General Certificate of Education
January 2005
Advanced Level Examination

**PHYSICS (SPECIFICATION A)**          **PA10**
**Unit 10   The Synoptic Unit**

AQA
ASSESSMENT and
QUALIFICATIONS
ALLIANCE

Tuesday 1 February 2005   Afternoon Session

**In addition to this paper you will require:**
- a calculator;
- a pencil and a ruler.

Time allowed: 2 hours

**Instructions**
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions in the spaces provided.  All working must be shown.
- Do all rough work in this book.  Cross through any work you do not want marked.

**Information**
- The maximum mark for this paper is 80.
- Mark allocations are shown in brackets.
- The paper carries 20% of the total marks for Physics Advanced.
- A *Data Sheet* is provided on pages 3 and 4.  You may wish to detach this perforated sheet at the start of the examination.
- You are expected to use a calculator where appropriate.
- In questions requiring description and explanation you will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary where appropriate.  The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.

**PA10**

**Data Sheet**

- A perforated *Data Sheet* is provided as pages 3 and 4 of this question paper.

- This sheet may be useful for answering some of the questions in the examination.

- You may wish to detach this sheet before you begin work.

# Data Sheet

## Fundamental constants and values

| Quantity | Symbol | Value | Units |
|---|---|---|---|
| speed of light in vacuo | $c$ | $3.00 \times 10^8$ | m s$^{-1}$ |
| permeability of free space | $\mu_0$ | $4\pi \times 10^{-7}$ | H m$^{-1}$ |
| permittivity of free space | $\varepsilon_0$ | $8.85 \times 10^{-12}$ | F m$^{-1}$ |
| charge of electron | $e$ | $1.60 \times 10^{-19}$ | C |
| the Planck constant | $h$ | $6.63 \times 10^{-34}$ | J s |
| gravitational constant | $G$ | $6.67 \times 10^{-11}$ | N m$^2$ kg$^{-2}$ |
| the Avogadro constant | $N_A$ | $6.02 \times 10^{23}$ | mol$^{-1}$ |
| molar gas constant | $R$ | 8.31 | J K$^{-1}$ mol$^{-1}$ |
| the Boltzmann constant | $k$ | $1.38 \times 10^{-23}$ | J K$^{-1}$ |
| the Stefan constant | $\sigma$ | $5.67 \times 10^{-8}$ | W m$^{-2}$ K$^{-4}$ |
| the Wien constant | $\alpha$ | $2.90 \times 10^{-3}$ | m K |
| electron rest mass (equivalent to $5.5 \times 10^{-4}$u) | $m_e$ | $9.11 \times 10^{-31}$ | kg |
| electron charge/mass ratio | $e/m_e$ | $1.76 \times 10^{11}$ | C kg$^{-1}$ |
| proton rest mass (equivalent to 1.00728u) | $m_p$ | $1.67 \times 10^{-27}$ | kg |
| proton charge/mass ratio | $e/m_p$ | $9.58 \times 10^7$ | C kg$^{-1}$ |
| neutron rest mass (equivalent to 1.00867u) | $m_n$ | $1.67 \times 10^{-27}$ | kg |
| gravitational field strength | $g$ | 9.81 | N kg$^{-1}$ |
| acceleration due to gravity | $g$ | 9.81 | m s$^{-2}$ |
| atomic mass unit (1u is equivalent to 931.3 MeV) | u | $1.661 \times 10^{-27}$ | kg |

## Fundamental particles

| Class | Name | Symbol | Rest energy /MeV |
|---|---|---|---|
| photon | photon | $\gamma$ | 0 |
| lepton | neutrino | $\nu_e$ | 0 |
| | | $\nu_\mu$ | 0 |
| | electron | $e^\pm$ | 0.510999 |
| | muon | $\mu^\pm$ | 105.659 |
| mesons | pion | $\pi^\pm$ | 139.576 |
| | | $\pi^0$ | 134.972 |
| | kaon | $K^\pm$ | 493.821 |
| | | $K^0$ | 497.762 |
| baryons | proton | p | 938.257 |
| | neutron | n | 939.551 |

