Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2003
Advanced Subsidiary Examination

PHYSICS (SPECIFICATION A) **PA01**
Unit 1 Particles, Radiation and Quantum Phenomena

Monday 13 January 2003 Morning Session

In addition to this paper you will require:
- a calculator;
- a pencil and a ruler.

Time allowed: 1 hour 30 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 60.
- Mark allocations are shown in brackets.
- The paper carries 30% of the total marks for Physics Advanced Subsidiary and carries 15% of the total marks for Physics Advanced.
- A *Data Sheet* is provided on pages 3 and 4. You may 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			
6			
7			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

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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.

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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 $= Tt$
$\Delta Q = \Delta U + \Delta W$
$\Delta W = p\Delta V$
$pV^{\gamma} =$ 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

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

$\epsilon = I(R + r)$

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

$P = I^2 R$

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

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

$E = \frac{1}{2}QV$
$F = BIl$
$F = BQv$
$Q = Q_0 e^{-t/RC}$
$\Phi = BA$

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

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

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

Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

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

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

Nuclear Physics and Turning Points in Physics

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

$$\text{force} = Bev$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

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

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

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

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

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Answer **all** questions in the spaces provided.

1 (a) How many protons, neutrons and electrons are there in an atom of ${}^{14}_{6}C$?

.... protons

.... neutrons

.... electrons *(2 marks)*

(b) The ${}^{14}_{6}C$ atom loses two electrons.
For the ion formed;

(i) calculate its charge in C,

....

(ii) state the number of nucleons it contains,

....

(iii) calculate the ratio $\frac{\text{charge}}{\text{mass}}$ in C kg^{-1}.

....

....

....

....

(4 marks)

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6

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2 In an experiment to investigate the structure of the atom, α particles are directed normally at a thin metal foil which causes them to be scattered.

(a) (i) In which direction will the number of α particles per second be a maximum?

....

(ii) State what this result suggests about the structure of the atoms in the metal.

....

....

(2 marks)

(b) A small number of α particles are scattered through 180°.

Explain what this suggests about the structure of the atoms in the metal.

....

....

....

....

(2 marks)

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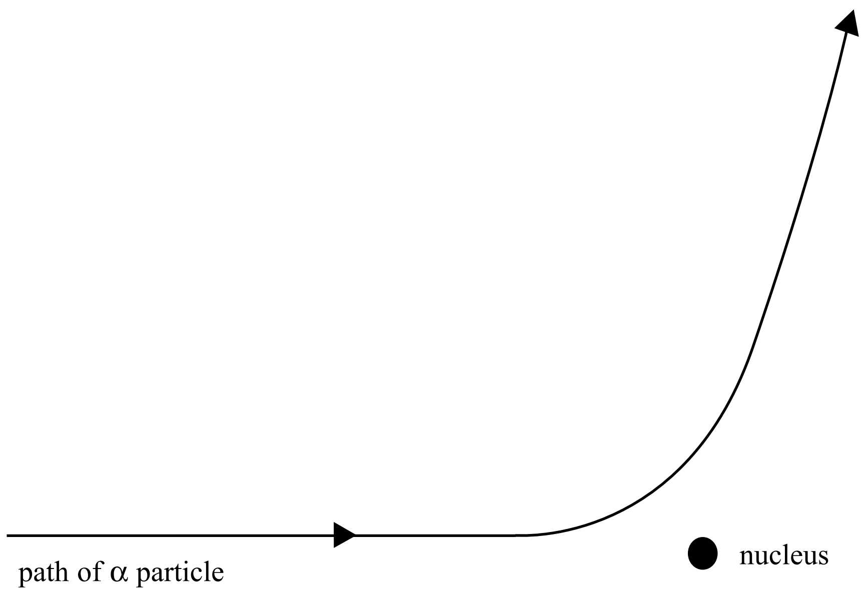
(c) The figure shows the path of an α particle passing near a nucleus.



(i) Name the force that is responsible for the deflection of the α particle.

....

(ii) Draw an arrow on the diagram in the direction of the force on the α particle in the position where the force is a maximum.

(iii) The nucleus is replaced with one which has a larger mass number and a smaller proton number.

Draw on the diagram the path of an α particle that starts with the same velocity and position as that of the α particle drawn. *(4 marks)*

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8

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3 Electrons travelling at a speed of 5.00×10^5 m s^{-1} exhibit *wave properties*.

(a) What phenomenon can be used to demonstrate the wave properties of electrons?
Details of any apparatus used are not required.

....

(1 mark)

(b) Calculate the wavelength of these electrons.

....

....

....

....

(2 marks)

(c) Calculate the speed of muons with the same wavelength as these electrons.
Mass of muon = 207 × mass of electron

....

....

....

....

(3 marks)

(d) Both electrons and muons were accelerated from rest by the same potential difference. Explain why they have different wavelengths.

....

....

....

....

(2 marks)

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8

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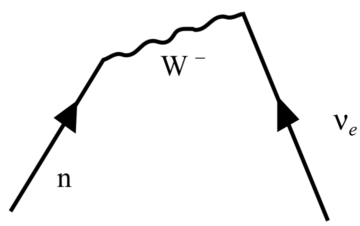
4 (a) A neutrino may interact with a neutron in the following way

$$\nu_e + n \Rightarrow p + e^-.$$

(i) Name the fundamental force responsible for this interaction.

....

(ii) Complete the Feynman diagram for this interaction and label all the particles involved.



