OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS) 2865/01

Advances in Physics

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

Candidates answer on the question paper.
Additional materials:
Insert (Advance Notice Article for this question paper)
Data, Formulae and Relationships Booklet
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.
- Show clearly the working in all calculations and give answers to only a justifiable number of significant figures.

INFORMATION FOR CANDIDATES

- Section A (questions 1 – 6) is based on the Advance Notice article. You are advised to spend no more than 60 minutes on Section A.
- The number of marks is given in brackets [ ] at the end of each question or part question.
- Four marks are available for the quality of written communication on this paper.
- The values of standard physical constants are given in the Data, Formulae and Relationships booklet. Any additional data required will be given in the appropriate question.

FOR EXAMINER'S USE		
Qu	Max.	Mark
1	8	
2	10	
3	11	
4	7	
5	14	
6	8	
7	16	
8	12	
QWC	4	
TOTAL	90	

This question paper consists of 20 printed pages and an insert.

For Examiner's Use

Answer **all** the questions.

Section A

The questions in this section are based on the Advance Notice article. You are advised not to spend more than 60 minutes on this section.

1 This question is about the properties of pure silicon. (Lines 10–12 in the article.)

(a) Explain what is meant by the term *crystalline structure*.

[2]

(b) Lines 10–12 describe the structure of silicon. Suggest why a material with this structure is likely to be **brittle**.

[2]

(c) Pure silicon is classified as a **semiconductor**. With reference to Fig. 4 in the article, explain the meaning of this term.

[2]

(d) ICs are made from pure single crystals, not from polycrystalline silicon. Suggest, with an explanation, a reason for the use of pure single crystals in ICs.

[2]

[Total: 8]

For Examiner's Use

2 This question is about using induced currents to heat the crucible for melting silicon. (Lines 15–23 and Fig. 2 in the article.)

	specific thermal capacity / $J\,kg^{-1}\,K^{-1}$	electrical conductivity / $S\,m^{-1}$	melting point / K
ceramic alumina	660	1.0×10^{-14}	2300
graphite	710	1.0×10^{5}	3800
silicon, pure	690	1.0	1700
aluminium metal	900	3.8×10^{7}	930

(a) The crucible is made from graphite. By referring to the properties from the table above, explain

(i) why aluminium metal is **not** used for the crucible

(ii) why ceramic alumina is **not** used for the crucible.

[2]

(b) Explain how alternating current in the coil surrounding the graphite crucible produces an electric current in the graphite crucible itself.

[2]

(c) The magnetic flux density B in a coil of length L consisting of N turns carrying a current I is given approximately by the equation

$$B = \mu_o \frac{NI}{L}$$

where the constant $\mu_o = 4\pi \times 10^{-7}\,\text{T m A}^{-1}$.

(i) Use the data from lines 17–18 and Fig. 2 in the article to show that the peak magnetic flux density created by the high-frequency current in the coils is about 0.02 T.

[2]

(ii) The crucible has a cross-sectional area of $0.2\,\text{m}^2$. Show that the peak flux linked with the crucible is about 5×10^{-3} Wb.

[1]

(iii) Assuming that the 10 kHz alternating flux changes from its peak value to zero in one quarter of a cycle, estimate the emf induced in the wall of the crucible.

emf =…………………… V
[3]

[Total: 10]

For Examiner's Use

3 This question is about the limitations placed on the size of integrated circuits by diffraction. (Lines 51–53 and Fig. 5 in the article.) The light passing through the mask is assumed to be parallel.

The diagrams below show a section of mask being used to imprint an interconnecting track onto the surface of a chip.

