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Centre Number						Candidate Number					
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General Certificate of Education  
June 2003  
Advanced Subsidiary Examination



PA01

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

Friday 6 June 2003 Afternoon Session

<p><b>In addition to this paper you will require:</b></p> <ul style="list-style-type: none"> <li>• a calculator;</li> <li>• a pencil and a ruler.</li> </ul>
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For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
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7			
Total (Column 1)	→		
Total (Column 2)	→		
TOTAL			
Examiner's Initials			

Time allowed: 1 hour

**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 50.
- 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 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	$c$	$3.00 \times 10^8$	$\text{m s}^{-1}$
permeability of free space	$\mu_0$	$4\pi \times 10^{-7}$	$\text{H m}^{-1}$
permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12}$	$\text{F m}^{-1}$
charge of electron	$e$	$1.60 \times 10^{-19}$	C
the Planck constant	$h$	$6.63 \times 10^{-34}$	J s
gravitational constant	$G$	$6.67 \times 10^{-11}$	$\text{N m}^2 \text{kg}^{-2}$
the Avogadro constant	$N_A$	$6.02 \times 10^{23}$	$\text{mol}^{-1}$
molar gas constant	$R$	8.31	$\text{J K}^{-1} \text{mol}^{-1}$
the Boltzmann constant	$k$	$1.38 \times 10^{-23}$	$\text{J K}^{-1}$
the Stefan constant	$\sigma$	$5.67 \times 10^{-8}$	$\text{W m}^{-2} \text{K}^{-4}$
the Wien constant	$a$	$2.90 \times 10^{-3}$	m K
electron rest mass	$m_e$	$9.11 \times 10^{-31}$	kg
(equivalent to $5.5 \times 10^{-4}u$ )			
electron charge/mass ratio	$e/m_e$	$1.76 \times 10^{11}$	$\text{C kg}^{-1}$
proton rest mass	$m_p$	$1.67 \times 10^{-27}$	kg
(equivalent to 1.00728u)			
proton charge/mass ratio	$e/m_p$	$9.58 \times 10^7$	$\text{C kg}^{-1}$
neutron rest mass	$m_n$	$1.67 \times 10^{-27}$	kg
(equivalent to 1.00867u)			
gravitational field strength	$g$	9.81	$\text{N kg}^{-1}$
acceleration due to gravity	$g$	9.81	$\text{m s}^{-2}$
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	$\gamma$	0
lepton	neutrino	$\nu_e$	0
		$\nu_\mu$	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	pion	$\pi^\pm$	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**

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 =  $\frac{\text{power output}}{\text{power input}}$
- $\omega = \frac{v}{r} = 2\pi f$
- $a = \frac{v^2}{r} = r\omega^2$
- $I = \sum mr^2$
- $E_k = \frac{1}{2}I\omega^2$
- $\omega_2 = \omega_1 + at$
- $\theta = \omega_1 t + \frac{1}{2}at^2$
- $\omega_2^2 = \omega_1^2 + 2a\theta$
- $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$
- $T = I\alpha$
- 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**
- $\epsilon = \frac{E}{Q}$
- $\epsilon = I(R + r)$
- $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- $R_T = R_1 + R_2 + R_3 + \dots$
- $P = I^2 R$
- $E = \frac{F}{Q} = \frac{V}{d}$
- $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$
- $E = \frac{1}{2} QV$
- $F = BI l$
- $F = BQv$
- $Q = Q_0 e^{-t/RC}$
- $\Phi = BA$

Turn over ▶

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

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

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

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

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

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

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

$$\text{Hubble constant (H)} = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

### 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

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

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

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

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

Answer **all** questions.

- 1 (a) A stable atom contains 28 nucleons.

Write down a possible number of protons, neutrons and electrons contained in the atom.

..... protons

..... neutrons

..... electrons

(2 marks)

- (b) An unstable *isotope* of uranium may split into a caesium nucleus, a rubidium nucleus and four neutrons in the following process.



- (i) Explain what is meant by isotopes.

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

- (ii) How many neutrons are there in the  ${}_{55}^{137}\text{Cs}$  nucleus?

.....

- (iii) Calculate the ratio  $\frac{\text{charge}}{\text{mass}}$ , in  $\text{C kg}^{-1}$ , for the  ${}_{92}^{236}\text{U}$  nucleus.

