Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2004
Advanced Level Examination

ASSESSMENT and QUALIFICATIONS ALLIANCE

PHYSICS (SPECIFICATION A) **PA10**
Unit 10 The Synoptic Unit

Monday 28 June 2004 Afternoon Session

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

Time allowed: 2 hours

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 80.
- Mark allocations are shown in brackets.
- The paper carries 20% 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.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
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6			
7			
8			
Total (Column 1) →			
Total (Column 2) →			
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	3.00×10^{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 = [illegible]^2

Turn over ▶

area of cylinder [illegible]

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

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

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

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

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

$\Delta Q = ml$

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

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

Nuclear Physics and Turning Points in Physics

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

force $= Bev$

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

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

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 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}

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

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

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

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

$v = Hd$

$P = \sigma A T^4$

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

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

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

Medical Physics

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

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

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

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

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

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

$X_C = \frac{1}{2\pi f C}$

Alternating Currents

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

Operational amplifier

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

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

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

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

TURN OVER FOR THE FIRST QUESTION

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Answer **all** questions.

1 The Global Positioning System (GPS) is a system of satellites that transmit radio signals which can be used to locate the position of a receiver anywhere on Earth.

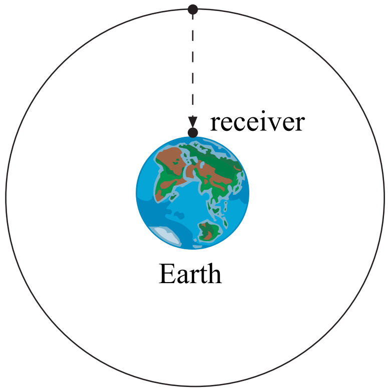

Figure 1

(a) A receiver at sea level detects a signal from a satellite in a circular orbit when it is passing directly overhead as shown in **Figure 1**.

(i) The microwave signal is received 68 ms after it was transmitted from the satellite. Calculate the height of the satellite.

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(ii) Show that the gravitational field strength of the Earth at the position of the satellite is $0.56\,\mathrm{N\,kg^{-1}}$.

mass of the Earth = 6.0×10^{24} kg
mean radius of the Earth = 6400 km

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(4 marks)

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(b) For the satellite in this orbit, calculate

(i) its speed,

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(ii) its time period.

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(5 marks)

9

TURN OVER FOR THE NEXT QUESTION

2 A plane-polarised laser beam is incident on a sheet of polaroid. The power of the transmitted laser beam is controlled by rotating the sheet of polaroid, as shown in **Figure 2**.

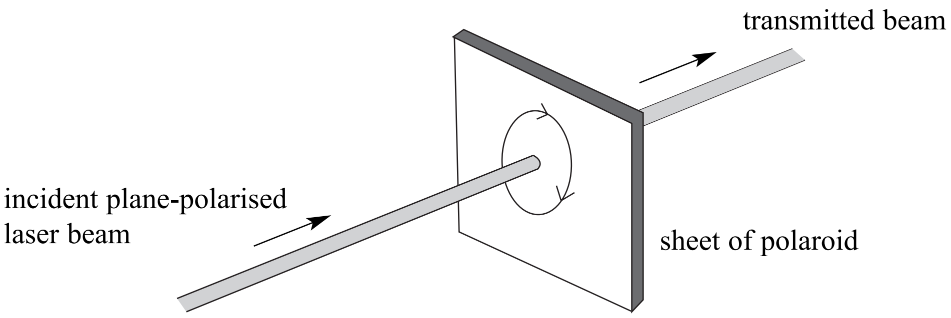

Figure 2

(a) Use the axes in **Figure 3** to sketch a graph to show how the power of the transmitted beam varies with the angle of rotation, θ, of the polaroid from its position at maximum transmitted power for one complete rotation of the polaroid sheet.