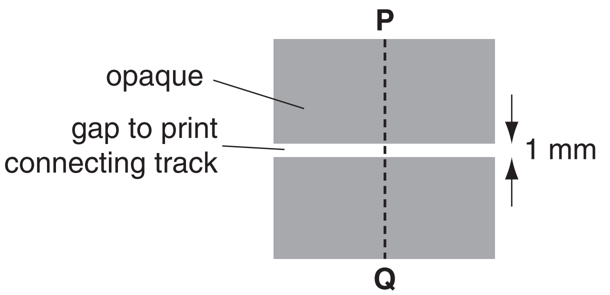


Fig. 3.1

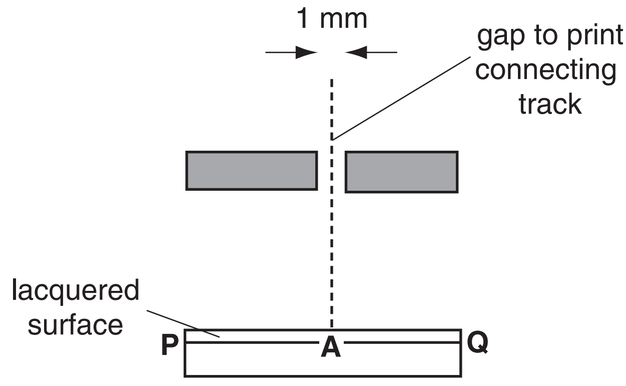


Fig. 3.2

The part of the mask in Fig. 3.1 is designed to print a straight length of interconnecting track 1 μm wide. Visible light of wavelength 0.5 μm shines through the mask to the lacquered surface below as shown in Fig. 3.2.

(a) Use the axes of Fig. 3.3 below to sketch the intensity of visible light reaching the lacquered surface, clearly showing the effect of diffraction. The position of the central y-axis marks the point **A** in Fig. 3.2. There is no need to add numerical values to the axes of your graph.

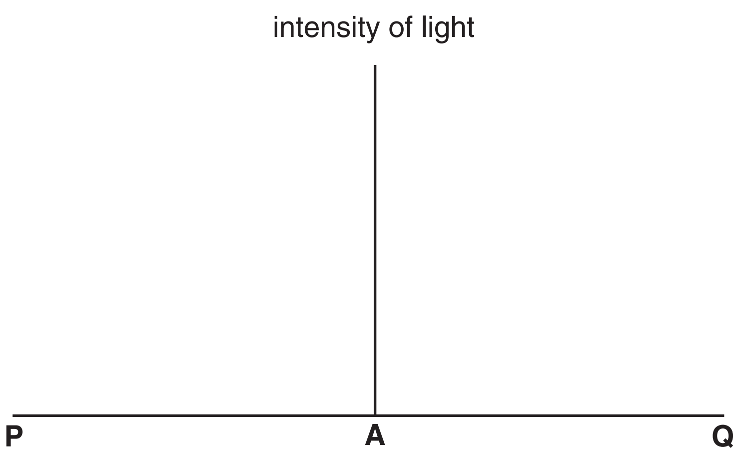


Fig. 3.3 [2]

(b) Explain why ultraviolet is more suitable than visible light for producing integrated circuits.

[2]

(c) It is proposed that electron beams are used instead of light to expose the lacquer. (Lines 106–108 in the article.)

(i) The electrons are accelerated though a potential difference of 3000 V. Show that each electron gains about 5×10^{-16} J of kinetic energy.

$e = -1.6 \times 10^{-19}$ C

[2]

(ii) A student uses the value 5×10^{-16} J to calculate the speed of the electron as shown below.

$$5 \times 10^{-16}\ \text{J} = \tfrac{1}{2} m_e v^2 \ \text{ so } v^2 = \frac{2 \times 5 \times 10^{-16}}{m_e} = \frac{2 \times 5 \times 10^{-16}}{9.1 \times 10^{-31}} = 1.099 \times 10^{15}\ \text{m}^2\,\text{s}^{-2}$$

$$v = \sqrt{1.099 \times 10^{15}} = 3.315 \times 10^{7}\ \text{m s}^{-1}$$

State the value of v to an appropriate number of significant figures.

v = ………………….. m s^{-1}

Justify your answer.

