Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2005
Advanced Level Examination

ASSESSMENT and QUALIFICATIONS ALLIANCE

PHYSICS (SPECIFICATION A) PA10
Unit 10 The Synoptic Unit

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.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
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4			
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6			
7			
8			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

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	3.00×10^{8}	$\mathrm{m\ s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\ m^{-1}}$
charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\ m^2\ kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\ K^{-1}\ mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\ K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\ m^{-2}\ K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4}u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	e/m_e	1.76×10^{11}	$\mathrm{C\ kg^{-1}}$
proton rest mass (equivalent to 1.00728u)	m_p	1.67×10^{-27}	kg
proton charge/mass ratio	e/m_p	9.58×10^{7}	$\mathrm{C\ kg^{-1}}$
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-27}	kg
gravitational field strength	g	9.81	$\mathrm{N\ kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\ s^{-2}}$
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

Fundamental particles

Class	*Name*	*Symbol*	*Rest energy* /MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^{\pm}$	0.510999
	muon	$\mu^{\pm}$	105.659
mesons	pion	$\pi^{\pm}$	139.576
		π^{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 $= 4\pi r^2$

Mechanics and Applied Physics

$v = u + at$

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

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

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

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

$P = Fv$

$efficiency = \frac{power\ output}{power\ input}$

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

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

$I = \sum mr^2$

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

$\omega_2 = \omega_1 + \alpha t$

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

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

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

$T = I\alpha$

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^{γ} = 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

$efficiency = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$

maximum possible

$efficiency = \frac{T_H - T_C}{T_H}$

Fields, Waves, Quantum Phenomena

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

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

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

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

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

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

$x = A\cos 2\pi ft$

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

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

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

$d\sin\theta = n\lambda$

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

${}_1n_2 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{c_1}{c_2}$

${}_1n_2 = \frac{n_2}{n_1}$

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

$E = hf$

$hf = \phi + E_k$

$hf = E_1 - E_2$

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

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

Electricity

$\epsilon = \frac{E}{Q}$

$\epsilon = I(R + r)$

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

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

$P = I^2 R$

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

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

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

$F = BIl$

$F = BQv$

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

Data Sheet

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

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

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

Mechanical and Thermal Properties

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

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

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

$\Delta Q = ml$

$pV = \frac{1}{3} N m\overline{c^2}$

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

Nuclear Physics and Turning Points in Physics

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

force $= Bev$

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

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

work done $= eV$

$F = 6\pi\eta rv$

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

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

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

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

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

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

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

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

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

Astrophysics and Medical Physics

Body	Mass/kg	Mean radius/m
Sun	2.00×10^{30}	7.00×10^{8}
Earth	6.00×10^{24}	6.40×10^{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}

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

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

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

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

$v = Hd$

$P = \sigma A T^4$

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

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

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

Medical Physics

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

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

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

$G = \dfrac{V_{out}}{V_{in}}$ voltage gain

$G = -\dfrac{R_f}{R_1}$ inverting

$G = 1 + \dfrac{R_f}{R_1}$ non-inverting

$V_{out} = -R_f\left(\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_3}{R_3}\right)$ 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 4.8×10^5 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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8

2 A beaker contains $1.3 \times 10^{-4}\,m^3$ 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 = $1000\,kg\,m^{-3}$

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

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(4 marks)

(b) The freezer uses electrical energy from the mains at a rate of $25\,J\,s^{-1}$. 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)

6

TURN OVER FOR THE NEXT QUESTION

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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7

TURN OVER FOR THE NEXT QUESTION

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

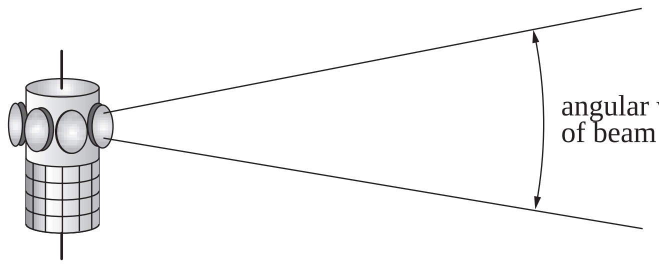

Figure 2

(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, υ, of a satellite in a circular orbit at height h above the Earth is given by

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

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 = 6.00×10^{24} kg
radius of the Earth = 6.40×10^{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)

13

TURNOVER FOR THE NEXT QUESTION

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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 $4w$ at the broad end to $2w$ 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.

