Oxford Cambridge and RSA

Monday 9 June 2025 – Morning

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Time allowed: 2 hours 15 minutes

You must have:
- a clean copy of the Advance Notice Article (inside this document)
- the Data, Formulae and Relationships Booklet

You can use:
- a scientific or graphical calculator
- a ruler (cm/mm)

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number						Candidate number				

First name(s) ____________________

Last name ____________________

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined page at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- **Use the Insert to answer questions in Section C.**
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **28** pages.

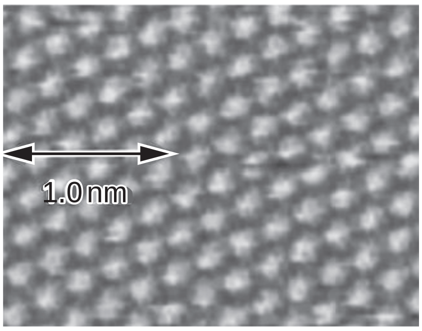
ADVICE
- Read each question carefully before you start your answer.

SECTION A

1 This question is about measuring the sizes of atoms and using the structure of materials on a microscopic scale to explain large-scale properties.

(a) **Fig. 1** shows an image of a sheet of gold atoms. Use the image to determine the radius of a gold atom. Explain your choice of the number of significant figures in your answer.

Fig. 1



radius = ... m

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.... **[3]**

(b) An estimate of the radius of a gold atom can be calculated from the density of gold.

One mole of gold contains 6.02×10^{23} atoms.

The mass of one mole of gold is 0.197 kg. The density of gold is 19 320 kg m^{-3}.

(i) Show that there are approximately 6×10^{28} gold atoms m^{-3}.

[2]

(ii) The manner in which the gold atoms are packed together means that only 74% of the volume of a sample of gold is taken up by the atoms themselves. Use this percentage and your answer from **(i)** to calculate the radius of a gold atom.

Assume that gold atoms are spherical.

radius of atom = ... m **[2]**

(c) Images of arrangements of atoms in a metal sometimes reveal **dislocations** in the microscopic structure. Describe what dislocations are and how the presence of dislocations changes the properties of the metal.

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.... **[3]**

2 An alpha particle of kinetic energy 5.4 MeV produces 4.4×10^6 ions per metre in dry air. It transfers all its kinetic energy over 0.035 m.

(a)

(i) Show that the average energy to remove an electron from a molecule (ionisation energy) in air is less than 6×10^{-18} J.

[2]

(ii) A free electron in air travels about 700 nm between collisions with molecules. Use your answer to **(a)(i)** to calculate the strength of a uniform electric field required to give an electron sufficient kinetic energy to ionise molecules in air.

Assume that the electron accelerates from rest for 700 nm.

field strength = ... $V\,m^{-1}$ **[2]**

(iii) Explain why the number of ions formed per second will initially rise at increasing rate after the first ionisation event.

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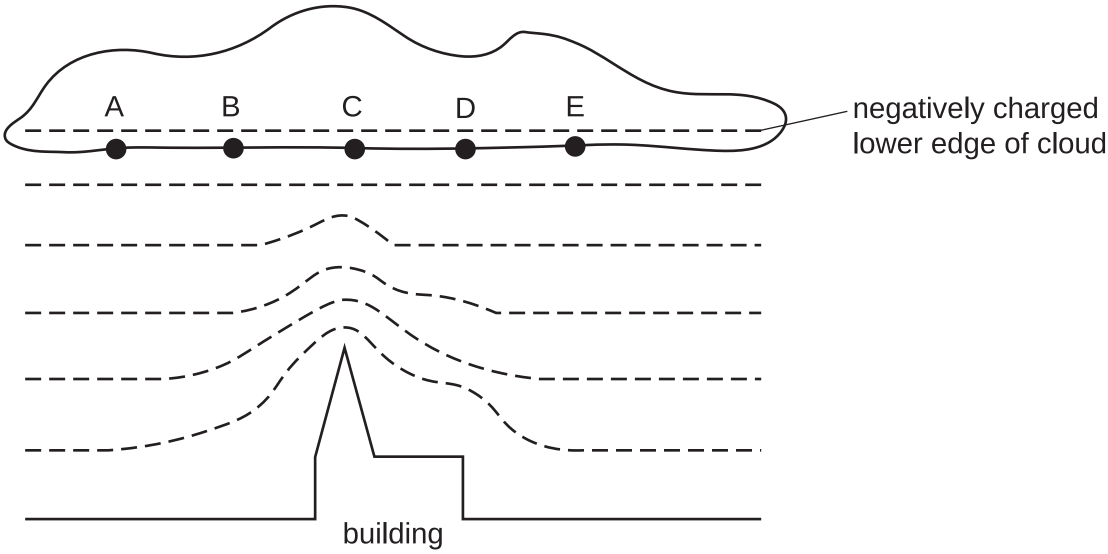
(b) **Fig. 2** is a representation of a thundercloud above a flat landscape with a tall building. The dotted lines represent equipotential lines with equal potential differences between each line.