[2]

(iii) Show that the momentum of the electron is about 3 x 10^{-23} kg m s^{-1}.

$m_e = 9.1 \times 10^{-31}$ kg

[1]

(iv) Calculate the de Broglie wavelength associated with these electrons. Comment on the suitability of using these electrons in the manufacture of integrated circuits.

$h = 6.6 \times 10^{-34}$ J s

[2]

[Total: 11]

4 This question is about the Boltzmann factor and the process of doping integrated circuits. (Lines 57–65 in the article.)

(a) The graph of Fig. 4.1 shows how the Boltzmann factor for this process varies over the range 200 K to 1400 K.

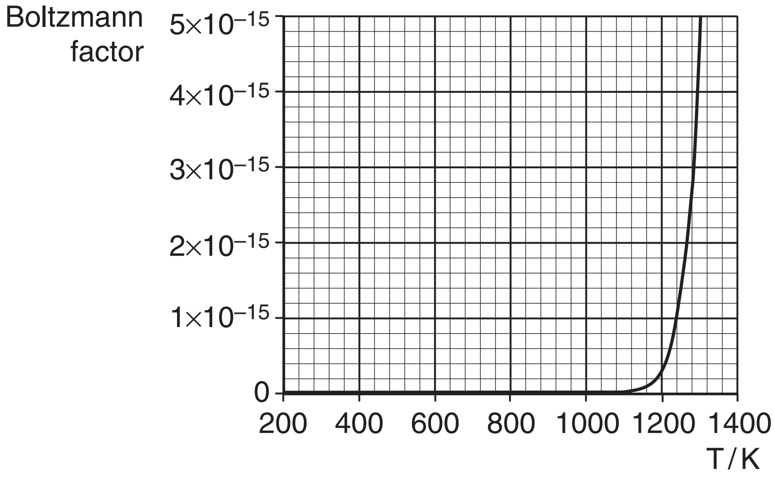


Fig. 4.1

(i) Explain why the Boltzmann factor has no units.

[1]

(ii) The activation energy for this process, $E_A = 5.92 \times 10^{-19}$ J. Show that the value of the Boltzmann factor at 1300 K agrees with the value in Fig. 4.1.

$k = 1.38 \times 10^{-23}$ J K^{-1}

[2]

(iii) Use the graph to explain why, even at 1300 K, atoms diffuse very slowly into the silicon.

[2]

For Examiner's Use

(b) Suggest and explain **one** reason for carrying out the doping process at the highest practicable temperature.

[2]

[Total: 7]

For Examiner's Use

5 This question is about Moore's Law and the future progress of silicon technology. (Lines 81–94 and Fig. 7 in the article.)

(a) Explain why Moore's Law, that the number of transistors per unit area of a CPU would double every two years, is an example of exponential growth.

[2]

(b) Explain how the graph in Fig. 7 in the article confirms that the growth is exponential.

[1]

(c) **(i)** Take data from the graph of Fig. 7 in the article to complete the table below.

year	1975	1995
number of transistors per unit area		

[2]

(ii) Show that Moore's Law correctly predicted the increase of number of transistors per unit area between 1975 and 1995.

[3]

For Examiner's Use

(d) By 1975, transistor lengths and widths had been reduced to about 3.5 μm.

(i) Use the data from lines 89–91 in in the article to show that the length and width of a transistor were about 0.35 μm by 1995.

[2]

(ii) The area of a CPU is 1.6×10^{-4} m^2. Use the answer to **(d)(i)** to show that more than 10^9 transistors would fit on a CPU in 1995.

