OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT **2865/01**

PHYSICS B (ADVANCING PHYSICS)

Advances in Physics

THURSDAY 21 JUNE 2007 Afternoon

Time: 1 hour 30 minutes

Additional materials:
Insert (Advance Notice Article for this question paper)
Data, Formulae and Relationships Booklet
Electronic calculator

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre Number and Candidate Number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED. ANSWERS WRITTEN ELSEWHERE WILL NOT BE MARKED.
- 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, a copy of which is included as an insert. You are advised to spend about 60 minutes on Section A.
- The number of marks for each question is given in brackets [ ] at the end of each question or part question.
- The total number of marks for this paper is 90.
- There are four marks 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 are given in the appropriate question.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**9**	
2	**9**	
3	**9**	
4	**8**	
5	**9**	
6	**13**	
7	**15**	
8	**14**	
QWC	**4**	
TOTAL	**90**	

This document consists of **23** printed pages, **1** blank page and an insert.

[Turn over

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 heat and work. (lines 3–24 in the article).

(a) Mass and charge are conserved in physical processes (lines 6–10 in the article). Explain the meaning of the word 'conserved' in this statement.

[1]

(b) There is a legend that James Joule, on his honeymoon, tried to measure the rise in temperature of water as it fell down a waterfall in the Alps.

Fig. 1.1

(i) Explain why Joule expected the water in the pool at the bottom of the waterfall to be warmer than the water at the top.

[2]

(ii) Show that the work done when 1 kg of water falls through a vertical distance of 270 m is about 3000 J.

$g = 9.8\,\text{N kg}^{-1}$

[2]

(iii) Joule was expecting a temperature rise of between 0.5 °C and 1 °C. Show that this is a reasonable estimate of the temperature rise to be expected when the internal energy of 1 kg of water increases by 3000 J.

specific thermal capacity of water, $c = 4200\,\text{J kg}^{-1}\,°\text{C}^{-1}$

[2]

(iv) Joule found it impossible to detect this temperature difference, even though he had a very sensitive thermometer. Suggest and explain one reason for this.

[2]

[Total: 9]

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2 This question is about the efficiency of heat engines (lines 26–39 and 82–91 in the article).

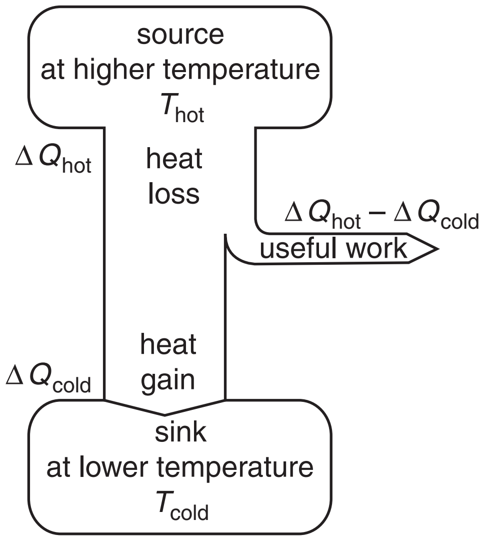


Fig. 2.1

(a) Carnot's relationship, maximum theoretical efficiency = $1 - \frac{T_{cold}}{T_{hot}}$, applies to any heat engine.

(i) Explain why the temperature of the sink, T_{cold}, of an early steam engine is not likely to be less than 273 K.

[1]

(ii) Show that the maximum theoretical efficiency of an early steam engine, for which the source temperature T_{hot} is about 373 K, is less than 30% (lines 35–36 in the article).

[2]

(b) Fig. 2.2 shows a heat engine working between a source at 400 K and a sink at 300 K.

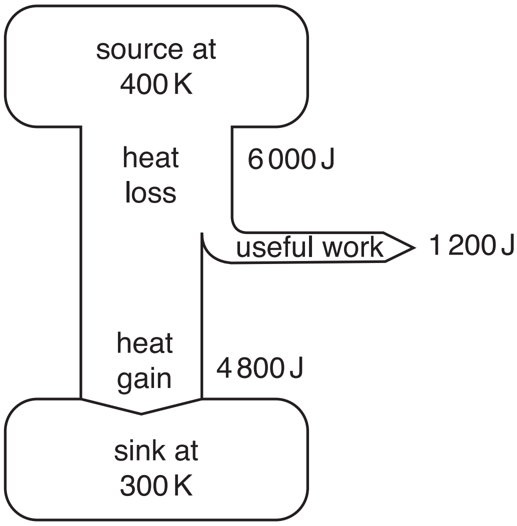


Fig. 2.2

(i) Use the equation $\Delta S = \frac{\Delta Q}{T}$ to calculate the entropy lost by the source at 400 K.

entropy loss .... unit .... [2]

(ii) Use the data in Fig. 2.2 to confirm that the entropy of the whole system does increase, as stated by the Second Law of Thermodynamics.