(3 marks)

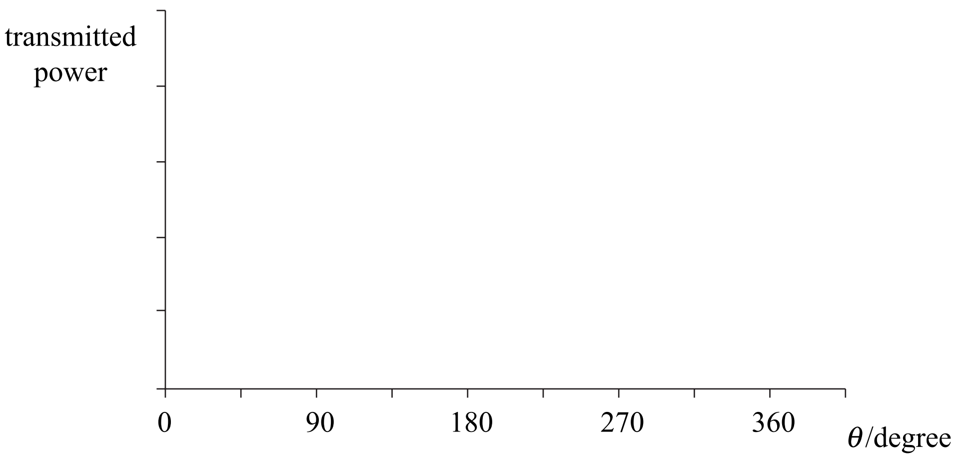

Figure 3

(b) The laser beam has a power of 0.50 mW and consists of monochromatic light of wavelength 650 nm.

(i) Calculate the energy of a photon emitted by the laser.

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(ii) Calculate how many photons the laser emits each second.

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(iii) The laser beam has an area of cross-section of 1.8 mm^2. When it is directed normally at a polaroid of thickness 1.0 mm, orientated for maximum absorption, almost all the incident light entering the polaroid is absorbed. Estimate the average number of photons absorbed per second by an atom, of diameter 0.30 nm, of the polaroid material.

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(6 marks)

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TURN OVER FOR THE NEXT QUESTION

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3 **Figure 4** shows how the impact force on the heel of a runner's foot varies with time during an impact when the runner is wearing cushioned sports shoes.

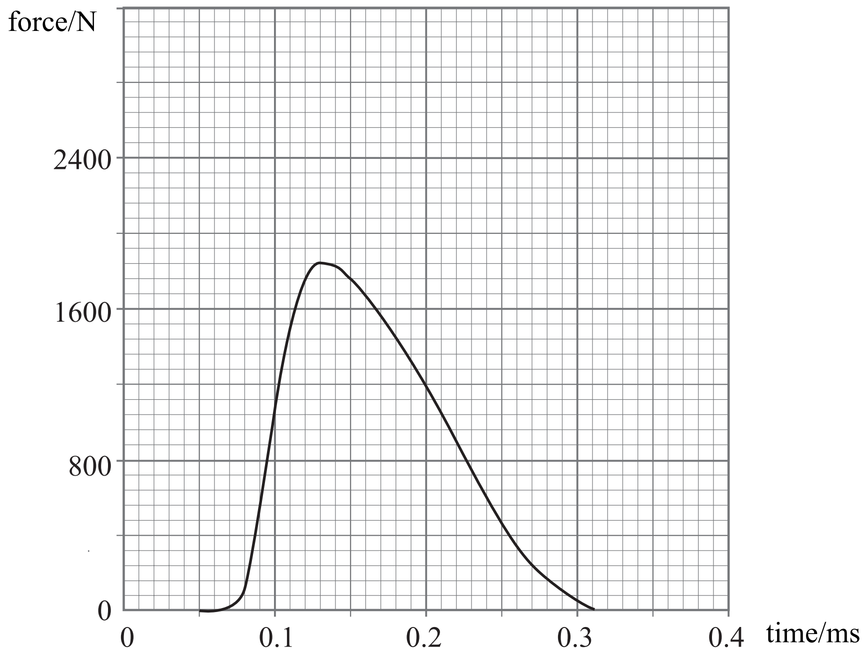

Figure 4

(a) Estimate the maximum stress on the cartilage pad in the knee joint as a result of this force acting on the cartilage pad over a contact area of 550 mm^2.

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(4 marks)

(b) On **Figure 4**, sketch the graph of force against time you would expect to see if a sports shoe with less cushioning had been used.

(3 marks)

7

4 An electric shower heats the water flowing through it from 10 °C to 42 °C when the volume flow rate is $5.2 \times 10^{-5}\,\mathrm{m^3\,s^{-1}}$.

