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) PHA6/W
Unit 6 Nuclear Instability: Medical Physics Option

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			
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.

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 $= 4\pi r^2$

volume of sphere $= \frac{4}{3}\pi r^3$

Mechanics and Applied Physics

$v = u + at$

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

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

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

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

$P = Fv$

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

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

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

$I = \sum mr^2$

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

$\omega_2 = \omega_1 + \alpha t$

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

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

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

$T = I\alpha$

angular momentum $= I\omega$
$W = T\theta$
$P = T\omega$

angular impulse = change of angular momentum $= Tt$
$\Delta Q = \Delta U + \Delta W$
$\Delta W = p\Delta V$
$pV^{\gamma} =$ 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

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

$\in = I(R + r)$

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

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

$P = I^2 R$

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

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

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

$F = BIl$

$F = BQv$

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

$\Phi = BA$

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

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

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

Mechanical and Thermal Properties

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

$$\textit{energy stored} = \tfrac{1}{2}Fe$$

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

$$\Delta Q = ml$$

$$pV = \tfrac{1}{3}Nm\overline{c^2}$$

$$\tfrac{1}{2}m\overline{c^2} = \tfrac{3}{2}kT = \frac{3RT}{2N_{\mathrm{A}}}$$

Nuclear Physics and Turning Points in Physics

$$\textit{force} = \frac{eV_{\mathrm{p}}}{d}$$

$$\textit{force} = Bev$$

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

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

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

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

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

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

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

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

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

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

$$E = mc^2 = \frac{m_0c^2}{\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

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

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

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 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}

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

$$M = \frac{f_{\mathrm{o}}}{f_{\mathrm{e}}}$$

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

$$R_{\mathrm{s}} \approx \frac{2GM}{c^2}$$

Medical Physics

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

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

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

$$I = I_0e^{-\mu x}$$

$$\mu_{\mathrm{m}} = \frac{\mu}{\rho}$$

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

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

$$\frac{1}{C_{\mathrm{T}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$$

$$C_{\mathrm{T}} = C_1 + C_2 + C_3 + \cdots$$

$$X_{\mathrm{C}} = \frac{1}{2\pi fC}$$

Alternating Currents

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

Operational amplifier

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

$$G = -\frac{R_{\mathrm{f}}}{R_1} \qquad \text{inverting}$$

$$G = 1 + \frac{R_{\mathrm{f}}}{R_1} \qquad \text{non-inverting}$$

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

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, θ.

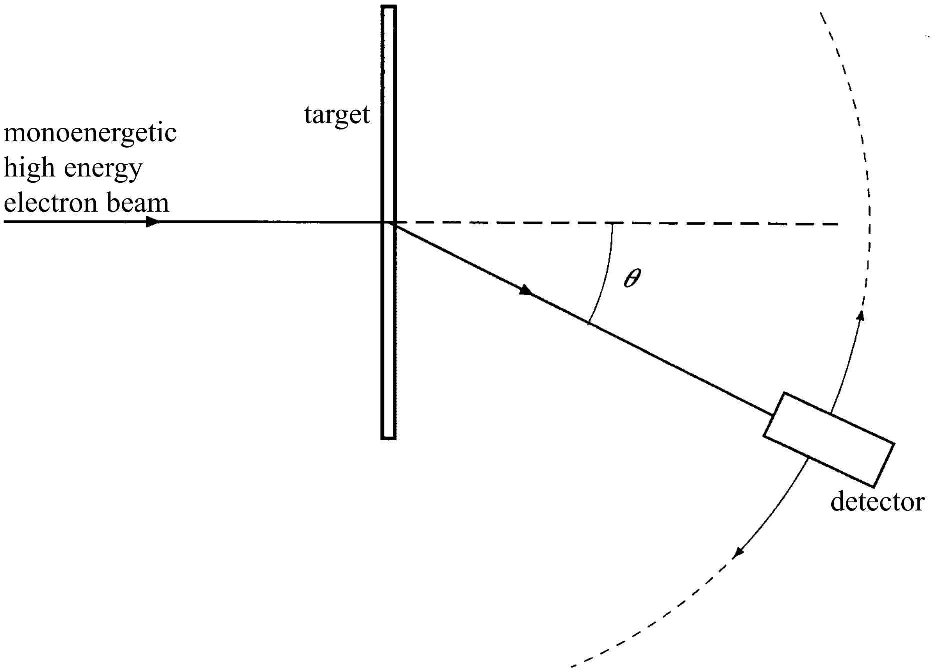
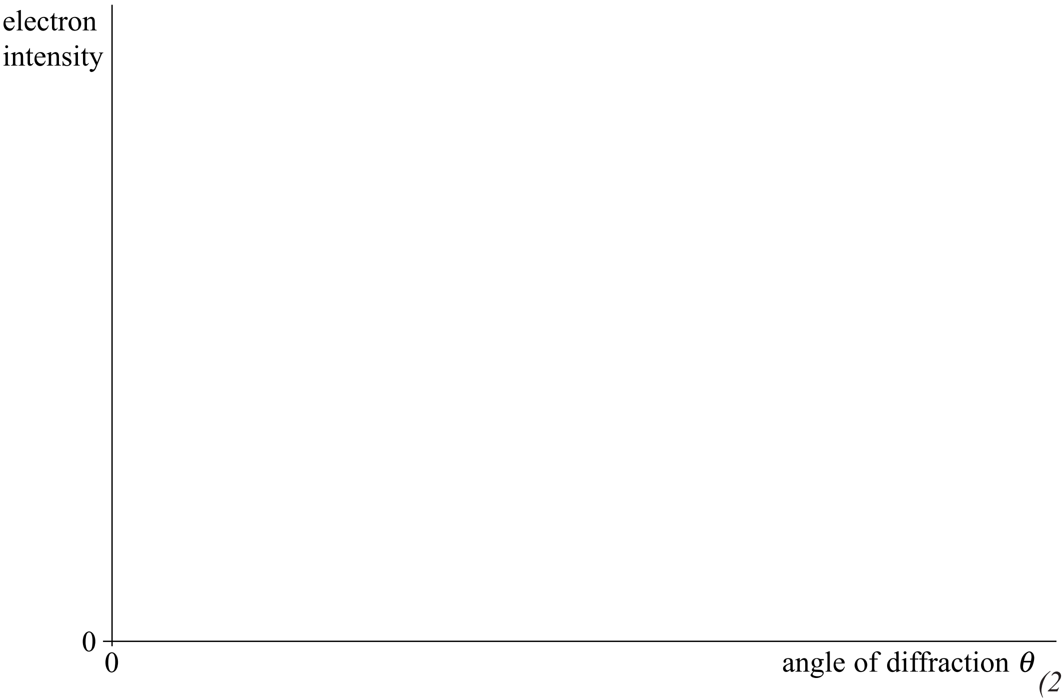