## Properties of quarks

| Type | Charge | Baryon number | Strangeness |
|---|---|---|---|
| u | $+\frac{2}{3}$ | $+\frac{1}{3}$ | 0 |
| d | $-\frac{1}{3}$ | $+\frac{1}{3}$ | 0 |
| s | $-\frac{1}{3}$ | $+\frac{1}{3}$ | $-1$ |

## Geometrical equations

arc length $= r\theta$

circumference of circle $= 2\pi r$

area of circle $= \pi r^2$

area of cylinder $= 2\pi rh$

volume of cylinder $= \pi r^2 h$

area of sphere $= 4\pi r^2$

volume of sphere $= \frac{4}{3}\pi r^3$

## Mechanics and Applied Physics

$v = u + at$

$s = \left(\dfrac{u+v}{2}\right)t$

$s = ut + \dfrac{at^2}{2}$

$v^2 = u^2 + 2as$

$F = \dfrac{\Delta(mv)}{\Delta t}$

$P = Fv$

$\text{efficiency} = \dfrac{\text{power output}}{\text{power input}}$

$\omega = \dfrac{v}{r} = 2\pi f$

$a = \dfrac{v^2}{r} = r\omega^2$

$I = \sum mr^2$

$E_k = \frac{1}{2}I\omega^2$

$\omega_2 = \omega_1 + \alpha t$

$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

$\omega_2^2 = \omega_1^2 + 2\alpha\theta$

$\theta = \frac{1}{2}(\omega_1 + \omega_2)t$

$T = I\alpha$

angular momentum $= I\omega$

$W = T\theta$

$P = T\omega$

angular impulse = change of angular momentum $= Tt$

$\Delta Q = \Delta U + \Delta W$

$\Delta W = p\Delta V$

$pV^\gamma = \text{constant}$

work done per cycle = area of loop

input power = calorific value × fuel flow rate

indicated power as (area of $p - V$ loop) × (no. of cycles/s) × (no. of cylinders)

friction power = indicated power − brake power

$\text{efficiency} = \dfrac{W}{Q_{in}} = \dfrac{Q_{in} - Q_{out}}{Q_{in}}$

maximum possible

$\text{efficiency} = \dfrac{T_H - T_C}{T_H}$

## Fields, Waves, Quantum Phenomena

$g = \dfrac{F}{m}$

$g = -\dfrac{GM}{r^2}$

$g = -\dfrac{\Delta V}{\Delta x}$

$V = -\dfrac{GM}{r}$

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

$v = \pm 2\pi f \sqrt{A^2 - x^2}$

$x = A\cos 2\pi ft$

$T = 2\pi\sqrt{\dfrac{m}{k}}$

$T = 2\pi\sqrt{\dfrac{l}{g}}$

$\lambda = \dfrac{\omega s}{D}$

$d\sin\theta = n\lambda$

$\theta \approx \dfrac{\lambda}{D}$

$_1 n_2 = \dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{c_1}{c_2}$

$_1 n_2 = \dfrac{n_2}{n_1}$

$\sin\theta_c = \dfrac{1}{n}$

$E = hf$

$hf = \phi + E_k$

$hf = E_1 - E_2$

$\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$

$c = \dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$

## Electricity

$\in = \dfrac{E}{Q}$

$\in = I(R + r)$

$\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \cdots$

$R_T = R_1 + R_2 + R_3 + \cdots$

$P = I^2 R$

$E = \dfrac{F}{Q} = \dfrac{V}{d}$

$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r^2}$

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

$F = BIl$

$F = BQv$

$Q = Q_0 e^{-t/RC}$

$\Phi = BA$

**Turn over ▶**

## Data Sheet

$$magnitude\ of\ induced\ e.m.f. = N \frac{\Delta\Phi}{\Delta t}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

