Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2004
Advanced Level Examination

ASSESSMENT and QUALIFICATIONS ALLIANCE

PHYSICS (SPECIFICATION A) PA10
Unit 10 The Synoptic Unit

Friday 30 January 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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4			
5			
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.

Data Sheet

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}	$N\ m^{2}\ kg^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$J\ K^{-1}\ mol^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	$J\ K^{-1}$
the Stefan constant	σ	5.67×10^{-8}	$W\ m^{-2}\ K^{-4}$
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}	$C\ kg^{-1}$
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}	$C\ kg^{-1}$
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-27}	kg
gravitational field strength	g	9.81	$N\ kg^{-1}$
acceleration due to gravity	g	9.81	$m\ s^{-2}$
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

$v = u + at$

$s = \left(\frac{u+v}{2}\right) t$

$s = ut + \frac{at^2}{2}$

$v^2 = u^2 + 2as$

$F = \frac{\Delta(mv)}{\Delta t}$

$P = Fv$

$efficiency = \frac{power\ output}{power\ input}$

$\omega = \frac{v}{r} = 2\pi f$

$a = \frac{v^2}{r} = r\omega^2$

$I = \sum mr^2$

$E_k = \frac{1}{2} I\omega^2$

$\omega_2 = \omega_1 + \alpha t$

$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

$\omega_2^2 = \omega_1^2 + 2\alpha\theta$

$\theta = \frac{1}{2}(\omega_1 + \omega_2)t$

$T = I\alpha$

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 ▶

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

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

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

Mechanical and Thermal Properties

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

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

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

$\Delta Q = ml$

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

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

Nuclear Physics and Turning Points in Physics

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

$\text{force} = Bev$

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

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

$\text{work done} = eV$

$F = 6\pi\eta rv$

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

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

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

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

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

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

$E = mc^2 = \dfrac{m_0 c^2}{\left(1 - \dfrac{v^2}{c^2}\right)^{\frac{1}{2}}}$

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

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

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}

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

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

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

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

$v = Hd$

$P = \sigma A T^4$

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

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

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

Medical Physics

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

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

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

$G = \dfrac{V_{out}}{V_{in}}$ voltage gain

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

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

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

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Answer **all** questions in the spaces provided

1 (a) A 3.0 kW electric kettle heats 2.4 kg of water from 16 °C to 100 °C in 320 seconds.

(i) Calculate the electrical energy supplied to the kettle.

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(ii) Calculate the heat energy supplied to the water.
specific heat capacity of water = 4200 $J\,kg^{-1}\,K^{-1}$

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(iii) Give **one** reason why not all the electrical energy supplied to the kettle is transferred to the water.

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(4 marks)

(b) The potential difference supplied to the kettle in part (a) is 230 V.

(i) Calculate the resistance of the heating element of the kettle.

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(ii) The heating element consists of an insulated conductor of length 0.25 m and diameter 0.65 mm. Calculate the resistivity of the conductor.

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(5 marks)

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9

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2 In a vehicle impact, a car ran into the back of a lorry. The car driver sustained serious injuries, which would have been much less had the car been fitted with a driver's air bag.

(a) Explain why the effect of the impact on the driver would have been much less if an air bag had been fitted and had inflated in the crash.

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

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(4 marks)

(b) Calculate the deceleration of the car if it was travelling at a speed of $18\,\mathrm{m\,s^{-1}}$ when the impact occurred and was brought to rest in a distance of 2.5 m.

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(2 marks)

6

Turn over

3 A student intends to use a potential divider and a data logger to investigate the oscillations of a pivoted ruler. The body of the potential divider is clamped. The ruler is attached to the shaft of the potential divider, as shown in **Figure 1**. As the ruler oscillates, the shaft turns and moves the sliding contact along the circular track in the potential divider. The electrical connections of the potentiometer to the data logger are shown in **Figure 2**.

