OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS
Advanced GCE

PHYSICS A

2825/03

Materials

Wednesday **26 JANUARY 2005** Morning 1 hour 30 minutes

Candidates answer on the question paper.
Additional materials:
Electronic calculator

Candidate Name	Centre Number	Candidate Number

TIME 1 hour 30 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name in the space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers in the spaces provided on the question paper.
- Read each question carefully and make sure you know what you have to do before starting your answer.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [ ] at the end of each question or part question.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- The first six questions concern Materials. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	10	
2	11	
3	10	
4	10	
5	17	
6	12	
7	20	
TOTAL	90	

This question paper consists of 16 printed pages.

SP (NF/AR) S72321/5

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall,	$g = 9.81\ \mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
refractive index,	$n = \frac{1}{\sin C}$
capacitors in series,	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$
capacitors in parallel,	$C = C_1 + C_2 + \ldots$
capacitor discharge,	$x = x_0 e^{-t/CR}$
pressure of an ideal gas,	$p = \frac{1}{3}\frac{Nm}{V}<c^2>$
radioactive decay,	$x = x_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$
critical density of matter in the Universe,	$\rho_0 = \frac{3H_0^2}{8\pi G}$
relativity factor,	$= \sqrt{(1 - \frac{v^2}{c^2})}$
current,	$I = nAve$
nuclear radius,	$r = r_0 A^{1/3}$
sound intensity level,	$= 10 \lg\left(\frac{I}{I_0}\right)$

[Turn over

Answer **all** the questions.

1 **(a)** Explain in terms of forces between atoms what is meant by the *equilibrium separation* of a pair of atoms in a solid.

....

....

....[2]

(b) The graph in Fig. 1.1 shows the variation with separation r of the resultant force F between a pair of atoms in a metal wire.