Fig. 2



The surface of the ground and the building are at zero potential.

(i) Draw field lines linking the points on the bottom of the cloud marked A to E to points of zero potential. **[2]**

(ii) State and explain where the force on free electrons will be the greatest in the region between the zero potential surface and the lower edge of the cloud.

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.... **[2]**

3 This question is about radioactive decay and time-dilation when bodies move at near-light speeds.

A radioisotope thermal generator (RTG) uses the decay of plutonium-238 (Pu-238) to generate electrical power.

In a science fiction story, an RTG provides 3.50×10^4 W to the living quarters of a spaceship when the spaceship is launched.

(a)
(i) Show that the initial activity of the plutonium source is about 4×10^{16} Bq.

Energy released in one decay of Pu-238 = 8.96×10^{-13} J

[1]

(ii) Calculate the initial mass of Pu-238 in the generator.

Decay constant of Pu-238 = $2.48 \times 10^{-10}\,\text{s}^{-1}$

Mass of one plutonium-238 atom = 3.95×10^{-25} kg

mass = ... kg **[2]**

(b)
(i) Show that the power output of a **stationary** RTG will have fallen to about 72% of its original value after 42 years.

Initial power of RTG = 3.50×10^4 W

[2]

When the spaceship is launched a radio signal is sent to WST-A, a planet 30 light years away. The spaceship arrives at WST-A 12 years after the radio signal is detected at the planet.

(ii) Calculate the average velocity of the spaceship during its 42-year journey.

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

(iii) Explain by using relevant calculations, why the power output of the RTG when the spaceship lands on WST-A is approximately 79% of its value at launch. Assume that the spaceship travels at constant velocity throughout the journey.

[4]

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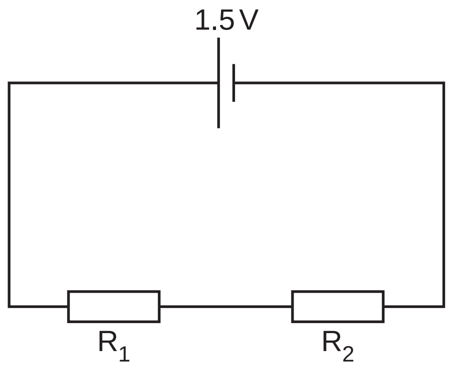
SECTION B

4 This question is about a temperature sensor. **Fig. 4.1** shows a potential divider circuit.

Fig. 4.1



(a) The e.m.f. of the cell is 1.5 V. The cell has negligible internal resistance. The potential difference across R_1 is 0.4 V.

(i) Explain the difference in the meaning of the terms *e.m.f.* and *potential difference*.

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.... **[2]**

(ii) R_1 has a resistance of 30 Ω. Calculate the resistance of R_2.

resistance = ... Ω **[2]**

(b) A student sets up the circuit shown in **Fig. 4.2** to calibrate a thermistor to measure the temperature of a baby bath.