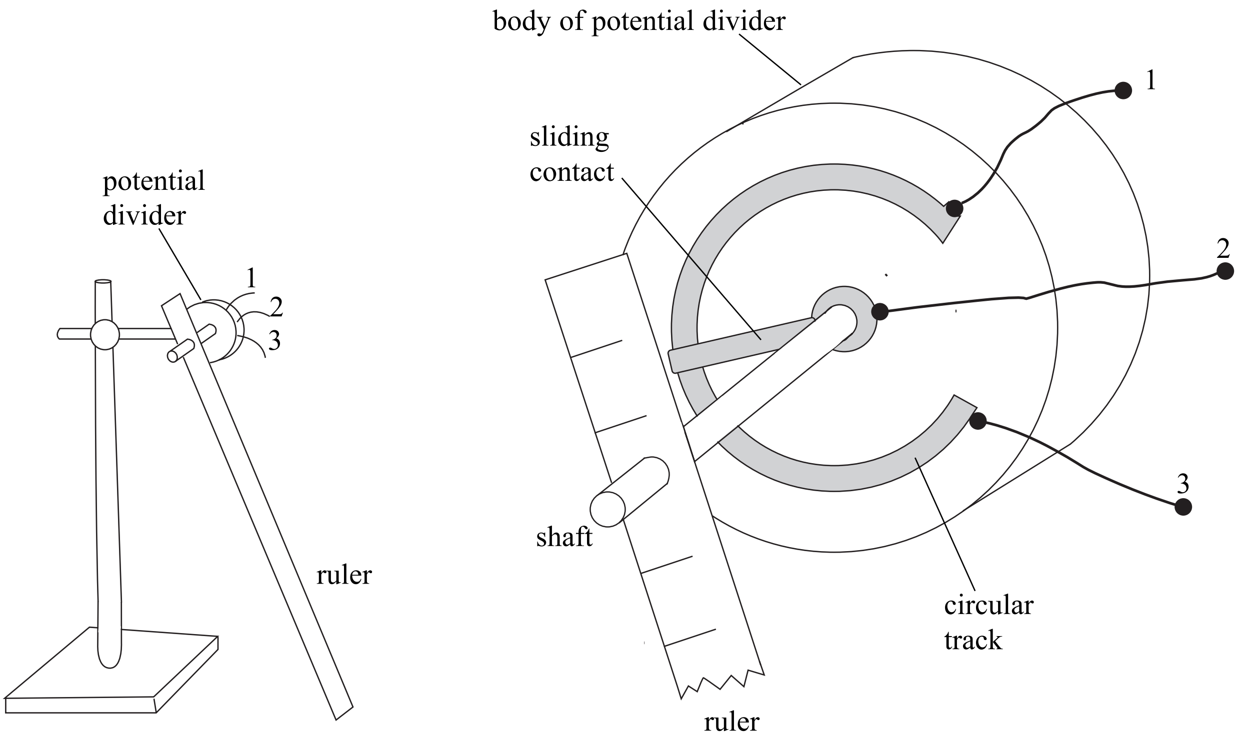

Figure 1

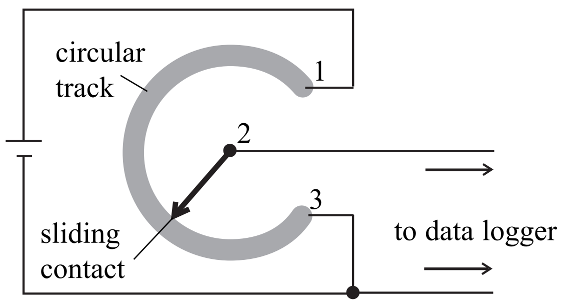

Figure 2

(a) In a preliminary test, the student displaced the lower end of the ruler by a distance of 50 mm from equilibrium, released it and timed 5 oscillations in 4.2 seconds. The data logger is capable of recording 1000 readings at a rate of 100 readings/second.

(i) Estimate how many oscillations could be recorded at this rate.

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(ii) What would be the time interval between successive readings at this rate?

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(iii) Assuming the ruler oscillated with simple harmonic motion, estimate the maximum displacement of the end of the ruler between successive readings.

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(8 marks)

(b) The potential divider in part (a) has a resistance of 4.7 kΩ. It is used to supply a voltage in the range 0 – 1.0 V from a 1.3 V cell to a data logger. To do this, a resistor R is connected in series with the cell and the potential divider, as shown in **Figure 3**. Calculate a suitable value for R.

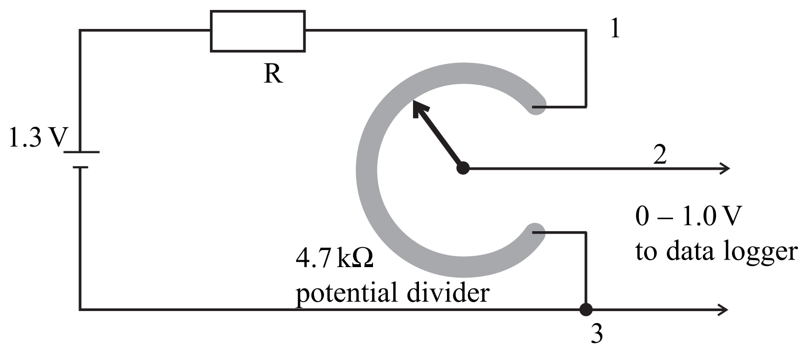

Figure 3

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(3 marks)

11

4 **Figure 4** shows a cross-section through a rectangular light-emitting diode (LED). When current passes through the LED, light is emitted from the semiconductor material at P and passes through the transparent material and into the air at Q.