[2]

(iii) Suggest and explain **one** improvement to this heat engine which would result in an increase in its theoretical efficiency.

[2]

[Total: 9]

3 This question is about the number of ways in which gas molecules can be arranged (lines 41–52 in the article).

(a) Fig. 3.1 shows a sample of gas in one half of a container with a removable panel down the centre. The right-hand half is completely empty.

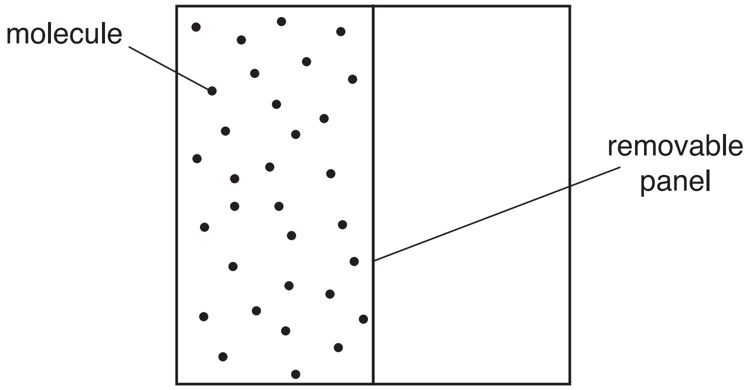


Fig. 3.1

(i) The sample of gas is at standard temperature and pressure, and each half of the container has a volume of $0.18\,m^3$. Show that there are about 8 mol of gas in the container.

molar gas constant, $R = 8.3\,J\,mol^{-1}\,K^{-1}$
standard temperature and pressure are 273 K and 1.0×10^5 Pa

[3]

(ii) Calculate the number of gas molecules present.

the Avogadro constant, $N_A = 6.0 \times 10^{23}\,mol^{-1}$

[1]

(b) The panel down the centre of the container is now removed, so that each molecule can be anywhere in the container (Fig. 3.2).

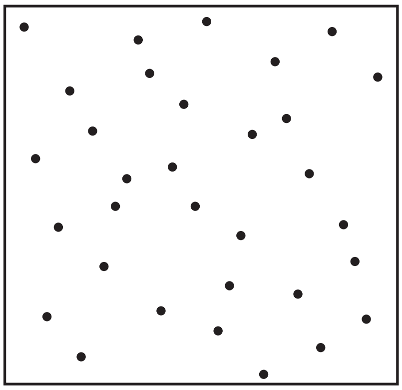


Fig. 3.2

(i) The temperature of the gas does not change.

State and explain how the mean-square velocity of the molecules before the removal of the panel compares with their mean-square velocity afterwards.

[2]

(ii) Explain why 'each molecule can be arranged in twice as many ways' after the panel has been removed (lines 45–47 in the article).

[1]

(iii) If the gas contains N molecules, removing the panel results in 2^N times as many ways of arranging the gas molecules in the container. Use your answer to **(a)(ii)** to justify the statement 'Allowing each molecule to occupy any part of the container … greatly increases the entropy' (lines 51–52 in the article).

[2]

[Total: 9]

4 This question is about energy levels in hot and cold solids (lines 63–81 in the article).

The distributions of numbers of atoms with different energies in small samples of a cold solid and of a hot solid are shown in Fig. 4.1.