[2]

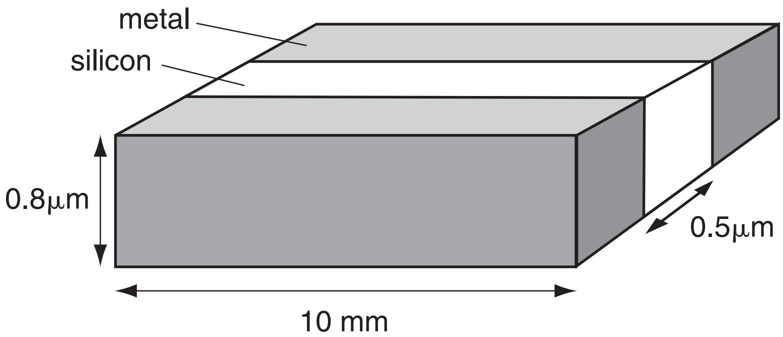
(iii) Use data from Fig. 7 in the article to show that the transistors actually present occupied less than 1% of a CPU in 1995.

[2]

[Total: 14]

For Examiner's Use

6 This question is about the capacitance between adjacent tracks. (Lines 110–124 and Fig. 8 in the article.) Fig. 6.1 shows a pair of metal tracks of length 10 mm and height 0.8 μm separated by 0.5 μm of silicon.



not to scale

Fig. 6.1

(a) Use the equation $C = \varepsilon_r \varepsilon_o \frac{A}{d}$ to show that the capacitance between the tracks is about 3×10^{-13} F.

permittivity of free space, $\varepsilon_o = 8.9 \times 10^{-12}\ \text{F m}^{-1}$
relative permittivity of silicon, $\varepsilon_r = 2.4$

[2]

The resistance of the two tracks is about 900 Ω. The electrical behaviour of the pair of tracks can be modelled using the circuit of Fig. 6.2.

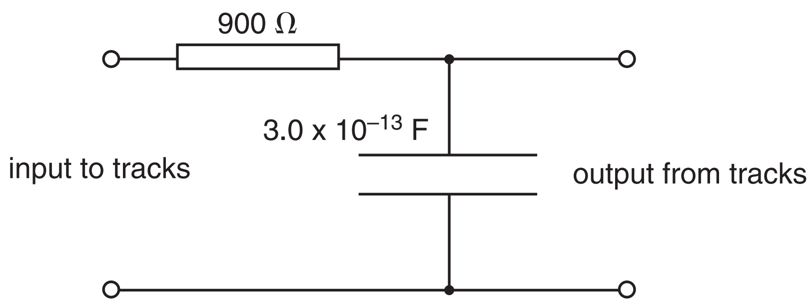


Fig. 6.2

(b) Show that the time constant for the capacitor – resistor circuit is about 3×10^{-10} s.

[2]

(c) A digital pulse, going from 0 V to 5 V, is applied to the input to the tracks as shown in Fig. 6.3. The time scale is calibrated in multiples of the time constant. Sketch the pulse that comes from the output from the tracks on the lower graph. The line has been started for you.