Fig. 4.2

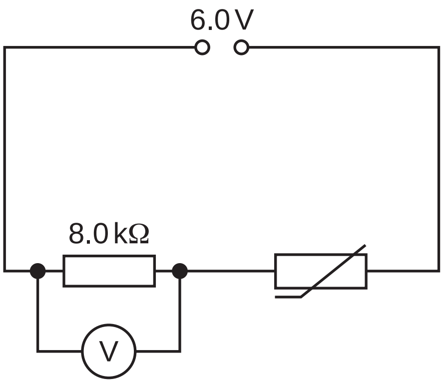
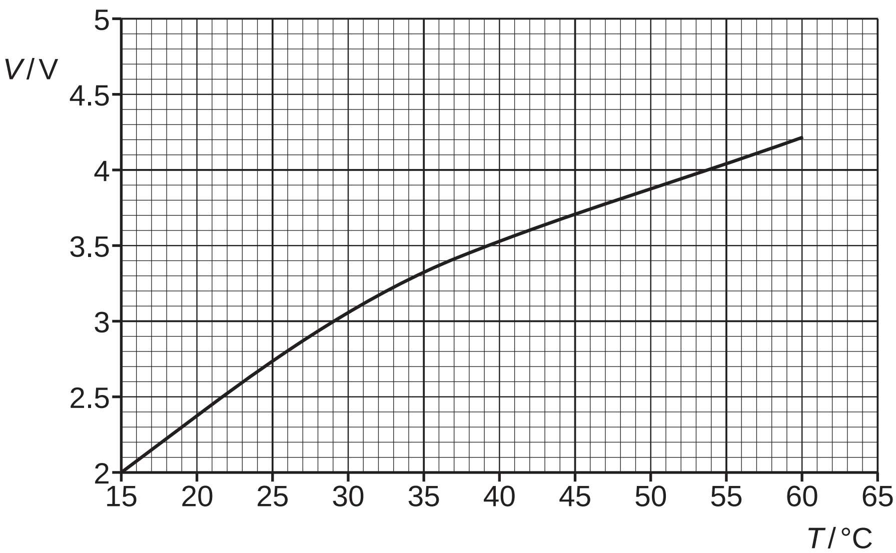


Fig. 4.3 shows how the p.d. across the 8.0 kΩ resistor varies with the temperature of the thermistor.

Fig. 4.3



(i) Describe an experimental method that could be used to obtain such a calibration curve. Give **one** possible source of experimental uncertainty and suggest how it can be reduced.

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(ii)* The ideal temperature for a baby bath is 37 °C. The voltmeter reads to the nearest 0.01 V. The resistance of the thermistor varies from approximately 13 kΩ to 3 kΩ over the temperature range.

Calculate the sensitivity **and** resolution of the temperature sensor at 37 °C. Explain the effect of changing the value of the fixed resistor to 80 kΩ on the sensitivity of the sensor. You may use calculations in your explanation.

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.... **[6]**

(c) The resistance of the thermistor (a semiconductor) decreases when its temperature increases.

Explain this by considering the behaviour and number density of the mobile charge carriers in the semiconductor.

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Section B continues on page 14

5 This question is about gravitational and electrical fields.

(a)
(i) The Earth orbits the Sun at a distance of 1.5×10^{11} m. Calculate the angular velocity and the orbital speed of the Earth.

Orbital period = 3.2×10^{7} s (1 year)

angular velocity = ... rad s^{-1}

orbital speed = ... m s^{-1}
[2]

(ii) Use your answer to **(a)(i)** to show that the centripetal acceleration of the Earth in its orbit is about 6×10^{-3} m s^{-2}.

[1]

(iii) Use the value from **(a)(ii)** to calculate the mass of the Sun.

mass = ... kg **[3]**

(b)

(i) Calculate the ratio of the force due to the electric field (electrostatic force) between a proton and an electron and the gravitational force between the same particles at a separation *r*.

ratio $\dfrac{\text{electrostatic force}}{\text{gravitational force}}$ = ... **[3]**

(ii) State why gravity is the dominant force in the large-scale structure of the Universe even though it is weaker than the electrostatic force on an atomic level.

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.... **[2]**

(c) An early model of the hydrogen atom pictured the electron orbiting the proton in a similar manner to a planet orbiting the Sun. This is called the 'planetary model'.

(i) Calculate the centripetal acceleration of an electron orbiting a proton at a separation of 0.5×10^{-10} m.

centripetal acceleration = ... m s^{-2} **[2]**

(ii) Accelerating charges emit electromagnetic radiation. Suggest and explain why this shows that the planetary model of the hydrogen atom is incorrect.