### Mechanical and Thermal Properties

$$the\ Young\ modulus = \frac{tensile\ stress}{tensile\ strain} = \frac{F}{A}\frac{l}{e}$$

$$energy\ stored = \tfrac{1}{2}Fe$$

$$\Delta Q = mc\,\Delta\theta$$

$$\Delta Q = ml$$

$$pV = \tfrac{1}{3}Nm\overline{c^2}$$

$$\tfrac{1}{2}m\overline{c^2} = \tfrac{3}{2}kT = \frac{3RT}{2N_A}$$

### Nuclear Physics and Turning Points in Physics

$$force = \frac{eV_p}{d}$$

$$force = Bev$$

$$radius\ of\ curvature = \frac{mv}{Be}$$

$$\frac{eV}{d} = mg$$

$$work\ done = eV$$

$$F = 6\pi\eta rv$$

$$I = k\frac{I_0}{x^2}$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$N = N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

$$R = r_0 A^{\frac{1}{3}}$$

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

$$t = \frac{t_0}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

### Astrophysics and Medical Physics

| Body | Mass/kg | Mean radius/m |
|------|---------|---------------|
| Sun | $2.00 \times 10^{30}$ | $7.00 \times 10^{8}$ |
| Earth | $6.00 \times 10^{24}$ | $6.40 \times 10^{6}$ |

1 astronomical unit = $1.50 \times 10^{11}$ m

1 parsec = 206265 AU = $3.08 \times 10^{16}$ m = 3.26 ly

1 light year = $9.45 \times 10^{15}$ m

Hubble constant ($H$) = 65 km s$^{-1}$ Mpc$^{-1}$

$$M = \frac{angle\ subtended\ by\ image\ at\ eye}{angle\ subtended\ by\ object\ at\ unaided\ eye}$$

$$M = \frac{f_o}{f_e}$$

$$m - M = 5 \log \frac{d}{10}$$

$$\lambda_{max}T = constant = 0.0029\ m\ K$$

$$v = Hd$$

$$P = \sigma A T^4$$

$$\frac{\Delta f}{f} = \frac{v}{c}$$

$$\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$$

$$R_s \approx \frac{2GM}{c^2}$$

### Medical Physics

$$power = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad and \quad m = \frac{v}{u}$$

$$intensity\ level = 10 \log \frac{I}{I_0}$$

$$I = I_0 e^{-\mu x}$$

$$\mu_m = \frac{\mu}{\rho}$$

### Electronics

Resistors

Preferred values for resistors (E24)
Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9  4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms
and multiples that are ten times greater

$$Z = \frac{V_{rms}}{I_{rms}}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$$

$$C_T = C_1 + C_2 + C_3 + \cdots$$

$$X_C = \frac{1}{2\pi f C}$$

### Alternating Currents

$$f = \frac{1}{T}$$

### Operational amplifier

$$G = \frac{V_{out}}{V_{in}} \qquad voltage\ gain$$

$$G = -\frac{R_f}{R_1} \qquad inverting$$

$$G = 1 + \frac{R_f}{R_1} \qquad non\text{-}inverting$$

$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) \qquad summing$$

**TURN OVER FOR THE FIRST QUESTION**

Answer **all** questions in the spaces provided.

1   An electric car is driven by an electric motor connected to a 120 V battery.  When the car travels on a horizontal road at a steady speed of $21\,m\,s^{-1}$, the battery delivers 7.2 kW of power to the motor.

(a)   (i)   Calculate the battery current.

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(ii)   The battery is capable of delivering a charge of $4.8 \times 10^{5}\,C$ before it needs to be recharged. Calculate the range of the car at a speed of $21\,m\,s^{-1}$ on a horizontal road.

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*(4 marks)*

(b)   When the car travels downhill at the same steady speed of $21\,m\,s^{-1}$, the motor current is less than the current calculated in part (a)(i).  Explain why this is so.

You may be awarded marks for the quality of written communication in your answer.

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*(4 marks)*

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**2** A beaker contains $1.3 \times 10^{-4} \, \text{m}^3$ of water at a temperature of 18 °C. The beaker is placed in a freezer. The water cools to 0 °C and freezes in a total time of 1700 s.

