

Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
 January 2003
 Advanced Level Examination



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

PHA5/W

Monday 27 January 2003 Morning Session

In addition to this paper you will require:

- a calculator;
- a pencil and a ruler.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
Total (Column 1)	→		
Total (Column 2)	→		
TOTAL			
Examiner's Initials			

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.

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

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^8	m s^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ϵ_0	8.85×10^{-12}	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}	$\text{N m}^2 \text{kg}^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$\text{J K}^{-1} \text{mol}^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass	m_e	9.11×10^{-31}	kg
(equivalent to $5.5 \times 10^{-4}u$)			
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}
proton rest mass	m_p	1.67×10^{-27}	kg
(equivalent to 1.00728u)			
proton charge/mass ratio	e/m_p	9.58×10^7	C kg^{-1}
neutron rest mass	m_n	1.67×10^{-27}	kg
(equivalent to 1.00867u)			
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit	u	1.661×10^{-27}	kg
(1u is equivalent to 931.3 MeV)			

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

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 = $\frac{\text{power output}}{\text{power input}}$
- $\omega = \frac{v}{r} = 2\pi f$
- $a = \frac{v^2}{r} = r\omega^2$
- $I = \sum mr^2$
- $E_k = \frac{1}{2}I\omega^2$
- $\omega_2 = \omega_1 + at$
- $\theta = \omega_1 t + \frac{1}{2}at^2$
- $\omega_2^2 = \omega_1^2 + 2a\theta$
- $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$
- $T = I\alpha$
- 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 \times fuel flow rate
- indicated power as (area of $p-V$ loop) \times (no. of cycles/s) \times (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

- $g = \frac{F}{m}$
- $g = -\frac{GM}{r^2}$
- $g = -\frac{\Delta V}{\Delta x}$
- $V = -\frac{GM}{r}$
- $a = -(2\pi f)^2 x$
- $v = \pm 2\pi f \sqrt{A^2 - x^2}$
- $x = A \cos 2\pi ft$
- $T = 2\pi \sqrt{\frac{m}{k}}$
- $T = 2\pi \sqrt{\frac{l}{g}}$
- $\lambda = \frac{\omega s}{D}$
- $d \sin \theta = n\lambda$
- $\theta \approx \frac{\lambda}{D}$
- $n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$
- $n_2 = \frac{n_2}{n_1}$
- $\sin \theta_c = \frac{1}{n}$
- $E = hf$
- $hf = \phi + E_k$
- $hf = E_1 - E_2$
- $\lambda = \frac{h}{p} = \frac{h}{mv}$
- $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$
- Electricity**
- $\epsilon = \frac{E}{Q}$
- $\epsilon = I(R+r)$
- $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- $R_T = R_1 + R_2 + R_3 + \dots$
- $P = I^2 R$
- $E = \frac{F}{Q} = \frac{V}{d}$
- $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$
- $E = \frac{1}{2} QV$
- $F = BI$
- $F = BQv$
- $Q = Q_0 e^{-t/RC}$
- $\Phi = BA$

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

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

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

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

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

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

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

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

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

- 1 The radioactive isotope of sodium ${}_{11}^{22}\text{Na}$ has a half life of 2.6 years. A particular sample of this isotope has an initial activity of 5.5×10^5 Bq (disintegrations per second).

- (a) Explain what is meant by the *random nature* of radioactive decay.

