



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.
- **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 **24** pages.

ADVICE

- Read each question carefully before you start your answer.

SECTION A

- 1 Digestion is an example of an activation process. The energy required for a particular molecule to break apart is 1.2×10^{-19} J.

(a) (i) Calculate the Boltzmann factor for this process.

Human body temperature = 310 K

$$f = e^{-E/kT} = \exp(-1.2 \times 10^{-19} / (1.38 \times 10^{-23} \times 310))$$

$$= e^{-28.05}$$

Boltzmann factor = 6.6×10^{-13} [1]

- (ii) Explain how an individual particle can gain sufficient energy to complete a reaction when the energy required is far greater than the average energy of the particles in the reaction.

The particle makes many random collisions with other particles. If it happens to gain energy in several successive collisions it may (by chance) build up the energy required. [2]

The presence of an enzyme increases the Boltzmann factor of the process by a large amount.

- (b) (i) Explain why this change to the Boltzmann factor affects the rate at which the digestion reaction takes place. Include a description of the information the Boltzmann factor gives about the individual particles involved in an activation process.

*The Boltzmann factor gives the probability that a given particle has
energy $\geq E$ (the fraction of particles with enough energy to react).
A higher Boltzmann factor means a greater number of particles have
energy $\geq E$,
so more reactions take place per second: a greater rate of reaction.* [3]

- (ii) The enzyme increases the Boltzmann factor at 310 K to a value of 6.7×10^{-7} by reducing the activation energy required for the reaction.

Calculate the activation energy of the reaction in the presence of the enzyme.

$$6.7 \times 10^{-7} = e^{-E/kT} = e^{-E/(1.38 \times 10^{-23} \times 310)}$$

$$\ln(6.7 \times 10^{-7}) = -E / (1.38 \times 10^{-23} \times 310)$$

$$E = -\ln(6.7 \times 10^{-7}) \times 1.38 \times 10^{-23} \times 310 = 14.2 \times 4.28 \times 10^{-21}$$

activation energy = *6.1×10^{-20}* J [3]

- 2 A 'T-shirt cannon' fires a wrapped T-shirt from the ground into the spectators sitting at a height of 10 m above the ground as indicated in **Fig. 2.1**.

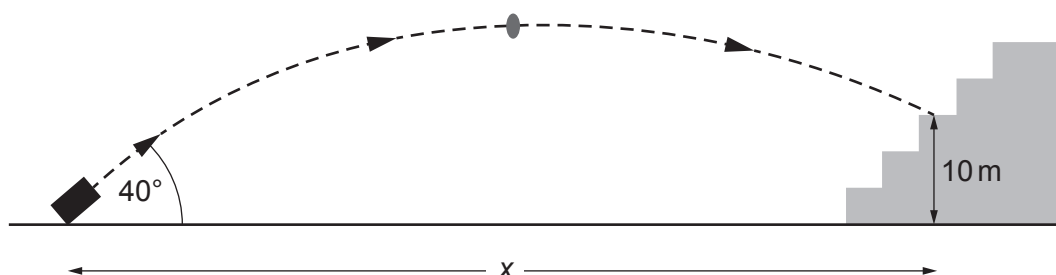


Fig. 2.1 (not to scale)

- (a) (i) The velocity of the shirt when it leaves the cannon is 30 m s^{-1} at an angle of 40° to the horizontal. Ignoring the effects of air resistance, show that the highest point reached by the shirt is less than 20 m vertically above the cannon. Assume the shirt is fired from ground level.

vertical component $u = 30 \sin 40^\circ = 19.3 \text{ m s}^{-1}$; at the top $v = 0$

$$v^2 = u^2 - 2gs, \text{ so } (30 \sin 40^\circ)^2 = 2 \times 9.8 \times s$$

$$s = 371.8 / 19.6 = 19.0 \text{ m, which is less than 20 m}$$

[2]

- (ii) Calculate the horizontal distance x between the cannon and the place where the T-shirt landed in the spectators.

$$\text{time to max height} = 30 \sin 40^\circ / 9.8 = 1.97 \text{ s}$$

$$\text{fall from 19.0 m to 10 m} = 9.0 \text{ m: } t = \sqrt{(2 \times 9.0 / 9.8)} = 1.36 \text{ s}$$

$$\text{total time} = 1.97 + 1.36 = 3.33 \text{ s}$$

$$x = (1.97 + 1.36) \times 30 \cos 40^\circ = 3.33 \times 23.0$$

horizontal distance = 77..... m [3]

