

Surname						Other Names					
Centre Number						Candidate Number					
Candidate Signature											

Leave blank

General Certificate of Education
 June 2005
 Advanced Level Examination



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

Thursday 16 June 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			
5			
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				Mechanics and Applied Physics		Fields, Waves, Quantum Phenomena	
Quantity	Symbol	Value	Units				
speed of light in vacuo	c	3.00×10^8	m s^{-1}	$v = u + at$		$g = \frac{F}{m}$	
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}	$s = \left(\frac{u+v}{2}\right)t$		$g = -\frac{GM}{r^2}$	
permittivity of free space	ϵ_0	8.85×10^{-12}	F m^{-1}	$s = ut + \frac{at^2}{2}$		$g = -\frac{\Delta V}{\Delta x}$	
charge of electron	e	1.60×10^{-19}	C	$v^2 = u^2 + 2as$		$V = -\frac{GM}{r}$	
the Planck constant	h	6.63×10^{-34}	J s	$F = \frac{\Delta(mv)}{\Delta t}$		$a = -(2\pi f)^2 x$	
gravitational constant	G	6.67×10^{-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	6.02×10^{23}	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	1.38×10^{-23}	J K^{-1}	$a = \frac{v^2}{r} = r\omega^2$		$T = 2\pi\sqrt{\frac{l}{g}}$	
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$	$I = \sum mr^2$		$\lambda = \frac{\omega s}{D}$	
the Wien constant	α	2.90×10^{-3}	m K	$E_k = \frac{1}{2} I\omega^2$		$d \sin \theta = n\lambda$	
electron rest mass	m_e	9.11×10^{-31}	kg	$\omega_2 = \omega_1 + at$		$\theta = \frac{\lambda}{D}$	
(equivalent to $5.5 \times 10^{-4}u$)				$\theta = \omega_1 t + \frac{1}{2} at^2$		${}_1n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$	
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}	$\omega_2^2 = \omega_1^2 + 2a\theta$		${}_1n_2 = \frac{n_2}{n_1}$	
proton rest mass	m_p	1.67×10^{-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	9.58×10^7	C kg^{-1}	<i>angular momentum</i> = $I\omega$		$hf = \phi + E_k$	
neutron rest mass	m_n	1.67×10^{-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	N kg^{-1}	<i>angular impulse</i> = change of <i>angular momentum</i> = Tt		$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$	
acceleration due to gravity	g	9.81	m s^{-2}	$\Delta Q = \Delta U + \Delta W$		Electricity	
atomic mass unit	u	1.661×10^{-27}	kg	$\Delta W = p\Delta V$		$\epsilon = \frac{E}{Q}$	
(1u is equivalent to 931.3 MeV)				$pV^\gamma = \text{constant}$		$\epsilon = I(R + r)$	
				<i>work done per cycle</i> = area of loop		$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$	
				<i>input power</i> = calorific value \times fuel flow rate		$R_T = R_1 + R_2 + R_3 + \dots$	
				<i>indicated power</i> as (area of $p-v$ loop) \times (no. of cycles/s) \times (no. of cylinders)		$P = I^2 R$	
				<i>friction power</i> = indicated power - brake power		$E = \frac{F}{Q} = \frac{V}{d}$	
				<i>efficiency</i> = $\frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$		$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$	
				<i>maximum possible efficiency</i> = $\frac{T_H - T_C}{T_H}$		$E = \frac{1}{2} QV$	
						$F = BIl$	
						$F = BQv$	
						$Q = Q_0 e^{-t/RC}$	