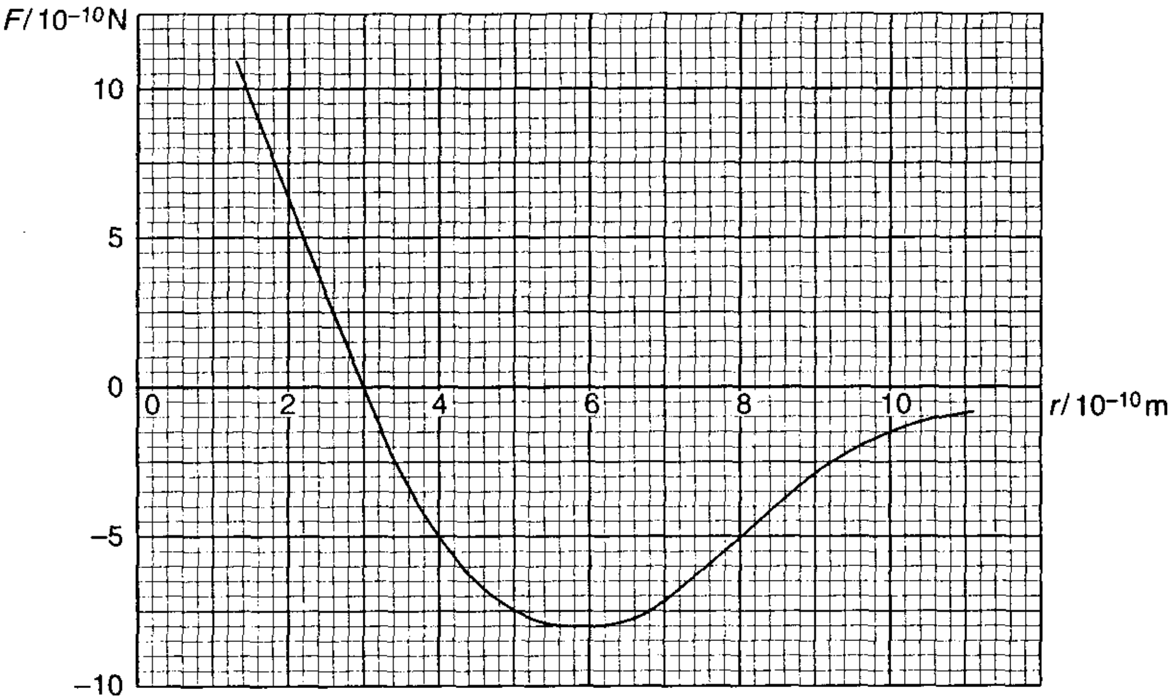

Fig. 1.1

(i) State the equilibrium separation of the atoms.

....[1]

(ii) The atoms increase or decrease their separation by 0.2×10^{-10} m from their equilibrium separation. Describe the feature of the graph which shows that the wire obeys Hooke's law.

....[1]

(iii) The theoretical breaking stress of the wire is given by the expression $\frac{F_{max}}{r_o^2}$, where F_{max} is the maximum attractive force between the pair of atoms, and r_o is their equilibrium separation.

Calculate the theoretical breaking stress, stating the unit of your answer.

breaking stress = ... unit .... [3]

(c) Describe the stages leading to the breaking of a wire made of a ductile metal when increasing loads are applied. Where relevant your answer should be in terms of atoms and crystal planes.

....

....

....

....

....[3]

[Total: 10]

2 **(a)** Distinguish between *single-crystal* and *polycrystalline* materials, and state an example of each.

....

....

....

....

single-crystal example ....

polycrystalline example ....
[4]

(b) **(i)** State **two** types of *point defect* which occur in crystal structures.

1. ....

2. ....[2]

(ii) A crystalline structure with no defects can undergo plastic deformation. Explain this process with reference to *slip planes*.

....

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....[2]

(c) Fig. 2.1 represents a part of a plane of atoms in a small section of a crystal.

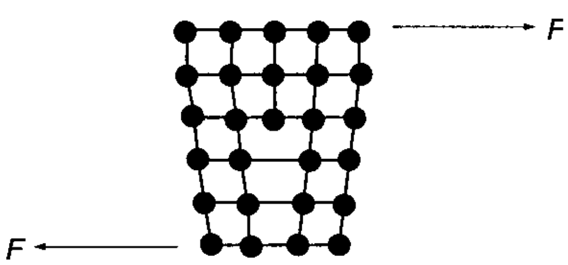

Fig. 2.1

(i) State the type of defect present in this plane of atoms.

....[1]

For Examiner's Use

(ii) The forces *F* shown by the arrows in Fig. 2.1 are sufficient to deform the crystal by movement of crystal planes. Sketch an arrangement of the atoms in Fig. 2.1 which occurs as the deformation takes place.

[2]

[Total: 11]

3 (a) (i) State in terms of band theory what is meant by a *free electron*.

....

....[1]

(ii) Describe the motion of free electrons in a metal wire during the passage of a current.
Include an explanation of the term *drift velocity*.

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....[4]

(b) A thermistor made of semiconducting material is connected to a voltage source using copper wire. The current in the circuit is 2.5 mA.

(i) The free electron concentration in copper is $8.5 \times 10^{28}\,\text{m}^{-3}$. The cross-sectional area of the wire is $1.1 \times 10^{-7}\,\text{m}^2$. Calculate the drift velocity of free electrons in the wire.

drift velocity = ... m s^{-1} [2]

(ii) The cross-sectional areas of the thermistor and wire are similar. Suggest why the drift velocity of free electrons in the thermistor is greater than the drift velocity in the wire.

....[1]

(c) The temperature of the thermistor in **(b)** is raised. Using band theory, explain why the current in the circuit increases.

....