(a) (i) Calculate the mass of water in the beaker.

density of water = $1000 \, \text{kg} \, \text{m}^{-3}$

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(ii) Calculate the average energy per second transferred from the water. Assume the beaker has negligible heat capacity.

specific heat capacity of water       =     $4200 \, \text{J} \, \text{kg}^{-1} \text{K}^{-1}$
specific latent heat of fusion of ice    =     $3.4 \times 10^5 \, \text{J} \, \text{kg}^{-1}$

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*(4 marks)*

(b) The freezer uses electrical energy from the mains at a rate of $25 \, \text{J} \, \text{s}^{-1}$. Calculate the total energy transferred to the surroundings from the time the beaker of water is placed in the freezer to when it freezes completely.

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*(2 marks)*

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**TURN OVER FOR THE NEXT QUESTION**

**Turn over ▶**

**3** In a football match, a player kicks a stationary football of mass 0.44 kg and gives it a speed of 32 m s⁻¹.

(a)  (i)  Calculate the change of momentum of the football.

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(ii) The contact time between the football and the footballer's boot was 9.2 ms. Calculate the average force of impact on the football.

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*(3 marks)*

(b) A video recording showed that the toe of the boot was moving on a circular arc of radius 0.62 m centred on the knee joint when the football was struck. The force of the impact slowed the boot down from a speed of 24 m s⁻¹ to a speed of 15 m s⁻¹.



**Figure 1**

(i) Calculate the deceleration of the boot along the line of the impact force when it struck the football.

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(ii)  Calculate the centripetal acceleration of the boot just before impact.

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(iii)  Discuss briefly the radial force on the knee joint before impact and during the impact.

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*(4 marks)*

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**TURN  OVER  FOR  THE  NEXT  QUESTION**

**Turn over** ▶

**4** A dish on a communications satellite is used to transmit a beam of microwaves of wavelength $\lambda$. The beam spreads with an angular width $\lambda/d$, in radians, where $d$ is the diameter of the dish.
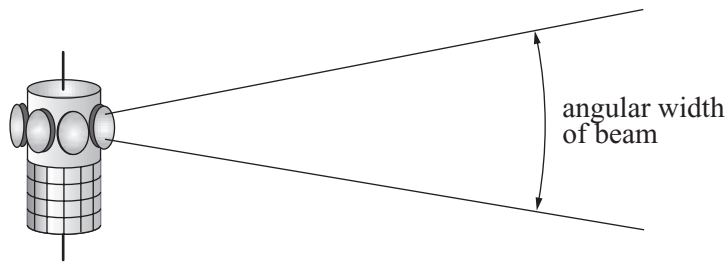


**Figure 2**

(a)  (i)  Calculate the angular width, in degrees, of a beam of frequency 1200 MHz transmitted using a dish of diameter 1.8 m.

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(ii)  Show that the beam has a width of 2100 km at a distance of 15 000 km from the satellite.

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*(4 marks)*

(b)  (i)  Show that the speed, $v$, of a satellite in a circular orbit at height $h$ above the Earth is given by

$$v = \sqrt{\frac{GM}{(R + h)}}$$

where $R$ is the radius of the Earth and $M$ is the mass of the Earth.

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(ii) Calculate the speed and the time period of a satellite at a height of 15 000 km in a circular orbit about the Earth.

mass of the Earth    =    $6.00 \times 10^{24}$ kg
radius of the Earth  =    $6.40 \times 10^{6}$ m

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(iii) The satellite passes directly over a stationary receiver at the North Pole. Show that the beam moves at a speed of $1.3$ km s$^{-1}$ across the Earth's surface and that the receiver can remain in contact with the satellite for no more than 27 minutes each orbit.

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*(9 marks)*

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**TURNOVER FOR THE NEXT QUESTION**