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 = $\frac{4}{3}\pi r^3$

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

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

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

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

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

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

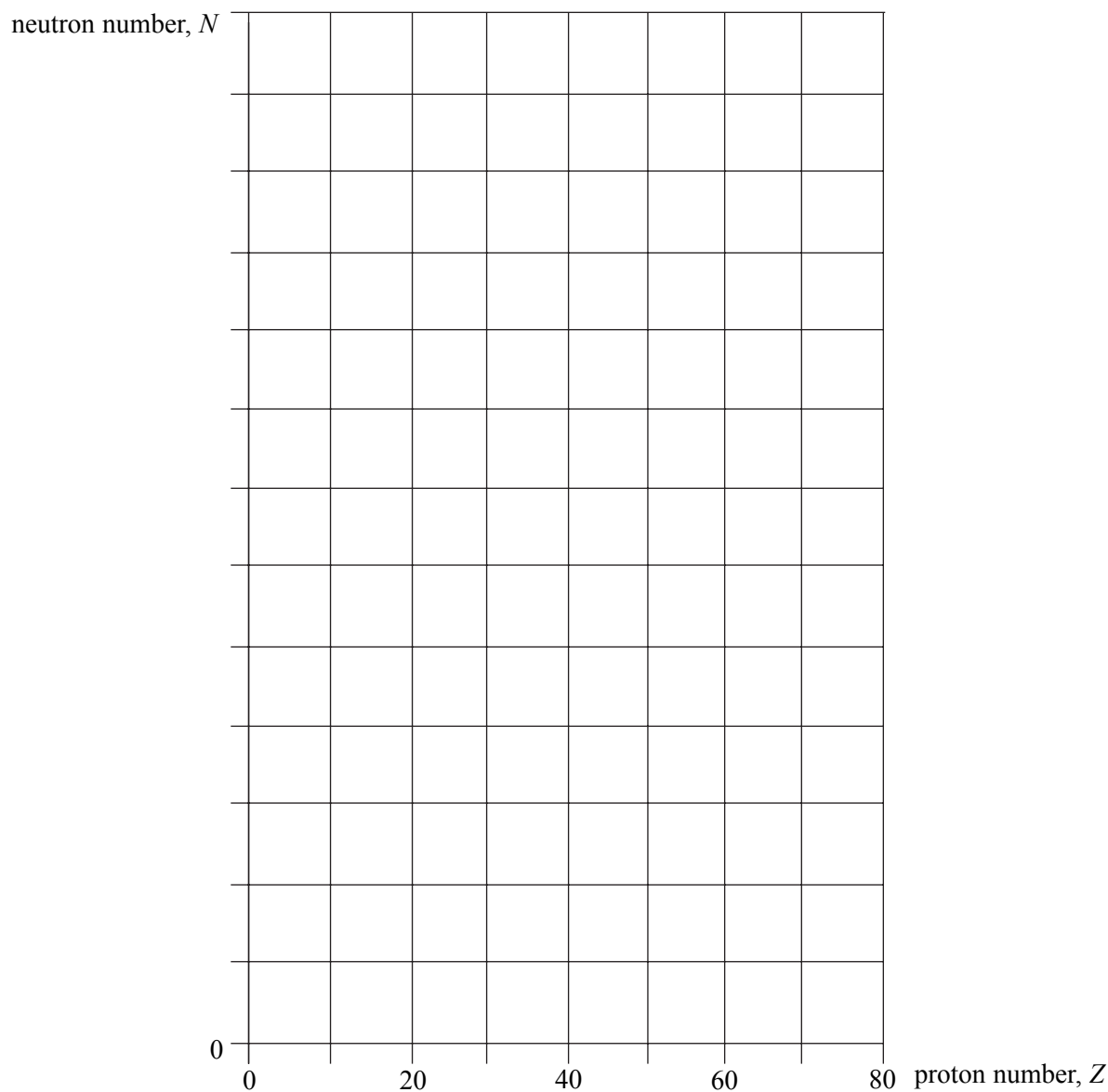
$$G = 1 + \frac{R_f}{R_1} \quad \text{non-inverting}$$

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

TURN OVER FOR THE FIRST QUESTION

SECTION A: NUCLEAR INSTABILITYAnswer **all** parts of the question.

- 1 (a) Sketch, using the axes provided, a graph of neutron number, N , against proton number, Z , for stable nuclei over the range $Z = 0$ to $Z = 80$. Show suitable numerical values on the N axis.

*(2 marks)*

- (b) On the graph indicate, for each of the following, a possible position of a nuclide that may decay by
- α emission, labelling the position with **W**,
 - β^- emission, labelling the position with **X**,
 - β^+ emission, labelling the position with **Y**.

(3 marks)

- (c) The isotope ${}_{86}^{222}\text{Rn}$ decays sequentially by emitting α particles and β^- particles, eventually forming the isotope ${}_{82}^{206}\text{Pb}$. Four α particles are emitted in the sequence.

Calculate the number of β^- particles in the sequence.

.....
.....
.....
.....

(2 marks)

- (d) A particular nuclide is described as proton-rich. Discuss **two** ways in which the nuclide may decay.

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

.....
.....
.....
.....
.....
.....
.....

(3 marks)

10

TURN OVER FOR SECTION B

SECTION B: MEDICAL PHYSICS

Answer **all** questions.

- 2 (a) A detailed, coloured object is illuminated by white light. Compare what is seen under high intensity light with that seen under low intensity light by an observer with normal eyesight.

Your explanation should refer to rods and cones.

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

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(3 marks)

- (b) A person suffering from a defect of vision has an unaided far point of 2.0 m.

- (i) Name this defect of vision.

- (ii) Calculate the power of the correcting lens needed to allow the person to see distant objects clearly.