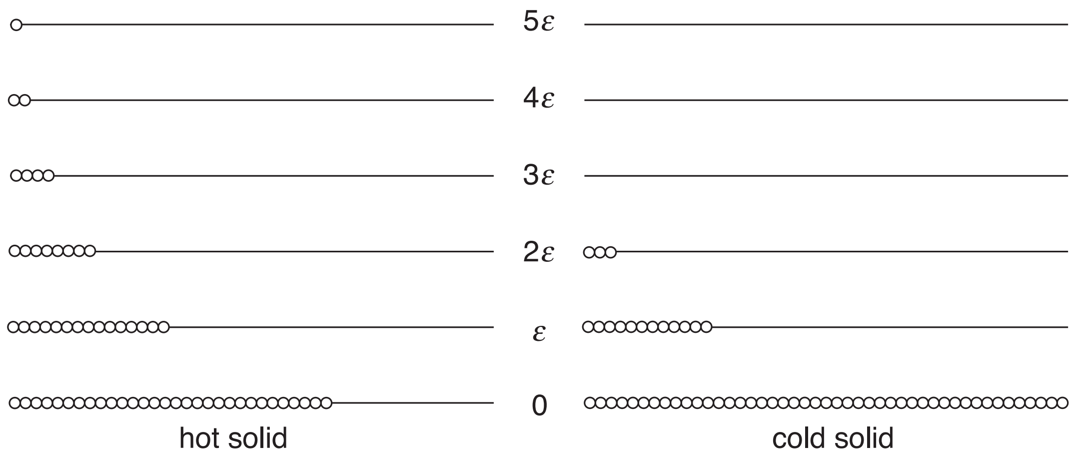


Fig. 4.1

(a) State the feature of Fig. 4.1 that shows that the two solids have the same number of atoms.

[1]

(b) Explain how Fig. 4.1 shows that the solid represented by the left-hand energy distribution is hotter than the one represented by the right-hand energy distribution.

[2]

(c) (i) Explain how Fig. 4.1 shows that the Boltzmann factor for the cold solid is about 0.25.

[1]

(ii) Show that the temperature of the cold solid is about 300 K, given that the energy levels are each separated by an energy $\varepsilon = 5.8 \times 10^{-21}$ J.

Boltzmann constant, $k = 1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$

[2]

(iii) Use the Boltzmann factor to show that the hot solid in Fig. 4.1 has a higher temperature than the cold solid.

[2]

[Total: 8]

5 This question is about the evolution of the Universe.

(a) The article states that 'Astronomical evidence suggests that the Universe started in a hot, dense state about 13.7 billion years ago and expanded rapidly, cooling as it did so' (lines 112–113 in the article).

(i) State one astronomical observation which supports the view that the Universe has cooled down from an initial hot state.

[1]

(ii) Explain how this observation supports this view.

[2]

(iii) State one astronomical observation which supports the view that the Universe has expanded. Explain how this observation supports this view.

[3]

(b) As the Universe expanded, the radiation filling it stretched a thousand-fold (lines 125–126 in the article).

Explain why stretching the radiation 1000 times decreases the energy of the photons 1000 times.

[3]

[Total: 9]

6 This question is about nuclear fusion in stars.

(a) Stars form when gases compressed by gravity reach temperatures and pressures where nuclear fusion can take place (lines 115–117 in the article).

(i) The temperature needed for nuclear fusion to start is about 1×10^7 K (line 116 in the article).

Show that the typical speed of hydrogen ions (protons) at this temperature is about $4 \times 10^5\,\mathrm{m\,s^{-1}}$.

mass of proton, $m_p = 1.7 \times 10^{-27}$ kg
Boltzmann constant, $k = 1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$

[3]

(ii) Each m^3 of the core of a star contains about 10^{31} protons.

Show that the pressure due to these protons is about 10^{15} Pa (line 117 in the article).

[3]

(iii) State the assumption that must be made to calculate the pressure in part **(ii)**.

[1]

(b) The binding energy per nucleon of different nuclei is shown in Fig. 6.1.

