



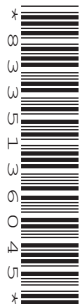
Oxford Cambridge and RSA

Thursday 14 October 2021 – 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

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Candidate number

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First name(s)

Last name

StemUp Model Solution

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 pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- 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 **24** pages.

ADVICE

- Read each question carefully before you start your answer.

SECTION A

Answer **all** the questions.

- 1 (a) Gravitational potential of a point mass and electrical potential of a point charge are both examples of inverse relationships.

- (i) State what is meant by the term **gravitational potential**.

Gravitational potential energy per unit mass (per kg) at a point in a gravitational field, the work done per kg bringing a mass from infinity. [1]

- (ii) Explain why gravitational potential is always a negative quantity.

Gravitational potential is defined as zero at infinity (infinite separation). Gravity is always attractive, so work must be done to separate masses (to move a mass out to infinity): at any distance less than infinity the potential is below zero, so it is negative. [2]

- (iii) Explain why electrical potential can be positive or negative.

Electric charges can attract (unlike charges, giving a negative potential) or repel (like charges, giving a positive potential): when like charges are brought together energy is stored. [1]

- (b) The gravitational potential at the surface of the Earth is about $-6.3 \times 10^7 \text{ J kg}^{-1}$.

Write down the minimum initial kinetic energy required for a 1 kg body to escape the gravitational field of the Earth when projected vertically from the surface. Explain your reasoning and suggest why this is a minimum value.

minimum initial kinetic energy = *(+)6.3 × 10⁷* J

Explanation:

The body escapes when k.e. + g.p.e. = 0: all its k.e. is transferred to g.p.e., reaching zero potential (infinity).

Suggestion:

Assumes no energy is transferred in the atmosphere (no work done against air resistance/friction).

[3]

- (c) The Voyager 1 spacecraft was launched in 1977. It has travelled further into space than any other human-made device. In May 2019 it was more than 2.2×10^{13} m from the Sun, moving at a velocity of $1.7 \times 10^4 \text{ ms}^{-1}$.

Calculate its total energy at this distance and explain the significance of your answer.

mass of Sun = $2.0 \times 10^{30} \text{ kg}$

mass of Voyager spacecraft = 720 kg

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 720 \times (1.7 \times 10^4)^2 = 1.04 \times 10^{11} \text{ J}$$

$$E_p = -GMm/r = -6.67 \times 10^{-11} \times 2.0 \times 10^{30} \times 720 \div 2.2 \times 10^{13}$$

$$E_p = -4.37 \times 10^9 \text{ J}$$

$$\text{total} = 1.04 \times 10^{11} + (-4.37 \times 10^9) = 9.97 \times 10^{10} \text{ J}$$

$$\text{total energy} = \dots 1.0 \times 10^{11} \dots \text{ J}$$

Explanation:

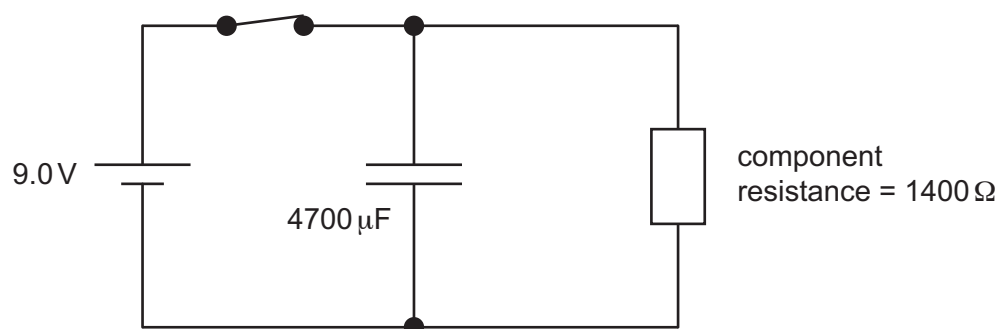
The total energy is positive (k.e. is greater than the size of the negative g.p.e.), so Voyager will continue to move further from the Sun: it will leave the Sun's gravitational field.

[4]

- 2 This question is about using capacitors as energy storage devices.

The diagram below shows a simple circuit which models how a capacitor can be used as a back-up power supply. The component is modelled as a single resistor.

In normal use the switch is closed and the p.d. across the component is 9.0 V. Opening the switch models a failure in the power supply.



- (a) (i) The operating range of the component is 5.2 V to 9.0 V.

Show that 3.5 s after the switch is opened the p.d. across the component will be about 5.3 V.

$$RC = 4700 \times 10^{-6} \times 1400 = 6.58 \text{ s}$$

$$V = V_0 e^{-t/RC} = 9.0 \times e^{-3.5/6.58}$$

$$V = 9.0 \times 0.588 = 5.29 \text{ V} \approx 5.3 \text{ V}$$

[2]

- (ii) Estimate the average power delivered to the component during this time. Explain why the value is an average.

$$\Delta E = \frac{1}{2} C (V_1^2 - V_2^2) = \frac{1}{2} \times 4700 \times 10^{-6} \times (9.0^2 - 5.29^2)$$

$$\Delta E = 0.125 \text{ J}, \quad P = \Delta E / t = 0.125 \div 3.5$$

average power = ...0.036..... W

Explanation:

.....The p.d. across (and current through) the component is not constant;.....
both fall exponentially as the capacitor discharges, so the power (V^2/R).....
decreases during the 3.5 s.