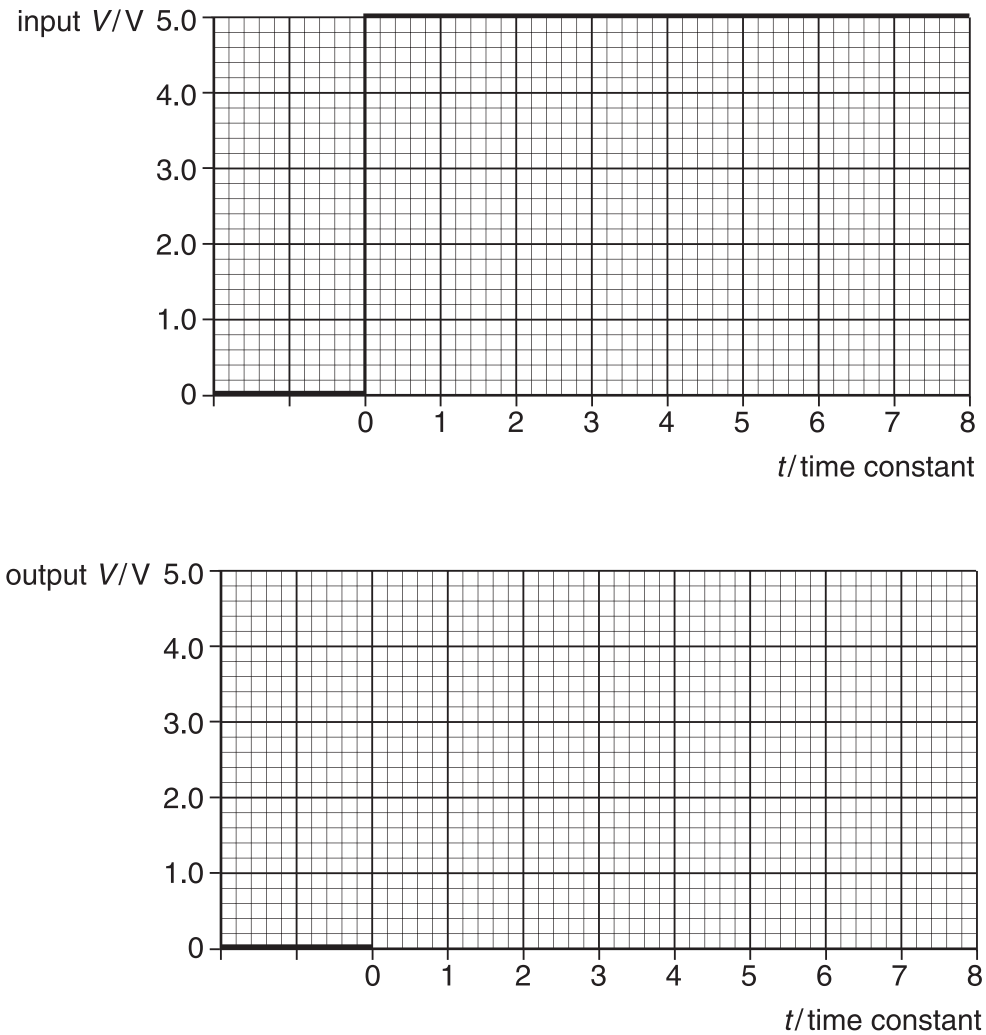


Fig. 6.3

[4]

[Total: 8]

Section B

7 This question is about remote sensing.

(a) The table below gives information about the electromagnetic spectrum.

frequency / Hz	wavelength in vacuum / m	type of radiation
10^{24}	3×10^{-16}	gamma
10^{21}	3×10^{-13}	
10^{18}	3×10^{-10}	
10^{15}	3×10^{-7}	
10^{12}	3×10^{-4}	
10^{9}	3×10^{-1}	microwave
10^{6}	3×10^{2}	
10^{3}	3×10^{5}	

(i) Write down the equation relating the frequency of the radiation to its wavelength.

[1]

(ii) Add the words **light** and **radio** in the column for the type of radiation in the table above, at the frequencies at which you would expect to find them.

[2]

(b) Remote sensing of the Earth is done by artificial satellites in orbit around it at different altitudes.

(i) Complete the table below by suggesting two **different** types of electromagnetic radiation that could be gathered by a satellite in orbit around the Earth and the information that each could give about the Earth.

type of radiation	information obtained

[2]

(ii) Low altitude and high altitude orbits have different advantages for imaging the surface of the Earth. Complete the table below to compare the advantages of low and high altitude orbits for **one** application you have chosen.

information to be gathered	
advantage of low altitude orbit	
advantage of high altitude orbit	

[2]

(c) Artificial satellites around the Earth can also be used to observe the Universe.

(i) State **one** advantage of using a telescope in space rather than on Earth.

[1]

(ii) Explain how the fact that the Universe is expanding can be deduced from observations of the light from distant galaxies.