(a) (i) Calculate the mass of water flowing through the shower each second.

density of water = $1000\,\mathrm{kg\,m^{-3}}$

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(ii) Calculate the power supplied to the shower, assuming all the electrical energy supplied to it is gained by the water as thermal energy.

specific heat capacity of water = $4200\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

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(4 marks)

(b) A jet of water emerges horizontally at a speed of $2.5\,\mathrm{m\,s^{-1}}$ from a hole in the shower head. The hole is 2.0 m above the floor of the shower. Calculate the horizontal distance travelled by this jet. Assume air resistance is negligible.

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(3 marks)

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Turn over

5 A student carried out an experiment to investigate how the resistance of a coil made from iron wire varied as its temperature changed. In the experiment, a constant potential difference of 2.00 V was maintained across the coil as the student measured the current through it at various temperatures.

(a) Draw a circuit diagram to show how such measurements could be made using a 3.0 V battery and other necessary apparatus.

(3 marks)

(b) The results are shown in the table.

temperature θ / °C	p.d. across the coil /V	current /mA	resistance R / Ω
10	2.00	790	
20	2.00	740	
35	2.00	680	
50	2.00	620	
65	2.00	590	
80	2.00	550	

The resistance, R, of a metal wire varies with temperature according to the equation

$$R = R_0 (1 + \alpha\theta)$$

where R_0 is the resistance of the wire at 0 °C, θ is the temperature of the wire in °C, and α is a constant which depends on the material from which the wire is made.

(i) Complete the table to show the value of the resistance, R, of the iron coil at each temperature.

(ii) Use the data to plot a graph to confirm the equation.

(6 marks)

QUESTION 5 CONTINUES ON PAGE 14

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(c) (i) Use your graph to determine the value of the resistance of the coil at 0 °C (R_0).

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(ii) Use your graph to determine the value of the constant α and state its unit.

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(5 marks)

(d) Explain why the resistance of a metal wire changes when its temperature is increased.

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

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(2 marks)

16

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6 A diffraction grating was used to measure the wavelength of a certain line of a line emission spectrum.

(a) The grating had 600 lines per millimetre. The angle of diffraction of the second order line was 35.8°.

(i) Calculate the wavelength of this line.

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(ii) Calculate the energy, in eV, of a photon of this wavelength.

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(5 marks)

QUESTION 6 CONTINUES ON THE NEXT PAGE

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(b) The line emission spectrum observed in part (a) was produced by a hot gas.

(i) The energy level diagram for the atoms that produced the line spectrum is shown in **Figure 5**. Mark on the diagram a vertical arrow to show the electron transition between the two levels that produced photons of energy 6.8 eV.

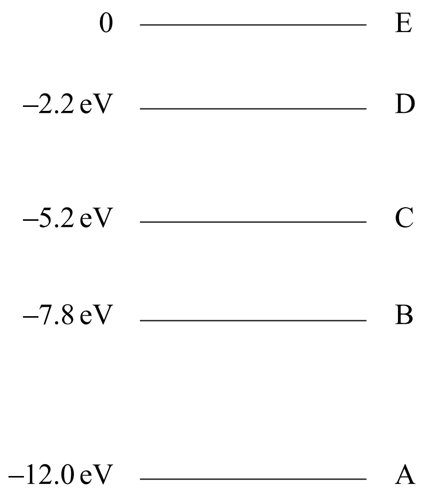

Figure 5

(ii) The temperature of the gas was 5000 K. Show that the mean kinetic energy of a gas atom at this temperature is 0.65 eV.

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(iii) Describe how the atoms of a gas produce a line emission spectrum and explain why the gas at a temperature of 5000 K can produce a line of the wavelength calculated in part (a) (i).

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

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(6 marks)

11

TURN OVER FOR THE NEXT QUESTION

Turn over

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7 (a) An α particle emitted from a certain isotope has a kinetic energy of 2.8 MeV.

(i) Show that the speed of the α particle immediately after it is emitted is $1.2 \times 10^7\,\text{m}\,\text{s}^{-1}$.

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(ii) Calculate the de Broglie wavelength of the α particle immediately after it is emitted.

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(4 marks)

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(b) In a Rutherford scattering experiment, a beam of 2.8 MeV α particles is directed normally at a thin gold foil. An α particle in the beam approaches the nucleus of an atom of the gold isotope $^{197}_{79}Au$ head on as shown in **Figure 6**.

