Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2006
Advanced Level Examination

PHYSICS **PHA5/W**
Unit 5 Nuclear Instability: Astrophysics 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 (Column 1) →			
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	3.00×10^{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 $= \frac{\textit{power output}}{\textit{power input}}$

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

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

$I = \sum mr^2$

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

$\omega_2 = \omega_1 + \alpha t$

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

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

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

$T = I\alpha$

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^{γ} = 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

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

$\epsilon = I(R + r)$

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

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

$P = I^2 R$

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

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

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

$F = BIl$

$F = BQv$

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

$\Phi = BA$

Turn over ▶

Data Sheet

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

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

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

Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

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

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

Nuclear Physics and Turning Points in Physics

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

$$\textit{force} = Bev$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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}

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

Medical Physics

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

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

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

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

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

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

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

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Turn over for the first question

Turn over ▶

LEAVE MARGIN BLANK

SECTION A: NUCLEAR INSTABILITY

Answer **all** of this question.

1 (a) Calculate the radius of the $^{238}_{92}\mathrm{U}$ nucleus.

$r_0 = 1.3 \times 10^{-15}$ m

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(2 marks)

(b) At a distance of 30 mm from a point source of γ rays the corrected count rate is C. Calculate the distance from the source at which the corrected count rate is $0.10\,C$, assuming that there is no absorption.

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(2 marks)

(c) The activity of a source of β particles falls to 85% of its initial value in 52 s. Calculate the decay constant of the source.

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(3 marks)

(d) Explain why the isotope of technetium, $^{99}Tc_m$, 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.

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(3 marks)

10

Turn over for the next question

SECTION B: ASTROPHYSICS

Answer **all** questions.

2 The last refracting telescope that could be called 'the largest optical telescope in the world' was one with an objective lens of diameter 0.90 m. It was superseded in 1889 by a reflecting telescope with an objective mirror of diameter 1.52 m.

(a) Calculate

(i) the ratio $\dfrac{\text{resolving power of the reflector}}{\text{resolving power of the refractor}}$,

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(ii) the ratio $\dfrac{\text{the amount of light energy that can be collected per second by the reflector}}{\text{the amount of light energy that can be collected per second by the refractor}}$.

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(3 marks)

(b) Spherical aberration can be a problem with reflecting telescopes.

(i) Draw a ray diagram to show how spherical aberration arises in a reflecting telescope.

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(ii) State how this problem can be prevented.

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(2 marks)

(c) The image produced by a refracting telescope can be clearer than that of a similar diameter reflector because of the position of the secondary mirror.

(i) Sketch a diagram to show the position of the mirrors in a Cassegrain telescope.

(ii) Give **two** reasons why the secondary mirror in the Cassegrain telescope affects the clarity of the image.

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(3 marks)

8

Turn over for the next question

3 Charge coupled devices (CCDs) are commonly used in astronomy because of their high *quantum efficiency*.

(a) Describe the structure and operation of a CCD.

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

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(4 marks)

(b) Explain what is meant by quantum efficiency, and state a typical value of the quantum efficiency of a CCD.

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(2 marks)

6

4 (a) Define the *absolute magnitude* of a star.

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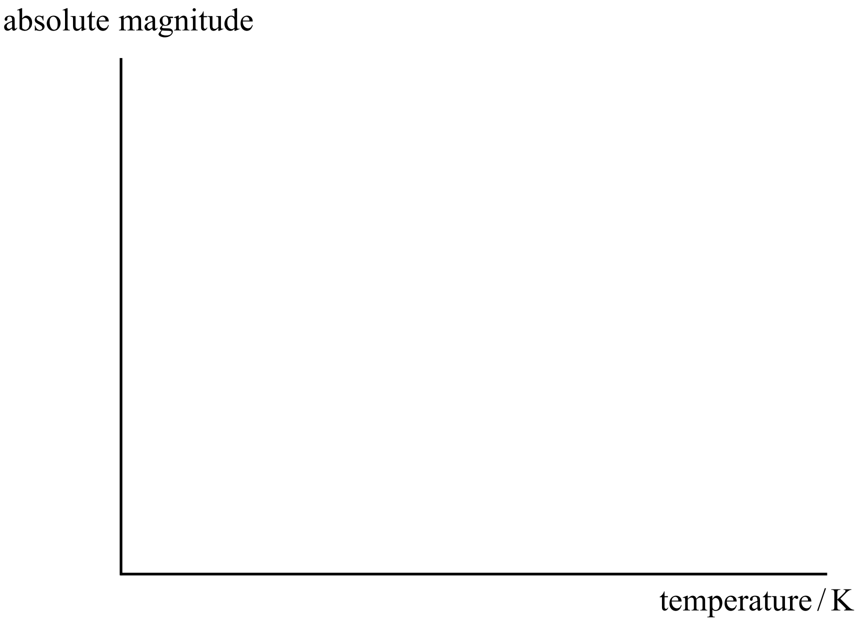
(1 mark)

(b) **Figure 1** shows the axes of a Hertzsprung-Russell (H-R) diagram.

Figure 1



(i) On each axis indicate a suitable range of values.

(ii) Label with an S the current position of the Sun on the H-R diagram.

(iii) Label the positions of the following stars on the H-R diagram:

(1) star W, which is significantly hotter and brighter than the Sun,

(2) star X, which is significantly cooler and larger than the Sun,

(3) star Y, which is the same size as the Sun, but significantly cooler,

(4) star Z, which is much smaller than the Sun, and has molecular bands as an important feature in its spectrum. *(7 marks)*

8

Turn over for the next question

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5 Treated as a single source, the Andromeda galaxy has an apparent magnitude of 3.54 and an absolute magnitude of –20.62.

(a) Calculate the distance to the Andromeda galaxy.

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(2 marks)

(b) The Andromeda galaxy is believed to be approaching the Milky Way at a speed of 105 km s^{-1}.
Calculate the wavelength of the radio waves produced by atomic hydrogen which would be detected from a source approaching the observer at a speed of 105 km s^{-1}.
wavelength of atomic hydrogen measured in a laboratory = 0.21121 m.

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(2 marks)

(c) Some astronomers believe the Andromeda galaxy may collide with the Milky Way in the distant future. Estimate a time, in s, which will elapse before a possible impact with the Milky Way.

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(2 marks)

6

Quality of Written Communication *(2 marks)*

2

END OF QUESTIONS