[3]

In recent years, **supercapacitors** have been developed. These components charge and discharge in a similar manner to standard capacitors but can have capacitances of more than 10 000 F.

These can be used as back-up power supplies in many circumstances.

(b) A 120 F supercapacitor has an internal resistance of 30 mΩ. At time $t = 0.0$ s it stores 300 J.

Calculate the minimum time taken for the capacitor to transfer 250 J through discharging. Suggest why this is a minimum value.

$$\text{at } 300 \text{ J: } V_0 = \sqrt{2E/C} = \sqrt{2 \times 300 \div 120} = \sqrt{5} = 2.24 \text{ V}$$

after 250 J is transferred, 50 J remains:

$$V = \sqrt{2 \times 50 \div 120} = 0.913 \text{ V}$$

$$RC = 30 \times 10^{-3} \times 120 = 3.6 \text{ s}$$

$$V = V_0 e^{-t/RC} \text{ so } t = RC \ln(V_0/V)$$

$$t = 3.6 \times \ln(2.24 \div 0.913) = 3.6 \times 0.896 = 3.2 \text{ s}$$

time = ...3.2..... s

Suggestion:

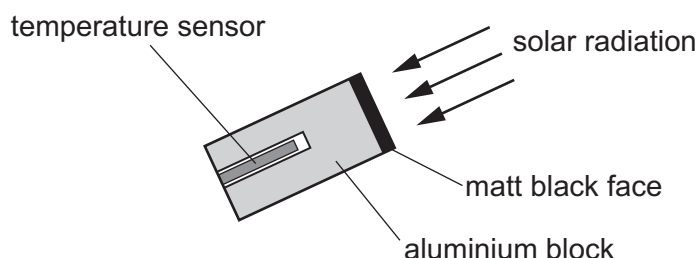
.....It assumes the only resistance is the internal resistance (no external load).....

.....Any external load adds resistance, increasing RC, so discharge takes longer.....

[4]

3 This question is about the power output of the Sun.

A student places an aluminium block with a matt black face in direct sunlight, facing the Sun so that the solar radiation strikes the face as shown in the diagram below. The block has a temperature sensor embedded within it.



After ten minutes the temperature of the block has risen by 2.1 K.

- (a) Use the data below to calculate the power per square metre of the radiation incident on the block. You may assume that all the energy incident on the face is retained as internal energy of the block.

Mass of block = 0.28 kg

Area of matt black face = 0.0013 m²

specific thermal capacity of aluminium = 920 J kg⁻¹ K⁻¹

$$\text{energy gained} = mc\Delta\theta = 0.28 \times 920 \times 2.1 = 541 \text{ J}$$

$$\text{power} = 541 \div (10 \times 60) = 0.902 \text{ W}$$

$$\text{power per m}^2 = 0.902 \div 0.0013 = 694 \text{ W m}^{-2}$$

power per square metre = ...690..... W m⁻² [2]

- (b) The power per m² of solar radiation of all wavelengths striking the top of the Earth's atmosphere is 1.4 kW m⁻². The distance from the Earth to the Sun is 1.5×10^{11} m.

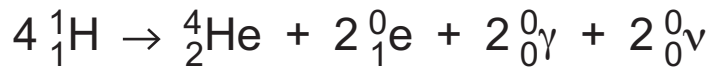
Show that these figures suggest that the power output of electromagnetic radiation of the Sun is about 4×10^{26} W.

$$\text{area of sphere} = 4\pi r^2 = 4\pi \times (1.5 \times 10^{11})^2 = 2.83 \times 10^{23} \text{ m}^2$$

$$P = 1.4 \times 10^3 \times 2.83 \times 10^{23} = 3.96 \times 10^{26} \text{ W} \approx 4 \times 10^{26} \text{ W}$$

[2]

- (c) The ultimate source of the Sun's energy is the fusion of hydrogen into helium. This is a three-stage process which can be summarised in the single equation below.



- (i) Explain how the equation shows that lepton number is conserved in the fusion reactions.

The positron (e^+) is an antilepton, lepton number -1 ; each neutrino is a lepton, lepton number $+1$. Left side: protons have lepton number 0 , total 0 . Right side: $2 \times (-1) + 2 \times (+1) = 0$ (helium and γ are 0). Zero on both sides, so it is conserved. [2]

- (ii) Use the data below to calculate an estimate of the number of fusion three-stage reactions occurring in the Sun each second. 98% of the energy released in the process consists of electromagnetic radiation in the form of gamma ray photons.

power output of Sun (electromagnetic radiation) = $3.8 \times 10^{26} \text{ W}$

mass of electron = 0.000549 u

mass of proton = 1.007276 u

mass of helium-4 nucleus = 4.001506 u

$$\Delta m = 4m_p - (m_{\text{He}} + 2m_e)$$

$$\Delta m = 4 \times 1.007276 - (4.001506 + 2 \times 0.000549) = 0.0265 \text{ u}$$

$$\Delta m = 0.0265 \times 1.661 \times 10^{-27} = 4.40 \times 10^{-29} \text{ kg}$$

$$E = \Delta mc^2 = 4.40 \times 10^{-29} \times (3.00 \times 10^8)^2 = 3.96 \times 10^{-12} \text{ J}$$

$$e\text{-}m \text{ radiation per reaction} = 0.98 \times 3.96 \times 10^{-12} = 3.88 \times 10^{-12} \text{ J}$$

$$\text{number per second} = 3.8 \times 10^{26} \div 3.88 \times 10^{-12}$$

$$\text{number of fusion reactions per second} = 9.8 \times 10^{37} \text{ [4]}$$

SECTION B

Answer **all** the questions.