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.... **[2]**

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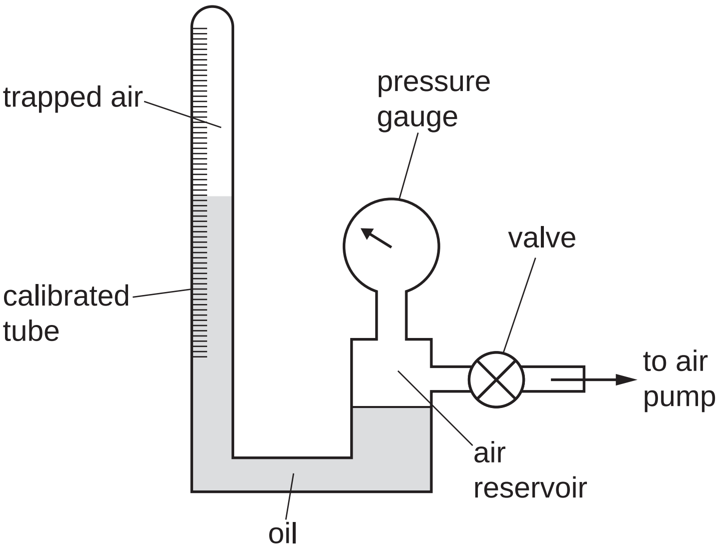
Section B continues on page 18

6 This question is about Boyle's Law and ideal gas behaviour.

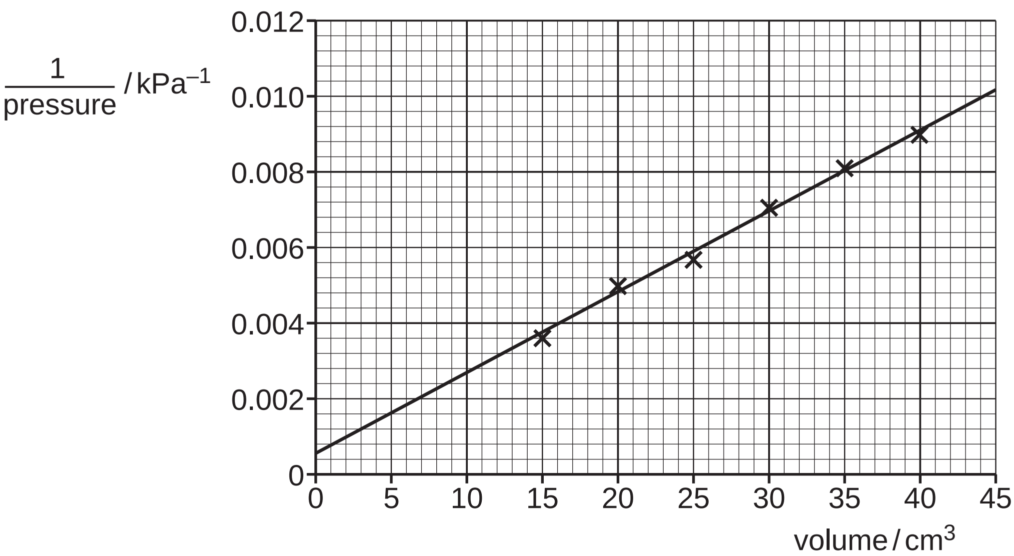
A demonstration is performed to show the relationship between the volume of a gas and the pressure it exerts. **Fig. 6.1** shows the apparatus used.

Fig. 6.1



Readings of pressure and volume are taken as the pressure of the trapped air is increased. The graph in **Fig. 6.2** is plotted using the results of the demonstration.

Fig. 6.2



(a)

(i) Explain why it is necessary to keep the temperature of the air constant during the demonstration. Use ideas from kinetic theory to explain the effect of the temperature of the air increasing as the pressure increases.

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(ii) Suggest and explain why the graph is a straight line with a positive *y* intercept.

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.... **[2]**

(b)

(i) The temperature of the trapped air is 293 K. Show that the root mean square speed of the air molecules is about 500 $m\,s^{-1}$.

Assume the mass of a molecule is 4.8×10^{-26} kg.