(3 marks)

(b) The neutral kaon, which is a meson of strangeness +1, may decay in the following way

$$K^\circ \Rightarrow \pi^+ + \pi^-.$$

(i) Apart from conservation of energy and momentum, state **two** other conservation laws obeyed by this decay and **one** conservation law which is **not** obeyed.

.... conservation law is obeyed

.... conservation law is obeyed

.... conservation law is not obeyed

(ii) Deduce the quark composition of all the particles involved in the K° decay.

....

....

....

....

K°...

π^+ ....

π^- .... *(6 marks)*

9

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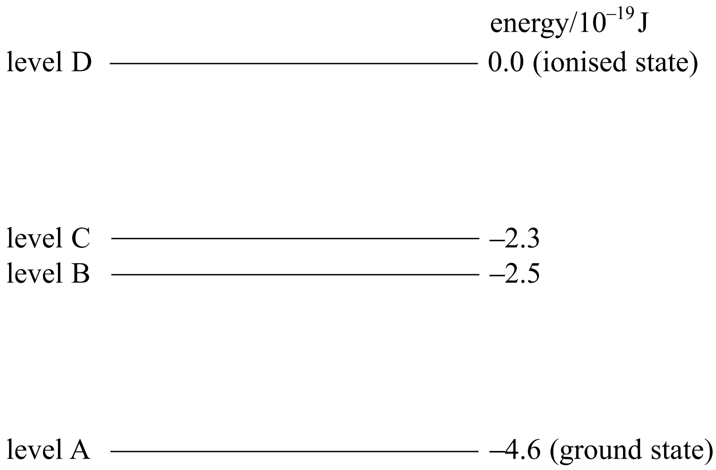
5 The diagram shows four energy levels of an atom not drawn to scale.



(a) (i) Explain how this atom emits a line spectrum following excitation.

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

(ii) The longest wavelength of emitted radiation is produced by a transition between which two levels?

(iii) Draw on the diagram **two** vertical arrows between levels to indicate two different transitions that result in emitted radiation of the same frequency. *(4 marks)*

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(b) In its ground state the atom absorbs 2.3×10^{-19} J of energy from a collision with an electron.

(i) Calculate all the possible frequencies of radiation that the atom may subsequently emit.

....

....

....

....

....

....

(ii) How much energy, in eV, would be required to ionise the atom in its ground state?

....

....

(5 marks)

$\overline{}$ *9*

TURN OVER FOR THE NEXT QUESTION

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6 (a) (i) Explain the meaning of the term *work function* of a metal.

....

....

....

(ii) State what you would need to change in an experiment to investigate the effect of the work function on the photoelectric effect.

....

(3 marks)

(b) Experiments based on the photoelectric effect support the particle theory of light. State **one** conclusion drawn from these experiments and explain how it supports the particle theory.

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

....

....

....

....

....

....

(2 marks)

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(c) Monochromatic light of wavelength 4.80×10^{-7} m falls onto a metal surface which has a work function of 1.20×10^{-19} J.

Calculate

(i) the energy, in J, of a single photon of this light,

....

....

....

....

....

(ii) the maximum kinetic energy, in J, of an electron emitted from the surface.

....

....

....

....

....

(5 marks)

$\overline{}$ *10*

TURN OVER FOR THE NEXT QUESTION

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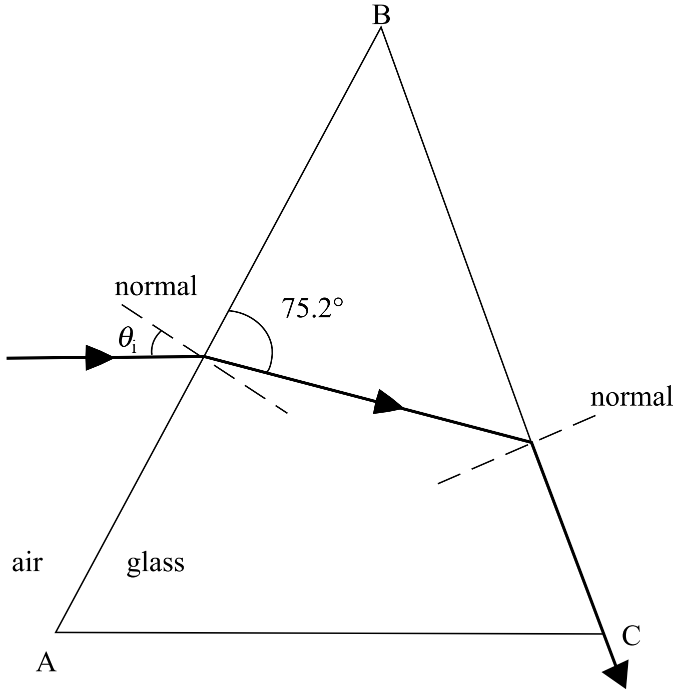
7 The diagram shows a ray of light passing from air into a glass prism at an angle of incidence θ_i. The light emerges from face BC as shown.
refractive index of the glass = 1.55



(a) (i) Mark the critical angle along the path of the ray with the symbol θ_c.

(ii) Calculate the critical angle, θ_c.

....

....

....

....

(3 marks)

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(b) For the ray shown calculate the angle of incidence, θ_i.

....

....

....

....

(2 marks)

(c) Without further calculations draw the path of another ray of light incident at the same point on the prism but with a smaller angle of incidence.
The path should show the ray emerging from the prism into the air. *(3 marks)*

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8

QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

—
2

END OF QUESTIONS

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