- 4 This question is about the macroscopic behaviour of a metal under tension and a model of the microscopic structure of the metal.

A 3.951 m length of copper wire with cross-sectional area $5.90 \times 10^{-8} \text{ m}^2$ extends to a length of 3.953 m when a tensile force of 3.43 N is applied.

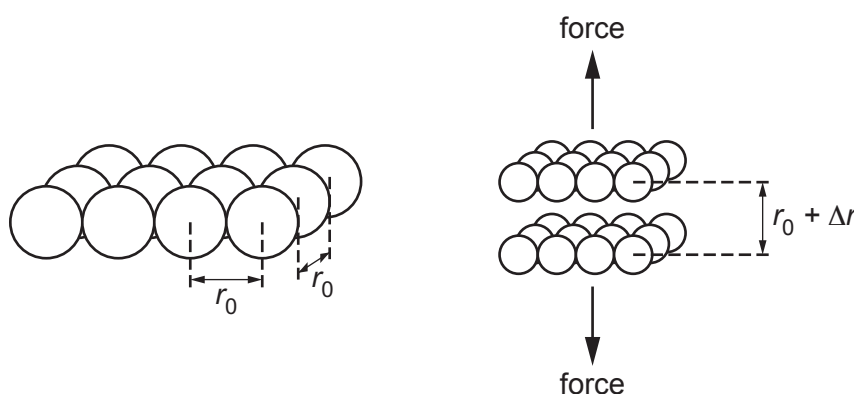
- (a) Calculate the Young modulus of the sample.

$$E = FL/A\Delta L = 3.43 \times 3.951 \div (5.90 \times 10^{-8} \times 0.002)$$

$$E = 1.15 \times 10^{11} \text{ Pa}$$

Young modulus = ...1.15 × 10¹¹..... Pa [2]

- (b) The microscopic structure of copper can be pictured as planes of atoms as shown in the diagram.



The distance between the centres of neighbouring atoms, r_0 , is $2.3 \times 10^{-10} \text{ m}$.

When the copper wire is not under tension the distance between the planes is also $2.3 \times 10^{-10} \text{ m}$.

The bonds between the atoms can be considered to act like microscopic springs. When the copper is put under tension the separation between the planes increases to $r_0 + \Delta r$.

- (i) Using data from the question, calculate the number of atoms in one plane of area $5.90 \times 10^{-8} \text{ m}^2$ and use this value to calculate the tension force between pairs of atoms in neighbouring planes when the wire experiences a tension force of 3.43 N.

$$\text{area per atom} = r_0^2 = (2.3 \times 10^{-10})^2 = 5.29 \times 10^{-20} \text{ m}^2$$

$$\text{atoms per plane} = 5.90 \times 10^{-8} \div 5.29 \times 10^{-20} = 1.12 \times 10^{12}$$

$$\text{tension per pair} = 3.43 \div 1.115 \times 10^{12} = 3.08 \times 10^{-12} \text{ N}$$

$$\text{tension} = \dots 3.1 \times 10^{-12} \dots \text{ N [3]}$$

- (ii) Using data from the question, calculate the increase in distance of separation Δr of the planes of copper atoms when the wire experiences a tension force of 3.43 N.

$$\text{strain} = \Delta L/L = 0.002 \div 3.951 = 5.06 \times 10^{-4}$$

$$\Delta r = \text{strain} \times r_0 = 5.06 \times 10^{-4} \times 2.3 \times 10^{-10}$$

$$\Delta r = 1.16 \times 10^{-13} \text{ m}$$

$$\text{increase in separation} = \dots 1.2 \times 10^{-13} \dots \text{ m [2]}$$

- (iii) Use your answers to (b)(i) and (b)(ii) to calculate the force constant k between a pair of copper atoms.

$$k = F/\Delta r = 3.08 \times 10^{-12} \div 1.16 \times 10^{-13}$$

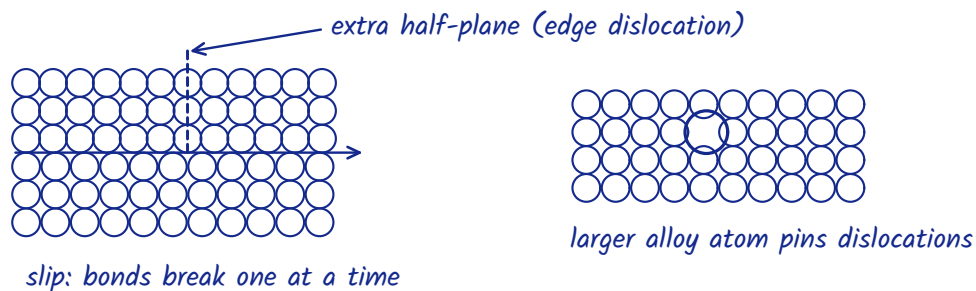
$$k = 26.6 \text{ N m}^{-1}$$

$$\text{force constant} = \dots 27 \dots \text{ N m}^{-1} [2]$$

- (c)* This simple model of the microscopic structure of copper cannot be used to predict its yield stress.

