drawn from the 40 V a.c. supply if the current in the secondary coil is 0.75 A. Assume that the transformer is 100% efficient.

$$N_s / N_p = I_p / I_s \quad (\text{or } V_p I_p = V_s I_s)$$

$$800 / 250 = I_p / 0.75$$

$$I_p = 3.2 \times 0.75 = 2.4 \text{ A}$$

Current = 2.4 A [3]

[Turn over]



- 2 (a) Define capacitance.

Capacitance is the charge stored per unit potential difference across the capacitor ($C = Q / V$).

[1]

- (b) Most smart phones, tablets and computers use capacitive touchscreens. These touch sensitive screens use the touch of a human finger or stylus for input and control.

- (i) A capacitor within a touchscreen is connected to a 6 V supply. A finger touches the screen and the capacitance increases by 50 nF. This causes charge to flow onto the capacitor. Calculate the amount of charge that flows onto the capacitor.

$$\Delta C = 50 \text{ nF} = 50 \times 10^{-9} \text{ F}$$

$$Q = CV$$

$$\Delta Q = 50 \times 10^{-9} \times 6$$

$$\Delta Q = 3.0 \times 10^{-7} \text{ C}$$

Charge = 3.0×10^{-7} C

[4]

- (ii) Calculate the increase in energy stored when the charge has moved onto the capacitor.

$$E = \frac{1}{2}QV$$

$$\Delta E = \frac{1}{2} \times 3.0 \times 10^{-7} \times 6$$

$$\Delta E = 9.0 \times 10^{-7} \text{ J}$$

Energy = 9.0×10^{-7} J

[3]



- (c) (i) Many touchscreens incorporate polarising filters to plane-polarise the light emitted which reduces reflections and improves contrast. Explain what is meant by plane-polarised light.

*Light in which the vibrations (of the electric field) are confined
to a single plane.*

[1]

- (ii) Most modern touchscreens emit blue light. Calculate the energy of a photon of blue light of wavelength $4.50 \times 10^{-7} \text{ m}$.

$$E = hf = hc / \lambda$$

$$E = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 4.50 \times 10^{-7}$$

$$E = 4.42 \times 10^{-19} \text{ J}$$

$$\text{Energy} = 4.42 \times 10^{-19} \text{ J}$$

[3]

[Turn over]



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

- 3 The Standard Model of particle physics is a theory concerning the four fundamental forces in nature and is used to classify all subatomic particles that are known to exist. One of the four fundamental forces, the weak nuclear force, acts on leptons and quarks. Its associated exchange particles are the W^+ , W^- and Z^0 .

(a) Write a brief account of the **other three** fundamental forces. In your answer include:

- the name of each force;
- the type of particle that each force acts on;
- its associated exchange particle.

The gravitational force acts on all particles with mass. Its exchange particle is the graviton (which has not yet been detected). It is always attractive, has infinite range and is the weakest of the four forces.

The electromagnetic force acts on charged particles, such as protons and electrons. Its exchange particle is the (virtual) photon. It can be attractive or repulsive and has infinite range.

The strong nuclear force acts on quarks, and so on hadrons such as protons and neutrons. Its exchange particle is the gluon. It holds the quarks together inside hadrons and binds nucleons in the nucleus, but has a very short range.

[6]



(b) Hadrons (which are made up of quarks) can be classified as either baryons or mesons.

Complete **Table 3.1** for the two hadrons that are named by indicating whether each is a baryon or meson and stating the quark structure and baryon number of each hadron.

Table 3.1

hadron	baryon or meson	quark structure	baryon number
antiproton	<i>baryon</i>	$\bar{u} \bar{u} \bar{d}$	-1
neutron	<i>baryon</i>	$u d d$	$+1$

[3]

[Turn over]



4 (a) What is a gravitational field?

A region of space around a mass within which another mass will experience a force. The force is always attractive.

[3]

(b) The position on Earth of the receiver of a Global Positioning System (GPS) can be accurately determined when it receives radio wave signals from GPS satellites orbiting the Earth. Each GPS satellite orbits the Earth twice every day.

- (i) Calculate the height of a GPS satellite above the Earth's surface.
The mass of the Earth is 5.98×10^{24} kg.
The radius of Earth is 6.37×10^6 m.

