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Centre Number						Candidate Number					
Candidate Signature											

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General Certificate of Education  
 January 2005  
 Advanced Level Examination



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

**PHA9/W**

Wednesday 26 January 2005 Morning 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.

## Data Sheet

Fundamental constants and values				Mechanics and Applied Physics		Fields, Waves, Quantum Phenomena	
Quantity	Symbol	Value	Units				
speed of light in vacuo	$c$	$3.00 \times 10^8$	$\text{m s}^{-1}$	$v = u + at$	$g = \frac{F}{m}$		
permeability of free space	$\mu_0$	$4\pi \times 10^{-7}$	$\text{H m}^{-1}$	$s = \left(\frac{u+v}{2}\right)t$	$g = -\frac{GM}{r^2}$		
permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12}$	$\text{F m}^{-1}$	$s = ut + \frac{at^2}{2}$	$g = -\frac{\Delta V}{\Delta x}$		
charge of electron	$e$	$1.60 \times 10^{-19}$	C	$v^2 = u^2 + 2as$	$V = -\frac{GM}{r}$		
the Planck constant	$h$	$6.63 \times 10^{-34}$	J s	$F = \frac{\Delta(mv)}{\Delta t}$	$a = -(2\pi f)^2 x$		
gravitational constant	$G$	$6.67 \times 10^{-11}$	$\text{N m}^2 \text{kg}^{-2}$	$P = Fv$	$v = \pm 2\pi f \sqrt{A^2 - x^2}$		
the Avogadro constant	$N_A$	$6.02 \times 10^{23}$	$\text{mol}^{-1}$	$\text{efficiency} = \frac{\text{power output}}{\text{power input}}$	$x = A \cos 2\pi ft$		
molar gas constant	$R$	8.31	$\text{J K}^{-1} \text{mol}^{-1}$	$\omega = \frac{v}{r} = 2\pi f$	$T = 2\pi \sqrt{\frac{m}{k}}$		
the Boltzmann constant	$k$	$1.38 \times 10^{-23}$	$\text{J K}^{-1}$	$a = \frac{v^2}{r} = r\omega^2$	$T = 2\pi \sqrt{\frac{l}{g}}$		
the Stefan constant	$\sigma$	$5.67 \times 10^{-8}$	$\text{W m}^{-2} \text{K}^{-4}$	$I = \sum mr^2$	$\lambda = \frac{\omega s}{D}$		
the Wien constant	$\alpha$	$2.90 \times 10^{-3}$	m K	$E_k = \frac{1}{2} I \omega^2$	$d \sin \theta = n\lambda$		
electron rest mass	$m_e$	$9.11 \times 10^{-31}$	kg	$\omega_2 = \omega_1 + at$	$\theta \approx \frac{\lambda}{D}$		
(equivalent to $5.5 \times 10^{-4} \text{u}$ )				$\theta = \omega_1 t + \frac{1}{2} at^2$	${}_1n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$		
electron charge/mass ratio	$e/m_e$	$1.76 \times 10^{11}$	$\text{C kg}^{-1}$	$\omega_2^2 = \omega_1^2 + 2a\theta$	${}_1n_2 = \frac{n_2}{n_1}$		
proton rest mass	$m_p$	$1.67 \times 10^{-27}$	kg	$\theta = \frac{1}{2} (\omega_1 + \omega_2)t$	$\sin \theta_c = \frac{1}{n}$		
(equivalent to 1.00728u)				$T = I\alpha$	$E = hf$		
proton charge/mass ratio	$e/m_p$	$9.58 \times 10^7$	$\text{C kg}^{-1}$	$\text{angular momentum} = I\omega$	$hf = \phi + E_k$		
neutron rest mass	$m_n$	$1.67 \times 10^{-27}$	kg	$W = T\theta$	$hf = E_1 - E_2$		
(equivalent to 1.00867u)				$P = T\omega$	$\lambda = \frac{h}{p} = \frac{h}{mv}$		
gravitational field strength	$g$	9.81	$\text{N kg}^{-1}$	$\text{angular impulse} = \text{change of angular momentum} = Tt$	$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$		
acceleration due to gravity	$g$	9.81	$\text{m s}^{-2}$	$\Delta Q = \Delta U + \Delta W$			
atomic mass unit	$u$	$1.661 \times 10^{-27}$	kg	$\Delta W = p\Delta V$			
(1u is equivalent to 931.3 MeV)				$pV^\gamma = \text{constant}$			
<b>Fundamental particles</b>				$\text{work done per cycle} = \text{area of loop}$	<b>Electricity</b>		
Class	Name	Symbol	Rest energy /MeV	$\text{input power} = \text{calorific value} \times \text{fuel flow rate}$	$\epsilon = \frac{E}{Q}$		
photon	photon	$\gamma$	0	$\text{indicated power as (area of } p-V \text{ loop)} \times (\text{no. of cycles/s}) \times (\text{no. of cylinders})$	$\epsilon = I(R + r)$		
lepton	neutrino	$\nu_e$	0	$\text{friction power} = \text{indicated power} - \text{brake power}$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$		
		$\nu_\mu$	0	$\text{efficiency} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$	$R_T = R_1 + R_2 + R_3 + \dots$		
	electron	$e^\pm$	0.510999	$\text{maximum possible efficiency} = \frac{T_H - T_C}{T_H}$	$P = I^2 R$		
	muon	$\mu^\pm$	105.659		$E = \frac{F}{Q} = \frac{V}{d}$		
mesons	pion	$\pi^\pm$	139.576		$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$		
		$\pi^0$	134.972		$E = \frac{1}{2} QV$		
	kaon	$K^\pm$	493.821		$F = BIl$		
		$K^0$	497.762		$F = BQv$		
baryons	proton	p	938.257		$Q = Q_0 e^{-t/RC}$		
	neutron	n	939.551		$\Phi = BA$		
<b>Properties of quarks</b>							
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				
<b>Geometrical equations</b>							
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 = $\frac{4}{3}\pi r^3$							

