Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

General Certificate of Education
June 2003
Advanced Level Examination

AQA

ASSESSMENT and
QUALIFICATIONS
ALLIANCE

PHYSICS (SPECIFICATION A)   **PHA9/W**
Unit 9 Nuclear Instability: Electronics Option

Friday 20 June 2003   Afternoon Session

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

Time allowed: 1 hour 15 minutes

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 40.
● Mark allocations are shown in brackets.
● The paper carries 10% 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			
3			
4			
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.

Fundamental constants and values

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^8	m s^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ε_0	8.85×10^{-12}	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}	N m^2 kg^{-2}
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	J K^{-1} mol^{-1}
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	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}	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	C kg^{-1}
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-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	1.661×10^{-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 = πr^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

$v = u + at$

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

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

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

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

$P = Fv$

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

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

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

$I = \sum mr^2$

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

$\omega_2 = \omega_1 + \alpha t$

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

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

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

$T = I\alpha$

angular momentum $= I\omega$

$W = T\theta$

$P = T\omega$

angular impulse = change of angular momentum $= Tt$

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

$\Delta W = p\Delta V$

$pV^\gamma = constant$

work done per cycle = area of loop

input power = calorific value $\times$ fuel flow rate

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

friction power = indicated power – brake power

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

maximum possible

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

Fields, Waves, Quantum Phenomena

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

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

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

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

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

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

$x = A \cos 2\pi ft$

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

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

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

$d \sin\theta = n\lambda$

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

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

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

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

$E = hf$

$hf = \phi + E_k$

$hf = E_1 - E_2$

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

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

Electricity

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

$\epsilon = I(R + r)$

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

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

$P = I^2 R$

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

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

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

$F = BIl$

$F = BQv$

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

$\Phi = BA$

Turn over ▶

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

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

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

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

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

$$force = Bev$$

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

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

$$work\ done = eV$$

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

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

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

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

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

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

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

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

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

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

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 = 1.50×10^{11} m

1 parsec = 206265 AU = 3.08×10^{16} m = 3.26 ly

1 light year = 9.45×10^{15} m

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

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

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

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

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

$$v = Hd$$

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

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

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

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

Medical Physics

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

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

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

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

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

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

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

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

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

$$X_C = \frac{1}{2\pi fC}$$

Alternating Currents

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

Operational amplifier

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

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

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

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

SECTION A: NUCLEAR INSTABILITY

Answer **all** parts of this question.

1   **Figure 1** shows a grid of neutron number against proton number. A nucleus $_Z^A X$ is marked.

