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Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education  
 January 2006  
 Advanced Subsidiary Examination



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

Thursday 12 January 2006 9.00 am to 10.00 am

<p><b>For this paper you must have:</b></p> <ul style="list-style-type: none"> <li>• a calculator</li> <li>• a pencil and a ruler</li> </ul>
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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.
- 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 50. 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			
6			
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.

**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	$\alpha$	$2.90 \times 10^{-3}$	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**

- $v = u + at$
- $s = \left(\frac{u+v}{2}\right)t$
- $s = ut + \frac{at^2}{2}$
- $v^2 = u^2 + 2as$
- $F = \frac{\Delta(mv)}{\Delta t}$
- $P = Fv$
- $\text{efficiency} = \frac{\text{power output}}{\text{power input}}$
- $\omega = \frac{v}{r} = 2\pi f$
- $a = \frac{v^2}{r} = r\omega^2$
- $I = \sum mr^2$
- $E_k = \frac{1}{2} I\omega^2$
- $\omega_2 = \omega_1 + at$
- $\theta = \omega_1 t + \frac{1}{2} at^2$
- $\omega_2^2 = \omega_1^2 + 2\alpha\theta$
- $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$
- $T = I\alpha$
- 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  $\times$  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
- $\text{efficiency} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$
- maximum possible efficiency =  $\frac{T_H - T_C}{T_H}$

**Fields, Waves, Quantum Phenomena**

- $g = \frac{F}{m}$
- $g = -\frac{GM}{r^2}$
- $g = -\frac{\Delta V}{\Delta x}$
- $V = -\frac{GM}{r}$
- $a = -(2\pi f)^2 x$
- $v = \pm 2\pi f \sqrt{A^2 - x^2}$
- $x = A \cos 2\pi ft$
- $T = 2\pi\sqrt{\frac{m}{k}}$
- $T = 2\pi\sqrt{\frac{l}{g}}$
- $\lambda = \frac{\omega s}{D}$
- $d \sin \theta = n\lambda$
- $\theta = \frac{\lambda}{D}$
- $n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$
- $n_2 = \frac{n_2}{n_1}$
- $\sin \theta_c = \frac{1}{n}$
- $E = hf$
- $hf = \phi + E_k$
- $hf = E_1 - E_2$
- $\lambda = \frac{h}{p} = \frac{h}{mv}$
- $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

**Electricity**

- $\epsilon = \frac{E}{Q}$
- $\epsilon = I(R + r)$
- $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- $R_T = R_1 + R_2 + R_3 + \dots$
- $P = I^2 R$
- $E = \frac{F}{Q} = \frac{V}{d}$
- $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$
- $E = \frac{1}{2} QV$
- $F = BIl$
- $F = BQv$
- $Q = Q_0 e^{-t/RC}$

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

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

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

### Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

$$pV = \frac{1}{3} Nmc^2$$

$$\frac{1}{2} mc^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

### 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	$6.00 \times 10^{24}$	$6.40 \times 10^6$

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

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

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

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

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

### 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

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

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

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

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

### 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 in the spaces provided.

1 A radioactive isotope of carbon is represented by  ${}^{14}_6\text{C}$ .

(a) Using the same notation, give the isotope of carbon that has two fewer neutrons.

.....  
(1 mark)

(b) Calculate the charge on the ion formed when **two** electrons are removed from an atom of  ${}^{14}_6\text{C}$ .

.....  
.....  
.....  
(2 marks)

(c) Calculate the value of  $\frac{\text{charge}}{\text{mass}}$  for the nucleus of an atom of  ${}^{14}_6\text{C}$ .

.....  
.....  
.....  
(2 marks)

**Turn over for the next question**

5
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- 2 (a) One quantity in the photoelectric equation is a characteristic property of the metal that emits photoelectrons. Name and define this quantity.

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

*(2 marks)*

- (b) A metal is illuminated with monochromatic light. Explain why the kinetic energy of the photoelectrons emitted has a range of values up to a certain maximum.

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

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

*(3 marks)*

- (c) A gold surface is illuminated with monochromatic ultraviolet light of frequency  $1.8 \times 10^{15}$  Hz. The maximum kinetic energy of the emitted photoelectrons is  $4.2 \times 10^{-19}$  J.  
Calculate, for gold,

- (i) the work function, in J,

.....

.....

.....

.....

.....

- (ii) the threshold frequency.

.....

.....

.....