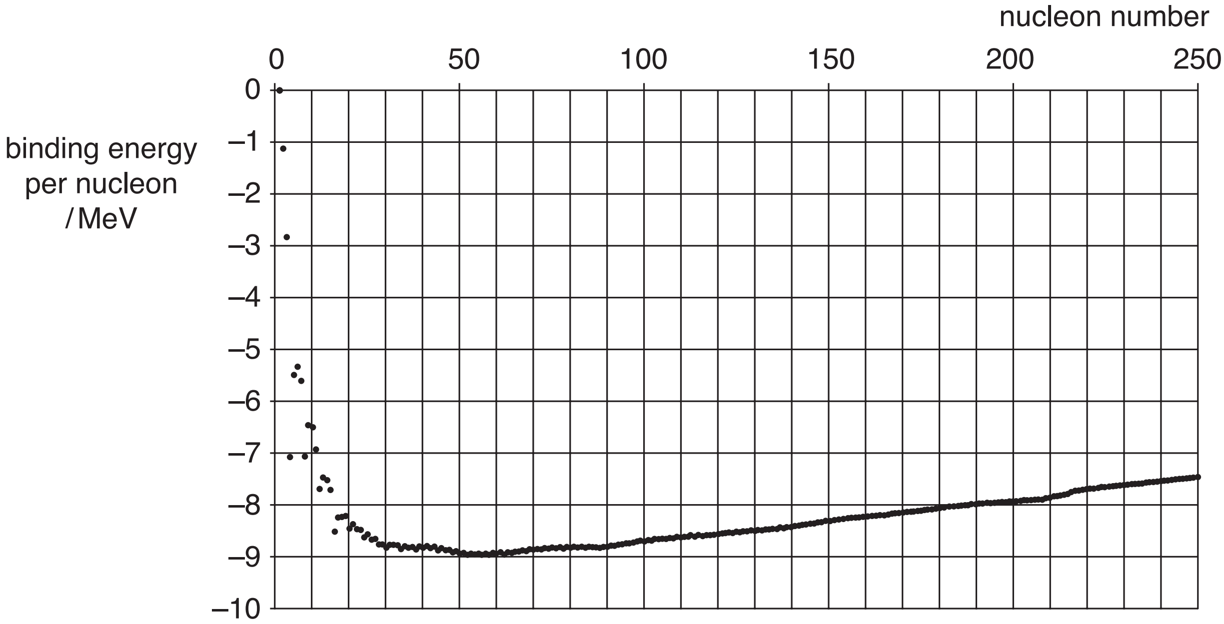


Fig. 6.1

(i) 'Once nuclei with the strongest binding energies have been produced, no further fusion is possible...' (lines 122–124 in the article). Use the graph of Fig. 6.1 to estimate the nucleon number of one of the nuclei formed at the end of the process.

nucleon number .... [1]

(ii) For the nucleus you have chosen, calculate the total binding energy, in joules.

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

binding energy .... J [3]

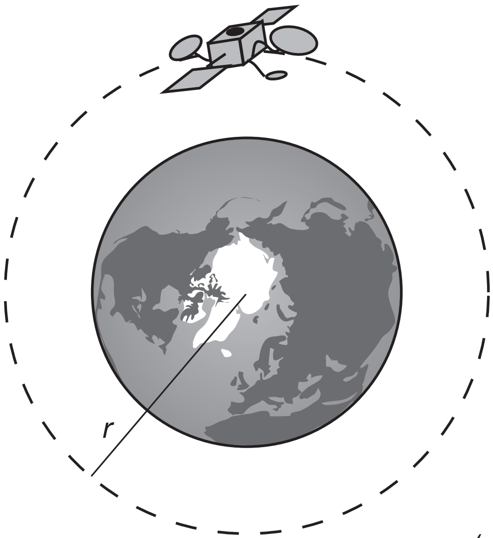
(iii) The core of a massive star at the end of its life contains about 10^{56} of these nuclei.
Use this number to calculate an estimate of the total energy, in joules, released by the star from its formation up to that time.
State any assumption you make in this calculation.

energy .... J [2]

[Total: 13]

Section B

7 This question is about the use of space tethers, long strings or wires which link two objects that are in orbit together.



(not to scale)

Fig. 7.1

Fig. 7.1 shows a satellite in a circular orbit around the Earth. The relationship

$$\frac{GMm}{r^2} = \frac{mv^2}{r} \qquad \textbf{equation 1}$$

is used to derive the expression for the orbital speed, v.

$$v = \sqrt{\frac{Gm}{r}} \qquad \textbf{equation 2}$$

(a) (i) State what physical quantity the left hand side of **equation 1** represents.

[1]

(ii) State what physical quantity the right hand side of **equation 1** represents.

[1]

(b) A 10 kg mass attached to the end of a 5 km tether is projected from a satellite. When furthest from the satellite, it points towards the centre of the Earth as shown in Fig. 7.2.