[3]

(ii) The movement of particles in an ideal gas can be described as a 'random walk'. State the meaning of 'random walk' in this context.

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.... **[1]**

(c)
(i) The gradient of the graph is about $2 \times 10^{-4}\,\text{kPa}^{-1}\,\text{cm}^{-3}$.
Explain why this is equivalent to $0.2\,\text{Pa}^{-1}\,\text{m}^{-3}$.

[2]

(ii) Use the value in **(c)(i)** to calculate the number of moles of trapped air in the tube.

number = ... mol **[3]**

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Section C begins on page 22

SECTION C

This section is based on the Advance Notice Article, which is an insert.

7 A scan of a phonoautogram (lines 18–28) produces a signal variation of 2 mV and a noise level of 75 μV.

Calculate the number of bits to best represent this sample. Make your reasoning clear.

Calculation:

number of bits = ...

Reasoning:

....

.... **[3]**

8

(a) Explain why the sensitivity of dynamic microphones falls at high frequencies and how this can affect the accuracy of recordings (lines 66–69).

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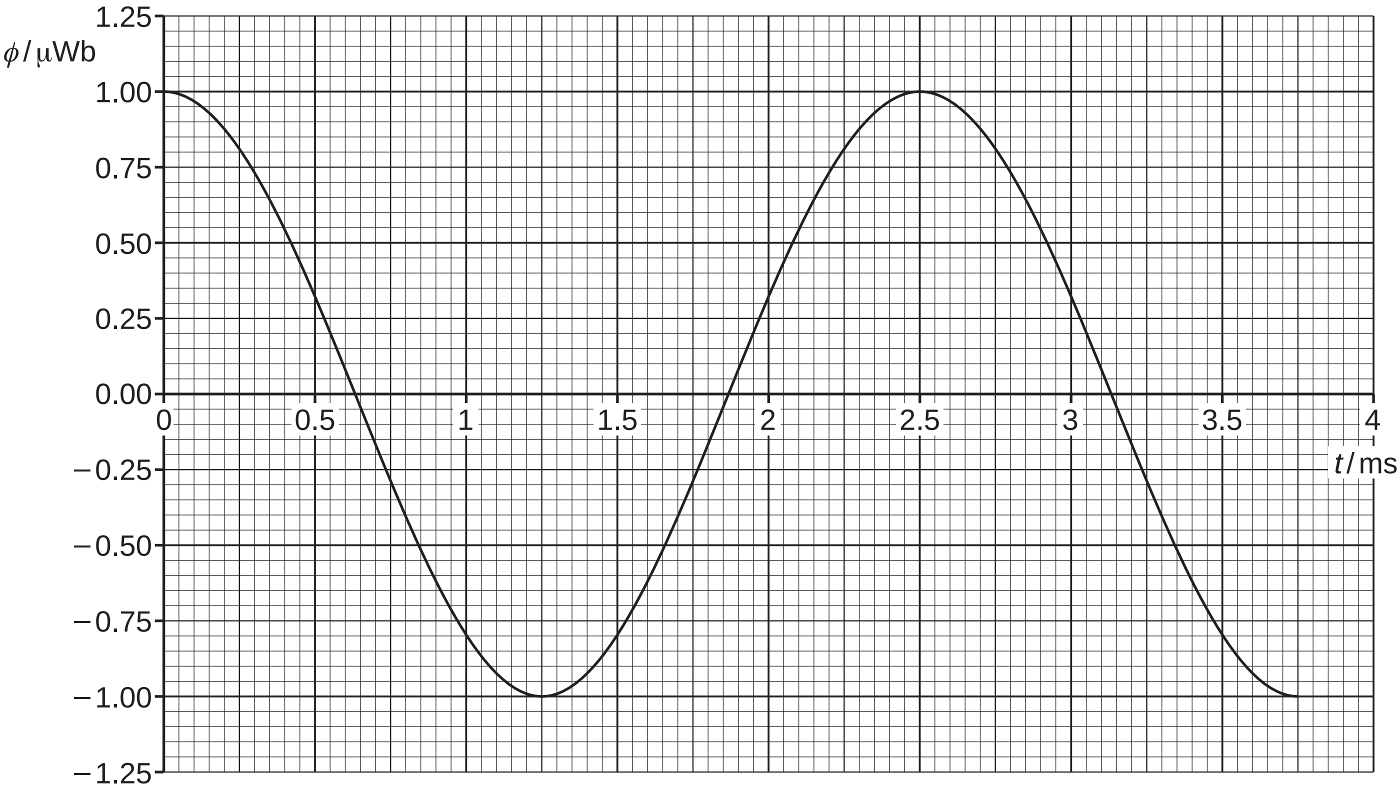
.... **[3]**