neutron number
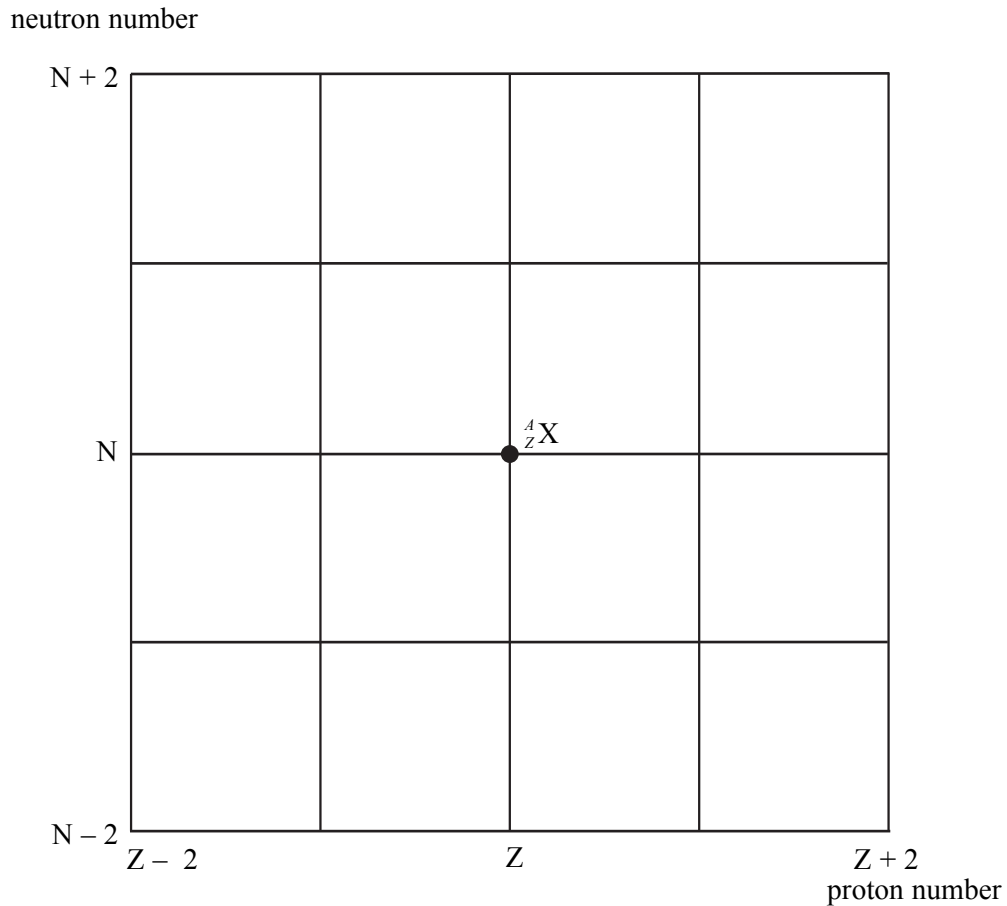
Figure 1

(a)   Draw arrows on **Figure 1**, each starting on $_Z^A X$ and ending on a daughter nucleus after the following transitions:

(i) β^- emission   (label this arrow A)
       neutron emission (label this arrow B)
       electron capture   (label this arrow C).

(ii)   Give the equation for electron capture by the nucleus $_Z^A X$.

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(4 marks)

Turn over ▶

(b)   When $^{27}_{12}$Mg decays to $^{27}_{13}$Al by β⁻ decay, the daughter nucleus is produced in one of two possible excited states. These two states are shown in **Figure 2** together with their corresponding energies.

$^{27}_{12}$Mg   E/10^{-13}J

—————————————————————— 4.18

—————————— 1.63

—————————— 1.33

$^{27}_{13}$Al — — — — — — 0.00 (ground state)
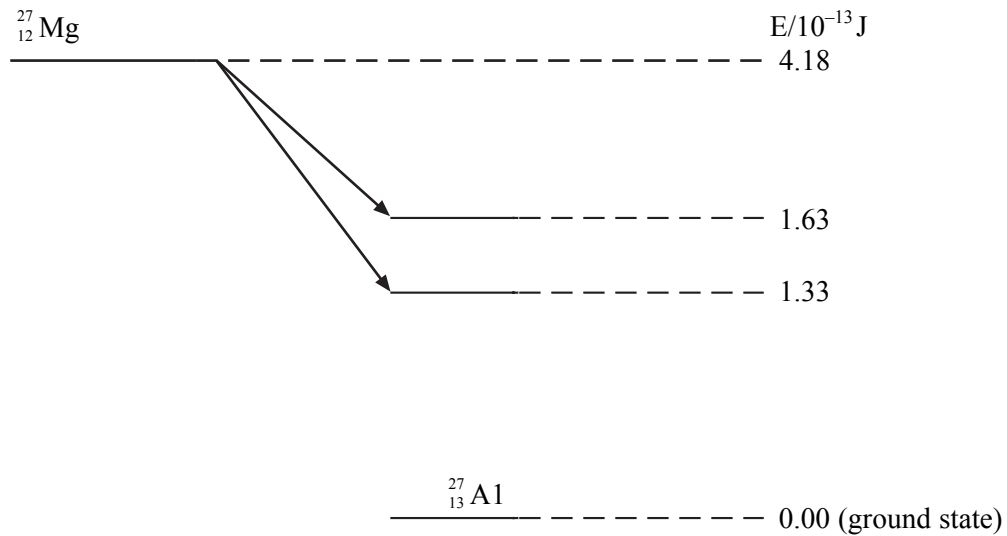
Figure 2

(i)   Calculate the maximum possible kinetic energy, in J, which an emitted β⁻ particle can have.

