

Surname						Other Names					
Centre Number						Candidate Number					
Candidate Signature											

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General Certificate of Education
January 2003
Advanced Level Examination



PHYSICS (SPECIFICATION A) PHA6/W
Unit 6 Nuclear Instability: Medical Physics Option

Monday 27 January 2003 Morning Session

<p>In addition to this paper you will require:</p> <ul style="list-style-type: none"> • a calculator; • a pencil and a ruler.
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For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
Total (Column 1)	→		
Total (Column 2)	→		
TOTAL			
Examiner's Initials			

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.

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}	$\text{N m}^2 \text{kg}^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$\text{J K}^{-1} \text{mol}^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass	m_e	9.11×10^{-31}	kg
(equivalent to $5.5 \times 10^{-4} \text{u}$)			
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}
proton rest mass	m_p	1.67×10^{-27}	kg
(equivalent to 1.00728u)			
proton charge/mass ratio	e/m_p	9.58×10^7	C kg^{-1}
neutron rest mass	m_n	1.67×10^{-27}	kg
(equivalent to 1.00867u)			
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit	u	1.661×10^{-27}	kg
(1u is equivalent to 931.3 MeV)			

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	μ^\pm	105.659
mesons	pion	π^\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

- $v = u + at$
- $s = \left(\frac{u+v}{2}\right)t$
- $s = ut + \frac{at^2}{2}$
- $v^2 = u^2 + 2as$
- $F = \frac{\Delta(mv)}{\Delta t}$
- $P = Fv$
- efficiency = $\frac{\text{power output}}{\text{power input}}$
- $\omega = \frac{v}{r} = 2\pi f$
- $a = \frac{v^2}{r} = r\omega^2$
- $I = \sum mr^2$
- $E_k = \frac{1}{2}I\omega^2$
- $\omega_2 = \omega_1 + at$
- $\theta = \omega_1 t + \frac{1}{2}at^2$
- $\omega_2^2 = \omega_1^2 + 2a\theta$
- $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$
- $T = I\alpha$
- 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 \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 = $\frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$
- maximum possible efficiency = $\frac{T_H - T_C}{T_H}$

Fields, Waves, Quantum Phenomena

- $g = \frac{F}{m}$
- $g = -\frac{GM}{r^2}$
- $g = -\frac{\Delta V}{\Delta x}$
- $V = -\frac{GM}{r}$
- $a = -(2\pi f)^2 x$
- $v = \pm 2\pi f \sqrt{A^2 - x^2}$
- $x = A \cos 2\pi ft$
- $T = 2\pi\sqrt{\frac{m}{k}}$
- $T = 2\pi\sqrt{\frac{l}{g}}$
- $\lambda = \frac{\omega s}{D}$
- $d \sin \theta = n\lambda$
- $\theta \approx \frac{\lambda}{D}$
- $n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$
- $n_2 = \frac{n_2}{n_1}$
- $\sin \theta_c = \frac{1}{n}$
- $E = hf$
- $hf = \phi + E_k$
- $hf = E_1 - E_2$
- $\lambda = \frac{h}{p} = \frac{h}{mv}$
- $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$
- Electricity**
- $\epsilon = \frac{E}{Q}$
- $\epsilon = I(R+r)$
- $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- $R_T = R_1 + R_2 + R_3 + \dots$
- $P = I^2 R$
- $E = \frac{F}{Q} = \frac{V}{d}$
- $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$
- $E = \frac{1}{2} QV$
- $F = BI$
- $F = BQv$
- $Q = Q_0 e^{-t/RC}$
- $\Phi = BA$

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

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

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

Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

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

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

Nuclear Physics and Turning Points in Physics

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

$$\text{force} = Bev$$

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

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

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

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

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

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

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

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

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

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

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

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

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

Astrophysics and Medical Physics

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

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

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

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

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

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

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

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

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

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

SECTION A NUCLEAR INSTABILITY

Answer **all** parts of the question.

- 1 The radioactive isotope of sodium ${}_{11}^{22}\text{Na}$ has a half life of 2.6 years. A particular sample of this isotope has an initial activity of 5.5×10^5 Bq (disintegrations per second).

- (a) Explain what is meant by the *random nature* of radioactive decay.