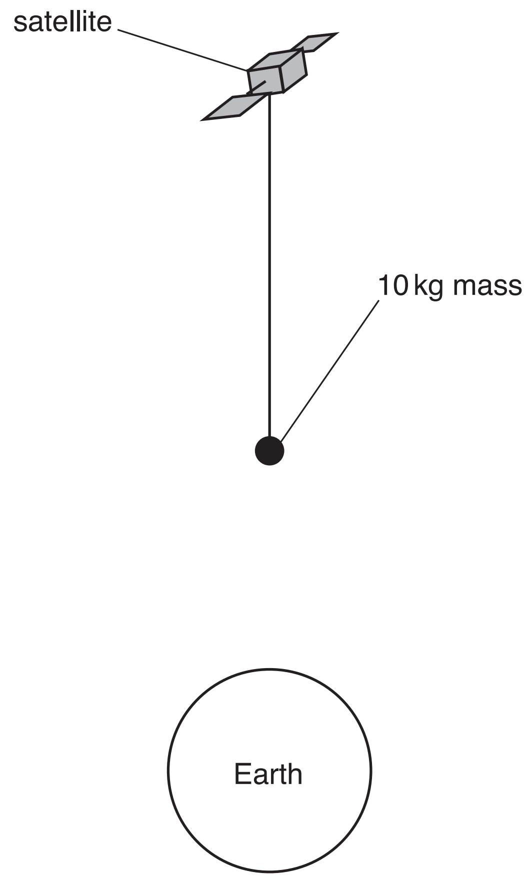


Fig 7.2

(i) Mark and label on Fig. 7.2 the forces acting on the 10 kg mass.

[2]

(ii) Explain why **equation 2** does **not** give the orbital speed of the 10 kg mass.

[2]

(c) If the tether material is a conductor it will have an e.m.f. induced across it as it passes through the Earth's magnetic field as shown in Fig. 7.3.

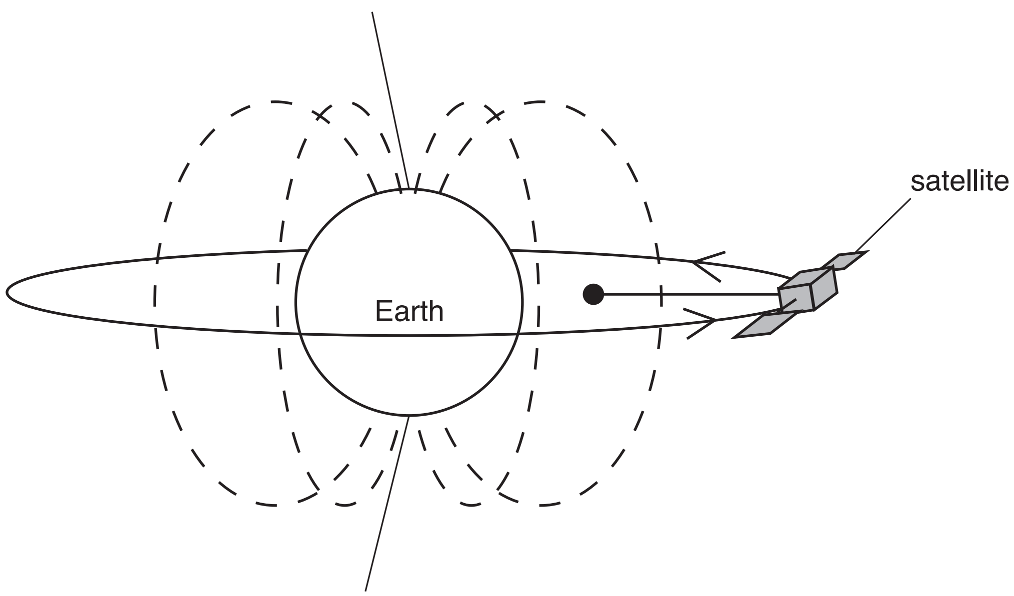


Fig. 7.3

(i) Show that the electrical resistance of a 5.0 km tether made of aluminium of cross-sectional area $8.0 \times 10^{-5}\,\text{m}^2$ is about $2\,\Omega$.

resistivity of aluminium = $2.7 \times 10^{-8}\,\Omega\,\text{m}$

[2]

(ii) Show that an e.m.f. of about 800 volts should appear between the ends of the 5.0 km tether moving perpendicular to a magnetic field of $21\,\mu\text{T}$ at a speed of $8000\,\text{m}\,\text{s}^{-1}$.

[3]

(d) The plasma in space provides an effectively zero resistance return path for the charge.

(i) Use the answers to part **(c)** to show that the current in the tether is about 500 A.

[1]

(ii) Use data from part **(c)** to calculate the magnitude of the force acting on the tether as a result of this current.

[1]

(iii) Suggest and explain the effect of this force on the movement of the satellite.