**Turn over** ▶

**THERE ARE NO QUESTIONS PRINTED ON THIS PAGE**

**5**   A student investigates the variation of electric potential with distance along a strip of conducting paper of length *l* and of uniform thickness.  The strip tapers uniformly from a width 4*w* at the broad end to 2*w* at the narrow end, as shown in **Figure 3**.  A constant pd is applied across the two ends of the strip, with the narrow end at positive potential, $V_l$, and the broad end at zero potential.  The student aims to produce a graph of pd against distance *x*, measured from the broad end of the strip.
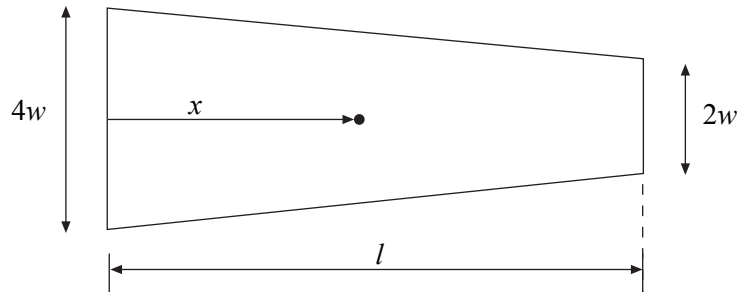


**Figure 3**

(a)   Draw a labelled circuit diagram which would be suitable for the investigation.

*(2 marks)*

(b)   The student obtained some preliminary measurements which are shown below.

| pd, *V*/ V | 0 | 2.1 | 4.5 | 7.2 |
|---|---|---|---|---|
| Distance, *x*/m | 0 | 0.100 | 0.200 | 0.300 |

By reference to the physical principles involved, explain why the increase of *V* with *x* is greater than a linear increase.

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*(4 marks)*

**Turn over ▶**

(c)   The potential, $V$, at a distance $x$ from the broad end is given by

$$V = k - 1.44\, V_l \ln (2l - x),$$

where $V_l$ is the potential at the narrow end, and $k$ is a constant.

(i)   The student's results are given below.  Complete the table.
$l = 0.400\,\text{m}$

| distance $x$/m | potential $V$/V | $(2l - x)$/m | $\ln (2l - x)$ |
|---|---|---|---|
| 0.100 | 2.1 | 0.700 | − 0.357 |
| 0.200 | 4.5 | | |
| 0.270 | 6.4 | | |
| 0.330 | 8.3 | | |
| 0.360 | 9.3 | | |
| 0.380 | 10.1 | | |

(ii)   Plot a graph of $V$ against $\ln (2l - x)$ and explain whether or not it confirms the equation.

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(iii)   Use the graph to calculate $V_l$.

