OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A **2825/03**

Materials

Thursday **22 JUNE 2006** Afternoon 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	**13**	
4	**15**	
5	**13**	
6	**8**	
7	**20**	
TOTAL	**90**	

This question paper consists of 18 printed pages and 2 blank pages.

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, $n = \dfrac{1}{\sin C}$

capacitors in series, $\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$

capacitors in parallel, $C = C_1 + C_2 + \ldots$

capacitor discharge, $x = x_0 e^{-t/CR}$

pressure of an ideal gas, $p = \frac{1}{3}\dfrac{Nm}{V}<c^2>$

radioactive decay, $x = x_0 e^{-\lambda t}$

$t_{\frac{1}{2}} = \dfrac{0.693}{\lambda}$

critical density of matter in the Universe, $\rho_0 = \dfrac{3H_0^{\,2}}{8\pi G}$

relativity factor, $= \sqrt{(1 - \dfrac{v^2}{c^2})}$

current, $I = nAve$

nuclear radius, $r = r_0 A^{1/3}$

sound intensity level, $= 10\lg\left(\dfrac{I}{I_0}\right)$

For Examiner's Use

Answer **all** the questions.

1 The resultant force F between a pair of adjacent atoms in a solid can be attractive or repulsive, and depends upon the separation x of the atoms.
For a particular solid, when $x = 0.22\,\text{nm}$, the atoms are at their equilibrium separation.
When $x = 0.28\,\text{nm}$, the resultant force is attractive and has reached a maximum value of $1.8 \times 10^{-10}\,\text{N}$.

(a) Taking repulsive force to be positive, sketch the shape of the graph of F against x on the axes of Fig. 1.1. [4]

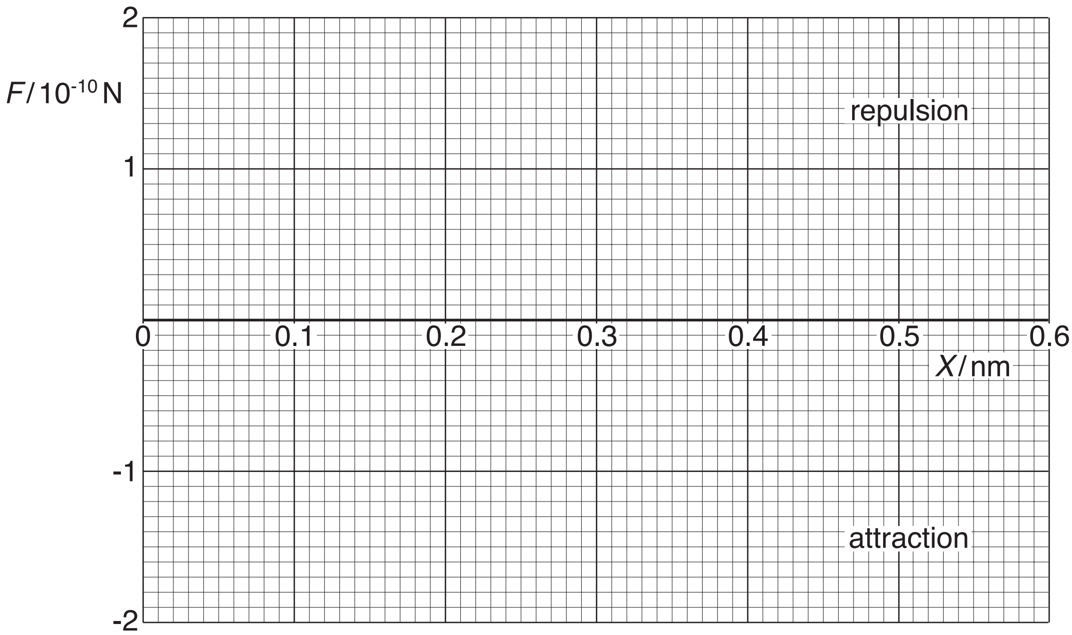


Fig. 1.1

(b) **(i)** How is the magnitude of the resultant force related to the magnitudes of the attractive and repulsive forces between the atoms?