Describe how an improved model can predict the way in which metals under stress fail in different ways.

You should include an explanation of the term **yield stress** in your answer and describe how the macroscopic properties of metals can be changed by making changes to their microscopic structure. You may include diagrams in your answer. [6]



Yield stress is the stress at which a metal starts to deform plastically; beyond it the metal does not return to its original shape when the stress is removed, because planes of atoms slip past each other. The simple spring model assumes a perfect crystal, so a whole plane of bonds would have to break at once for slip to occur. It predicts a yield stress far above the measured value. An improved model includes defects: missing atoms (vacancies) and dislocations, an extra half-plane of atoms (diagram). Dislocations are mobile: under stress the bonds next to the dislocation break and re-form one at a time, so the dislocation moves through the crystal instead of the whole plane failing at once. This greatly reduces the stress needed for the metal to yield: metals with mobile dislocations are ductile and fail by plastic flow (necking); if dislocations cannot move they fail by brittle fracture. Alloying adds atoms of a different size which pin the dislocations, so a

Additional answer space if required.

larger stress is needed to move them: the alloy has a higher yield stress
and is harder and stronger, but usually more brittle. Work hardening
increases the number of dislocations, which tangle and pin each other, also
making the metal harder and more brittle. Rapid cooling gives smaller
grains, whose boundaries stop dislocations, raising the yield stress.

Question 5 begins on page 12

5 This question is about oscillations.

A 0.84 kg mass is attached to two springs as shown in **Fig. 5.1**. The mass is displaced 0.24 m from the equilibrium point and released. There is negligible friction between the mass and the surface.

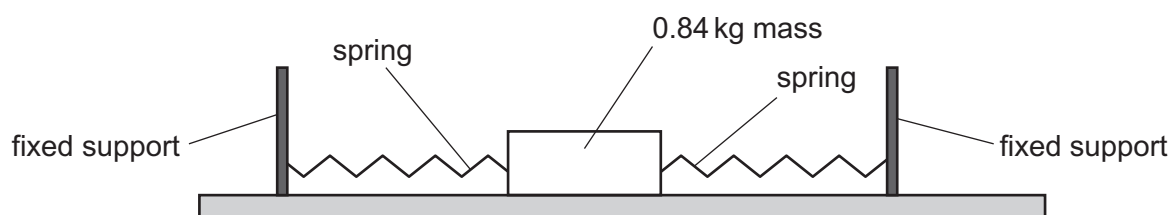


Fig. 5.1

(a) The mass oscillates between the springs with a time period of 1.3 s.

Calculate the spring constant k of the system.

$$k = 4\pi^2 m / T^2 = 4\pi^2 \times 0.84 \div 1.3^2 = 19.6 \text{ N m}^{-1}$$

spring constant = ...19.6..... N m^{-1} [2]

(b) Calculate the maximum velocity of the mass.

$$E_{k \text{ max}} = \frac{1}{2} k A^2 = \frac{1}{2} \times 19.6 \times 0.24^2 = 0.565 \text{ J}$$

$$v_{\text{max}} = \sqrt{(2E_k / m)} = \sqrt{(2 \times 0.565 \div 0.84)} = 1.16 \text{ m s}^{-1}$$

maximum velocity = ...1.16..... m s^{-1} [3]

(c) Explain why the kinetic energy of the oscillator will equal the elastic potential in the system when its displacement = $\frac{\text{maximum displacement}}{\sqrt{2}}$.

Elastic p.e. = $\frac{1}{2} k x^2$, so p.e. is proportional to x^2 . When $x = x_{\text{max}} / \sqrt{2}$, $x^2 = x_{\text{max}}^2 / 2$, so p.e. is half its maximum value. Total energy (k.e. + p.e.) is constant, so the k.e. is the other half: k.e. = p.e.

..... [2]

- (d) Calculate the time interval between releasing the mass from its position of maximum displacement and the first time the kinetic energy of the mass is equal to the elastic potential energy of the system.

$$x = A \cos(2\pi t/T): A/\sqrt{2} = A \cos(2\pi t/1.3)$$

$$\cos(2\pi t/1.3) = 1/\sqrt{2}, \text{ so } 2\pi t/1.3 = \pi/4$$

$$t = 1.3 \div 8 = 0.163 \text{ s}$$

time = ...0.163..... s [2]

- (e) A powerful magnet is fixed to the side of the mass as shown in **Fig. 5.2**. An aluminium sheet is placed below the mass. The friction between the mass and the metal surface is still negligible.