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

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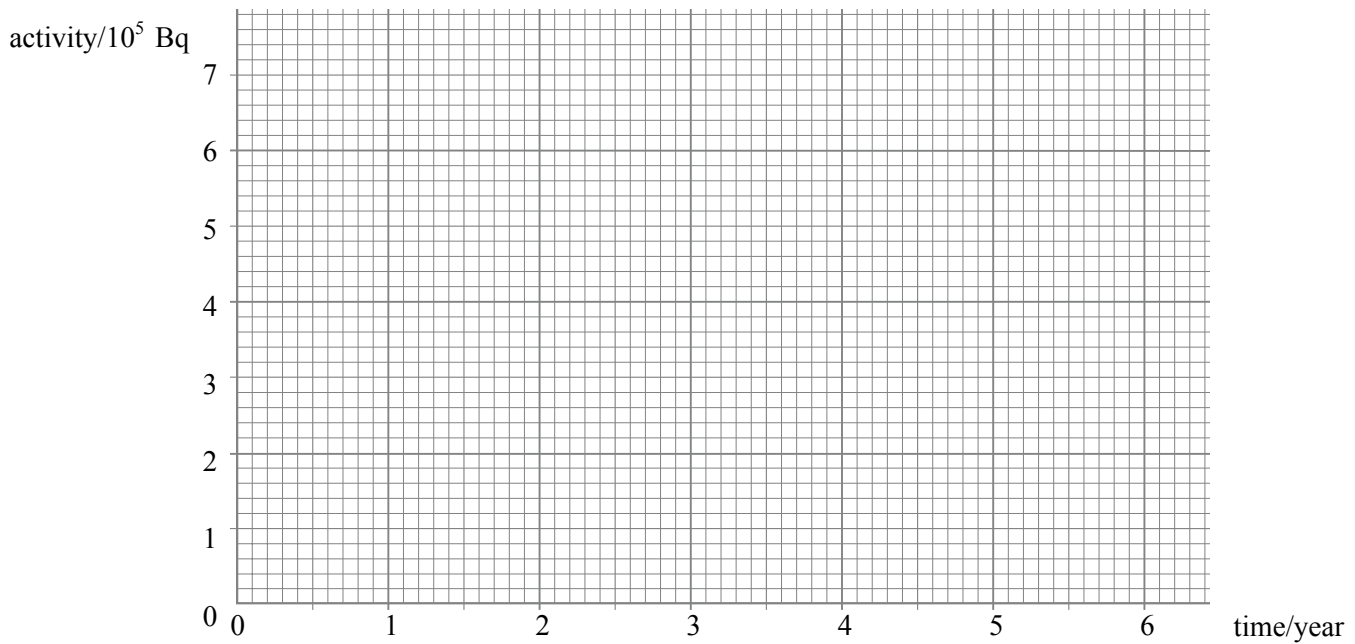
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(2 marks)

- (b) Use the axes to sketch a graph of the activity of the sample of sodium over a period of 6 years.



(2 marks)

(c) Calculate

- (i) the decay constant, in s^{-1} , of ${}^{22}_{11}\text{Na}$,
1 year = $3.15 \times 10^7 \text{s}$

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- (ii) the number of atoms of ${}^{22}_{11}\text{Na}$ in the sample initially,

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- (iii) the time taken, in s, for the activity of the sample to fall from $1.0 \times 10^5 \text{ Bq}$ to $0.75 \times 10^5 \text{ Bq}$.

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(6 marks)

10

TURN OVER FOR THE NEXT QUESTION

Turn over ▶

SECTION B MEDICAL PHYSICS

Answer **all** questions.

- 2 A defective eye has an unaided far point of 2.5 m and an unaided near point of 0.20 m. A correcting lens is used to produce an aided far point at infinity.

- (a) (i) Name the defect of vision affecting the eye.

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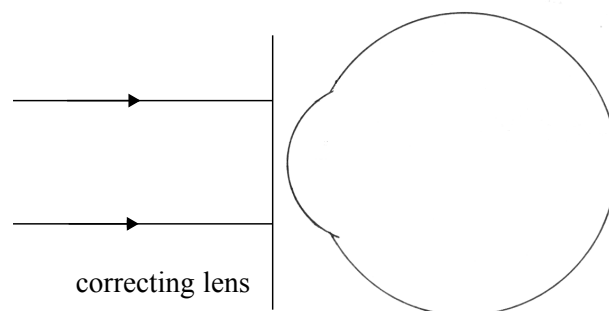
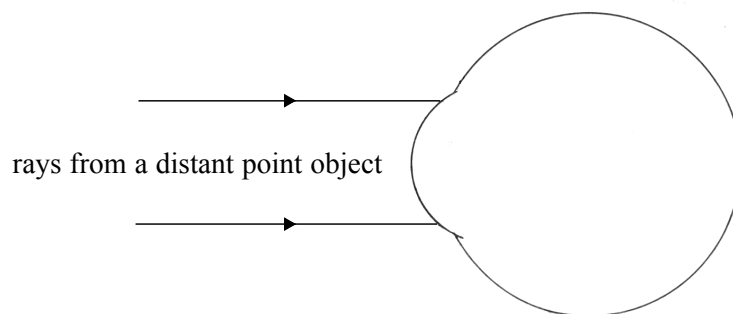
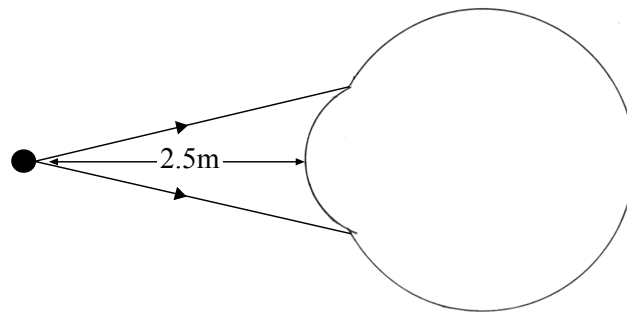
- (ii) State **one** possible cause of this defect of vision.

