Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

General Certificate of Education
January 2003
Advanced Level Examination

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

AQA
ASSESSMENT and
QUALIFICATIONS
ALLIANCE

Friday 31 January 2003   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			
3			
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 = πr^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

$$\Delta Q = \Delta U + \Delta W$$

$$\Delta W = p\Delta V$$

$$pV^\gamma = constant$$

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

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

$$\epsilon = I(R + r)$$

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

$$R_T = R_1 + R_2 + R_3 + \cdots$$

$$P = I^2 R$$

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

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

$$E = \frac{1}{2}QV$$

$$F = BIl$$

$$F = BQv$$

$$Q = Q_0 e^{-t/RC}$$

$$\Phi = BA$$

Turn over ▶

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

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

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

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

$\Delta Q = ml$

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

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

Nuclear Physics and Turning Points in Physics

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

force $= Bev$

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

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

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 $= 1.50 \times 10^{11}$ m

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

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

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

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

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

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

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

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

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

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

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

1 A hydroelectric power station has a power output of 2.0 MW when water passes through its turbines at a rate of $1.4 \, m^3 s^{-1}$. The water is supplied from a reservoir which is 750 m above the power station turbines, as shown in **Figure 1**.

density of water = $1000 \, kg \, m^{-3}$
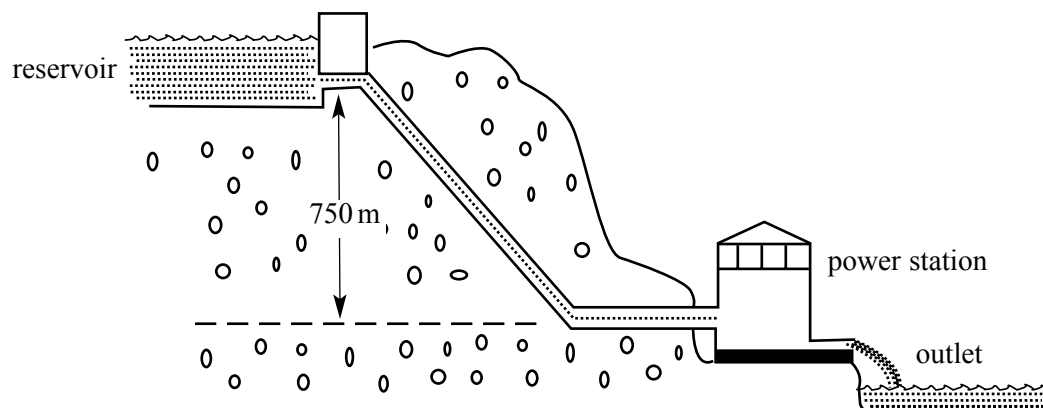
Figure 1

(a) Calculate

(i) the mass of water passing through the turbines each second,

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(ii) the loss of potential energy per second of the water flowing between the reservoir and the power station turbines,

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(iii) the efficiency of the power station.

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(6 marks)

(b) The turbines drive generators that produce alternating current at an rms potential difference of 25 kV which is then stepped up to an rms potential difference of 275 kV by means of a transformer.

(i) Calculate the rms current supplied by the generators to the transformer when the power output of the generators is 2.0 MW.

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(ii) The transformer has an efficiency of 95%. Calculate the output current of the transformer.

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(4 marks)

$\overline{10}$

TURN OVER FOR THE NEXT QUESTION

2 (a) The molecules of a gas are in continual *random motion*, making *elastic collisions* with each other and with the molecules on any surfaces in contact with the gas.
In relation to the molecules of a gas,

(i) explain the meaning of random motion,

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(ii) state what is meant by an elastic collision.

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(3 marks)

(b) The motion of conduction electrons in a metal can be compared with the motion of the molecules of an ideal gas.

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

(i) Use this comparison to show that the mean kinetic energy of a conduction electron in a metal at 300 K is approximately 6×10^{-21} J.

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(ii) The work function of a typical metal is approximately 10^{-19} J. Without further calculation, explain why electrons cannot be emitted from a metal surface in darkness at 300 K.

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(iii) Explain why electrons can be emitted from a metal surface at 300 K if the surface is illuminated by light above a certain frequency.