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

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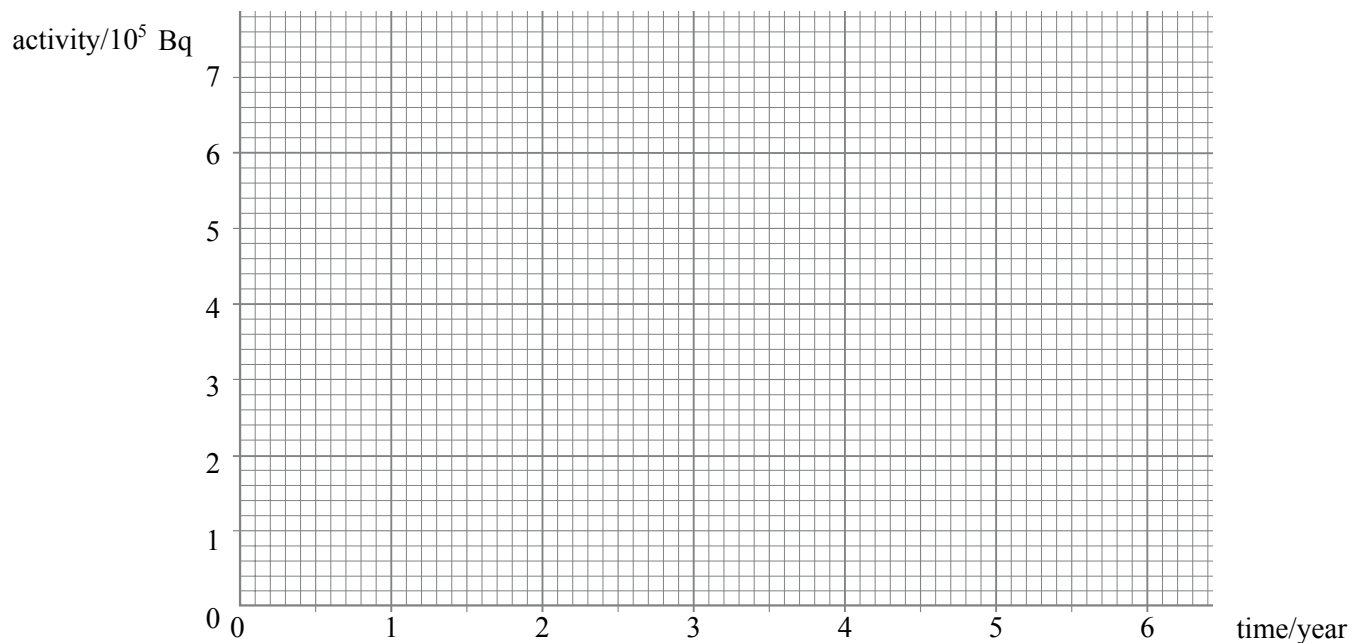
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(2 marks)

- (b) Use the axes to sketch a graph of the activity of the sample of sodium over a period of 6 years.



(2 marks)

(c) Calculate

- (i) the decay constant, in s^{-1} , of ${}^{22}_{11}\text{Na}$,
1 year = $3.15 \times 10^7 \text{s}$

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- (ii) the number of atoms of ${}^{22}_{11}\text{Na}$ in the sample initially,

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- (iii) the time taken, in s, for the activity of the sample to fall from $1.0 \times 10^5 \text{ Bq}$ to $0.75 \times 10^5 \text{ Bq}$.

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(6 marks)

10

TURN OVER FOR THE NEXT QUESTION

SECTION B ASTROPHYSICS

Answer **all** questions.

2 (a) A converging lens of focal length 4.0 cm is used to form an inverted image of a small upright object. The image produced is the same size as the object.

(i) State the distance of the lens from the object for this image to be formed.

.....

(ii) Draw a ray diagram to show how the image is formed. Mark the positions of the object, image and the principal foci of the lens.

(3 marks)

(b) (i) The lens in part (a) is replaced by another converging lens of focal length 12.0 cm, the distance between the lens and object staying the same. Calculate the distance between the image formed and the lens.

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

(ii) State **three** properties of this image.

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

(3 marks)

3 (a) The original dish design of the Lovell Radio Telescope at Jodrell Bank used a 50 mm open wire mesh. Estimate the minimum wavelength detectable using this design.

.....
.....

(1 mark)

(b) Before completion, the mesh was replaced by a solid metal surface of diameter 76 m capable of detecting radio signals as small as 60 mm wavelength. Calculate the resolving power of the telescope when detecting radiation of this wavelength.