## Data Sheet

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

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

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

### Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

$$pV = \frac{1}{3} Nmc^2$$

$$\frac{1}{2} mc^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

### Nuclear Physics and Turning Points in Physics

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

$$\text{force} = Bev$$

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

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

$$\text{work done} = eV$$

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

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

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

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

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

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

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

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

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

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

### Astrophysics and Medical Physics

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

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

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

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

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

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

### Medical Physics

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

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

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

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

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

### 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

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

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

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

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

### Alternating Currents

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

### Operational amplifier

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

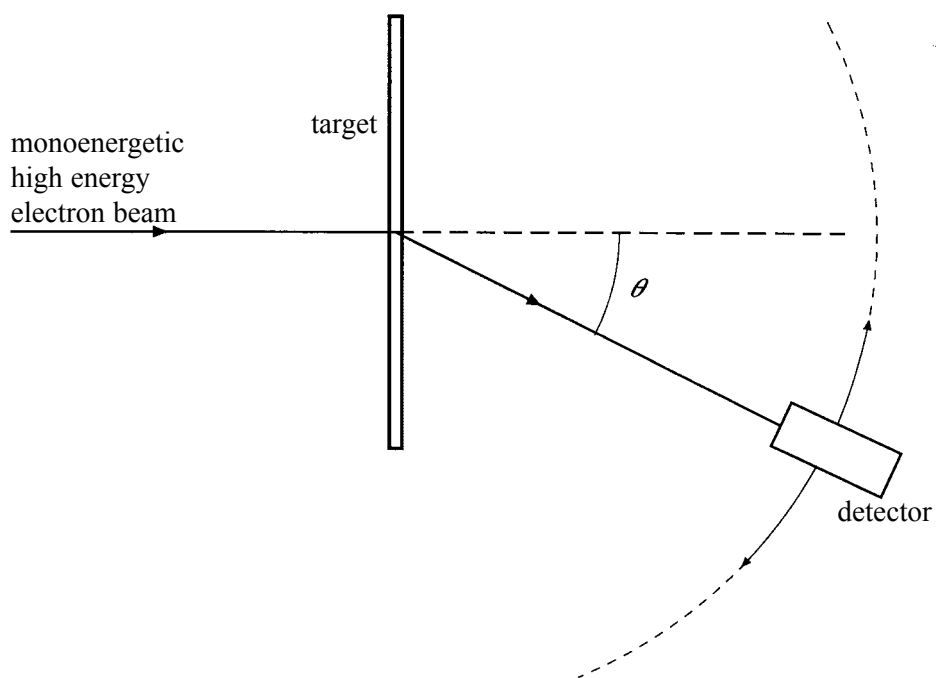
$$G = -\frac{R_f}{R_1} \text{ inverting}$$