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(2 marks)

- (b) Complete the ray diagrams below for the defective eye.



(3 marks)

(c) (i) Calculate the power of the correcting lens.

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(ii) Calculate the aided near point when wearing the correcting lens.

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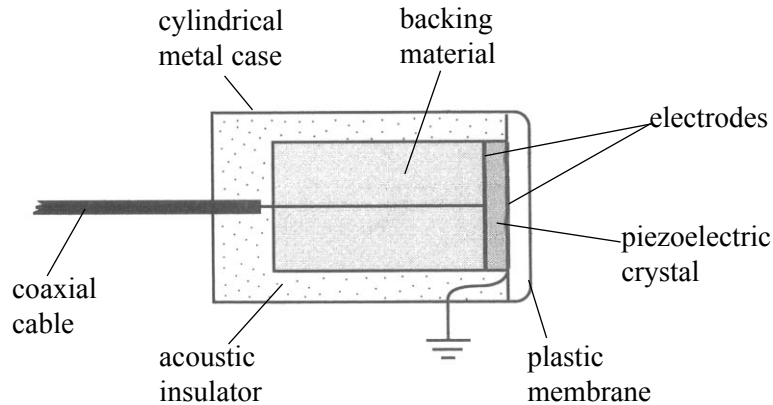
(4 marks)

9

TURN OVER FOR THE NEXT QUESTION

Turn over ▶

3 The diagram shows an ultrasound transducer as used in A-scans. The transducer produces short pulses of ultrasound.



(a) (i) Why is it necessary for the pulse to be short?

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(ii) Explain, with reference to the diagram, the process by which the transducer produces short pulses.

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

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(5 marks)

(b) State **one** advantage and **one** disadvantage of ultrasound compared with X-rays in medical imaging.

advantage:

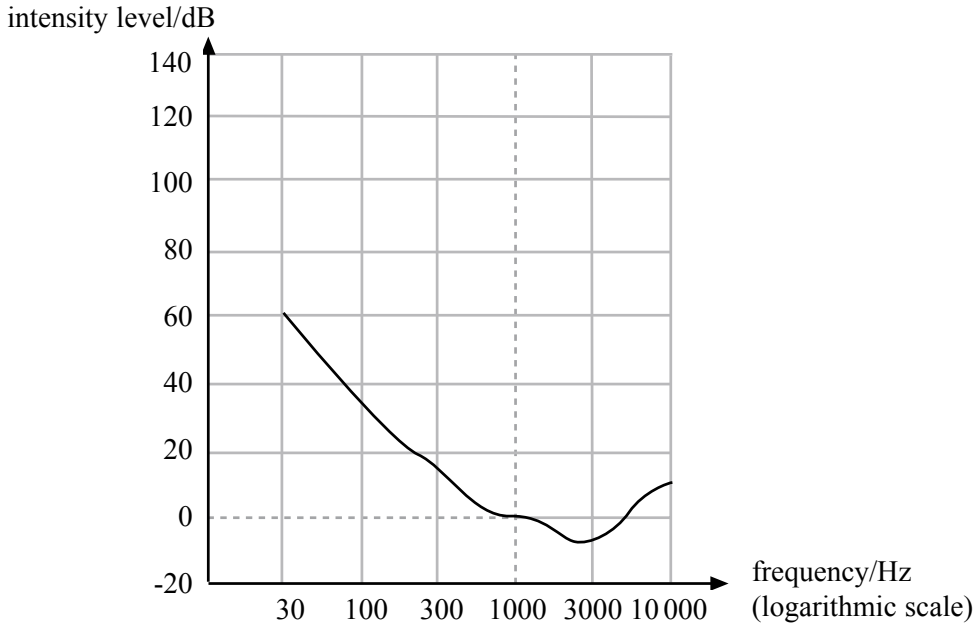
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disadvantage:

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(2 marks)

4 (a) The graph shows the equal loudness curve for the threshold of hearing.

