Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

For Examiner's Use

General Certificate of Education
June 2008
Advanced Level Examination

PHYSICS (SPECIFICATION A) **PHA5/W**
Unit 5 Nuclear Instability: Astrophysics Option

Wednesday 11 June 2008 9.00 am to 10.15 am

For this paper you must have:
- a pencil and a ruler
- a calculator
- a data sheet loose insert.

Time allowed: 1 hour 15 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- Answer the questions in the spaces provided. Answers written in margins or on blank pages will not be marked.
- Show all your working.
- Do all rough work in this book. Cross through any work you do not want to be 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 as a loose insert to this question paper.
- You are expected to use a calculator where appropriate.
- Questions 1(c) and 3(a) should be answered in continuous prose. In these questions you will be marked on your ability to use good English, to organise information clearly and to use specialist vocabulary where appropriate.

For Examiner's Use			
Question	Mark	Question	Mark
1			
2			
3			
4			
5			
Total (Column 1) →			
Total (Column 2) →			
Quality of Written Communication			
TOTAL			
Examiner's Initials			

SECTION A: NUCLEAR INSTABILITY

Answer **all** of this question.

1 (a) An isotope of technetium ${}^{99}_{43}\text{Tc}^{\text{m}}$, which is in a metastable state, decays emitting only γ rays. When the isotope is placed 20 cm from a γ ray detector the count rate is 25 counts per second. The background count rate is 120 counts per minute. Calculate the count rate, in counts per second, when the detector is placed 30 cm from the isotope.

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(3 marks)

1 (b) (i) Calculate the approximate radius of a nucleus of ${}^{99}_{43}\text{Tc}^{\text{m}}$, given that the nuclear radius of ${}^{28}_{14}\text{Si}$ is 3.7×10^{-15} m.

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1 (b) (ii) State **one** method by which the nuclear radius of ${}^{28}_{14}\text{Si}$ could be determined experimentally.

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(4 marks)

1 (c) Explain why sources of β radiation often also produce γ rays of discrete frequencies.

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

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(3 marks)

10

Turn over for the next question

Areas outside the box will not be scanned for marking

SECTION B: ASTROPHYSICS

Answer **all** questions.

2 (a) Draw a ray diagram to show how a converging lens forms a diminished image of a real object. Label the principal foci, the object and the image on your diagram.

(2 marks)

2 (b) A converging lens of power 12.5 D is used to produce an image of a real object placed 0.35 m from the lens.

2 (b) (i) Calculate the image distance.

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2 (b) (ii) State **three** properties of the image.

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(4 marks)

6

3 (a) Explain what is meant by the terms Rayleigh criterion and Airy disc.

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

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(3 marks)

3 (b) The Very Large Telescope (VLT) in the Atacama Desert in Chile is a combination of four Cassegrain telescopes each of diameter 8.2 m. It is used to detect electromagnetic radiation of wavelengths in the range 200 nm to 20 μm.

3 (b) (i) Show that the combination has a similar light-collecting power to that of a single 16 m diameter telescope.

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3 (b) (ii) The VLT is capable of an angular resolution similar to that of a 100 m diameter telescope. Calculate the maximum angular resolution of the VLT.

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3 (b) (iii) The Atacama Desert is possibly the driest place on Earth. What part of the electromagnetic spectrum is significantly absorbed by water vapour?

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(4 marks)

7

Turn over ▸

4 (a) Sketch a Hertzsprung–Russell (H–R) diagram on the axes below. Label the position of the main sequence, dwarf and giant stars. Complete the spectral class axis by labelling the spectral classes.

(3 marks)

4 (b) Beta Hydri is a star with the same black body temperature as the Sun, but is approximately 3.5 times brighter.

4 (b) (i) Label with the letter X the position of Beta Hydri on the H–R diagram.

4 (b) (ii) State and explain which star is larger, the Sun or Beta Hydri.

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(3 marks)

6

Areas outside the box will not be scanned for marking

5 IZW 1 is an active galaxy, which means it contains a supermassive *black hole* which produces a *quasar* as it consumes its host galaxy.

5 (a) Explain what is meant by

5 (a) (i) a quasar,

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5 (a) (ii) a black hole.

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(3 marks)

5 (b) Analysis of radio waves from the galaxy IZW 1, suggest it is 800 million light years from Earth.

5 (b) (i) Calculate the recessional speed of the galaxy.

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5 (b) (ii) The source of the radio waves is carbon monoxide molecules in the gas clouds of the galaxy. When measured from a lab-based source these waves have a frequency of 108 GHz. What is the frequency of the waves detected from the galaxy?

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(4 marks)

Question 5 continues on the next page

5 (c) The black hole at the centre of IZW 1 could have a mass 100 million times greater than the Sun. Calculate the radius of the event horizon of a black hole of this mass.

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(2 marks)

9

Quality of Written Communication *(2 marks)*

2

END OF QUESTIONS

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PHYSICS (SPECIFICATION A) **PHA5W**
Unit 5 Nuclear Instability: Astrophysics Option

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 $= Tt$

$\Delta Q = \Delta U + \Delta W$

$\Delta W = p\Delta V$

$pV^{\gamma} = \text{constant}$

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

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

$\epsilon = I(R + r)$

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

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

$P = I^2R$

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

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

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

$F = BIl$

$F = BQv$

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

$\Phi = BA$

Turn over ▶

This insert should **not** be sent to the examiner

$$\textit{magnitude of induced emf} = N\frac{\Delta\Phi}{\Delta t}$$

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

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

Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

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

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

Nuclear Physics and Turning Points in Physics

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

$$\textit{force} = Bev$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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}

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

Medical Physics

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

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

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

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

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

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

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