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

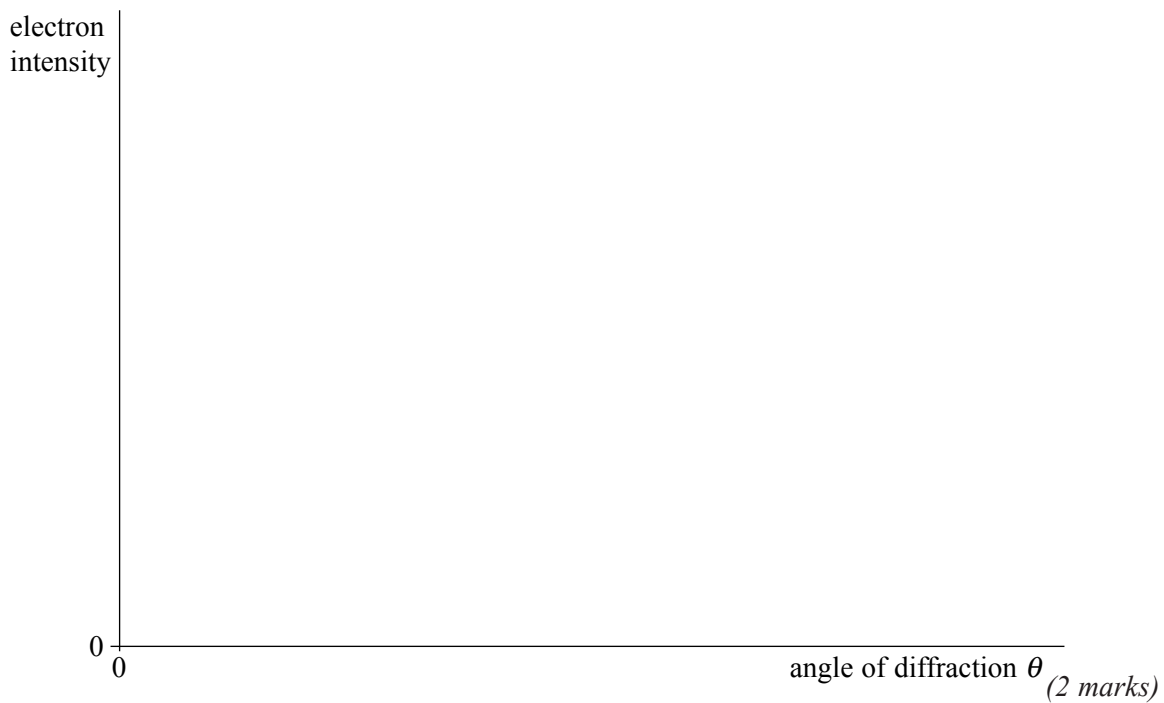
$$V_{\text{out}} = -R_f \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right) \text{ summing}$$

**SECTION A: NUCLEAR INSTABILITY**Answer **all** of this question

- 1 The high energy electron diffraction apparatus represented in **Figure 1** can be used to determine nuclear radii. The intensity of the electron beam received by the detector is measured at various diffraction angles,  $\theta$ .