....[1]

(ii) When $x = 0.25\,\text{nm}$, the attractive force between the atoms is $3.3 \times 10^{-10}\,\text{N}$. Use the value which your sketch graph gives to determine the repulsive force at this separation.

repulsive force = ... N [1]

(c) A cylindrical rod is made of this solid. The cross-section of the rod contains 2.5×10^{15} atoms.

(i) Calculate the theoretical value of the tensile force needed to break the rod.

force = ... N [2]

(ii) Suggest **two** reasons why the actual force may differ significantly from the theoretical value.

1. ....

....

2. ....

....[2]

[Total: 10]

For Examiner's Use

2 **(a)** Some metals and other substances have a superconducting transition temperature. State the values of the following quantities for such a material below this temperature.

(i) resistivity ....

(ii) electrical conductivity ....[2]

(b) **(i)** Describe how a superconducting material may be used to obtain a very strong uniform magnetic field.

....

....

....

....

....[3]

(ii) State two features which make the use of superconducting material ideal for this purpose.

1. ....

....

2. ....

....[2]

(c) When a superconductor **below** the transition temperature T_c is subjected to a sufficiently strong magnetic field, the superconductivity disappears. The maximum magnetic flux density, B, at which the material can remain superconducting at absolute temperature T, is given by

$$B = B_0 \left[1 - \frac{T^2}{T_c^2}\right]$$

where B_0 is the maximum flux density at which the material can remain superconducting at T = zero kelvin.

(i) For a certain material, T_c = 9.4 K and B_0 = 0.19 T. Calculate the maximum flux density, B, for which the material is superconducting at a temperature of 4.2 K.

B = ... T [2]

For Examiner's Use

(ii) Explain why the calculation in **(i)** suggests that for a material to remain superconducting below its transition temperature there is a maximum current that it may carry.

....

....[1]

(iii) What is the value of this current at $T = T_c$?

current = ... A [1]

[Total: 11]

[Turn over

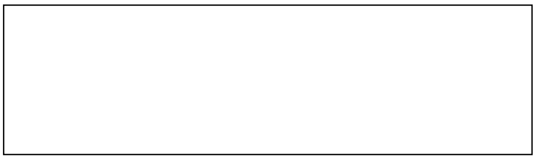
3 **(a)** **(i)** By referring to its atoms, explain how the magnetisation of a single domain in iron occurs.

....

....[1]

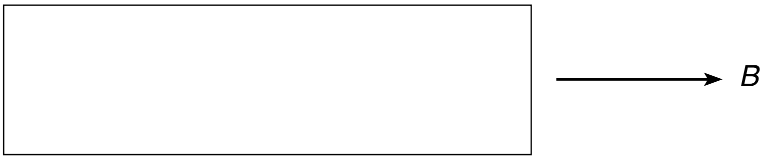
(ii) The rectangles below represent the outline of an iron bar placed in a magnetic field whose direction is shown by arrows. Sketch the domain structure in the bar when it is

1 unmagnetised

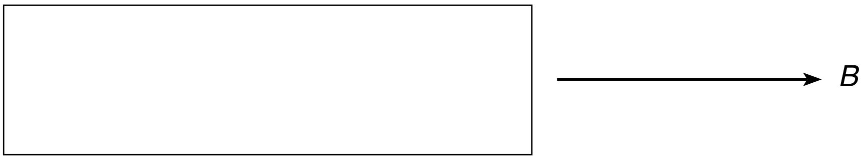


no field

2 partially saturated



3 fully saturated.



[4]

(b) A ring made of hard iron and a ring made of soft iron are both wound with many turns of copper wire carrying alternating current. Fig. 3.1 shows the hysteresis loops for the two rings. B_o is the magnetic flux density due to the current. B is the magnetic flux density in the iron.