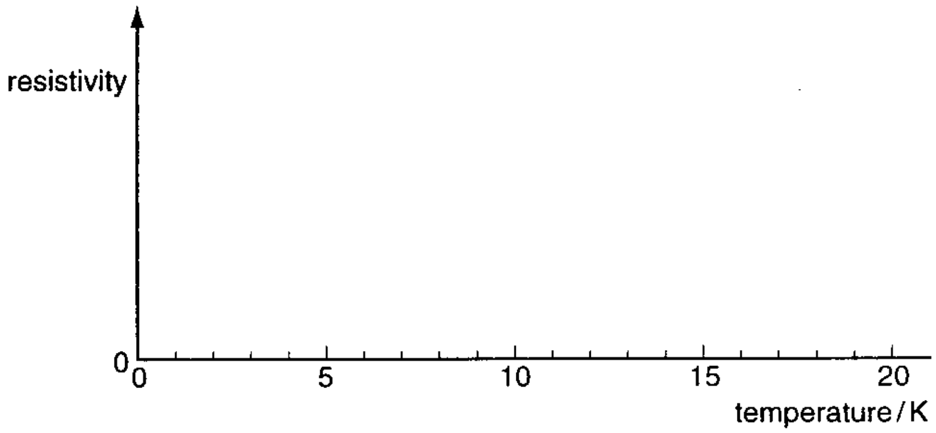
....

....[2]

[Total: 10]

For Examiner's Use

4 **(a)** The superconducting transition temperature of lead is 8.2 K. On the axes of Fig. 4.1, sketch a graph to show the variation with temperature of the resistivity of lead in the range 0 – 20 K.



[3]

Fig. 4.1

(b) Discuss the use of superconductors in the production of strong magnetic fields. The following issues should be addressed.

- how the required temperature is achieved and maintained
- the advantages of using superconductors rather than conventional conductors
- a practical use for such a strong magnetic field

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....[7]

[Total: 10]

5 (a) The primary coil of a transformer is connected to the 230 V mains supply. The 12 V output of the secondary coil is applied to a bulb which draws a current of 3.0 A. At the frequency of the mains the transformer operates with an efficiency of 96 %. Calculate

(i) the power supplied to the bulb

power = ... W [2]

(ii) the current in the primary coil.

current = ... A [3]

(b) On the axes of Fig. 5.1, sketch a hysteresis loop for a ferromagnetic material, labelling the axes with appropriate symbols.

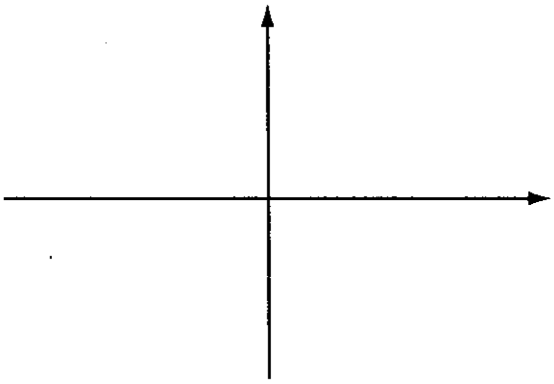

Fig. 5.1

Name the quantities plotted on each axis.

x-axis ....

y-axis ....[3]

(c) One cause of energy loss in the core of a transformer is due to the hysteresis of the core material. Explain why this energy loss is proportional to the frequency of the current in the transformer coils.

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....[2]

For Examiner's Use

(d) State the processes by which energy is lost from a transformer.
For each process, describe how the transformer design minimises the energy loss.

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....[7]

[Total: 17]

For Examiner's Use

6 **(a)** Fig. 6.1 shows a narrow beam of infra-red radiation approaching a plane boundary between a medium **X** of lower refractive index and a medium **Y** of higher refractive index.