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

- (iv) Determine the value of X for the rubidium nucleus.

.....

X = .....  
 (6 marks)

8

Turn over ▶

2 (a) (i) Underline the particles in the following list that may be affected by the weak interaction.  
positron          neutron          photon          neutrino          positive pion

(ii) Underline the particles in the following list that may be affected by the electromagnetic force.

electron          antineutrino          proton          neutral pion          negative muon  
(4 marks)

(b) A positive muon may decay in the following way,

$$\mu^+ \Rightarrow e^+ + \nu_e + \bar{\nu}_\mu.$$

(i) Exchange each particle for its corresponding antiparticle and complete the equation to show how a negative muon may decay.

$$\mu^- \Rightarrow$$

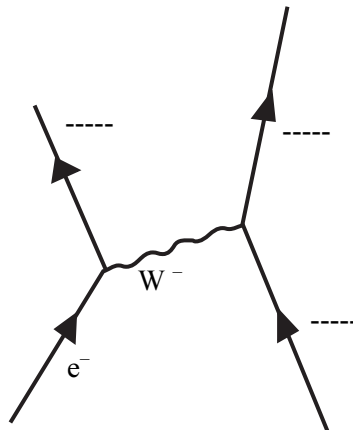
(ii) Give **one** difference and **one** similarity between a negative muon and an electron.

difference .....

similarity .....

(3 marks)

(c) Complete the Feynman diagram, which represents electron capture, by labelling all the particles involved.



(3 marks)

3 A fluorescent light tube contains mercury vapour at low pressure. The tube is coated on the inside, and contains two electrodes.

(a) Explain why the mercury vapour is at a low pressure.

.....  
.....

*(1 mark)*

(b) Explain the purpose of the coating on the inside of the tube.

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

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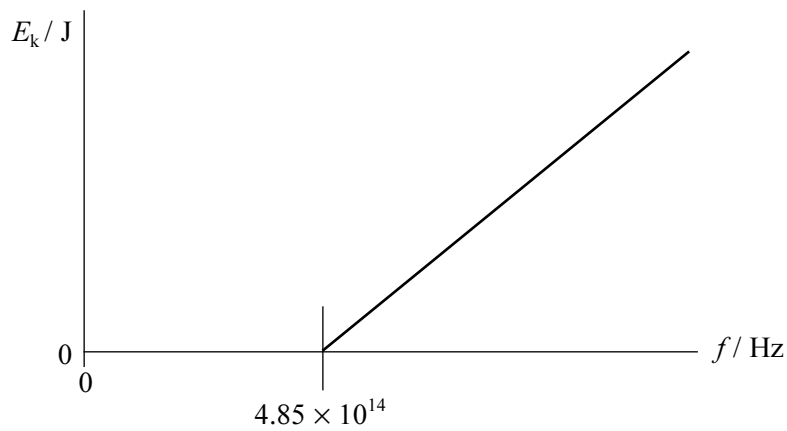
*(3 marks)*

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4

**TURN OVER FOR THE NEXT QUESTION**

**Turn over ▶**

- 4 The graph shows how the maximum kinetic energy,  $E_k$ , of electrons emitted from the surface of metal A, varies with the frequency,  $f$ , of the incident electromagnetic radiation.



- (a) Explain the meaning of the term *threshold frequency*.

.....  
 .....

(2 marks)

- (b) Calculate the work function of metal A,

- (i) in J,

.....  
 .....

- (ii) in eV.

.....  
 .....

(3 marks)



(c) Metal A is exchanged for metal B. The work function of metal B is half that of metal A. Add a line to the graph opposite to show how the maximum kinetic energy of electrons emitted from metal B varies with frequency. (2 marks)

(d) At a fixed frequency of the incident radiation, the emitted electrons are collected and a current is recorded.

State and explain a change that may be made to increase this current.