Gravitational force provides the centripetal force:

$$GM_E m / r^2 = mv^2 / r = 4\pi^2 mr / T^2$$

$$\text{so } r^3 = GM_E T^2 / 4\pi^2$$

$$\text{Two orbits per day: } T = 12 \text{ hours} = 12 \times 3600 = 43\,200 \text{ s}$$

$$r^3 = 6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 43\,200^2 / 4\pi^2$$

$$r^3 = 1.886 \times 10^{22} \text{ m}^3$$

$$r = 2.66 \times 10^7 \text{ m}$$

$$h = r - R_E = 2.66 \times 10^7 - 6.37 \times 10^6$$

$$h = 2.02 \times 10^7 \text{ m}$$

$$\text{Height above Earth's surface} = 2.02 \times 10^7 \text{ m}$$

[7]



- (ii) Determine the linear speed of the GPS satellite at this height above the Earth's surface.

$$v = 2\pi r / T$$

$$v = 2\pi \times 2.66 \times 10^7 / 43\,200$$

$$v = 3870 \text{ m s}^{-1}$$

Linear speed = 3870 m s⁻¹

[3]



- 5 (a) (i) The equation representing Coulomb's law contains the term ϵ_0 , the permittivity of a vacuum. Write down this equation and identify any other terms used.

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

F is the (electrostatic) force between the two charges,

q_1 and q_2 are the two point charges,

r is the separation of the charges.

[3]

- (ii) Determine the base units of ϵ_0 .

$$\epsilon_0 = q_1 q_2 / 4\pi F r^2, \text{ so units of } \epsilon_0 = C^2 N^{-1} m^{-2}$$

$$C = A s$$

$$N = kg m s^{-2}$$

$$\epsilon_0: A^2 s^2 / (kg m s^{-2} \times m^2)$$

$$= A^2 s^4 kg^{-1} m^{-3}$$

$$\text{Base units} = A^2 s^4 kg^{-1} m^{-3}$$

[4]



- (b) **Fig. 5.1** shows two parallel plates separated by a distance of 35 mm. A potential difference of 500 V is applied across the plates.

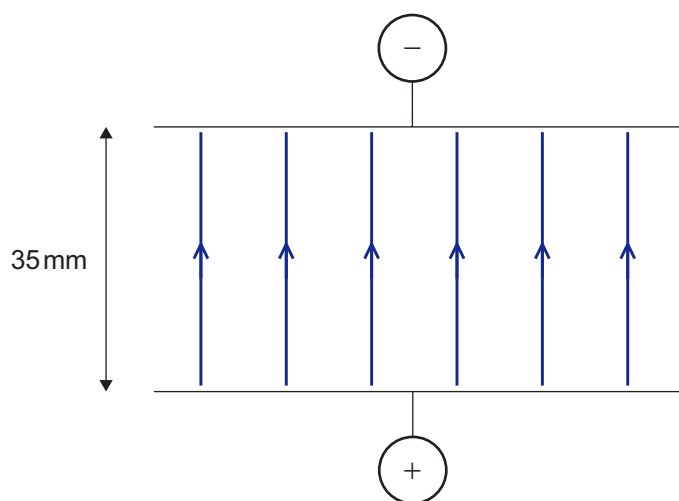


Fig. 5.1

- (i) On **Fig. 5.1**, sketch the electric field lines between the two plates and show the direction of the electric field with appropriate arrows. [3]
- (ii) Calculate the magnitude of the electric field strength between the plates.

$$E = V / d$$

$$d = 35 \text{ mm} = 0.035 \text{ m}$$

$$E = 500 / 0.035$$

$$E = 1.43 \times 10^4 \text{ V m}^{-1}$$

Electric field strength = $\underline{1.43 \times 10^4}$ V m⁻¹ [4]

[Turn over]



- (c) A beam of electrons enters the electric field between the two plates. It enters horizontally with a speed of $4.35 \times 10^7 \text{ m s}^{-1}$. The plates are of length L metres. The electron beam is deflected through a vertical distance of 5.72 mm on exiting the electric field. **Fig. 5.2** illustrates the situation.