[3]

(iii) The intensity of light from galaxy A is observed to be about 50 times greater than that from a similar galaxy B.
Show that this is consistent with galaxy B being about 7 times more distant from the Earth.
State a condition required for this to be correct.

[4]

(d) The cosmic background radiation is thought to be radiation 'left over' from an earlier, hotter state of the Universe.
State the part of the electromagnetic spectrum in which the peak of this radiation now lies.

[1]

[Total: 16]

8 This question is about the physics of pole-vaulting. This is a sport where athletes use springy poles to project themselves over a high bar, as shown in Fig. 8.1.

(a) Fig. 8.1 shows a pole-vaulter standing at the beginning of his run (A), and then at the point where he pushes the end of his pole into the ground (B). The pole then bends, slowing the athlete to a stop (C) and helping him to jump over the high bar (D).

An image has been removed due to third party copyright restrictions

Details: An image of a man pole-vaulting

Fig. 8.1

The graph of Fig. 8.2 shows how the horizontal velocity of the pole-vaulter changes during the run from X to Z.

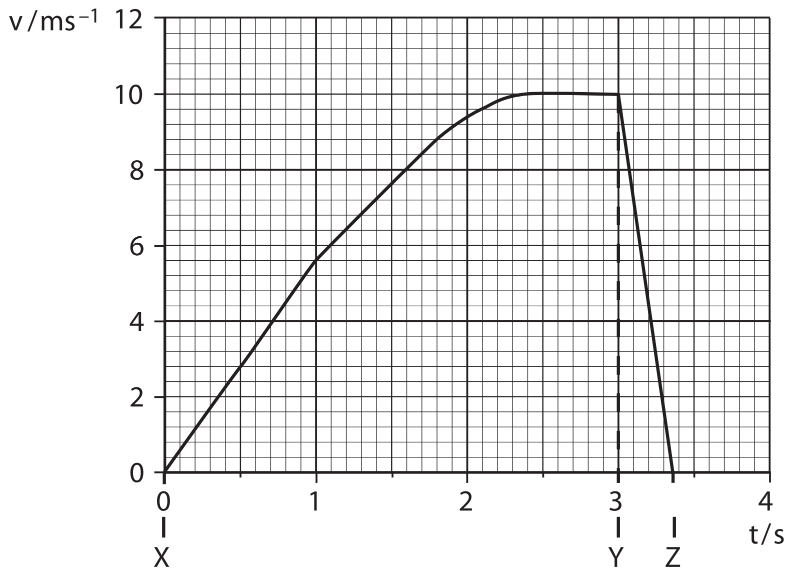


Fig. 8.2

For Examiner's Use

(i) Use the graph to estimate the length of the run from **X** to **Z**. Show clearly on the graph or in this space how you get your answer.

length = …………………… m [3]

(ii) Show that the maximum kinetic energy of the pole-vaulter is about 3.5 kJ.

mass of pole vaulter = 69 kg

[2]

(iii) Assuming that the gravitational potential energy gained by the pole-vaulter is 3.5 kJ, calculate the height *h* that he should rise.

$g = 9.81\ \text{N kg}^{-1}$

height = …………… m [2]

(iv) When he jumps, the pole-vaulter turns sideways (Fig. 8.1 **D**). Explain why this helps him to pass over a high bar.

[1]

[Turn over

For Examiner's Use

(b) The graph of Fig. 8.2 shows that between Y and Z the pole-vaulter rapidly decelerates as the pole becomes bent.

(i) Show that the change in the horizontal component of momentum of the 69 kg pole-vaulter as the pole bends is about 700 kg m s^{-1}.

[2]

(ii) The time taken for the pole-vaulter to decelerate to a stop is 0.35 s.
Calculate the average horizontal decelerating force on the pole-vaulter.

force = …………… N [2]

[Total: 12]

Quality of Written Communication [4]

END OF QUESTION PAPER