**Figure 1**

- (a) Sketch on the axes below a graph of the results expected from such an electron diffraction experiment.



(2 marks)

- (b) (i) Use the data in the table to plot a straight line graph that confirms the relationship  $R = r_0 A^{\frac{1}{3}}$ .

element	radius of nucleus, $R$ $10^{-15}\text{m}$	nucleon number, $A$	
lead	6.66	208	
tin	5.49	120	
iron	4.35	56	
silicon	3.43	28	
carbon	2.66	12	

- (ii) Estimate the value of  $r_0$  from the graph.

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(5 marks)

- (c) Discuss the merits of using high energy electrons to determine nuclear radii rather than using  $\alpha$  particles.

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

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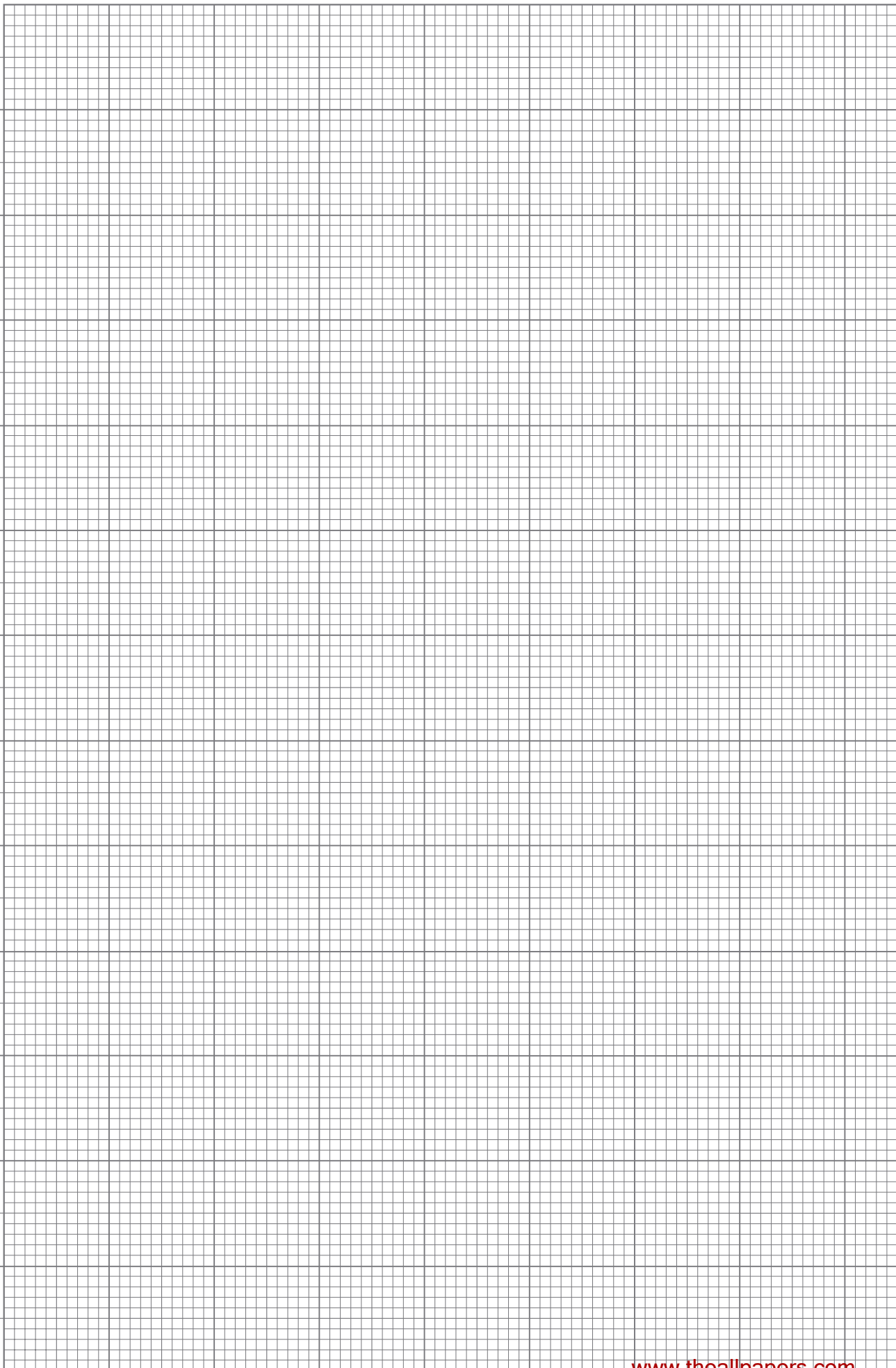
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(3 marks)