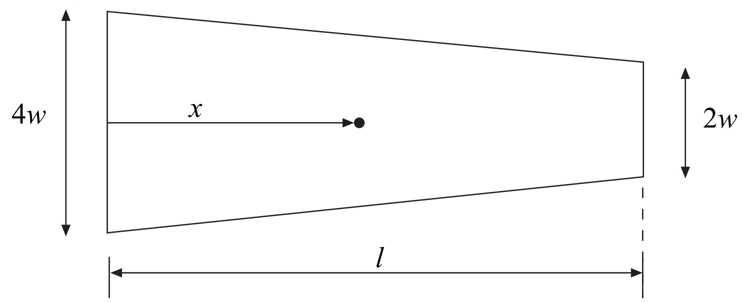

Figure 3

(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)

(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.

$l = 0.400$ 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

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MARGIN
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6 An accelerometer in a vehicle consists of 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.

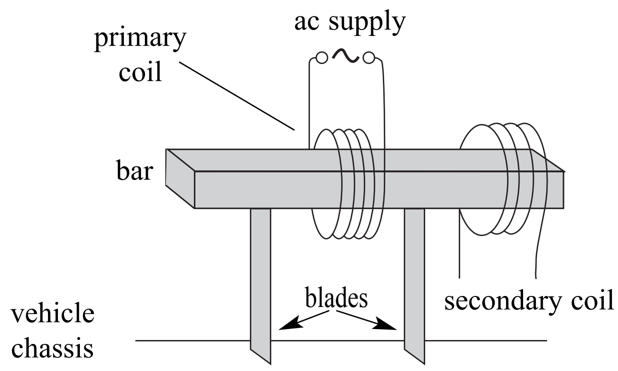

Figure 4

(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**.

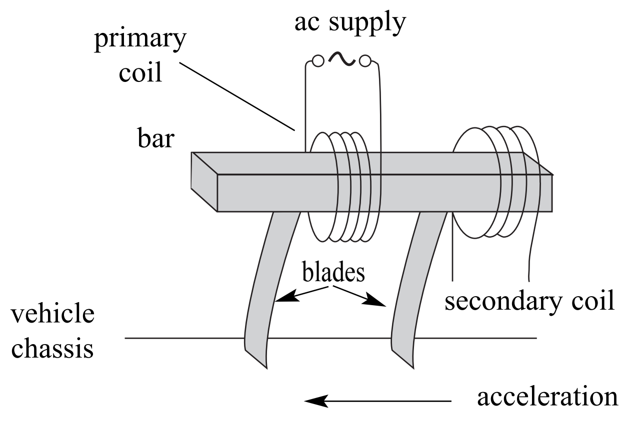

Figure 5

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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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(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.

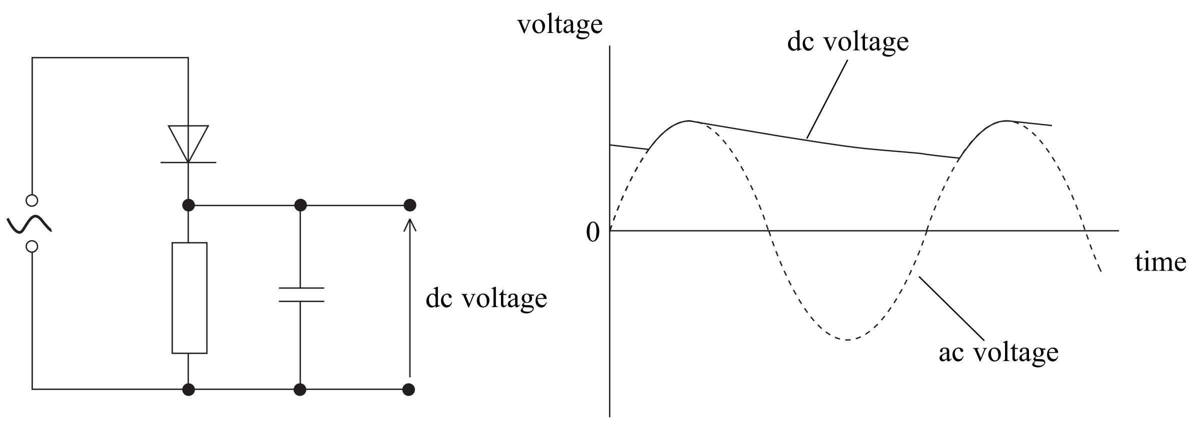

Figure 6

(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)

9

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 $3.9 \times 10^{6}\,\mathrm{m\,s^{-1}}$ collides with a carbon 12 nucleus which is initially at rest. Immediately after the collision, the carbon nucleus has a velocity of $6.0 \times 10^{5}\,\mathrm{m\,s^{-1}}$ 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 $3.3 \times 10^{6}\,\mathrm{m\,s^{-1}}$.

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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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11

TURN OVER FOR THE NEXT QUESTION

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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)

8

QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

2

END OF QUESTIONS