Surname			er Names			
Centre Number			Candid	ate Number		
Candidate Signature						



General Certificate of Education June 2006 Advanced Level Examination

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



Thursday 15 June 2006 9.00 am to 10.15 am

#### For this paper you must have:

- a calculator
- a pencil and 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.
- Answer the questions in the spaces provided.
- Show all your working.
- 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. This includes up to 2 marks for the Quality of Written Communication.
- The marks for questions are shown in brackets.
- 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.
- You are reminded of the need for good English and clear presentation in your answers. Questions indicated on the paper should be answered in continuous prose. Quality of Written Communication will be assessed in these answers.

For Examiner's Use						
Number	Mark	Number	Mark			
1						
2						
3						
4						
5						
Total (Co	Total (Column 1)					
Total (Co	Total (Column 2)					
Quality of Written Communication						
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	$3.00 \times 10^{8}$	m s <sup>-1</sup>		
permeability of free space	$\mu_0$	$4\pi \times 10^{-7}$	H m <sup>-1</sup>		
permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12}$	F m <sup>-1</sup>		
charge of electron	e	$1.60 \times 10^{-19}$	C		
the Planck constant	h	$6.63 \times 10^{-34}$	Js		
gravitational constant	G	$6.67 \times 10^{-11}$	N m <sup>2</sup> kg <sup>-2</sup>		
the Avogadro constant	$N_{\rm A}$	$6.02 \times 10^{23}$	mol <sup>-1</sup>		
molar gas constant	R	8.31	J K <sup>-1</sup> mol		
the Boltzmann constant	k	$1.38 \times 10^{-23}$	J K <sup>-1</sup>		
the Stefan constant	$\sigma$	$5.67 \times 10^{-8}$	W m <sup>-2</sup> K <sup>-</sup>		
the Wien constant	α	$2.90 \times 10^{-3}$	m K		
electron rest mass	$m_{\rm e}$	$9.11 \times 10^{-31}$	kg		
(equivalent to $5.5 \times 10^{-4}$ u)					
electron charge/mass ratio	$e/m_{\rm e}$	$1.76 \times 10^{11}$	C kg <sup>-1</sup>		
proton rest mass	$m_{\rm p}$	$1.67 \times 10^{-27}$	kg		
(equivalent to 1.00728u)					
proton charge/mass ratio	$e/m_{\rm p}$	$9.58 \times 10^{7}$	C kg <sup>-1</sup>		
neutron rest mass	$m_{\rm n}$	$1.67 \times 10^{-27}$	kg		
(equivalent to 1.00867u)					
gravitational field strength	g	9.81	N kg <sup>-1</sup> m s <sup>-2</sup>		
acceleration due to gravity	g	9.81	m s <sup>2</sup>		
atomic mass unit	u	$1.661 \times 10^{-27}$	kg		
(1u is equivalent to					
931.3 MeV)					

#### **Fundamental particles**

Class	Name	Symbol	Rest energy
			/MeV
photon	photon	γ	0
lepton	neutrino	$ u_{c}$	0
		$ u_{\mu}$	0
	electron	$\mathbf{e}^{\pm}$	0.510999
	muon	$\mu^{\pm}$	105.659
mesons	pion	$\boldsymbol{\pi}^{\pm}$	139.576
		$\pi^0$	134.972
	kaon	$K^{\pm}$	493.821
		$K^0$	497.762
baryons	proton	p	938.257
	neutron	n	939.551

#### Properties of quarks

Туре	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

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

indicated power as (area of p - Vloop) × (no. of cycles/s) × (no. of cylinders)

friction power = indicated power – brake power

$$efficiency = \frac{W}{Q_{\rm in}} = \frac{Q_{\rm in} - Q_{\rm out}}{Q_{\rm in}}$$

maximum possible

$$efficiency = \frac{T_{\rm H} - T_{\rm C}}{T_{\rm H}}$$

### Fields, Waves, Quantum Phenomena

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

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

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

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

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

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

$$x = A \cos 2\pi f t$$

$$T = 2\pi \sqrt{\frac{I}{g}}$$

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

$$d \sin \theta = n\lambda$$

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

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

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

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

$$E = hf$$

$$hf = \phi + E_k$$

$$hf = E_1 - E_2$$

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

$$c = \frac{1}{n}$$

#### Electricity

$$\begin{aligned}
&\in = \frac{E}{Q} \\
&\in = I(R+r) \\
&\frac{1}{R_{\rm T}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \\
&R_{\rm T} = R_1 + R_2 + R_3 + \cdots \\
&P = I^2 R \\
&E = \frac{F}{Q} = \frac{V}{d} \\
&E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \\
&E = \frac{1}{2} QV \\
&F = BIl \\
&F = BQv \\
&Q = Q_0 e^{-I/RC} \\
&\Phi = BA
\end{aligned}$$

Turn over

#### **Data Sheet**

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

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

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

## Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

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

$$\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT = \frac{3RT}{2N_A}$$

## **Nuclear Physics and Turning Points in Physics**

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

$$force = Bev$$

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

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

 $work\ done = eV$ 

$$F = 6\pi \eta r v$$

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

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

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

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

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

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

$$E = mc^{2} = \frac{m_{0}c^{2}}{\left(1 - \frac{v^{2}}{c^{2}}\right)^{\frac{1}{2}}}$$

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

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

# Astrophysics and Medical Physics

Body Mass/kg Mean radius/m

Sun  $2.00 \times 10^{30}$   $7.00 \times 10^{8}$ Earth  $6.00 \times 10^{24}$   $6.40 \times 10^{6}$ 

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

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

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

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

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

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

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

v = Hd

 $P = \sigma A T^4$ 

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

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

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

#### **Medical Physics**

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

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

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

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

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

#### **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

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

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

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

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

#### **Alternating Currents**

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

#### **Operational amplifier**

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

$$G = -\frac{R_{\rm f}}{R_{\rm 1}}$$
 inverting

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

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

### Turn over for the first question

### SECTION A: NUCLEAR INSTABILITY

Answer all of this question.