Figure 1

(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 $R = r_0A^{\frac{1}{3}}$.

element	**radius of nucleus, *R*** 10^{-15}**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 α particles.

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

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(3 marks)

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10

LEAVE
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SECTION B: MEDICAL PHYSICS

Answer **all** questions.

2 A patient has a hearing test to obtain an equal loudness curve at a level above the threshold of hearing. The curve obtained is shown in **Figure 2**.

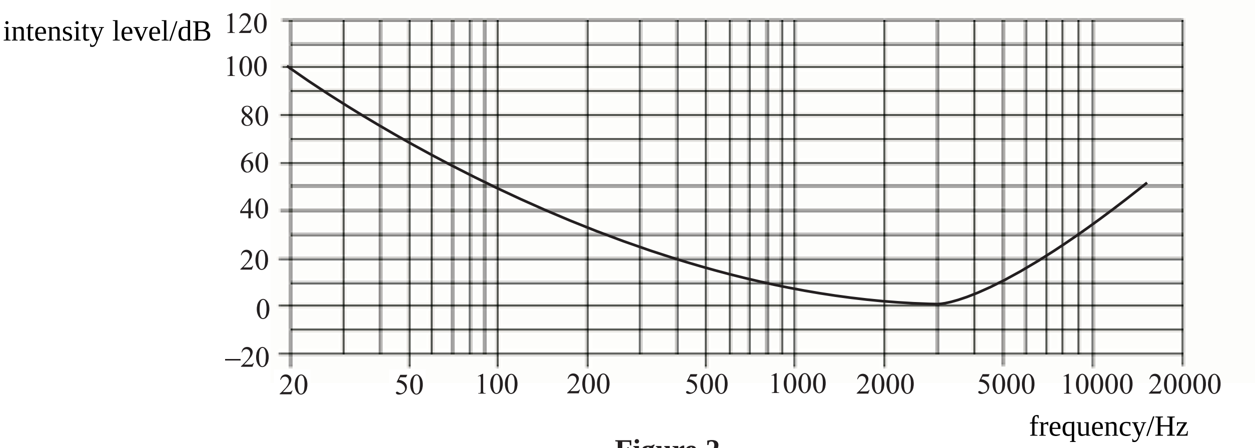

Figure 2

(a) (i) Describe how such a curve is obtained.

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

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(ii) On **Figure 2** draw an equal loudness curve which passes through 100 dB at a frequency of 1 kHz. *(5 marks)*

(b) (i) Define the threshold of hearing, I_0.

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(ii) A drill is heard by a passer-by. The intensity of the sound reaching the passer-by is $1.3 \times 10^{-3}\,\mathrm{W\,m^{-2}}$. Calculate the intensity level of the sound heard.

$I_0 = 1.0 \times 10^{-12}\,\mathrm{W\,m^{-2}}$

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(4 marks)

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9

TURN OVER FOR THE NEXT QUESTION

3 (a) State

(i) the cause of astigmatism,

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(ii) the effect of astigmatism on vision,

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(iii) the type of lens needed to correct astigmatism,

....

(iv) **two** parameters that must be determined for the correcting lens.

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(4 marks)

(b) A defective eye has an unaided near point at 0.65 m and an unaided far point at infinity. Calculate

(i) the power of the correcting lens needed to allow the eye to see clearly an object 0.25 m from the eye,

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(ii) the furthest distance from the eye that an object can be seen clearly when the correcting lens is used.

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(3 marks)

7

4 (a) Sketch a graph of the ECG trace for a healthy heart. Label each axis with appropriate units and scales.

(4 marks)

(b) When obtaining such a trace, electrodes are attached to the patient. State and explain **two** precautions which should be taken when attaching the electrodes to ensure reception of the best signal.

precaution 1:

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precaution 2:

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(2 marks)

6

5 (i) Explain what is meant by the *half-value thickness* of lead for X-rays.

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(ii) Calculate the linear attenuation coefficient of lead for 90 keV X-ray photons.

half value thickness of lead for 90 keV X-ray photons = 12 mm.

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(iii) Calculate the thickness of lead needed to reduce the intensity of a beam of 90 keV X-ray photons to 5.0 % of the intensity incident on the lead.

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(6 marks)

$\overline{}$ 6

$\overline{}$ 2

QUALITY OF WRITTEN COMMUNICATION

END OF QUESTIONS