[2]

[Total: 15]

8 This question is about imaging defects in materials using ultrasound.

In ultrasound transducers, pulses of ultrasound are produced by applying a potential difference between two conducting plates, **A** and **B**, fixed on each end of a piece of piezo-electric crystal. This causes the length of the crystal to change in the direction shown by the arrows in Fig. 8.1. When the potential difference is removed the crystal oscillates as it changes back to its initial shape.

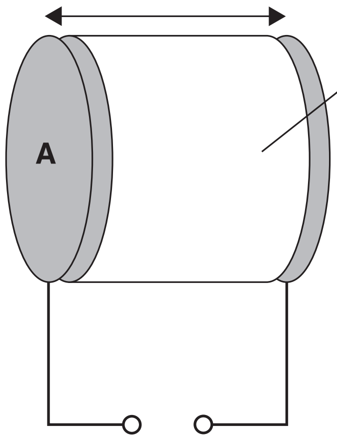


Fig. 8.1

(a) The piezo-electric crystal has a fundamental frequency of 5.0 MHz.

(i) Calculate the wavelength of the ultrasound in the piezo-electric crystal.

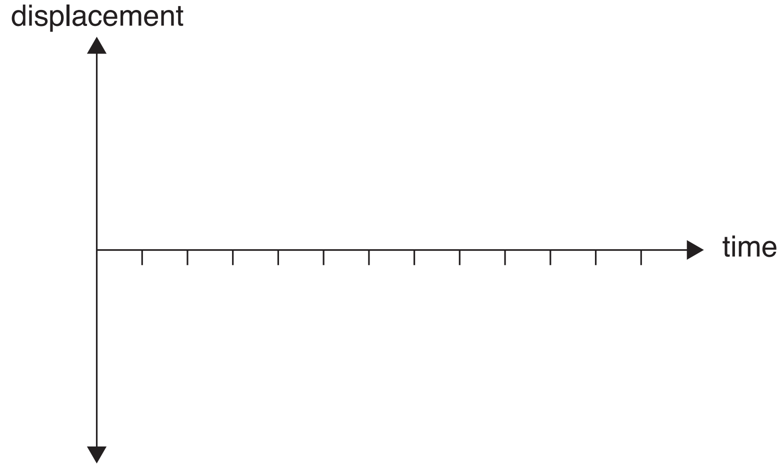
speed of sound in piezo-electric crystal = 2500 $m\,s^{-1}$

wavelength = ... m [2]

(ii) Explain clearly why the crystal should have a length equal to half this wavelength.

[2]

(iii) The oscillating crystal produces a pulse of oscillation whose amplitude dies away exponentially. The pulse is about six periods of oscillation in length. Sketch such a pulse on the axes below.



[2]

(b) The transducer of Fig. 8.1 can send pulses of ultrasound into a sample of material under test. The ultrasound will be reflected from any internal cracks in the material as shown in Fig. 8.2. Reflected waves will distort the transducer and cause a potential difference between the plates **A** and **B** which can be detected.

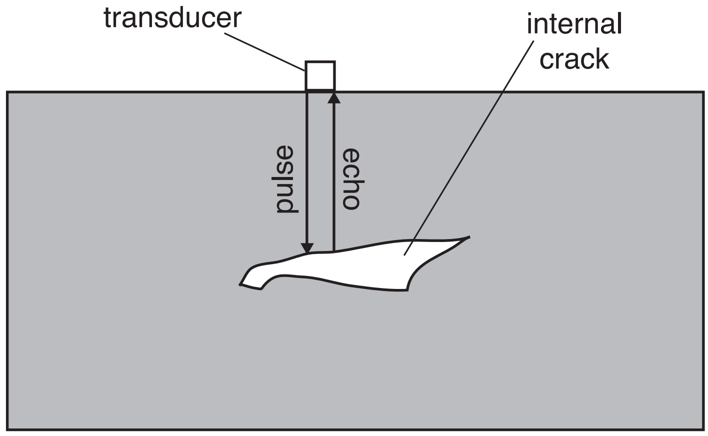


Fig. 8.2

Calculate the depth of the internal crack in the material if the delay time between a pulse and its reflection is 25 μs.

Speed of sound in the material = 4200 m s^{-1}

depth = ... m [2]

(c) Another design of ultrasound scanner has several transducers, as shown in Fig. 8.3, only one of which transmits pulses. The pulses travel outwards from the transmitter in all directions and are reflected at any cracks in the material. Each receiver detects both the direct pulse and reflected pulses.