*(5 marks)*

10
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**Turn over for the next question**

3 (a) (i) Give an example of an exchange particle other than a  $W^+$  or  $W^-$  particle, and state the fundamental force involved when it is produced.

exchange particle .....

fundamental force .....

(ii) State what roles exchange particles can play in an interaction.

.....

.....

.....

(4 marks)

(b) From the following list of particles,

$p$     $\bar{n}$     $\nu_e$     $e^+$     $\mu^-$     $\pi^0$

identify **all** the examples of

(i) hadrons, .....

(ii) leptons, .....

(iii) antiparticles, .....

(iv) charged particles. ....

(4 marks)



- 4 (i) A negative muon,  $\mu^-$ , is 207 times more massive than an electron.  
Calculate the de Broglie wavelength of a negative muon travelling at  $3.0 \times 10^6 \text{ m s}^{-1}$ .

.....

.....

.....

- (ii) Using values from the data sheet calculate the ratio  $\frac{\text{rest mass of } \pi^0}{\text{rest mass of } \mu^-}$   
where  $\pi^0$  is a neutral pion.

.....

.....

.....

- (iii) Calculate the speed necessary for a  $\pi^0$  to have the same de Broglie wavelength as that of the  $\mu^-$  in part (i).

.....

.....

.....

.....

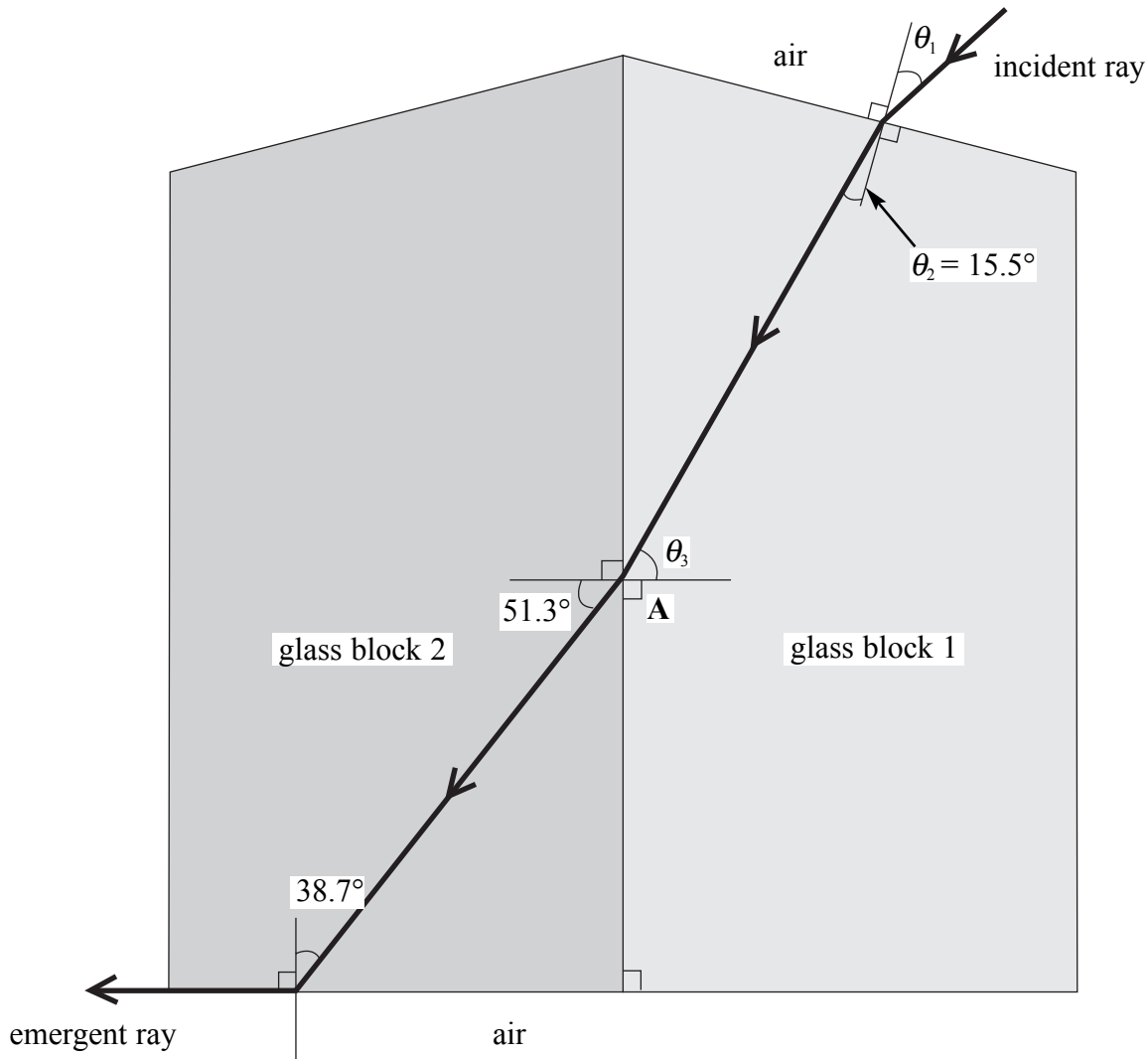
(6 marks)