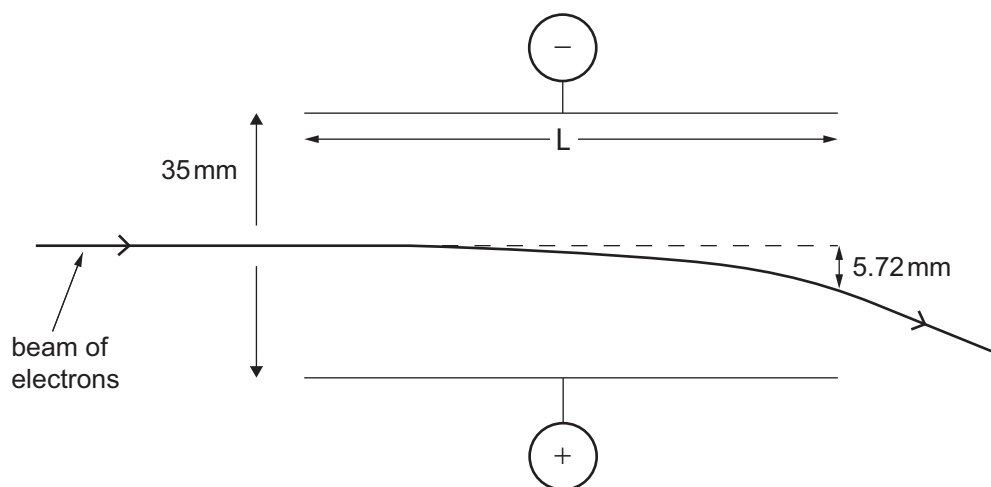


Fig. 5.2

- (i) Calculate the force on an electron in the beam due to the electric field.

$$F = eE$$

$$F = 1.6 \times 10^{-19} \times 1.43 \times 10^4$$

$$F = 2.29 \times 10^{-15} \text{ N}$$

Force = 2.29×10^{-15} N

[3]



- (ii) Calculate the acceleration of an electron in the beam due to the electric field.

$$a = F / m_e$$

$$a = 2.29 \times 10^{-15} / 9.11 \times 10^{-31}$$

$$a = 2.51 \times 10^{15} \text{ m s}^{-2}$$

$$\text{Acceleration} = \underline{2.51 \times 10^{15}} \text{ m s}^{-2} \quad [3]$$

- (iii) Calculate the length L of the plates.

Vertical motion ($u = 0$) gives the time in the field:

$$s = ut + \frac{1}{2}at^2$$

$$5.72 \times 10^{-3} = 0 + \frac{1}{2} \times 2.51 \times 10^{15} \times t^2$$

$$t = 2.13 \times 10^{-9} \text{ s}$$

Horizontal velocity is constant:

$$L = vt = 4.35 \times 10^7 \times 2.13 \times 10^{-9}$$

$$L = 0.093 \text{ m}$$

$$L = \underline{0.093} \text{ m} \quad [5]$$

[Turn over]



6 (a) (i) State Faraday's law of electromagnetic induction.

*The magnitude of the induced e.m.f. is equal to (proportional to)
the rate of change of magnetic flux linkage.*

[1]

(ii) State Lenz's law of electromagnetic induction.

*The direction of the induced current (e.m.f.) is such that it
opposes the change that is causing it.*

[1]



- (b) A circular coil of wire with 180 turns is placed perpendicular to a uniform magnetic field of flux density 0.40 T. The radius of the coil is 0.12 m and it has a resistance of 25 Ω .

- (i) Calculate the flux linkage through the coil and state the unit of flux linkage.

$$A = \pi r^2 = \pi \times 0.12^2 = 0.045 \text{ m}^2$$

$$\text{Flux linkage} = N\Phi = BAN$$

$$= 0.40 \times 0.045 \times 180$$

$$= 3.24 \text{ Wb}$$

$$\text{Flux linkage} = \underline{3.24}$$

$$\text{Unit of flux linkage} = \underline{\text{Wb (weber, or Wb turns)}}$$

[5]

- (ii) The coil is turned through 90° in 0.65 s. Calculate the average induced current in the coil.

$$\text{Flux linkage falls from 3.24 Wb to zero in 0.65 s}$$

$$E = \Delta(N\Phi) / \Delta t = 3.24 / 0.65 = 4.98 \text{ V}$$

$$I = E / R = 4.98 / 25 = 0.20 \text{ A}$$

$$\text{Induced current} = \underline{0.20} \text{ A}$$

[3]

[Turn over]



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- 7 (a) Fig. 7.1 shows the basic structure of a synchrotron. A synchrotron accelerates charged particles, in a circular path of fixed radius, to velocities approaching the speed of light.