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(ii)   The excited aluminium nuclei emit γ photons. Calculate each of the three possible γ photon energies in J.

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(iii)   Calculate the frequency of the most energetic γ photon emitted.

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(3 marks)

(c)　(i)　State and explain **two** precautions that should be taken when working with a sample of $^{27}_{12}\text{Mg}$ in a school laboratory.

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

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(ii)　Discuss which of the two types of radiation, β^- or γ, emitted from a sample of $^{27}_{12}\text{Mg}$ would be the more hazardous.

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(3 marks)

$\overline{10}$

TURN OVER FOR THE NEXT QUESTION

Turn over ▶

SECTION B: ELECTRONICS

Answer **all** questions.

2 (a) A capacitor is connected in series with an ac milliammeter and a 10 Vrms variable frequency sinusoidal alternating supply as shown in the circuit in **Figure 1**.
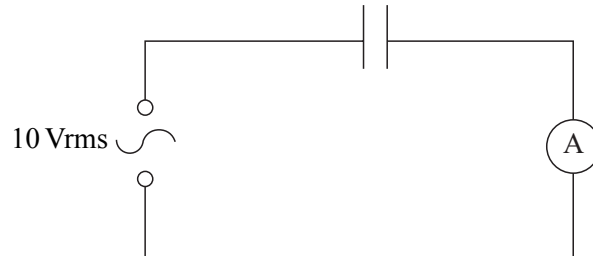
Figure 1

The frequency of the supply is increased in steps from a low value and the rms current is measured at these frequencies. The values obtained are shown in the table.

frequency/Hz	rms current/mA
200	2.26
500	5.70
800	8.80
1100	12.28
1400	15.80
1600	17.82

(i) Using suitable scales, plot a graph of current against frequency on the grid opposite.

(ii) Using your graph, calculate the capacitance of the capacitor.

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(5 marks)