(b) **Fig. 8** shows how the flux through a coil of 170 turns in a dynamic microphone oscillating in a magnetic field changes with time.

Fig. 8



Calculate the maximum emf induced during the cycle.

maximum emf = ... V **[2]**

9 Data for a capacitor in a condenser microphone with air as the dielectric are given below:

Diameter of circular diaphragm = 1.80 mm

Equilibrium separation of diaphragm and back plate = 9.6 μm

Relative permittivity of air = 1

Bias voltage = 12.0 V

A 340 Hz sine wave is incident on the diaphragm which oscillates at a frequency of 340 Hz with an amplitude of 0.1 μm.

(a) Use the equation given (line 76) in the article to show that the **maximum** value of capacitance during the oscillation is about 2.4 pF.

[2]

(b) Calculate the energy stored on the capacitor at this maximum value.

energy stored = ... **[1]**

(c) The capacitance at equilibrium position is 2.35 pF. Use this value and your value from **(a)** to calculate the mean current from the capacitor as the diaphragm moves from its position in **(a)** to the equilibrium position.

mean current = ... A **[3]**

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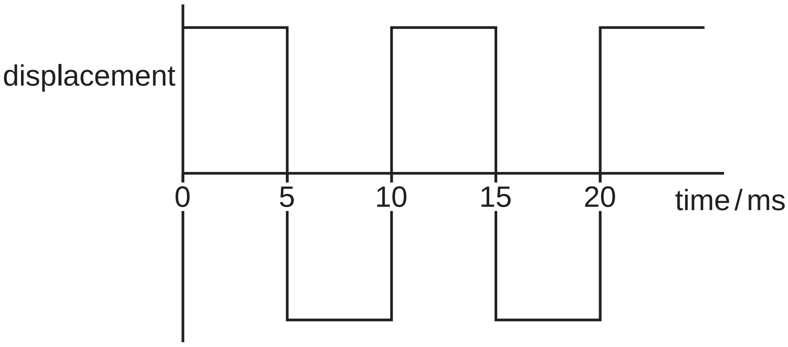
Question 10 begins on page 26

10* Using appropriate equations, explain and compare how the phase of the output signal from dynamic and condenser microphones relates to the phase of the incident sound wave (lines 73–74 and lines 90–92).

Describe how each type of microphone would respond to an incident square wave sound, as shown in **Fig. 10**, and explain which microphone is best suited to recording such a wave. You may include sketch graphs of signal amplitude (no unit) against time/ ms from the two microphones in your answer.

Fig. 10



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.... **[6]**

11 The total capacitance of two capacitors in series is given by:

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2}.$$

(a) Using equations for the capacitance of the membrane and air-gap capacitors in an electret microphone (lines 100–105) to show that the total capacitance of the two capacitors in series is given by:

$$C_{\text{total}} = \frac{\varepsilon_0\, \varepsilon_r\, S}{\varepsilon_r\, d + h}$$

[2]

Here are some data about an electret microphone capsule:

Surface area of membrane layer and metal backplate = $4.5 \times 10^{-6}\,\text{m}^2$

Thickness of membrane layer = $1.9 \times 10^{-5}\,\text{m}$

Relative permittivity of membrane layer = 1.8

Width of air gap = $3.8 \times 10^{-5}\,\text{m}$

(b) The total charge on the capacitors is $9.7 \times 10^{-11}\,\text{C}$. Calculate the potential difference across the two capacitors.

potential difference = ... V **[2]**

END OF QUESTION PAPER

EXTRA ANSWER SPACE

If you need extra space use this lined page. You must write the question numbers clearly in the margin.