## SECTION B: ELECTRONICS

Answer **all** questions.

- 2 A capacitor-resistor circuit is shown in **Figure 2**. The input voltage,  $V_{in}$ , is a 2.0 kHz square wave, shown in **Figure 3**.

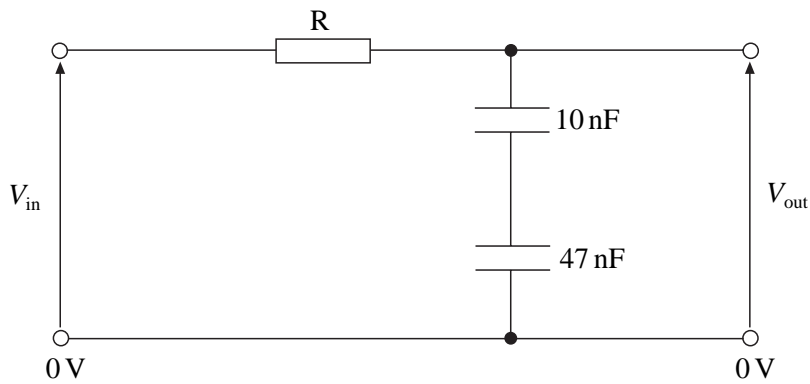


Figure 2

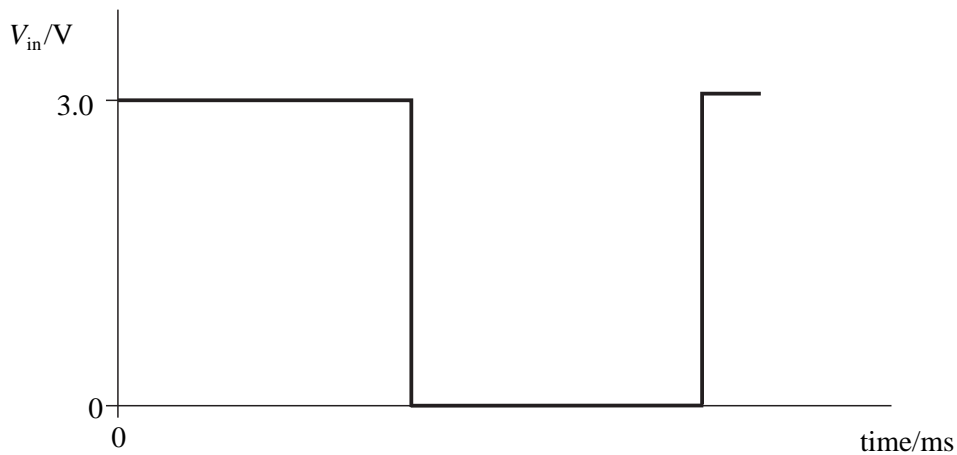


Figure 3

- (a) Calculate the period of the input square wave. Hence add a scale to the time axis on **Figure 3**.

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(2 marks)



- (b) (i) Show that the two capacitors in **Figure 2** are equivalent to a single capacitor of capacitance 8.25 nF.