QUESTION 2 CONTINUES ON PAGE 10
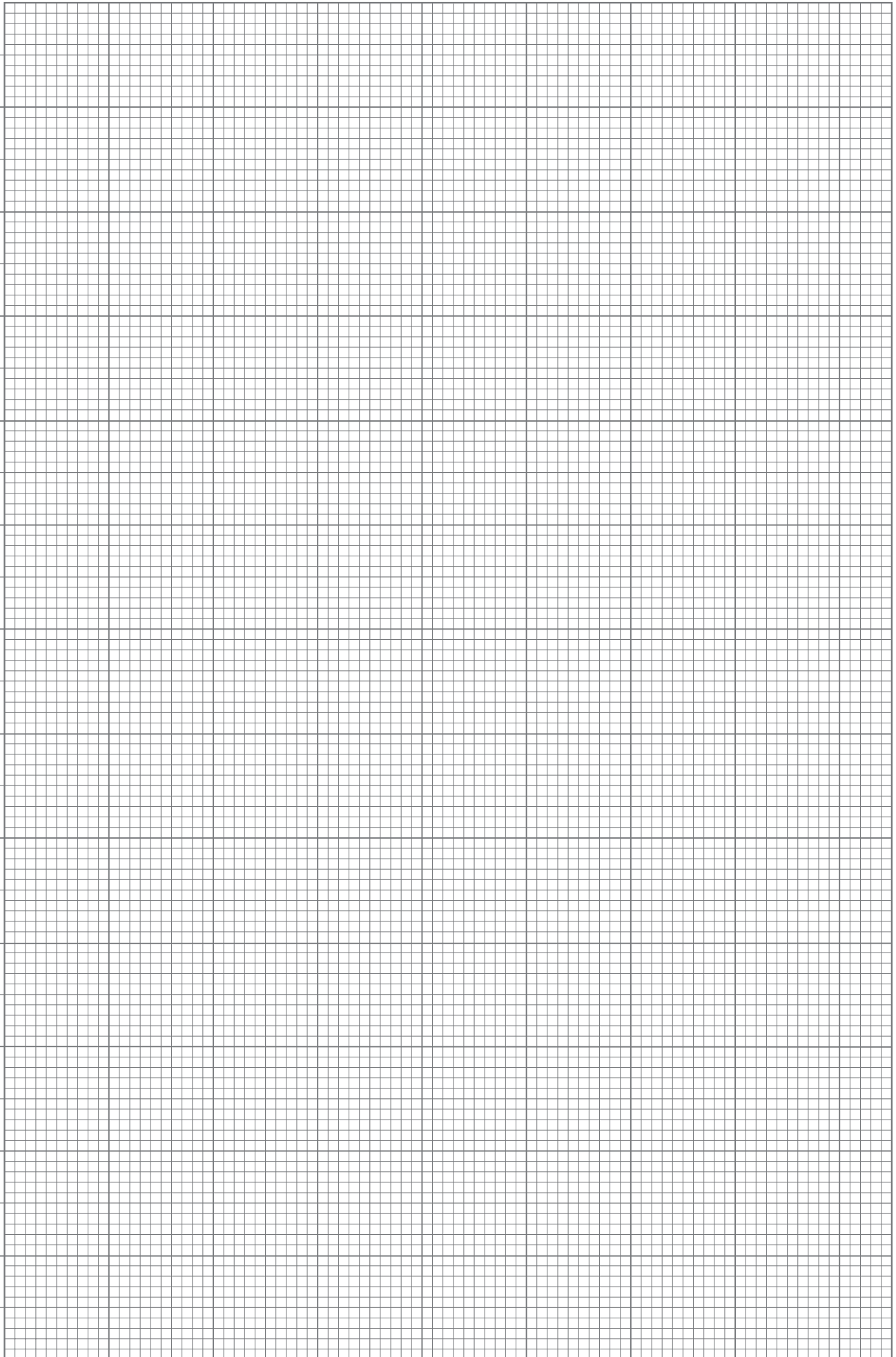
(b)   The same capacitor is now included in a low-pass filter circuit, as shown in **Figure 2**.
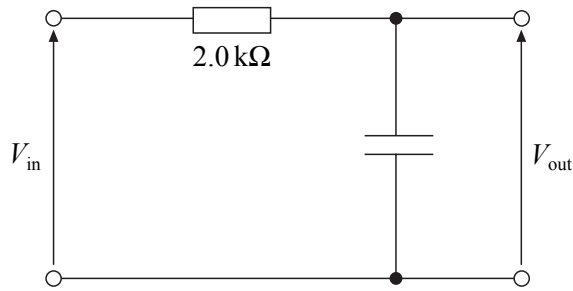
Figure 2

(i)   Explain why $\dfrac{V_{out}}{V_{in}}$ has a low value at high frequencies.

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(ii)   Calculate the frequency at which the reactance of the capacitor equals the resistance of the resistor.

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(iii) Deduce the approximate value of $\dfrac{V_{out}}{V_{in}}$ at frequencies considerably less than the value calculated in part (b)(ii).

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(5 marks)