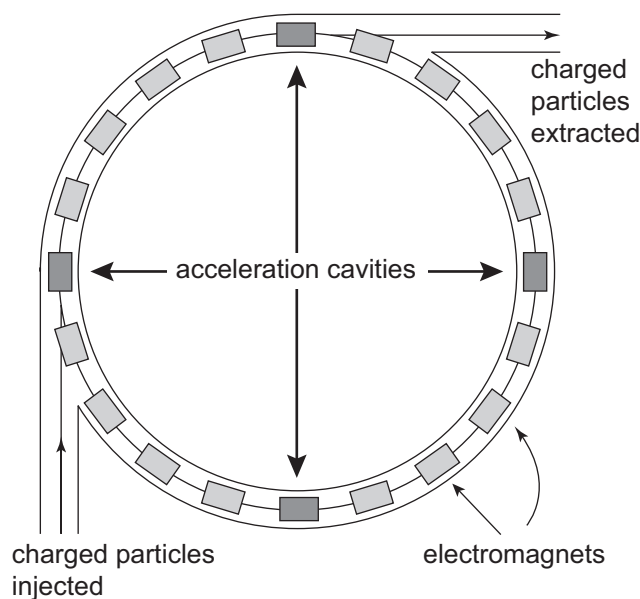


Fig. 7.1

- (i) Describe how the circular path of fixed radius is achieved.

The electromagnets provide the centripetal force; the strength of their magnetic field is increased as the particles speed up.

[2]

- (ii) Explain why there must be a vacuum in the pipes through which the particles travel.

To prevent energy losses due to collisions of the particles with air molecules in the pipes.

[2]

[Turn over]



(b) In 2020, the European Synchrotron Radiation Facility opened a synchrotron called the Extremely Brilliant Source. Here, electrons are first accelerated to $2.99 \times 10^8 \text{ m s}^{-1}$ in a booster ring and then transferred to a storage ring until required. When moving at this speed, electrons have an effective mass that is 12 times larger than their rest mass.

- (i) The storage ring has a circumference of 844 metres. Calculate how many orbits the electrons make every second. Assume that the speed of $2.99 \times 10^8 \text{ m s}^{-1}$ is maintained during each orbit. Give your answer to 3 significant figures.

$$\begin{aligned} \text{Orbits per second} &= v / \text{circumference} = 2.99 \times 10^8 / 844 \\ &= 354\,265 = 354\,000 \text{ (3 s.f.)} \end{aligned}$$

Number of orbits every second = 354 000 [3]

- (ii) Calculate the magnitude of the centripetal force acting on the electrons in the storage ring.

$$\text{Circumference} = 2\pi r, \text{ so } r = 844 / 2\pi = 134 \text{ m}$$

$$m = 12 \times 9.11 \times 10^{-31} \text{ kg}$$

$$F_c = mv^2 / r$$

$$F_c = 12 \times 9.11 \times 10^{-31} \times (2.99 \times 10^8)^2 / 134$$

$$F_c = 7.29 \times 10^{-15} \text{ N}$$

Centripetal force = 7.29×10^{-15} N [5]



(iii) Calculate the magnetic flux density produced by the electromagnets.

The magnetic force provides the centripetal force: $F_B = F_c$

$$F_B = Bqv$$

$$B = 7.29 \times 10^{-15} / (1.6 \times 10^{-19} \times 2.99 \times 10^8)$$

$$B = 1.52 \times 10^{-4} \text{ T}$$

Magnetic flux density = 1.52×10^{-4} T [4]

(iv) As the electrons orbit the storage ring they emit synchrotron radiation in the form of high frequency intense X-rays. The energy of each X-ray photon emitted from the synchrotron is 12440 eV.

If the energy delivered to each square millimetre every second is $2.67 \times 10^5 \text{ J}$, calculate the number of photons falling onto an area of 35 mm^2 each second.

$$\text{Energy of one photon} = 12\,440 \times 1.6 \times 10^{-19} = 1.99 \times 10^{-15} \text{ J}$$

$$\text{Energy per second on } 35 \text{ mm}^2 = 35 \times 2.67 \times 10^5 = 9.35 \times 10^6 \text{ J}$$

$$\text{Photons per second} = 9.35 \times 10^6 / 1.99 \times 10^{-15}$$

$$= 4.70 \times 10^{21}$$

Number of photons per second = 4.70×10^{21} [4]

[Turn over]



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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

$$v = H_0 d$$