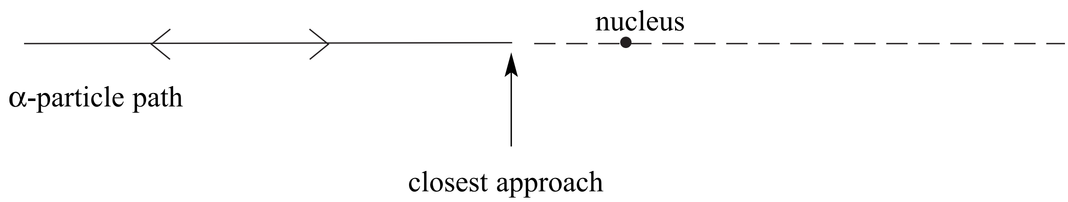

Figure 6

(i) Calculate the least distance of approach of the α particle from the centre of the gold nucleus.

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(ii) By comparing your answers to part (a) (ii) and part (b) (i), explain why diffraction of α particles by the gold nuclei is not significant.

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(5 marks)

9

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8 (a) In an accelerator experiment, protons were accelerated through a potential difference of 2.5×10^{10} V.

(i) Calculate the work done, in J, on each proton by the accelerating potential difference.

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(ii) Calculate the increase in the mass of the proton, in kg, which is equivalent to the energy transfer which occurs.

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(3 marks)

(b) The protons were directed at a solid target, causing antiprotons and negative pions, as well as other particles and antiparticles, to emerge at high speed from the target. A uniform magnetic field was used to separate the negative particles from the uncharged and positive particles, as shown **Figure 7**.

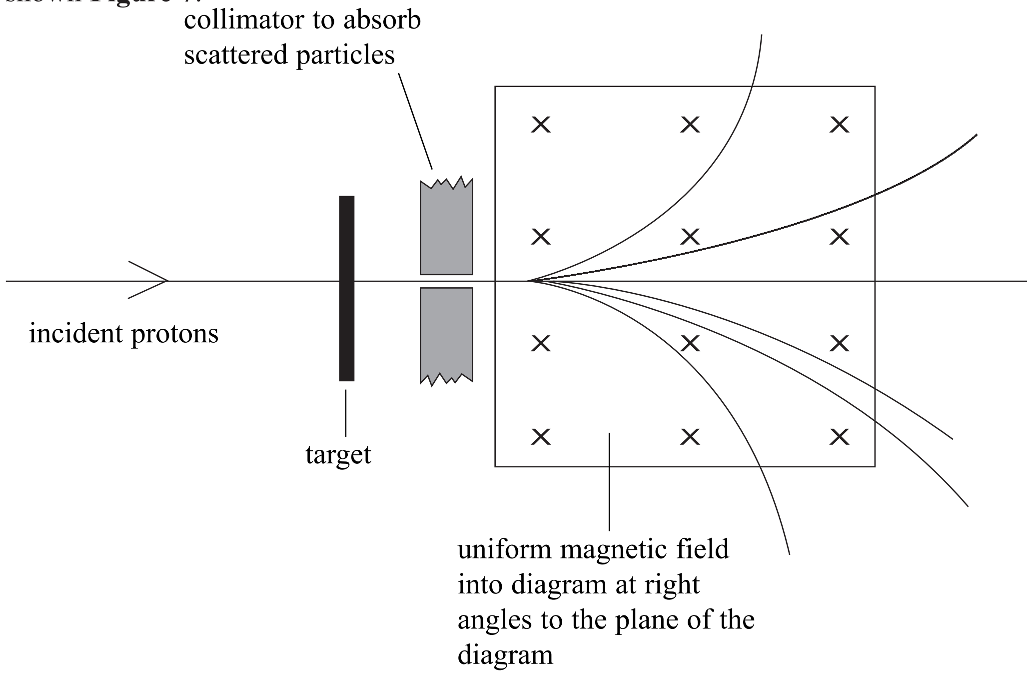

Figure 7

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(i) Show that the speed, v, of a charged particle moving in a circular path of radius r in a uniform magnetic field B is given by

$$v = \frac{BQr}{m}$$

where m is the mass of the particle and Q is its charge.

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(ii) An antiproton and a negative pion follow the same path in the magnetic field. Explain why they have the same momentum but different speeds.

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(iii) State, in terms of quarks and antiquarks, the composition of each of the following

antiproton ....

negative pion ....

(7 marks)

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QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

__/2

END OF QUESTIONS

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