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(5 marks)

8

TURN OVER FOR THE NEXT QUESTION

3 In a compact disc player, light of wavelength 635 nm is directed normally from air at the underside of the compact disc and is reflected from the reflective coating, as shown in **Figure 2**.

refractive index of transparent plastic layer = 1.53
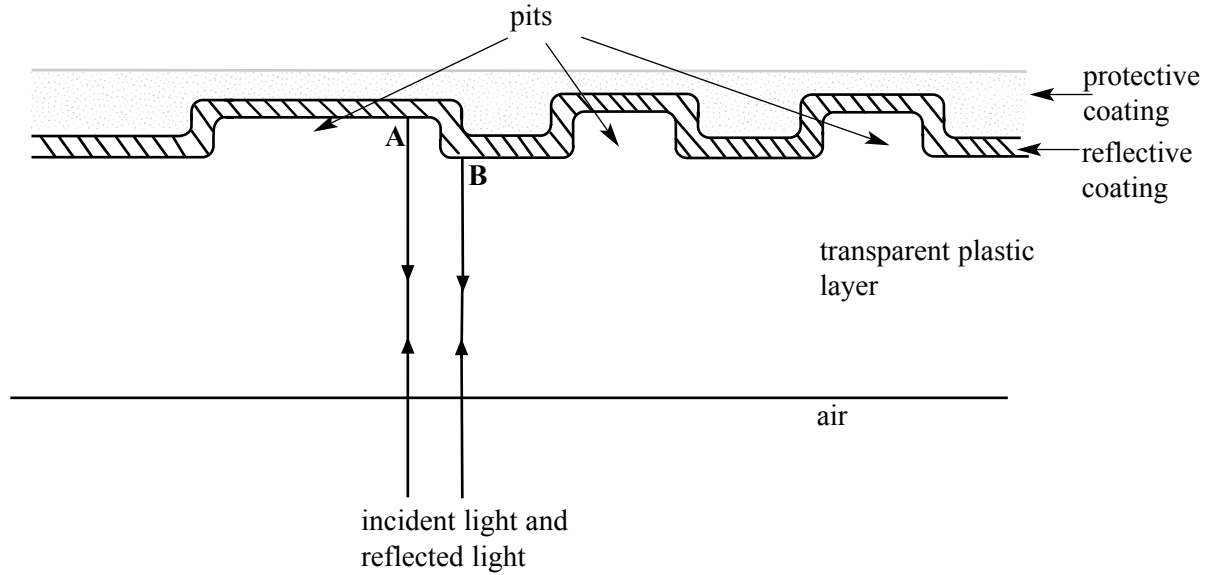
Figure 2

(a) The upper surface is encoded with pits in sequence. As the disc is rotated, the reflected light beam is encoded as the pits cross the beam.

(i) Calculate the wavelength of the light in the disc.

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(ii) Light reflected from inside a pit at **A** interferes destructively with light reflected outside the pit at point **B** because it travels further. Calculate the minimum depth of the pit for this effect to occur.

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(4 marks)

(b) Some light is not reflected normally by the reflective coating.

(i) Calculate the critical angle of light at the plastic/air boundary.

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(ii) In **Figure 3**, draw the continued path of the light ray that is incident on the plastic/air boundary at an angle of incidence of 50°.
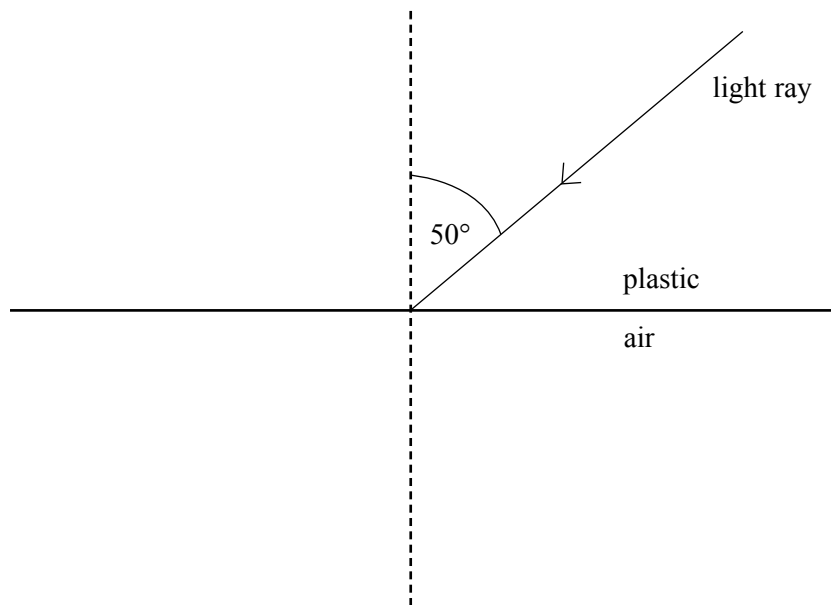
Figure 3