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

(2 marks)

(c) The Jodrell Bank Observatory also has a 13 m diameter radio telescope. State **two** advantages the telescope described in part (b) has over this smaller telescope when detecting radio waves of the same wavelength.

Support each answer with a calculation.

advantage 1:

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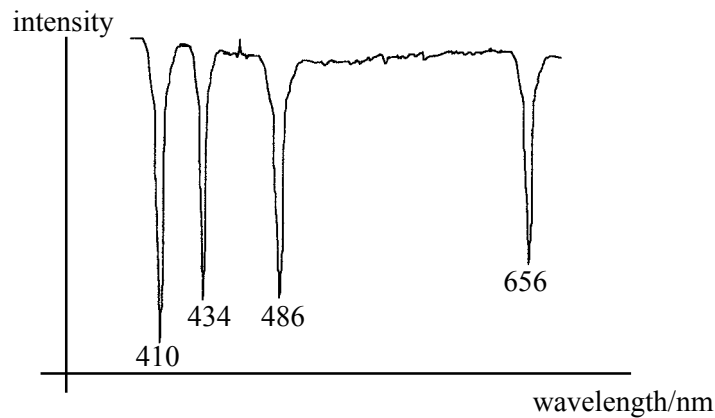
advantage 2:

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(4 marks)



- 4 (a) The graph shows part of the visible region of the spectrum of the star Vega.



The absorption lines are due to excited hydrogen atoms. The wavelength of each absorption is given in nm.

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

- (i) Explain how hydrogen atoms produce these absorption lines.

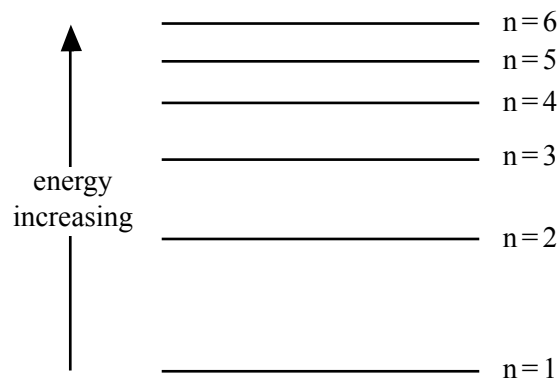
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- (ii) The diagram below shows the first six energy levels of a hydrogen atom. Draw an arrow to show the largest energy transition which produces an absorption line in the **visible** spectrum of Vega.



- (iii) State the value of the wavelength corresponding to this transition.
.....
- (iv) What is the name given to the series which gives rise to the visible region of the hydrogen spectrum?
.....
- (v) For which spectral classes are these lines the dominant feature?
.....
(4 marks)
- (b) (i) The wavelength at maximum intensity in the spectrum of Vega has a value of 300 nm. Show that this corresponds to a value of about 10 000 K for the surface temperature of Vega.
.....
.....
.....
- (ii) State the assumption made in your answer to (b)(i).
.....
(2 marks)
- (c) State the spectral class to which Vega belongs, giving a reason for your answer.
.....
.....
(1 mark)

7

TURN OVER FOR THE NEXT QUESTION

5 (a) Define

(i) apparent magnitude,

.....
.....

(ii) absolute magnitude.

.....
.....

(2 marks)

(b) Bellatrix and Elinath are two stars with the same apparent magnitude. The distance from the Earth to Bellatrix is 470 light years and its absolute magnitude is -4.2 .

(i) Calculate the distance to Bellatrix in parsecs.

.....
.....

(ii) Calculate the apparent magnitude of Bellatrix.

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(iii) Elinath has an absolute magnitude of -3.2 . State, giving a reason, which of the two stars is closer to the Earth.

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(6 marks)

QUALITY OF WRITTEN COMMUNICATION (2 marks)

8

2

END OF QUESTIONS