.....

.....

.....

- (iii) The person has an unaided near point at 0.22 m. Calculate the aided near point of the person when using the correcting lens.

.....

.....

.....

.....

(4 marks)

3 **Figure 1** shows a transducer used in an ultrasound A scan.

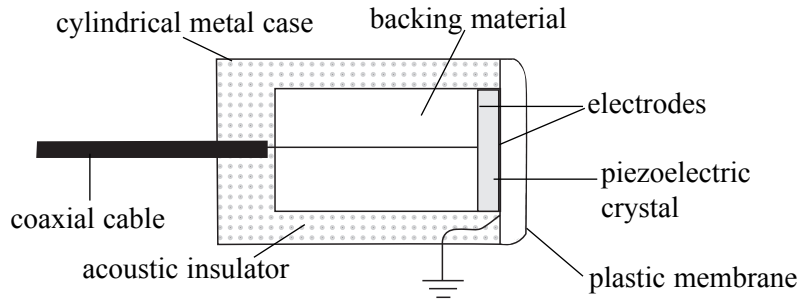


Figure 1

(a) Describe how pulses of ultrasound are produced by the transducer.

.....

.....

.....

.....

.....

.....

(3 marks)

(b) In an ultrasound A scan

(i) explain how the received signals are detected,

.....

.....

.....

.....

(ii) state why it is essential to use short pulses of ultrasound.

.....

.....

.....

.....

(3 marks)

- 4 (a) State the frequency of sound at which the normal ear is most sensitive.

.....
(1 mark)

- (b) State the main features of hearing loss in terms of frequency response for

- (i) age related hearing loss,

.....
.....

- (ii) noise related hearing loss.

.....
.....

(2 marks)

- (c) At the site of a machine in a factory, a sound meter was used to measure the sound level. The relative intensity level with the machine operating was 86 dB. The sound intensity reaching the meter when the machine was not operating was $7.0 \times 10^{-5} \text{ Wm}^{-2}$.

- (i) Show that with the machine operating, the sound intensity reaching the meter was about $4 \times 10^{-4} \text{ Wm}^{-2}$.

.....
.....
.....
.....

- (ii) Calculate the relative intensity level due to the machine alone.

.....
.....
.....
.....
.....

(4 marks)

7

5

intensity/
arbitrary units

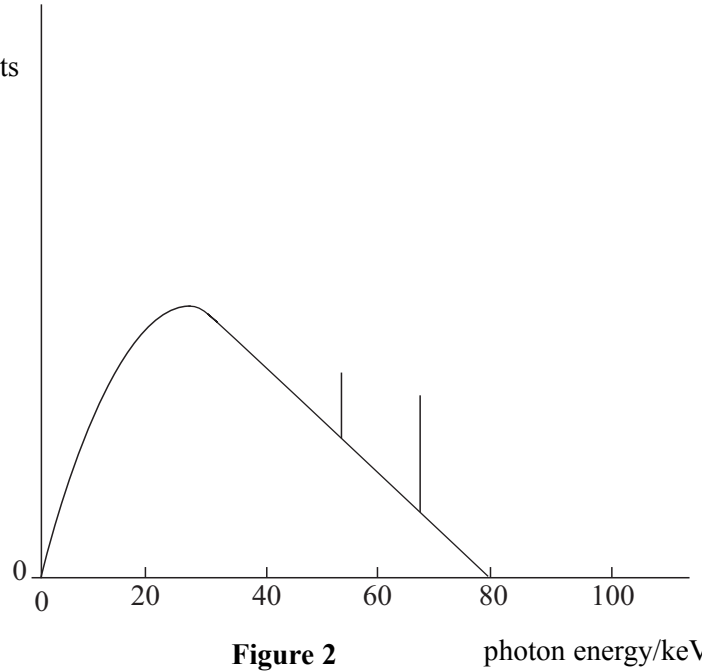


Figure 2

- (a) An X-ray tube operates with a pd across the tube of 80 kV. **Figure 2** shows the X-ray spectrum emitted. Explain why the spectrum has spikes at specific photon energies.

.....

.....

.....

.....

(2 marks)

- (b) The pd across the tube is increased to 90kV. Sketch on **Figure 2** the X-ray spectrum produced at this new pd.

(3 marks)

- (c) At the working pd of 80 kV, the anode current was 120 mA. The X-ray tube has an efficiency of 0.70%. Calculate the rate of production of heat at the anode.

.....

.....

.....

.....

(3 marks)

END OF QUESTIONS

QUALITY OF WRITTEN COMMUNICATION

(2 marks)

8

2

THERE ARE NO QUESTIONS PRINTED ON THIS PAGE