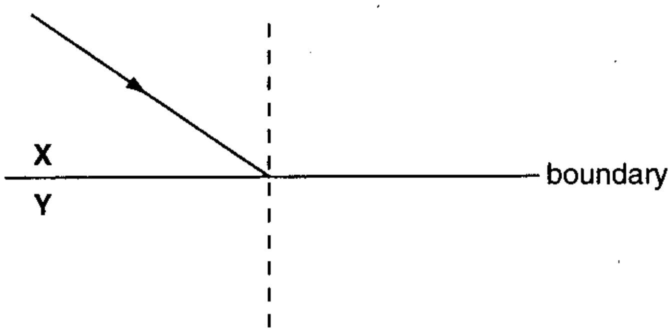

Fig. 6.1

(i) Complete Fig. 6.1 to show the path of the beam. [1]

(ii) Describe what happens to the speed of the radiation.

....[1]

(b) Fig. 6.2 (A) shows a cross-section of a step-index optic fibre. Fig. 6.2 (B) shows a length of the same fibre.

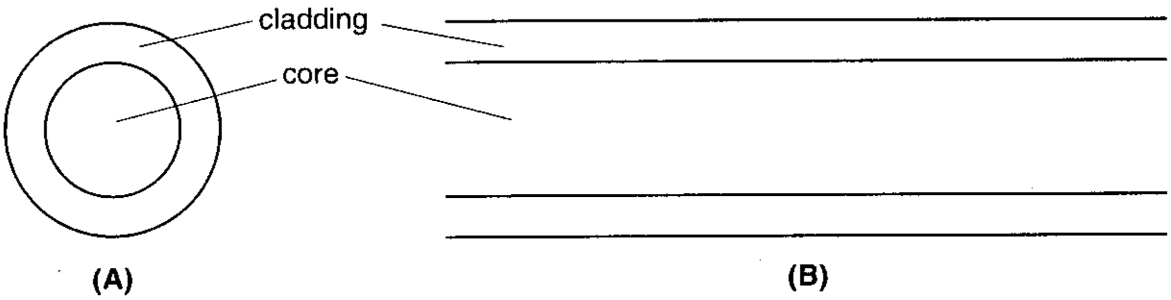

Fig. 6.2

This fibre is used to transmit infra-red pulses. The speed of infra-red in the core of the fibre is $2.03 \times 10^8\,\mathrm{m\,s^{-1}}$. The speed in the cladding is $2.04 \times 10^8\,\mathrm{m\,s^{-1}}$.

(i) Calculate the critical angle for the boundary between the core and the cladding.

critical angle = ... ° [3]

(ii) Sketch on Fig. 6.2 (B) the path of a ray which meets the core-cladding boundary with an angle of incidence greater than the critical angle. [1]

For Examiner's Use

(c) For long-distance communication through optic fibres, state and explain **three** reasons why infra-red from a laser is used rather than infra-red of the same wavelength emitted by an LED.

1. ....

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2. ....

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3. ....

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....[6]

[Total: 12]

7 Although the idea for the airbag was first suggested more than fifty years ago, it has only been a compulsory safety feature in the modern motor car since 1998. When a car experiences a serious head-on collision, the seat belt is designed to restrain the driver's body. However, without the cushioning effect of an airbag, the inertia in the driver's head will cause it to carry on moving at the speed of the car until it is stopped by the steering wheel or the windscreen. When activated, the airbag must be fully inflated before the driver's head reaches it so that the head hits a soft target.

One early system stored the gas for the airbag in a cylinder under the driver's seat. When the deceleration of the car was sufficiently large, a sensor caused an electrical circuit to operate and open a valve so that the compressed gas could rush into the airbag on the steering wheel.

The sensor used a steel ball and spring in a cylinder as shown in Fig. 7.1.