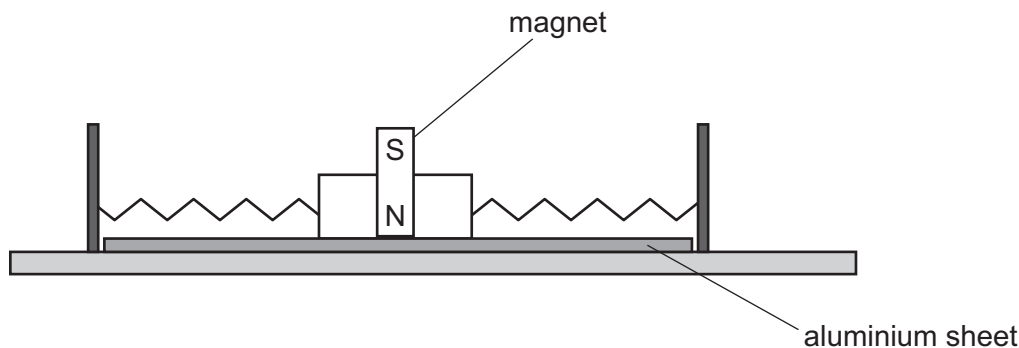


Fig. 5.2

When the experiment is repeated with the magnet and sheet present, the amplitude of oscillations falls rapidly due to eddy currents in the sheet.

Explain how these currents are formed and how they transfer energy away from the oscillation.

As the magnet moves over the aluminium sheet, the magnetic flux through parts of the sheet changes. By Faraday's law this changing flux linkage induces an e.m.f. in the sheet. The sheet is a conductor, so the e.m.f. drives circulating (eddy) currents in it. The currents heat the sheet (I^2R heating). By Lenz's law they produce a field opposing the motion, so work is done against this force: kinetic energy of the oscillator is transferred to internal energy of the sheet and the amplitude falls.

[4]

- (f) At a height of 632m, the Shanghai Tower is the world's second tallest building. A huge pendulum which oscillates at the natural frequency of the building reduces the effect of the wind. The oscillations of the pendulum are damped with hydraulic pistons and electromagnetic dampers. **Fig. 5.3** shows the tower with its electromagnetic damper.

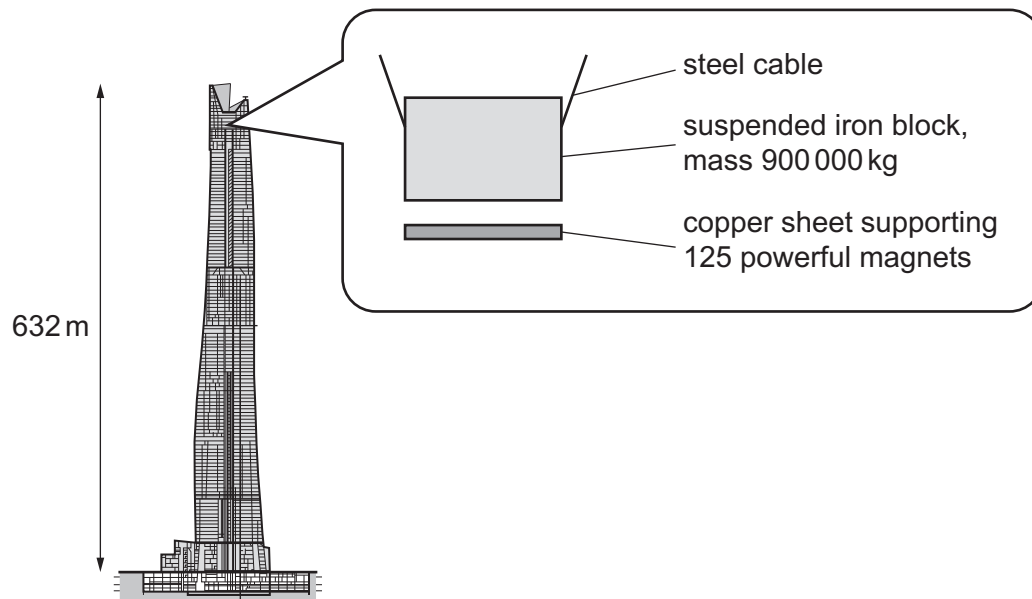


Fig. 5.3 Shanghai Tower. Pendulum diagram not to scale. Hydraulic dampers not illustrated.

Suggest how this system reduces the motion of the building in winds and explain the purpose of the damping systems.

The pendulum has the same natural frequency as the building, so when the wind makes the tower sway the pendulum resonates with the oscillations of the tower. Energy of the movement of the tower is transferred to the pendulum, reducing the amplitude of the building's motion. The hydraulic and electromagnetic dampers transfer the energy of the pendulum to internal energy (eddy currents heat the copper sheet), so the energy is removed rather than returned to the building and the pendulum's swing is limited. [3]

- 6 This question is about the conductivity of metals.

Fig. 6.1 shows a circuit used to determine the conductivity of nichrome wire.