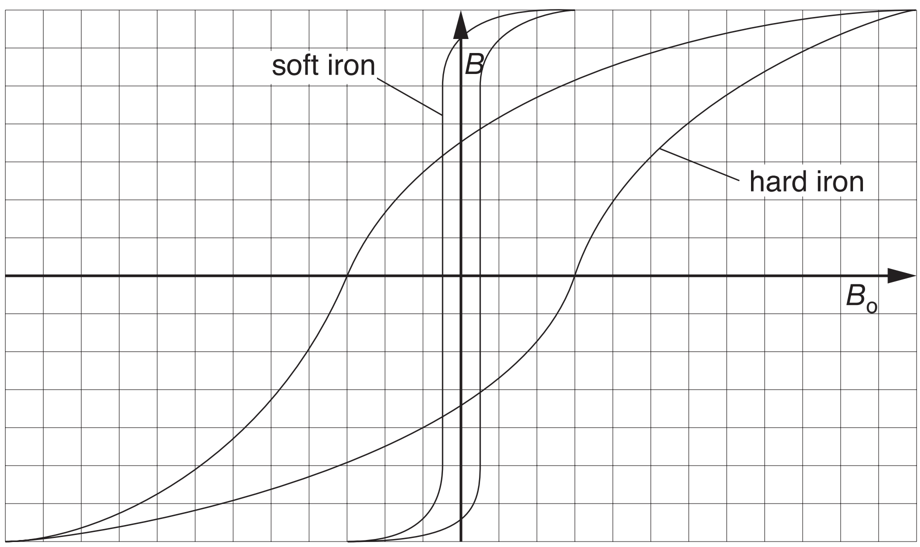


Fig. 3.1

(i) Use Fig. 3.1 to estimate, due to hysteresis effects, the ratio

$$\frac{\text{heat generated per unit time in hard iron ring}}{\text{heat generated per unit time in soft iron ring}}.$$

ratio = ... [3]

(ii) Use the following data to calculate the temperature rise of the soft iron ring in 1 minute.
Assume that no heat is lost to the surroundings.

mass of soft iron ring = 0.15 kg
specific heat capacity of iron = 450 J kg^{-1} K^{-1}
heat generated in the ring per hysteresis cycle = 0.030 J
frequency of alternating current in the coil = 50 Hz.

temperature rise = ... K [3]

(iii) In practice, the rise in temperature may be more than that caused by hysteresis. State and explain **one** other cause of heating in the ring.

....

....

....[2]

[Total: 13]

4 (a) (i) Show that the wavelength of a photon of energy 3.9 eV is 320 nm.

[2]

(ii) An insulator has an energy band gap of 3.9 eV. Explain why this insulator is transparent to visible light.

....

....

....

....[3]

(b) Several light emitting diodes (LEDs) which emit light of different known wavelengths are available. An experiment to determine the Planck constant *h* is to be carried out.

(i) Draw a suitable electric circuit for this experiment.

[2]

(ii) Describe the procedure to be carried out, explaining how *h* is determined from the results.

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For Examiner's Use

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....[8]

[Total: 15]

For Examiner's Use

5 **(a)** Explain in terms of band theory what is meant by a *free electron*.

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....[2]

(b) Describe in detail the motion of free electrons in a copper wire

- when there is no current in the wire
- when there is a current in the wire.

Your answer should include the meanings of root-mean-square speed and drift velocity and the factors that determine them.

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....[7]

(c) A current of 0.75 A is carried in a copper wire of cross-sectional area $4.0 \times 10^{-7}\,m^2$. The drift velocity of free electrons in the wire is $1.4 \times 10^{-4}\,m\,s^{-1}$.

(i) Calculate n, the number of free electrons per unit volume in copper.

n = ... m^{-3} [2]

(ii) Calculate the new drift velocity when

1 the current is changed to 0.25 A in the same wire

drift velocity = ... $m\,s^{-1}$ [1]

2 a current of 0.75 A is carried in a copper wire of twice the diameter.

drift velocity = ... $m\,s^{-1}$ [1]

[Total: 13]

For Examiner's Use

6 **(a)** Fig. 6.1 shows a solenoid carrying an electric current.