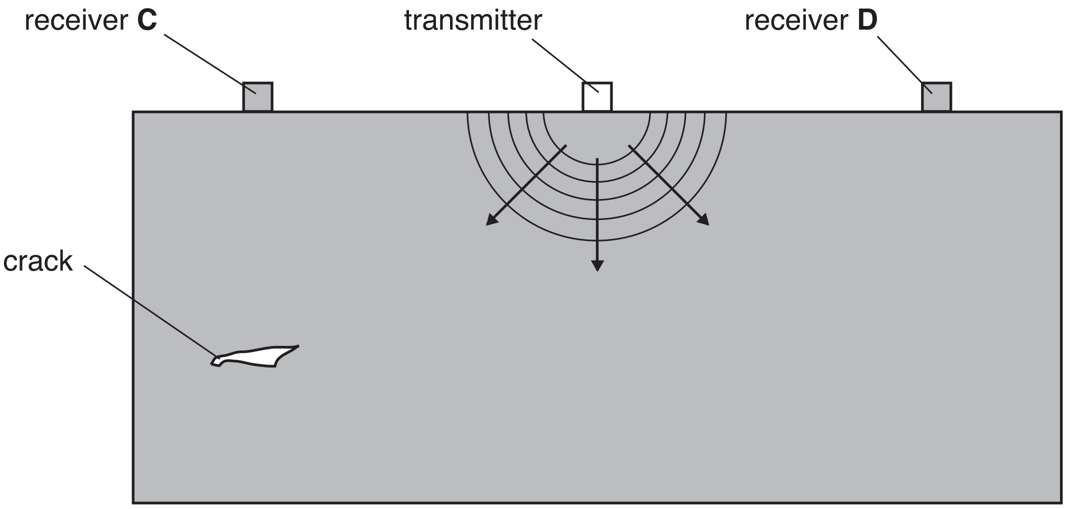


Fig. 8.3

(i) Explain why the delay time between a pulse and its reflection at receiver **C** in Fig. 8.3 is much less than at receiver **D**.

[1]

(ii) The same delay time at receiver **C** could be due to a crack at a number of different places. On Fig. 8.3, mark with an X **one** other position where a crack would give the same delay time at receiver **C** as the crack shown.

[1]

(iii) Explain how the delay time measured at receiver **D** can be combined with the delay time measured at receiver **C** to find the exact position of the crack. A diagram may help your answer.

[2]

(iv) It is necessary to image cracks throughout the whole specimen, not just in one cross-section as shown in Fig. 8.3.

This can be done by moving the transducers along the specimen as shown in Fig. 8.4.

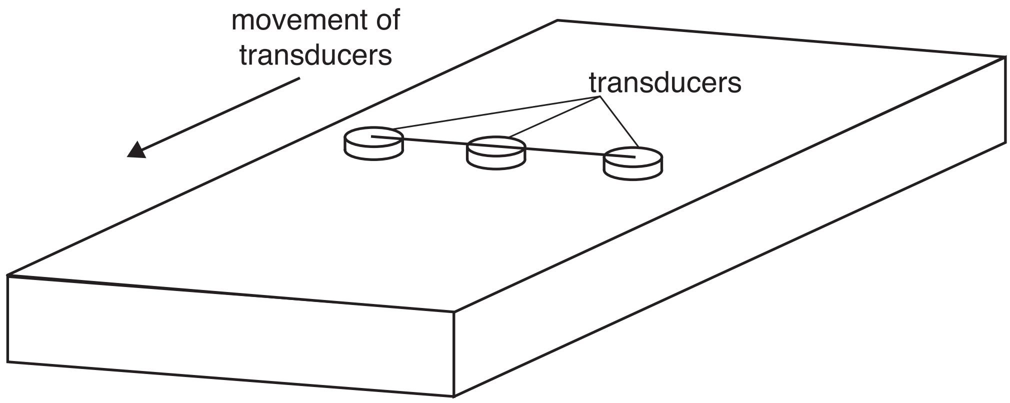


Fig. 8.4

The data produced in the scan is used to generate computer images showing the position of cracks throughout the whole specimen.

Suggest how this three-dimensional information could be most effectively displayed.

Diagrams may help your answer.

[2]

[Total: 14]

Quality of Written Communication [4]

END OF QUESTION PAPER

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