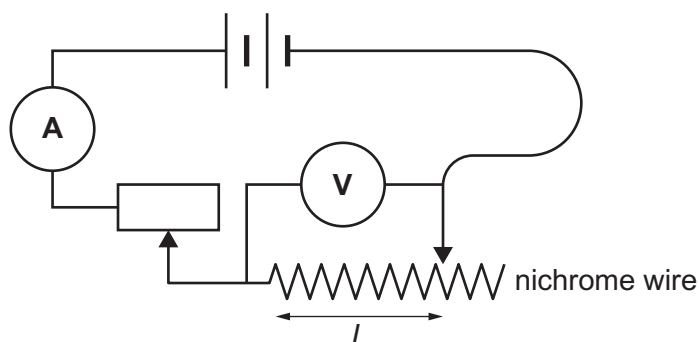


Fig. 6.1

The length L of nichrome wire the current passes through is varied. The variable resistor is used to keep the current in the circuit constant.

- (a) State and explain why it is important to keep the current constant when determining the resistivity of the nichrome wire.

The current has a heating effect: a higher current heats the wire to a higher equilibrium temperature, which changes the resistance (resistivity) of the wire. A constant current keeps the wire at a constant temperature, so only L changes V . [2]

(b) Fig. 6.2 shows a graph of the results obtained using the apparatus.

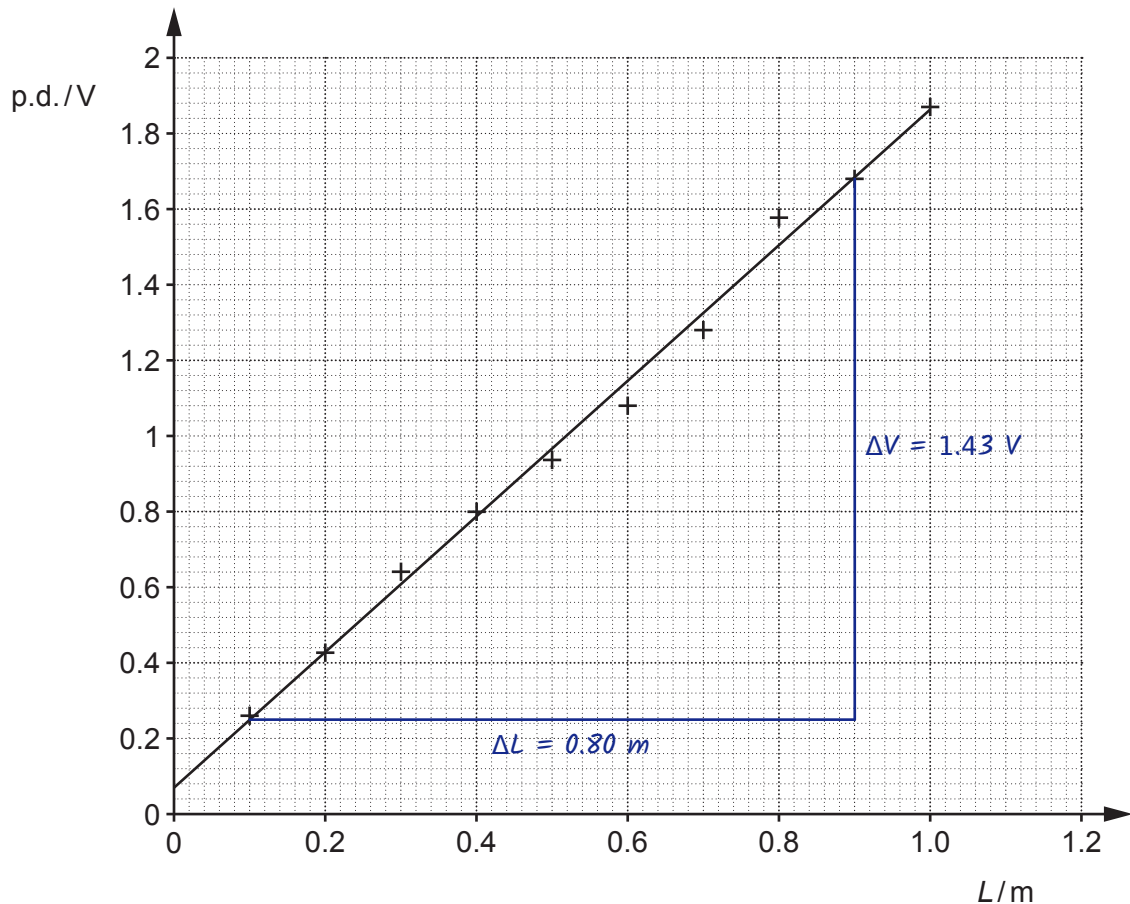


Fig. 6.2

- (i) State how the graph shows that there is a systematic error in the data and suggest a possible cause of the error.

The best-fit line does not pass through the origin: there is a non-zero p.d. intercept (about 0.07 V at $L = 0$). A possible cause is contact resistance where the wire is connected (or a zero error on the voltmeter).