6
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- 5 **Figure 1** shows a ray of light passing from air into glass at the top face of glass block 1 and emerging along the bottom face of glass block 2.

refractive index of the glass in block 1 = 1.45

**Figure 1**



(a) Calculate

(i) the incident angle  $\theta_1$ ,

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

(ii) the refractive index of the glass in block 2,

.....  
.....

(iii) the angle  $\theta_3$  by considering the refraction at point A.

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

(7 marks)

(b) In which of the two blocks of glass will the speed of light be greater?

.....

Explain your reasoning.

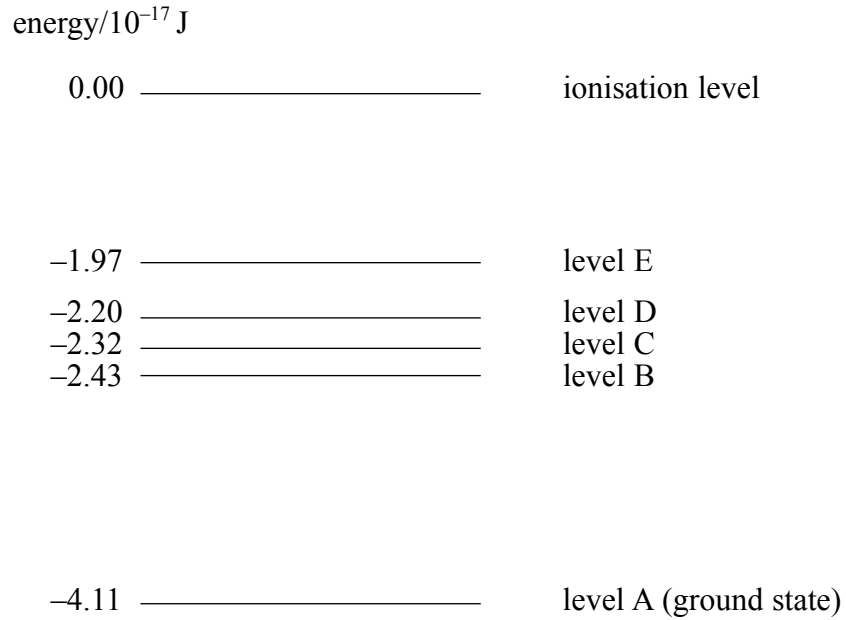
.....  
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(2 marks)

(c) Using a ruler, draw the path of a ray partially reflected at A on **Figure 1**. Continue the ray to show it emerging into the air. No calculations are expected.

(2 marks)

- 6 Some of the energy levels of an atom are shown below. The atom may be *ionised* by electron impact.



- (a) (i) State what is meant by the ionisation of an atom.

.....

.....

- (ii) Calculate the minimum kinetic energy, in eV, of an incident electron that could ionise the atom from its ground state.

.....

.....

*(2 marks)*

- (b) You may be awarded marks for the quality of written communication in your answer to parts (b)(i) and (b)(ii).

The atom in the ground state is given  $5.00 \times 10^{-17}$  J of energy by electron impact.

- (i) State what happens to this energy.

.....  
 .....

- (ii) Describe and explain what could happen subsequently to the electrons in the higher energy levels.

.....  
 .....

.....  
 .....

.....  
 .....

*(4 marks)*

- (c) Identify **two** transitions between energy levels that would give off electromagnetic radiation of the same frequency.

\_\_\_\_\_ to \_\_\_\_\_

and

\_\_\_\_\_ to \_\_\_\_\_

*(2 marks)*

8
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**Quality of Written Communication** *(2 marks)*

2
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**END OF QUESTIONS**

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