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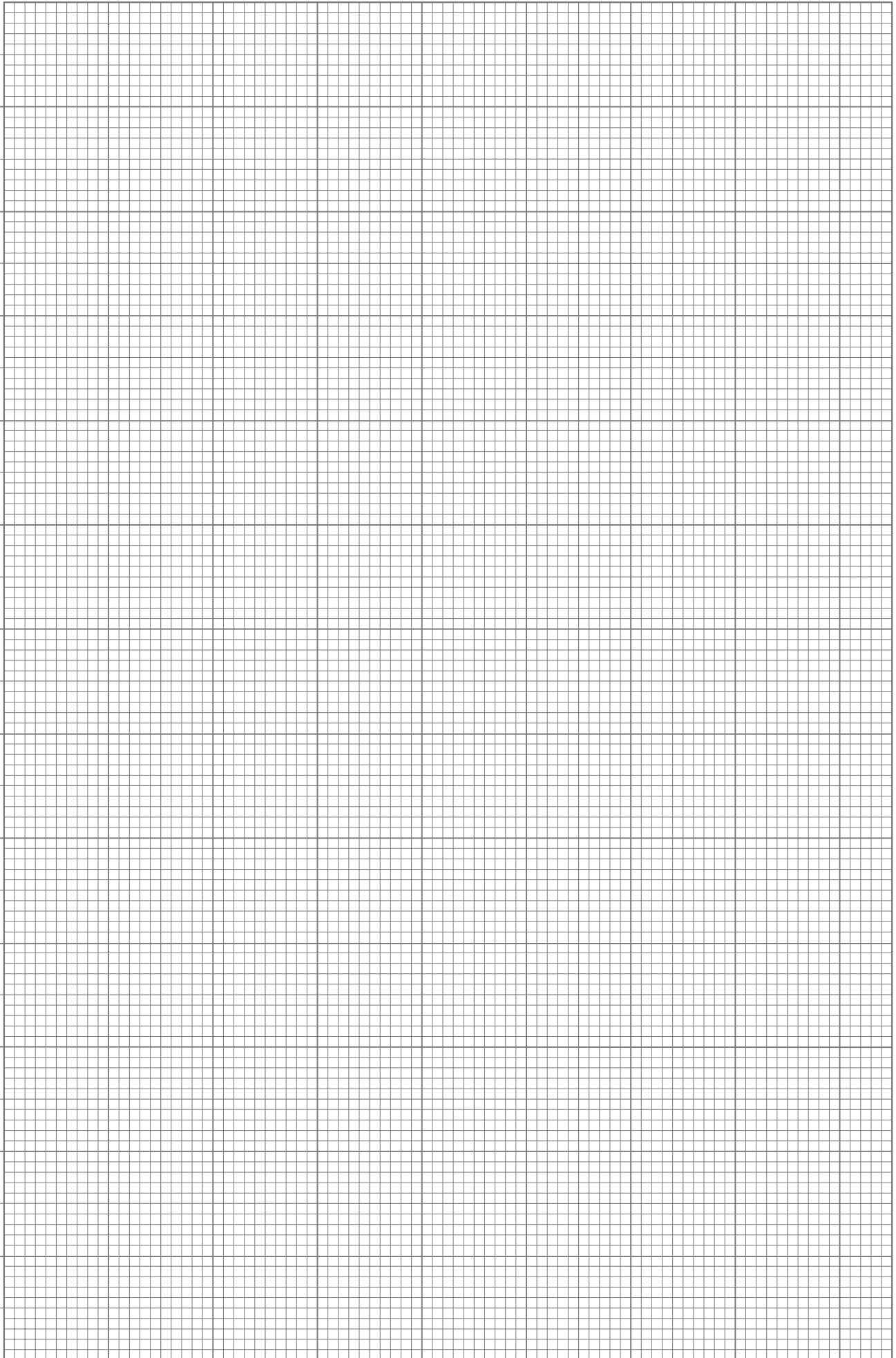
*(10 marks)*

16

**Turn over** ▶

**6** An accelerometer in a vehicle consists a steel bar mounted on two springy blades. The bar passes through two coils, as shown in **Figure 4**. An alternating voltage is applied to the primary coil.

You may be awarded marks for the quality of written communication in your answer.
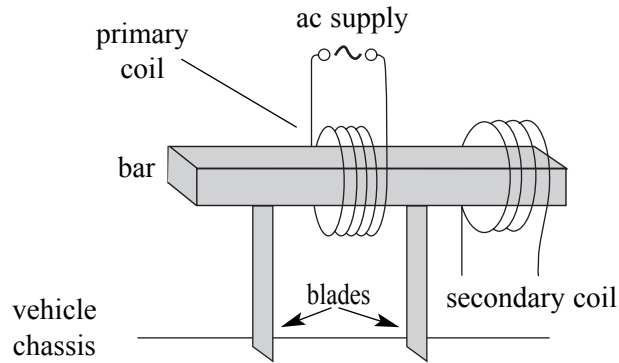


**Figure 4**

(a) (i) Explain why a voltage is induced in the secondary coil.

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(ii) Explain why the bar is displaced from its equilibrium position when the vehicle accelerates in a direction parallel to the axis of the bar, as shown in **Figure 5**.



**Figure 5**

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(iii) Explain why the amplitude of the secondary voltage changes when the bar is displaced from its equilibrium position in a direction along the axis of the bar.