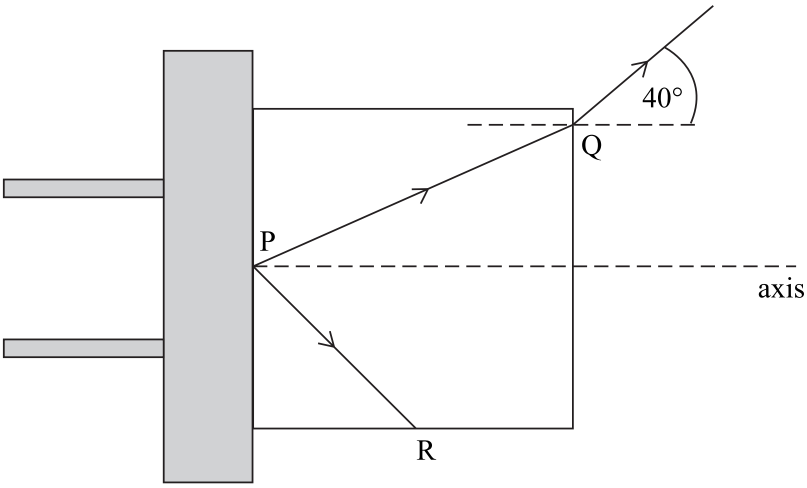

Figure 4

(a) (i) The refractive index of the transparent material of the LED is 1.5. Calculate the critical angle of this material when the LED is in air.

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(ii) **Figure 4** shows a light ray PQ incident on the surface at Q. Calculate the angle of incidence of this light ray at Q if the angle of refraction is 40°.

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(iii) **Figure 4** also shows a second light ray PR incident at R at an angle of incidence of 45°. Use **Figure 4** to explain why this light ray cannot escape into the air.

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(7 marks)

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(b) The LED in part (a) is used to send pulses of light down two straight optical fibres of the same refractive index as the transparent material of the LED. The fibres are placed end-on with the LED, as shown in **Figure 5**. Optical fibre 1 is positioned at Q and the other at S directly opposite P.

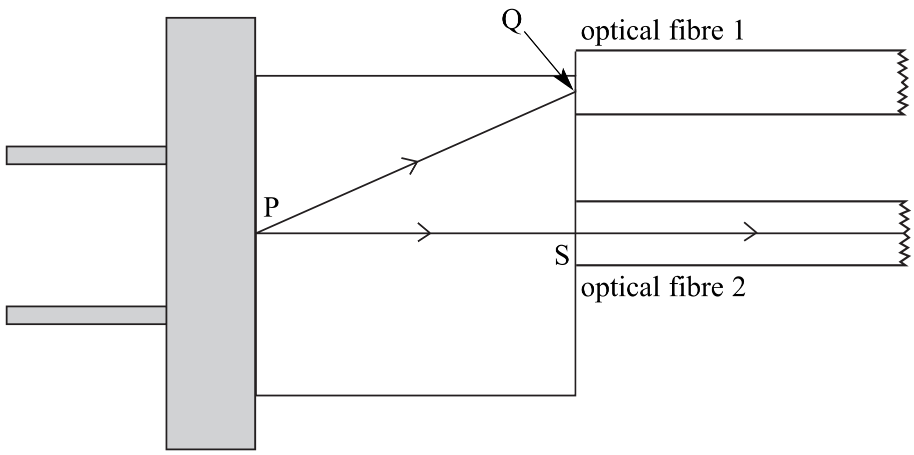

Figure 5

(i) Continue the path of the light ray PQ into and along the optical fibre.

(ii) Compare the times taken for pulses of light to travel along the same length of each fibre.

Give a reason for your answer.

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(3 marks)

10

Turn over

5 While investigating projectile motion, a student used stroboscopic photography to determine the position of a steel ball at regular intervals as it fell under gravity. With the stroboscope flashing 20 times per second, the ball was released from rest at the top of an inclined track, and left the foot of the track at P, as shown in **Figure 6**.

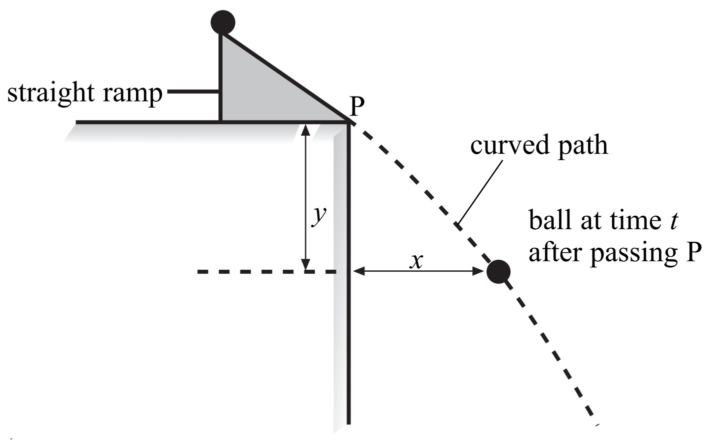

Figure 6

For each of the images on the photograph, the student calculated the horizontal distance, *x*, and the vertical distance, *y*, covered by the ball at time *t* after passing P. Both distances were measured from point P. He recorded his results for the distances *x* and *y* in the table.