[2]

- (ii) Calculate the gradient of the line, making your method clear.

from the triangle: $L = 0.10 \text{ m}$, $V = 0.25 \text{ V}$; $L = 0.90 \text{ m}$, $V = 1.68 \text{ V}$

$$\text{gradient} = \Delta V / \Delta L = (1.68 - 0.25) \div (0.90 - 0.10)$$

$$\text{gradient} = 1.43 \div 0.80 = 1.8 \text{ V m}^{-1}$$

gradient = ...1.8..... V m^{-1} [2]

- (iii) Use the value from (ii) and the data below to calculate the conductivity of the wire.

current through wire = 0.30 A
diameter of wire = 5.6×10^{-4} m

$$A = \pi d^2/4 = \pi \times (5.6 \times 10^{-4})^2 \div 4 = 2.46 \times 10^{-7} \text{ m}^2$$

$$\sigma = L/RA = 1/(A \times V/L) = 0.30 \div (2.46 \times 10^{-7} \times 1.8)$$

$$\sigma = 6.8 \times 10^5 \text{ S m}^{-1}$$

conductivity = 6.8×10^5 S m⁻¹ [3]

- (c) The experiment was repeated with nichrome wire of diameter 4.2×10^{-4} m carrying the same current of 0.30 A. The repeated experiment gave a different value for the conductivity of nichrome.

Suggest and explain why the second experiment gave a different value.

The thinner wire has a larger resistance (smaller A), so the same current of 0.30 A needs a greater p.d. and the heating effect (I^2R) is greater. The wire is hotter, so its resistance is higher and the conductance (and calculated conductivity) is lower. [2]

- (d) Metals have far higher electrical conductivities than insulators.

Explain this difference by referring to the microscopic properties of both classes of materials.

Metals have a very large number of free (delocalised) electrons; metallic bonding gives a 'sea' of electrons which can migrate through the lattice when a p.d. is applied. In insulators the electrons are bound to individual atoms, so there are far fewer free charge carriers. So under a given p.d. many more electrons (more charge) flow per second in a metal, giving a far larger current and a far higher conductivity. [3]

SECTION C

Answer **all** the questions.

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

- 7 This question is about the longitudinal resolution of ultrasound pulses used in medical imaging (lines 112–124).

An ultrasound scanner emits an ultrasound pulse into tissue which reflects at the boundary between tissue and a layer of fat. The time interval between the emission of the pulse and return is $15.5\mu\text{s}$.

- (a) Calculate the distance between the scanner and the layer of fat.

velocity of sound in tissue = 1540 m s^{-1}

$$d = vt/2 = 1540 \times 15.5 \times 10^{-6} \div 2 = 0.0119\text{ m}$$

distance = ...0.0119..... m [1]

- (b) The frequency of the ultrasound used is 3.5 MHz and each pulse lasts $1\mu\text{s}$.

Calculate the longitudinal resolution of the pulse.

$$\text{number of cycles in pulse} = 3.5 \times 10^6 \times 1 \times 10^{-6} = 3.5$$

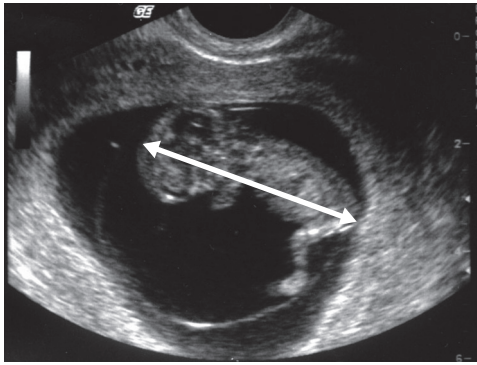
$$\lambda = v/f = 1540 \div 3.5 \times 10^6 = 4.4 \times 10^{-4}\text{ m}$$

$$\text{spatial pulse length} = 3.5 \times 4.4 \times 10^{-4} = 1.54 \times 10^{-3}\text{ m}$$

$$\text{resolution} = \frac{1}{2} \times 1.54 \times 10^{-3} = 7.7 \times 10^{-4}\text{ m}$$

longitudinal resolution = ... 7.7×10^{-4} m [3]

- 8 The figure below reproduces the ultrasound scan shown in the article on page 5.



The length of the foetus indicated by the double-headed arrow is 39mm. The whole image measures 920×700 pixels.

- (a) Calculate the resolution of the image.

measured: image width = 63 mm, arrow length = 30 mm

pixels along arrow = $(30 \div 63) \times 920 = 438$

resolution = $39 \div 438 = 0.089$ mm

resolution = ... *0.09* mm [2]

- (b) The image size is 644 000 bits.

Explain why this suggests that each pixel in the image is either white or black and suggest how the image appears to show shades of grey.

Explanation:

$920 \times 700 = 644\,000$ pixels, equal to the number of bits, so 1 bit per pixel; only 2 values (0 or 1), black or white.

Suggestion:

Shades of grey come from the density of white pixels: more white pixels in an area looks a lighter grey.

[2]

9 This question is about the spreading and attenuation of sound in air (lines 39–60).

- (a) (i) A bat emits a pulse from a single point. The intensity of the sound emitted varies with distance from that point in an inverse square relationship. The pulse strikes an object at distance R . The reflected pulse also spreads in an inverse square manner.

State what is meant by the term **inverse square relationship** and explain why the intensity of the echo the bat receives is given by the equation

intensity of echo = intensity of original pulse / R^4 .