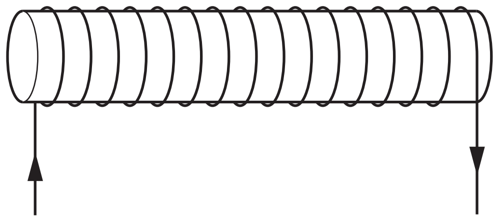

Fig. 6.1

On Fig. 6.1, sketch the pattern and show the direction of the magnetic field inside the solenoid. [3]

(b) State how the wafer of a Hall probe is placed relative to a uniform magnetic field when measuring the flux density of the field.

....[1]

(c) A Hall probe is used to measure the flux density at the centre of the axis of a current-carrying solenoid. The width of the Hall wafer is 5.0 mm. The drift velocity of charge carriers in the wafer is $36\,\text{m}\,\text{s}^{-1}$.

(i) The voltmeter connected to the probe reads 46 μV. Calculate the flux density of the magnetic field.

flux density = ... T [3]

(ii) The current in the solenoid is now reversed. The voltmeter reads 44 μV. Suggest a reason for the difference in readings.

....

....[1]

[Total: 8]

7 Most man-made objects launched into space are satellites placed in a particular orbit around the Earth to function as TV transmitters, telephone relays or weather stations. Some spacecraft, however, have been launched to travel into much deeper space to explore the outer planets of our solar system. All spacecraft, however, whether satellites or deep space probes, must communicate with Earth by transmitting a radio signal. The circuits producing the signal require battery power and batteries require recharging from an energy source.

Most satellites in orbit around the Earth derive their power from a panel of solar cells which convert sunlight into electrical energy. One such telecommunications satellite transmits a continuous 360 W signal powered from its battery for 24 hours per day. The battery is recharged from a solar panel which has an efficiency of 16% while in direct sunlight of light intensity 1.5 kW m^{-2}.

(a) Suggest what happens to the 84% of light energy which reaches the solar panel but is not converted to electrical energy.

....

....[1]

(b) **(i)** Calculate the minimum surface area of solar panel required to produce the 360 W for the transmitter.

surface area = ... m^2 [2]

(ii) Give **two** reasons why the surface area would have to be much greater than your answer above.

1. ....

....

2. ....

....[2]

For a spacecraft launched into the outer regions of the solar system, it is not practical to have its battery recharged by solar panels. Such spacecraft use a Radioisotope Thermoelectric Generator (RTG). This generator has no moving parts and contains two different metals joined to form a closed electric circuit. When the two junctions between these metals are kept at different temperatures, an electric current is produced. One junction is cooled by space while the other is heated by the decay from a radioactive isotope. RTGs are very reliable sources of power.

Nowadays, RTGs use plutonium-238 which is an alpha emitter with a half-life of 88 years. Each alpha particle is emitted with a kinetic energy of 5.0 MeV.

(c) State **one** reason why solar panels are not practical in deep space.

....

....[1]

(d) Suppose such a spacecraft transmits for 120 minutes each day from a 12 V circuit which draws a current of 5.0 A while transmitting back to Earth. During the rest of the day, the transmitting circuit is shut down. The battery charging, however, carries on continuously.

(i) Show that the energy required per day for transmission is about 0.4 MJ.

[2]

(ii) The overall efficiency in the RTG battery charging system is 25%. Show that the steady power output required from the RTG is about 20 W.

[2]

(iii) Calculate the minimum activity of the source required (i.e. the number of 5 MeV alpha particles emitted per second) to generate this power.

activity = ... Bq [2]

For Examiner's Use

(e) **(i)** Show that the decay constant λ of Pu-238 is 2.5×10^{-10} s^{-1}.

[2]

(ii) Calculate the number N of nuclei of Pu-238 required to generate the activity calculated in **(d)(iii)**.

N = ... [2]

(iii) Calculate the mass of Pu-238 corresponding to this number of nuclei.

mass = ... kg [2]

(f) Plutonium is one of the most dangerous chemical poisons known, as well as being a radioactive hazard. It has been estimated that 1 kg of this substance, suitably distributed, would be enough to kill everyone on Earth. Comment on the risks involved in using plutonium as a fuel for spacecraft.

....

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....[2]

[Total: 20]

END OF QUESTION PAPER

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