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

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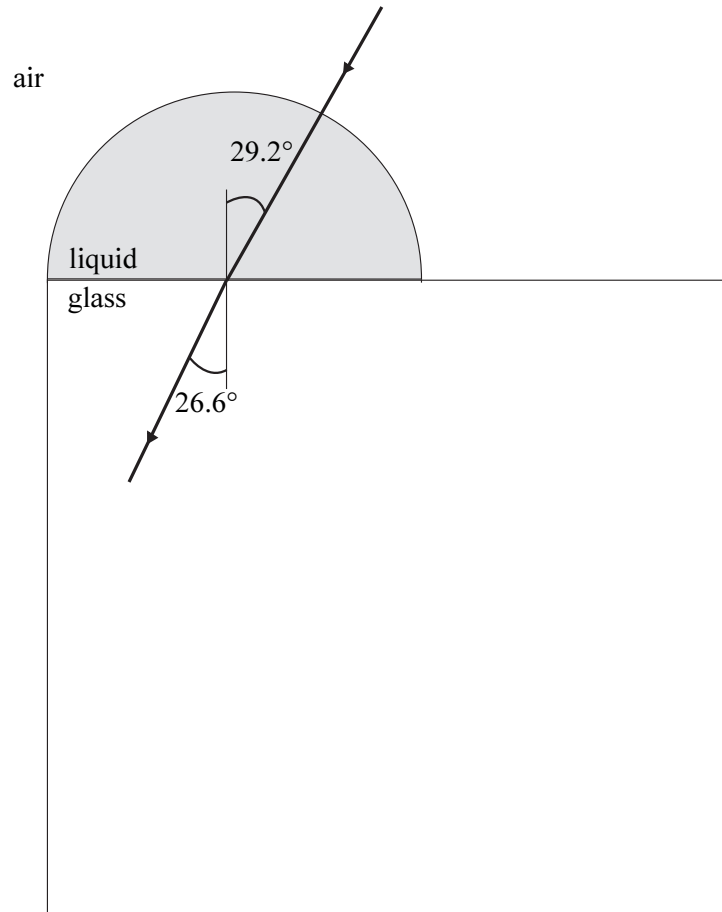
(3 marks)

10

**TURN OVER FOR THE NEXT QUESTION**

**Turn over ▶**

- 5 The diagram below shows a liquid droplet placed on a cube of glass. A ray of light from air, incident normally on to the droplet, continues in a straight line and is refracted at the liquid to glass boundary as shown.
- refractive index of the glass = 1.45



(a) Calculate the speed of light

(i) in the glass,

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

(ii) in the liquid droplet.

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

*(3 marks)*

(b) Calculate the refractive index of the liquid.

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

*(2 marks)*

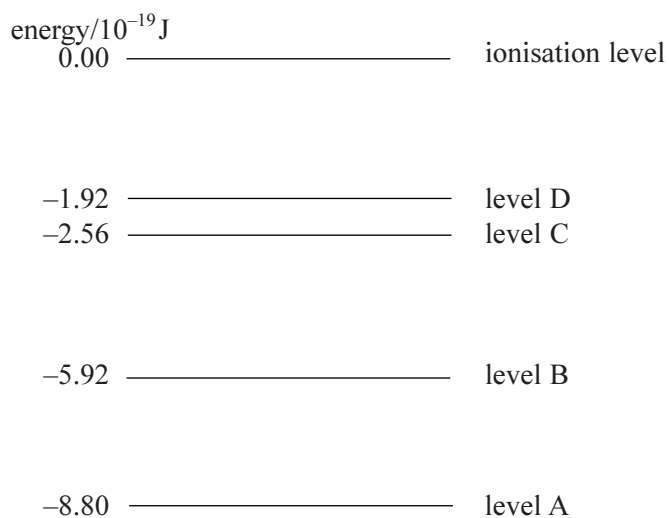
(c) On the diagram opposite, complete the path of the ray showing it emerge from the glass cube into the air.

No further calculations are required.

*(2 marks)*

7

6 The diagram shows some of the energy levels of the mercury atom.



(a) When electrons collide with mercury atoms, the atoms may be *excited* or may be *ionised*.

Explain what is meant by

(i) excitation,

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

(ii) ionisation.

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

(2 marks)

(b) Determine the lowest frequency of emitted radiation with reference to the energy levels in the diagram.

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

(2 marks)

7 (a) Electrons behave in two distinct ways. This is referred to as the *duality of electrons*.

(i) State what is meant by the duality of electrons.

.....  
.....

(ii) Give **one** example of each type of behaviour of electrons.

.....  
.....

(3 marks)

(b) Calculate the speed of electrons that have a de Broglie wavelength of  $1.70 \times 10^{-10}$  m.

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

(2 marks)

**QUALITY OF WRITTEN COMMUNICATION** (2 marks)

○  
—  
5

○  
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2

**END OF QUESTIONS**