You can assume that there is no absorption or scattering of the sound by the air and that all the energy incident on the object is reflected.

Inverse square: the intensity is proportional to $1/\text{distance}^2$. At the object the intensity is I_0/R^2 ; the object then acts as the source and the echo spreads back over R , falling by $1/R^2$ again: $\text{echo} = I_0/R^2 \times 1/R^2 = I_0/R^4$ [2]

- (ii) A pulse emitted by the bat returns after reflection from a small object at a distance of 2.4 m.

Calculate the change in power in decibels (dB) of the pulse from its emission to its return, assuming that there is no absorption or scattering of the sound and that all the energy incident on the object is reflected.

$$\text{intensity ratio} = 1/R^4 = 1 \div 2.4^4 = 0.0301$$

$$\text{change in power} = 10 \log_{10}(0.0301)$$

$$\text{change in power} = -15.2 \text{ dB}$$

change in power = ...-15..... dB [3]

- (b) (i) Ignoring the effects of spreading, the power of a sound wave of frequency 100 kHz falls to 93% of its original value after travelling 0.1 m.

Show that the attenuation coefficient of air for sound of frequency 100 kHz is about 0.7 m^{-1} .

$$P = P_0 e^{-\alpha R}; \quad 0.93 = e^{-\alpha \times 0.1}$$

$$\ln 0.93 = -0.0726 = -\alpha \times 0.1$$

$$\alpha = 0.0726 \div 0.1 = 0.73 \text{ m}^{-1} \approx 0.7 \text{ m}^{-1}$$

[2]

- (ii) By considering only the effects of spreading **and** attenuation calculate the difference in power in decibels between the transmitted pulse and detected echo when a bat sends an ultrasound pulse of frequency 100 kHz which strikes a moth at a distance of 3.0 m. Assume that the bat and the moth each acts like a point source of sound and that all the energy incident on the moth is reflected.

pulse travels $2R = 6.0 \text{ m}$; spreading out and back gives $1/R^4$

$$P/P_0 = e^{-\alpha(2R)}/R^4 = e^{-0.7 \times 6.0} \div 3.0^4$$

$$P/P_0 = 0.0150 \div 81 = 1.86 \times 10^{-4}$$

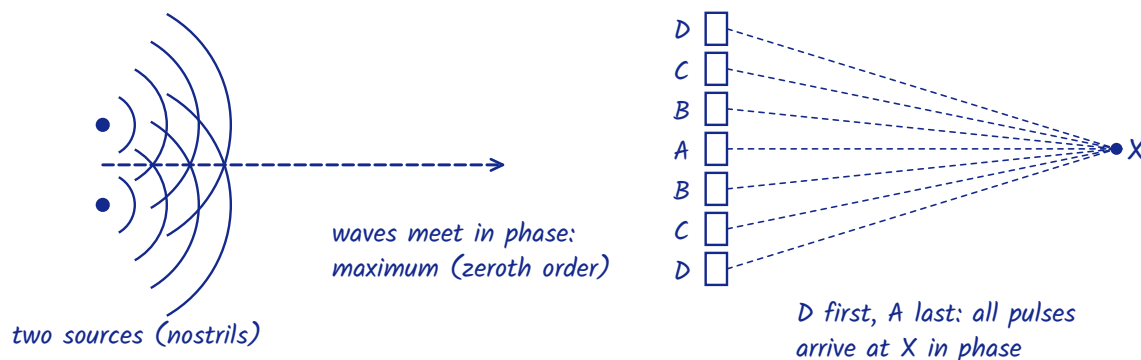
$$\text{power difference} = 10 \log_{10}(1.86 \times 10^{-4})$$

$$\text{power difference} = -37.3 \text{ dB}$$

power difference = ...-37.3..... dB [4]

Turn over for question 10

- 10* Explain how superposition is used by bats and in ultrasound scanners to increase the **power** of the ultrasound beam in a desired direction or location. You should include in your answer an explanation of the term **wave superposition**. You may include diagrams in your answer. [6]



Superposition: when two or more waves meet, the resultant displacement at any point is the sum of the individual displacements. Where waves meet in phase (path difference a whole number of wavelengths) they superpose constructively, giving the largest resultant amplitude. Intensity (power) is proportional to amplitude squared, so two equal waves in phase give twice the amplitude and four times the power of one wave.

Bats: some bats emit sound through their two nostrils, two coherent sources. Along the line at right angles to the sources, through their midpoint (zeroth-order direction), the path difference is zero, so the waves always meet in phase. Energy is redistributed and concentrated along this direction, so the beam ahead of the bat is more intense, travels further and gives a stronger echo from prey, with the same total energy emitted.

Ultrasound scanners: an array of transducers A to D is used. Pair D is pulsed first, then C, then B and A last, with delays chosen so that all the pulses arrive at point X at the same time, in phase. They superpose constructively.

Additional answer space if required.

there, concentrating the energy at that depth in a narrow, high power beam;
changing the delays focuses the beam at different depths. More energy is
reflected from X, so the echo is stronger, giving more detail (better latitudinal
resolution) and allowing greater depths to be imaged.

END OF QUESTION PAPER

[illegible]

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