(4 marks)

8

4 **Figure 4** shows, in cross-section, a flow meter fitted in a pipe. Fluid flowing along the pipe makes the rotor in the pipe turn, causing the eight magnets attached to the rotor to sweep past the sensor coil.

pipe

rotor

magnet

to sensor circuit
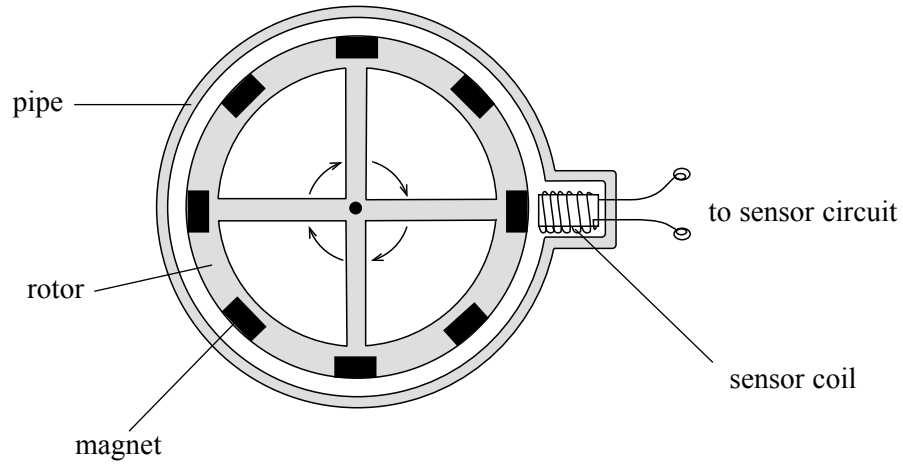
sensor coil

Figure 4

(a)   The graph shows how the emf induced in the sensor coil changed with time at a certain flow rate.

emf

0.1   0.2   0.3   time/s
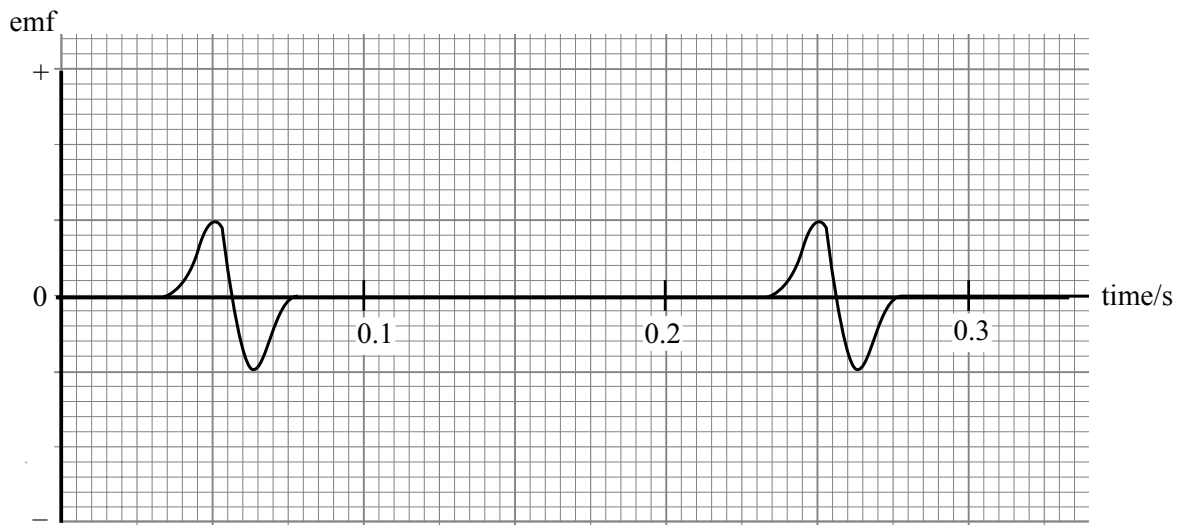
(i)   Explain why the emf induced in the sensor coil varies as shown in the graph.

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

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(ii) Calculate the frequency of rotation of the rotor.

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(iii) The rotor diameter is 0.18 m. Calculate the centripetal acceleration of one of the magnets.

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(6 marks)

(b) Using the same axes as the graph on page 12, show how the emf would change with time if the rotor rotated twice as fast.