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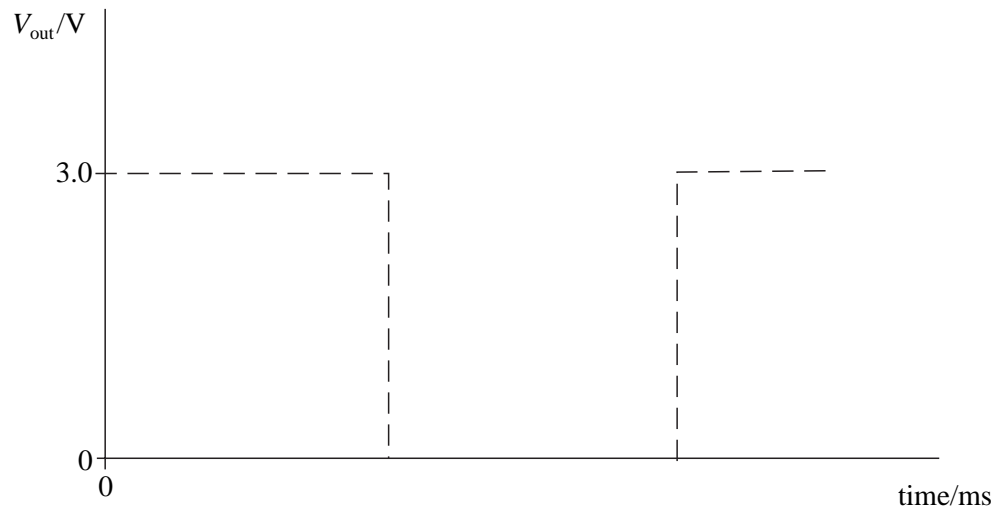
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- (ii) The resistor R has a value of 5.6 kΩ. Calculate the time constant of the RC network.

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- (iii) On **Figure 4**, sketch the waveform of the output voltage,  $V_{out}$ , and label the curve A.



**Figure 4**

(4 marks)

- (c) The 5.6 kΩ resistor is replaced with a 33 kΩ resistor. On **Figure 4**, sketch the new waveform of the output voltage,  $V_{out}$ , and label this curve B. Explain why curve B has this shape.

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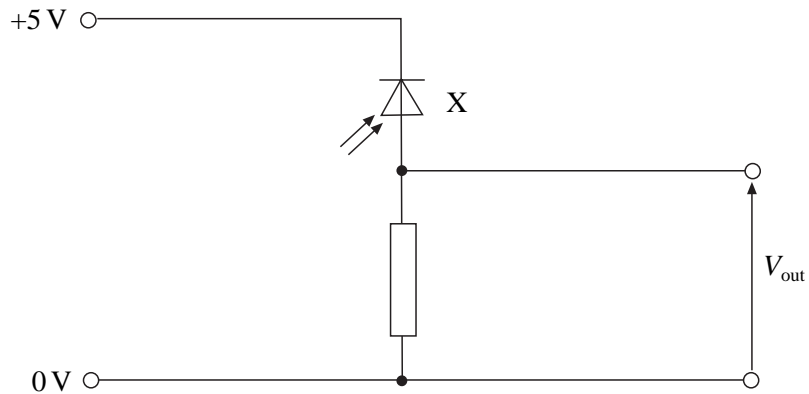
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(4 marks)

- 3 (a) **Figure 5** shows a circuit which produces an output voltage,  $V_{out}$ , which changes as the intensity of the light incident on component X changes.



**Figure 5**

- (i) Name component X. ....
- (ii) Explain why  $V_{out}$  changes as the intensity of the light incident on component X changes.