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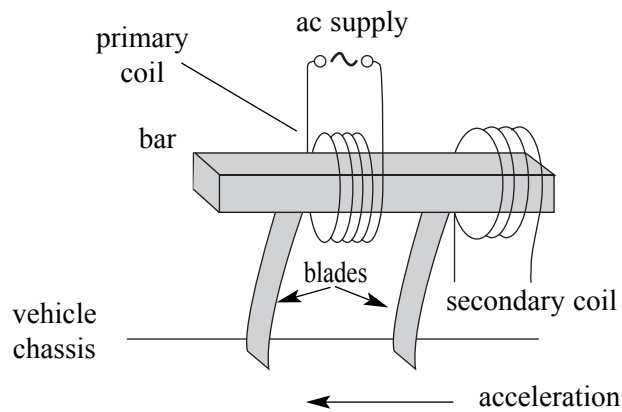
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*(6 marks)*

(b)  An ac voltage is converted to a dc voltage using the circuit shown in **Figure 6**.
The variation of the dc voltage with time is shown by the graph.
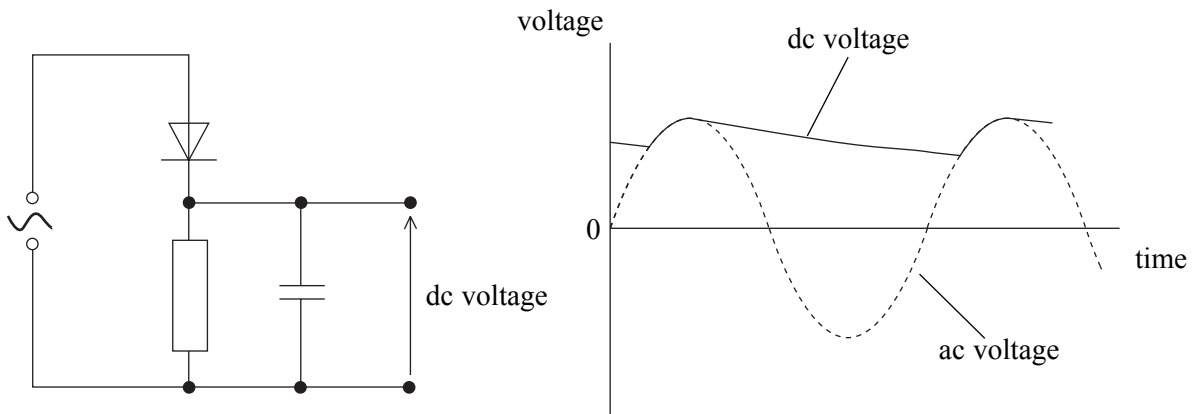
**Figure 6**

(i)  Explain why the dc voltage varies with time in this way.

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(ii)  Describe and explain how the variation of the dc voltage with time would change if the capacitance of the capacitor were increased by a factor of 10.

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*(3 marks)*

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**Turn over ▶**

**7**  (a)  (i)  State the function of the moderator in a thermal nuclear reactor.

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(ii)  By considering the free neutrons in a thermal nuclear reactor to behave like the atoms of an ideal gas, estimate the speed of free neutrons in the core of a thermal nuclear reactor when the core temperature is $700\,K$.

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*(4 marks)*

(b)  In the core of a nuclear reactor, a fission neutron moving at a speed of $3.9 \times 10^6\,m\,s^{-1}$ collides with a carbon 12 nucleus which is initially at rest. Immediately after the collision, the carbon nucleus has a velocity of $6.0 \times 10^5\,m\,s^{-1}$ in the same direction as the initial direction of the neutron.

   molar mass of carbon 12 = $0.012\,kg$

(i)  Show that the neutron rebounds with a speed of $3.3 \times 10^6\,m\,s^{-1}$.

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(ii)  Show that the collision is an elastic collision.

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(iii) Calculate the percentage of the initial kinetic energy of the neutron that is transferred to the carbon nucleus.

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*(7 marks)*

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**TURN OVER FOR THE NEXT QUESTION**

**Turn over ▶**

**8** (a) An electron is trapped in a solid between a group of atoms where the potential is +2.8 V.

The de Broglie wavelength of this electron is 1.2 nm. Calculate

    (i) its speed,

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    (ii) its kinetic energy,

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    (iii) the sum of its kinetic energy and its potential energy.

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*(5 marks)*

(b) (i) Calculate the energy of a photon of wavelength 650 nm.

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    (ii) State and explain whether or not the electron in part (a) can escape from this group of atoms as a result of absorbing this photon.

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*(3 marks)*

**QUALITY OF WRITTEN COMMUNICATION** *(2 marks)*

**END OF QUESTIONS**