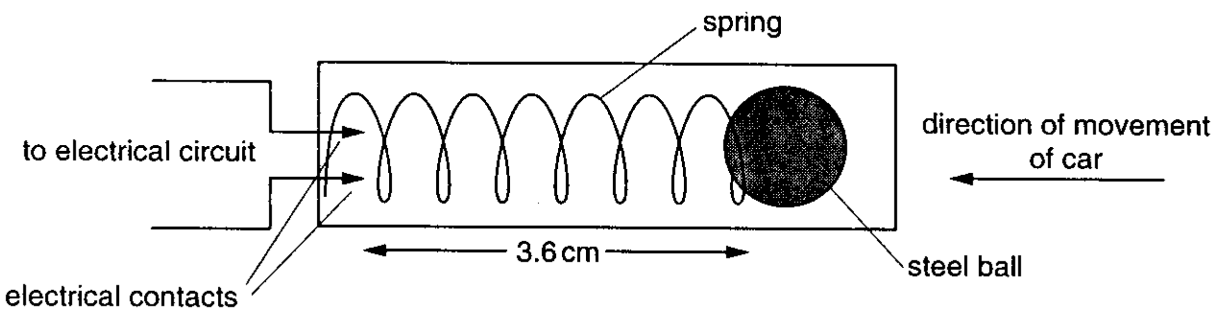

Fig. 7.1

When the car was being driven normally, the spring kept the steel ball apart from the two electrical contacts inside the cylinder. But if the deceleration became large enough, the inertia of the free ball compressed the spring and the ball touched the two contacts, thus activating the electrical circuit.

The method of storing compressed gas in a cylinder was not very reliable because some cylinders slowly leaked gas and so all had to be checked regularly.

The modern method of inflating an airbag is to generate the gas chemically by activating an electrical heater or detonator in an explosive chemical mixture. The heating starts a very rapid chemical reaction which produces nitrogen for the airbag. This means that the folded airbag along with chemicals and heater can all be located together in a compact container and positioned anywhere inside the car.

Consider the following data for a car running head-on into an immovable object.

initial velocity of car	$= 54\,\text{km}\,\text{hr}^{-1}$
final velocity of car	$= 0$
car front crumple distance	$= 1.25\,\text{m}$
distance from head to windscreen	$= 0.96\,\text{m}$

(a) Show that the car's speed in $\text{m}\,\text{s}^{-1}$ just before hitting the object is $15\,\text{m}\,\text{s}^{-1}$.

[2]

(b) Calculate

(i) the deceleration of the car during the collision (assumed to be constant)

deceleration = ... $m\,s^{-2}$ [2]

(ii) the time taken for the car to crumple to rest.

time = ... s [2]

(c) The data for a ball and spring sensor is given below.

mass of ball	= 0.12 kg
spring constant	= 30 $N\,m^{-1}$
distance to be compressed	= 3.6 cm

Calculate

(i) the force necessary to compress the spring by 3.6 cm

force = ... N [2]

(ii) the deceleration which the force in **(c)(i)** would cause in a mass of 0.12 kg.

deceleration = ... $m\,s^{-2}$ [1]

(d) When the airbag was fully inflated from a storage cylinder, the bag had a volume of $0.060\,m^3$, with the gas inside at a pressure of 250 kPa. If the storage cylinder had a volume of $3.0 \times 10^{-4}\,m^3$, calculate the stored gas pressure, assuming the gas was ideal and at constant temperature.

pressure = ... Pa [2]

(e) Suppose that the pressure inside the cylinder dropped by 20% over a period of 4 weeks. Assuming the mean temperature of the cylinder is 17 °C, calculate the average number of gas molecules leaving per second during this time.

number leaving per second = ... [4]

(f) The data for a modern airbag is given below.

energy required for reaction to start	= 0.96 J
heater wire cross sectional area	= $2.75 \times 10^{-8}\,m^2$
heater wire length	= 2.2 cm
resistivity of heater wire	= $1.5 \times 10^{-6}\,\Omega\,m$
battery voltage	= 12 V

(i) Show that the resistance of the heater filament is 1.2 Ω.

[2]

(ii) Hence calculate the time taken for the heater to start the chemical reaction.

time to start = ... s [3]

[Total: 20]

END OF QUESTION PAPER