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

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(4 marks)

- (b) A light-emitting diode (LED) has a *forward voltage drop* of 1.8V and a *reverse breakdown voltage* of 5.0V. Explain what is meant by

- (i) forward voltage drop,

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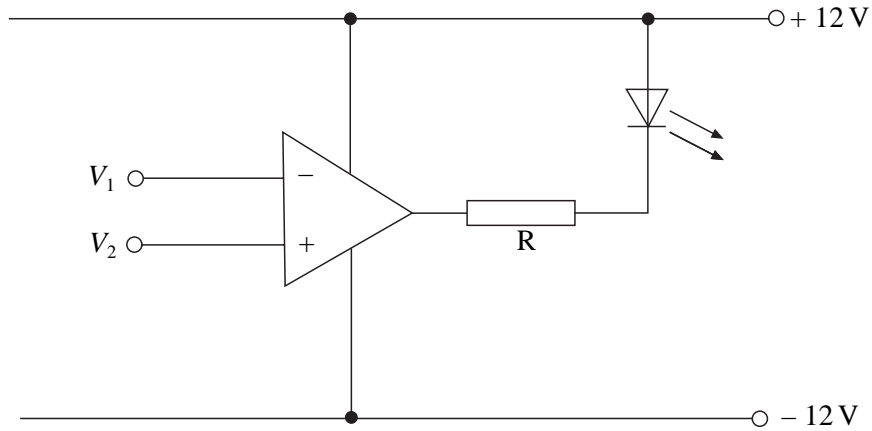
- (ii) reverse breakdown voltage.

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(2 marks)

(c) The circuit in **Figure 6** shows this LED used as an indicator.



**Figure 6**

(i) Explain how the state of the LED is related to the input voltages  $V_1$  and  $V_2$ .

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(ii) Explain why reverse breakdown voltage is **not** a problem in this circuit.

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(iii) The current passing through the LED when lit is 20 mA. Calculate the value of the resistor R.

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(iv) Which resistor from the E24 series would be used in practice for R?

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(6 marks)

4 Figure 7 shows an operational amplifier used as a summing amplifier.

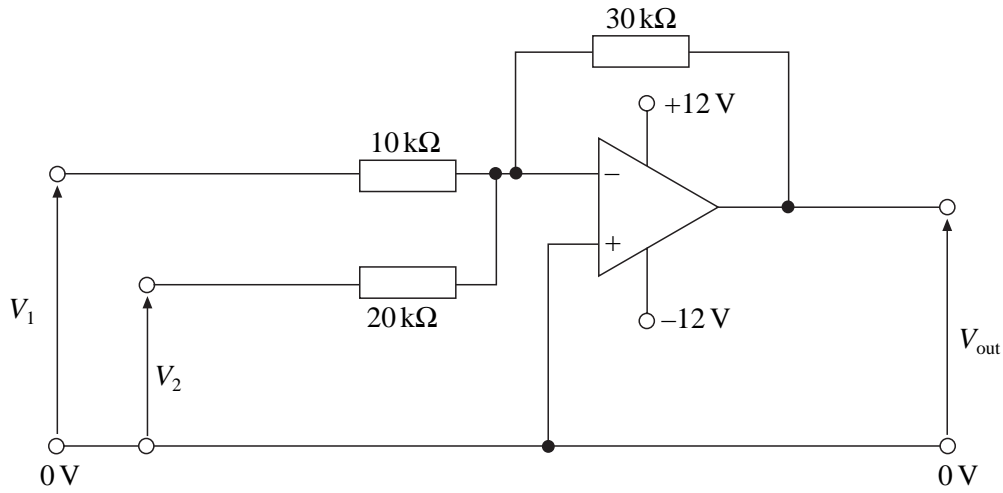


Figure 7

(a) State what type of feedback is used in this circuit.

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(1 mark)

(b) Calculate the output voltage,  $V_{out}$ , when the input voltages are  $V_1 = -3.0\text{ V}$  and  $V_2 = +2.0\text{ V}$ .

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(3 marks)

(c) Calculate the new output voltage if both input voltages are set to  $-3.0\text{ V}$ .

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(2 marks)

6  
2