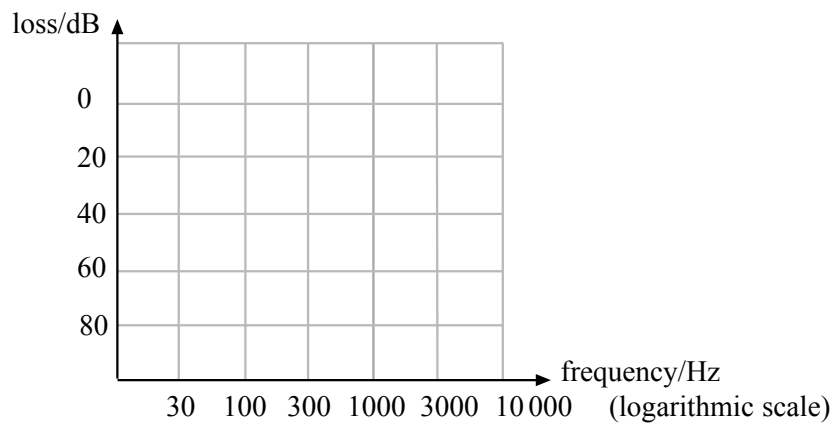


- (i) On the diagram sketch the equal loudness curve which has an intensity level of 120 dB at a frequency of 1000 Hz. (120 phon)
- (ii) What is the main similarity between the two curves?

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(2 marks)

(b) On the axes below draw the curves for:

- (i) age-related hearing loss and label it A,
- (ii) noise-induced hearing loss and label it B.



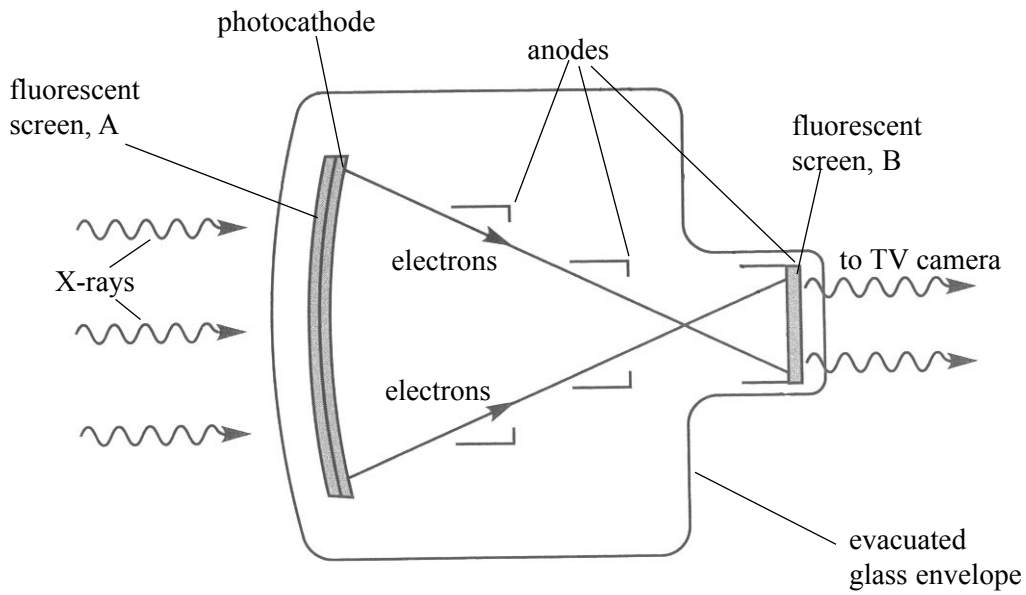
- (iii) What is the main difference between the two types of hearing loss?

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(4 marks)

6

Turn over ►

5 The diagram shows a fluoroscopic image intensifier.



- (a) State the purpose of:
 (i) the fluorescent screen, A,

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- (ii) the photocathode,

.....

- (iii) the anodes,

.....

- (iv) the fluorescent screen, B.

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(4 marks)

(b) Give **one** example of a medical application for which an image intensifier might be used. Explain why the use of an image intensifier is required.

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(2 marks)

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6

QUALITY OF WRITTEN COMMUNICATION (2 marks)

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2

END OF QUESTIONS