3 The circuit shown is that of a simple burglar alarm where the switch S is a **normally closed** window switch. Both relay switches are initially open. The transistor, TR, is used as a switch and is either switched off or fully conducting.
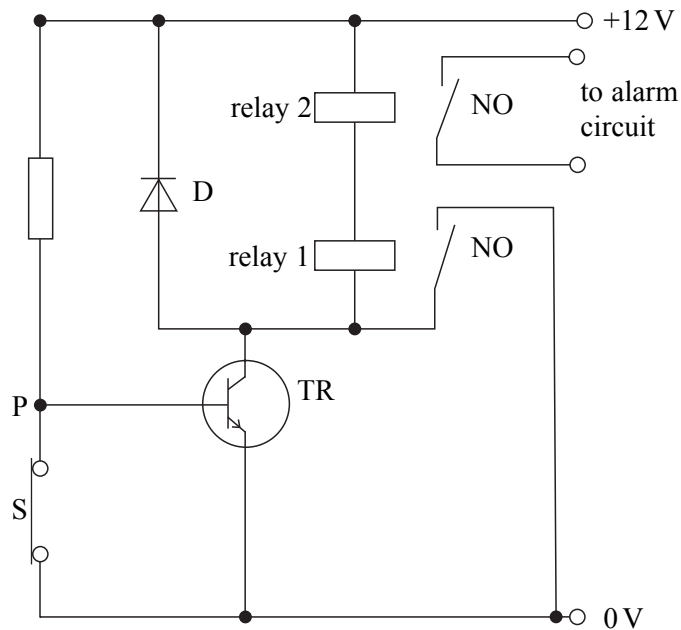
(a) (i) Give the approximate voltage at P when S is closed.

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(ii) Hence explain why the alarm is off.

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(3 marks)

(b) Switch S is now opened. Explain why the alarm is triggered.

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

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(2 marks)

(c) If S is closed again, explain why the alarm continues to ring.

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(2 marks)

(d) State the function of the diode D in the circuit.

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(1 mark)

$\overline{8}$

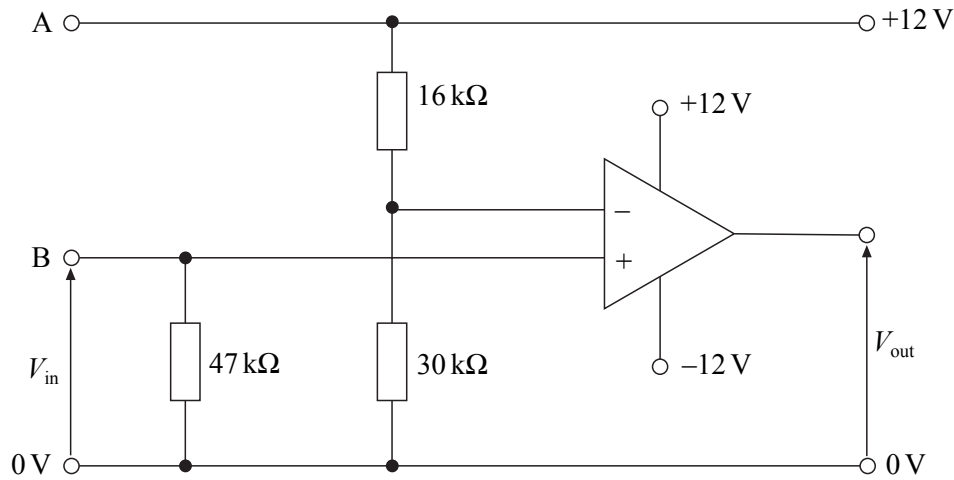**TURN OVER FOR THE NEXT QUESTION**

4 In the circuit shown, an ideal operational amplifier is used as a voltage comparator.

(a) The voltage V_{in} is steadily increased from 0 V. Calculate V_{in} when the sign of V_{out} changes from negative to positive.

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(2 marks)

(b) (i) The op-amp is required to operate an LED. Add to the circuit an LED and its limiting resistor so that the LED lights when V_{in} is less than the value calculated in part (a).

(ii) Explain why the LED functions in the position you have drawn it.

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(iii) Calculate the minimum value for the limiting resistor with the LED. Assume that the LED has a voltage drop of 2.0 V across it when emitting and a maximum current of 25 mA through it.