(2 marks)

8

TURN OVER FOR THE NEXT QUESTION

5 A uniform wooden beam of mass 35.0 kg and length 5.52 m is supported by two identical vertical steel cables **A** and **B** attached at either end, as shown in **Figure 5**.
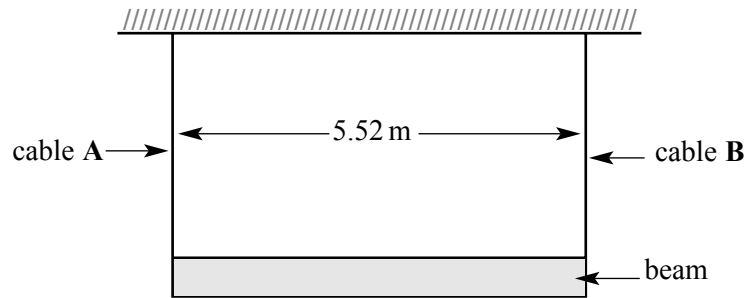
Figure 5

(a) Calculate

(i) the weight of the beam,

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(ii) the tension in each cable.

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(2 marks)

(b) Each unstretched cable has a diameter of 8.26 mm and a length 2.50 m. Calculate the extension of each cable when supporting the beam.

the Young modulus for steel = 2.10×10^{11} Pa

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(4 marks)

(c) An object of mass 20.0 kg is hung from the beam 1.00 m from cable A, as shown in **Figure 6**.
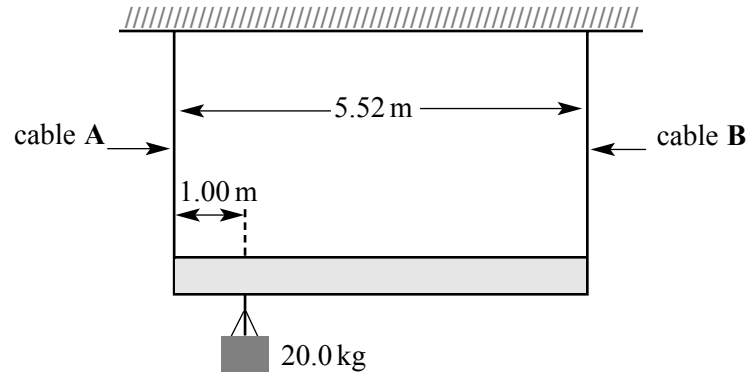
Figure 6

(i) Show that the new tension in cable **A** is 332 N.

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(ii) Calculate the new tension in cable **B**.

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(6 marks)

12

6 Columns **A and B** show some of the results from an experiment in which the current I through a component X was measured for various values of the potential difference V applied across it.

column A	column B	column C	column D
potential difference V / V	current I/ mA	$(V - 0.55)$ / V	ln $(I$ / mA)
0.70	12.5		
0.75	17.0		
0.80	22.0		
0.85	29.0		
0.90	39.0		
0.95	51.5		

(a) Draw a diagram of a circuit which could have been used to obtain these results.

(2 marks)

(b) (i) Calculate the resistance of X when the potential difference is 0.70 V.

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(ii) By considering **one** other value of potential difference, explain whether or not X is an ohmic conductor.