image	*x*/cm	*y*/cm	*t*/s	(y/t)/cm s^{-1}
1	11.6	9.3	0.05	
2	22.0	21.0	0.10	
3	32.4	35.0	0.15	
4	44.2	51.8	0.20	
5	54.8	71.0	0.25	
6	66.0	92.2	0.30	

(a) Using two sets of measurements from the table, calculate the horizontal component of velocity of the ball. Give a reason for your choice of measurements.

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(2 marks)

LEAVE MARGIN BLANK

Turn over

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(b) The student worked out that the variables y and t in the experiment could be represented by

$$\frac{y}{t} = u + kt$$

where u and k are constants.

(i) Complete the table on page 12.

(ii) Use the data in the table to plot a suitable graph on page 13 to confirm the equation.

(iii) Use your graph to find the values of u and k.

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(9 marks)

(c) State the physical significance of

u ....

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k..........

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(2 marks)

(d) Calculate the magnitude of the velocity of the ball at point P.

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(2 marks)

15

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6 (a) **Figure 7** shows an arrangement used to investigate the properties of microwaves.

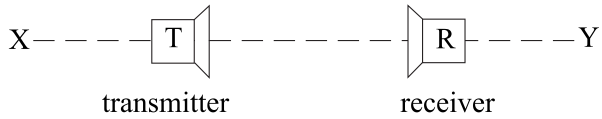

Figure 7

When the transmitter T was rotated through 90° about the straight line XY, the receiver signal decreased to zero. Explain why this happened and state the property of microwaves responsible for this effect.

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

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(3 marks)

(b) A microwave oven produces microwaves of wavelength 0.12 m in air.

(i) Calculate the frequency of these microwaves.

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(ii) In a certain oven, explain why food heated in a fixed position in this oven would be uncooked at certain points if stationary waves were allowed to form.

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(3 marks)

6

Turn over

7 Dry air ceases to be an insulator if it is subjected to an electric field strength of 3.3 kV mm^{-1} or more.

(a) (i) Show that the electric field strength E and the potential V at the surface of a charged sphere of radius R are related by

$$E = \frac{V}{R}$$

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(ii) The dome of a Van de Graaff generator has a radius of 0.20 m. Calculate the maximum potential of this dome in dry air.

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(5 marks)

(b) Two high voltage conductors are joined together using a small sphere, as shown in **Figure 8**.

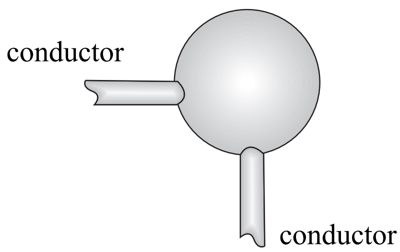

Figure 8

The conductors are used to transmit alternating current at an rms potential of 100 kV.

(i) Calculate the peak potential of the conductor,

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(ii) Calculate the minimum diameter of the sphere necessary to ensure the surrounding air does not conduct.

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(3 marks)

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8

TURN OVER FOR NEXT QUESTION

Turn over ▶

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8 The radioactive isotope ${}^{40}_{19}K$ decays by β^- emission to form a stable isotope of calcium (Ca) or by electron capture to form a stable isotope of argon (Ar).

(a) (i) Complete the following equation which represents the β^- decay of ${}^{40}_{19}K$.

$$ {}^{40}_{19}K \longrightarrow \beta^- + Ca + \bar{\nu}_e $$

(ii) Sketch the Feynman diagram for this process.

(4 marks)

(b) (i) Complete the following equation which represents electron capture by ${}^{40}_{19}K$.

$$ {}^{40}_{19}K + e^- \longrightarrow Ar + \nu_e $$

(ii) Sketch the Feynman diagram for this process.

(3 marks)

LEAVE MARGIN BLANK

(c) The isotope of argon formed as a result of electron capture by $^{40}_{19}K$ is found as a trapped gas in ancient rocks. The age of an ancient rock can be determined by measuring the proportion of this isotope of argon to $^{40}_{19}K$.

An ancient rock is found to contain 1 argon atom for every 4 atoms of $^{40}_{19}K$.

(i) The decay of $^{40}_{19}K$ by β^- emission is 8 times more likely than electron capture. Show that for every argon atom in this rock, there must have originally been 13 atoms of $^{40}_{19}K$.

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(ii) $^{40}_{19}K$ has a half life of 1250 million years. Calculate the age of this rock.

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(6 marks)

__ 13

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QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

END OF QUESTIONS