1	(a)	Calculate the radius of the $^{238}_{92}$ U nucleus.	
		$r_0 = 1.3 \times 10^{-15} \mathrm{m}$	
			(2 marks)
	(b)	At a distance of 30 mm from a point source of $\gamma$ rays the corrected count rate Calculate the distance from the source at which the corrected count rate is 0.3 assuming that there is no absorption.	
			(2 marks)
	(c)	The activity of a source of $\beta$ particles falls to 85% of its initial value in 52 s. the decay constant of the source.	Calculate
			(3 marks)

10

(d)	Explain why the isotope of technetium, <sup>99</sup> Tc <sub>m</sub> , is often chosen as a suitable source of radiation for use in medical diagnosis.
	You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.
	(3 marks)

Turn over for the next question

Turn over ▶

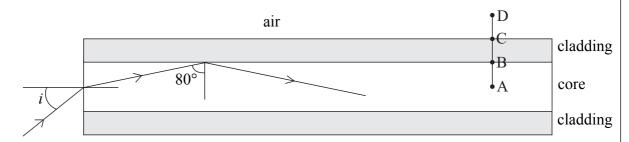
### **SECTION B: MEDICAL PHYSICS**

Answer all questions.

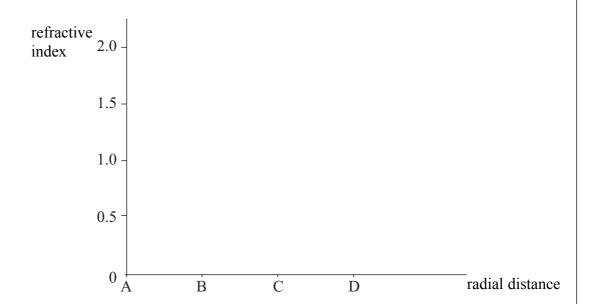
2	(a)		te and explain <b>two</b> physical properties of the light produced by a laser which ifferent from the light produced by a filament lamp.	makes
		prop	perty 1	
		prop	perty 2	
		•••••	(3	marks)
	(b)	An e	endoscope may use light from a filament lamp and light from a laser.	
		State	re	
		(i)	the use of the light from a filament lamp,	
		(ii)	a use of the light from a laser.	
			(2	marks)
			`	

(c) **Figure 1** shows a cross-section through an optical fibre used in an endoscope. The core is made from glass of refractive index 1.5.

Figure 1



(i) Complete the graph below to show how the refractive index changes with radial distance along the line ABCD in **Figure 1**.



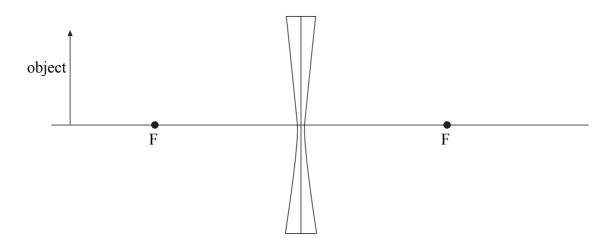
(ii) Calculate the value of the angle of incidence, i, shown in **Figure 1**.

 (4 marks)

9

3 (a) The diverging lens in **Figure 2** forms an image of the object. Complete **Figure 2** by drawing a ray diagram to show the formation of the image. Label the image.

Figure 2



(2 marks)

(b) A diverging spectacle lens of power −3.0 D is used to correct a defect of vision. When used to view a real object, the image is formed 0.21 m from the lens.

(i) State the defect of vision.

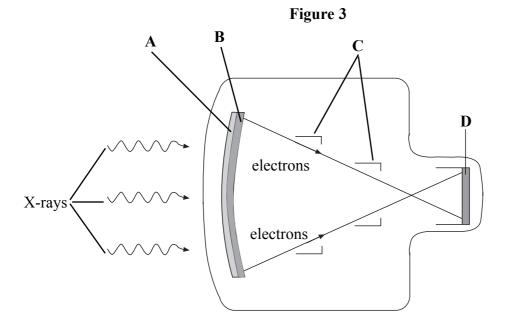

(ii) Calculate the distance of the object from the lens.

	• • • • • • • • • • • • • • • • • • • •	•••••
•••••	• • • • • • • • • • • • • • • • • • • •	•••••

(3 marks)

5

4 Figure 3 shows the design of an X-ray image intensifier.



The main components are labelled A to D. Name each component and state its purpose in the process of image intensification.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

<b>A</b>	
B	
<b>C</b>	
D	
	(8 marks)

Turn over for the next question

8

(i)	State the <b>two</b> physical properties of a material which determine its acoustic impedance.
(ii)	Under what condition is ultrasound strongly reflected at a boundary between two types of material?
(iii)	
(iii)	State where a coupling medium or gel is used in an ultrasound scan and explain why it is necessary.
(iii)	
(iii)	
(iii)	is necessary.
(iii)	
(iii)	is necessary.

END OF QUESTIONS

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