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(3 marks)
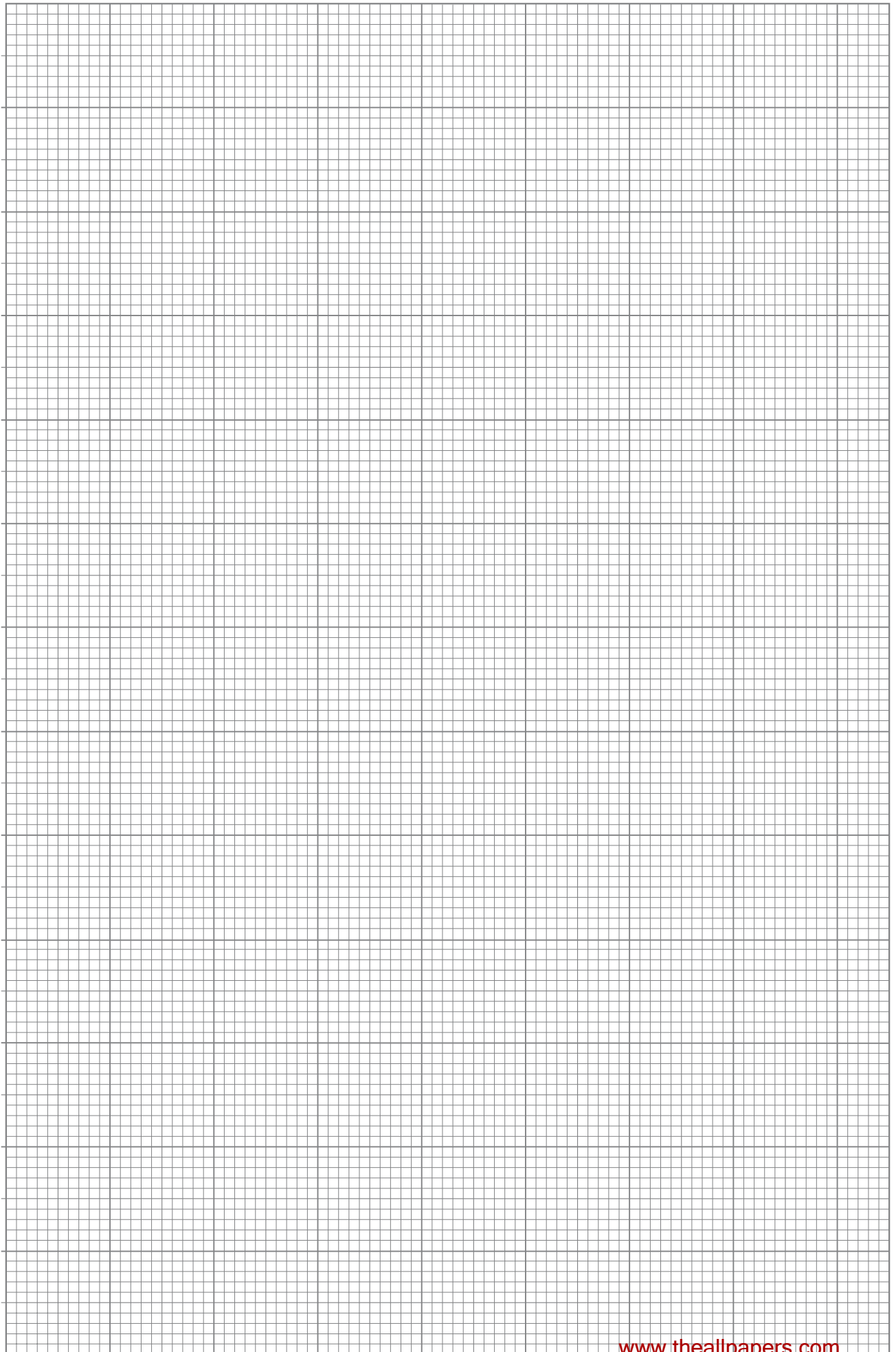
(c) It is suggested that for potential differences greater than 0.55 V, the current-voltage relationship for X is of the form.

$$I = A\ e^{k(V-0.55)}$$

where A and k are constants.

(i) Complete **column C** and **column D** in the table on page 16

(ii) Using the graph grid on page 17, plot a graph of ln (I/mA) on the y-axis against ($V - 0.55$) on the x-axis.

(iii) Use your graph to determine the constants k and A.

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(iv) On the basis of your graph, discuss the validity of the above relationship.

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(10 marks)

$\overline{15}$

7 Use the following data to answer the question below.

specific latent heat of fusion of lead = $23 \, kJ \, kg^{-1}$
molar mass of lead = $0.21 \, kg \, mol^{-1}$

(i) Estimate the mass of a lead atom.

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(ii) Estimate the energy supplied to an atom of lead when solid lead melts.

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(iii) Calculate the speed of a lead atom with the same kinetic energy as the energy supplied in part (ii).

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(5 marks)

5

8 (a) This part of the question is about protons.

(i) Calculate the electrostatic potential energy, in J, of **two** protons at a distance apart of 1.0×10^{-15} m.

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(ii) Two protons moving in opposite directions at the same initial speed collide head-on with each other. The least distance apart of the two protons is 1.0×10^{-15} m. By considering conservation of energy, estimate the initial kinetic energy, in MeV, of each proton.

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(5 marks)

(b) State the quark composition of

(i) a proton,

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(ii) a positive pion, π^+.

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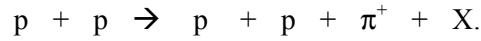
(2 marks)

(c)   A proton collides with another proton moving in the opposite direction at the same speed, creating a positive pion and a further particle X in the process. This process is represented by the equation

$$p + p \rightarrow p + p + \pi^+ + X.$$

(i)   State the charge, Q, and baryon number, B, of X.

Q ....

B ....

(ii)   State the identity and quark composition of X.

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(iii)   Explain why two protons with initial kinetic energies as in part (a)(ii) could not produce the reaction in part (c).

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(5 marks)

$\overline{12}$

QUALITY OF WRITTEN COMMUNICATION   *(2 marks)*

$\overline{2}$

END OF QUESTIONS