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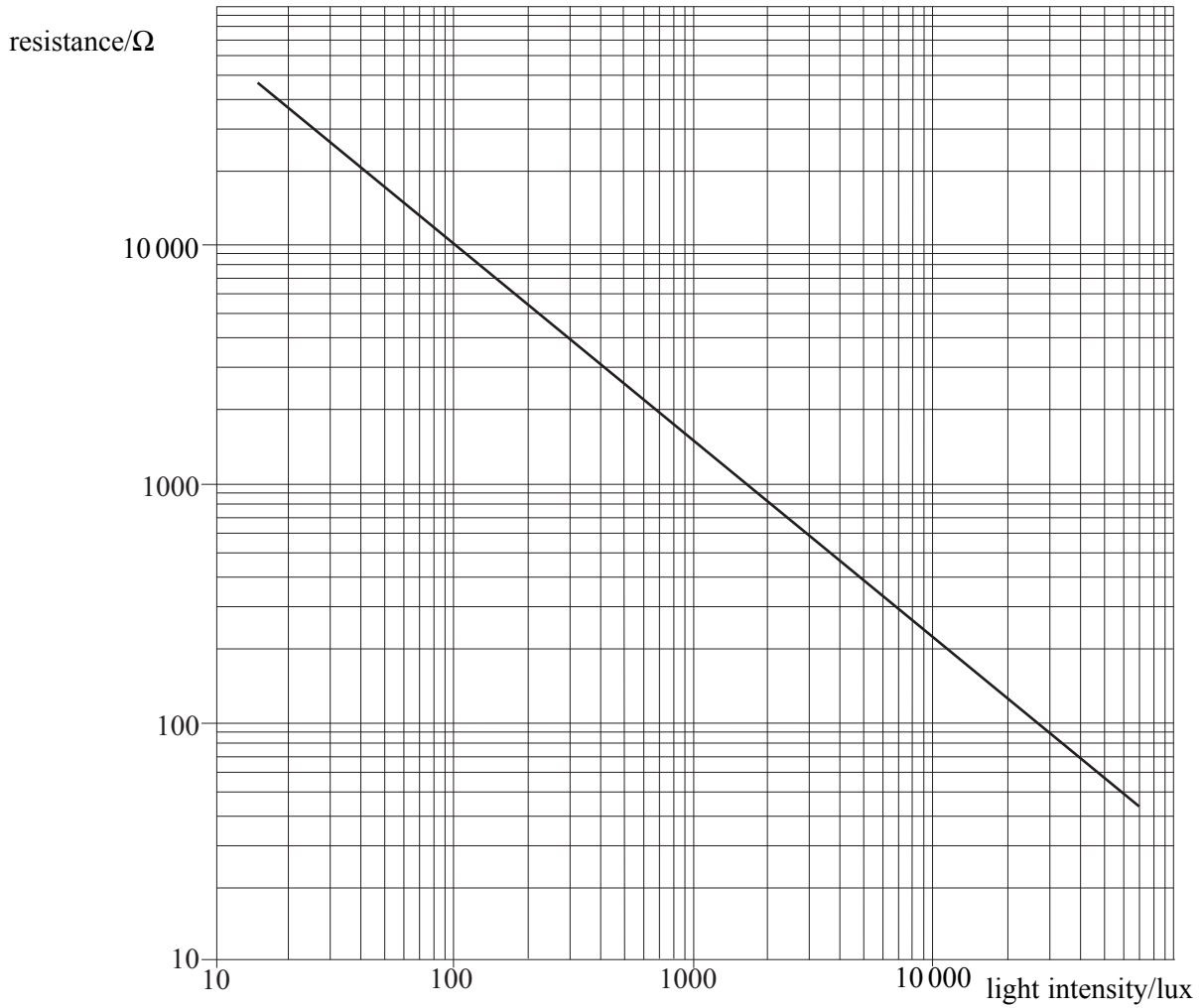
(5 marks)

(c) An LDR is now connected between the points A and B in the circuit. The characteristic of the
LDR is shown below.

Determine the light intensity at which the LED switches.

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(3 marks)

QUALITY OF WRITTEN COMMUNICATION   *(2 marks)*

END OF QUESTIONS