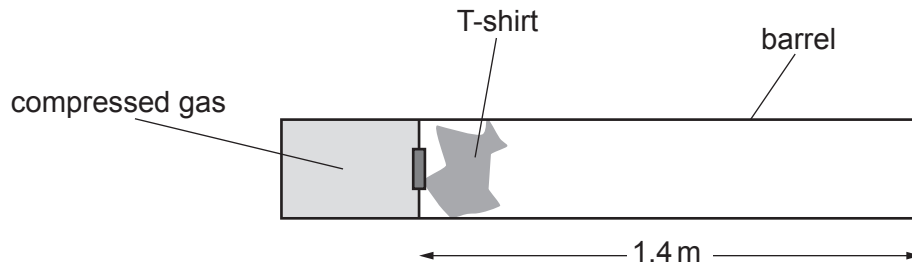


Fig. 2.2

- (b) The wrapped t-shirt is accelerated by a release of compressed gas into the barrel of the cannon. The barrel is 1.4 m long as shown in Fig. 2.2.

Calculate the average force exerted on the T-shirt as it accelerates through the barrel.

mass of shirt = 0.50 kg

$$v^2 = u^2 + 2as; 30^2 = 0^2 + 2 \times a \times 1.4$$

$$a = 900 / 2.8 = 321 \text{ m s}^{-2}$$

$$F = ma = 0.50 \times 321 = 161 \text{ N}$$

force = 160..... N [2]

- (c) The barrel has a uniform radius of 0.05 m. When the compressed gas is released the pressure on the left side of the T-shirt is $4.0 \times 10^4 \text{ Pa}$ greater than atmospheric pressure. Calculate the initial force on the T-shirt and explain why it is greater than the average force.

$$A = \pi r^2 = \pi \times 0.05^2 = 7.85 \times 10^{-3} \text{ m}^2$$

$$F = \Delta p A = 4.0 \times 10^4 \times 0.05^2 \times \pi$$

initial force = 314..... N

As the T-shirt moves along the barrel the gas expands (its volume increases), so the pressure difference reduces and the force falls below its initial value...... [3]

- 3 A sample of argon gas is very slowly compressed in a piston as indicated in **Fig. 3.1**.

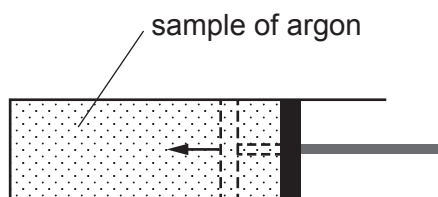


Fig. 3.1

- (a) Draw graphs on **Fig. 3.2a** and **Fig. 3.2b** showing how the pressure P of the gas varies with the volume V and how the pressure varies with $\frac{1}{V}$. Assume that the temperature of the gas does not change during compression.

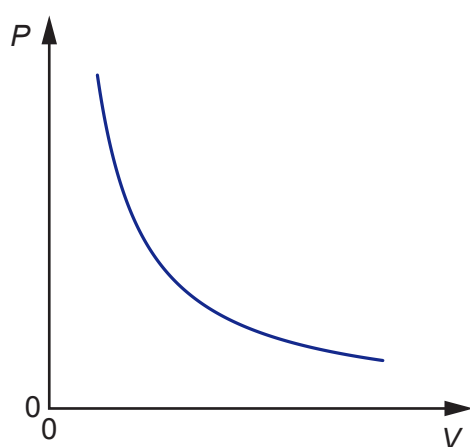


Fig. 3.2a

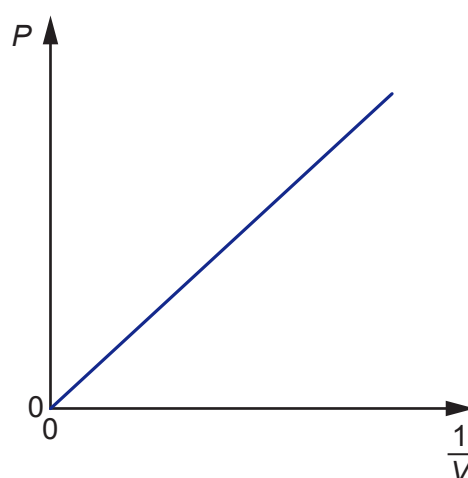


Fig. 3.2b

[2]

- (b) The temperature of the gas is 298 K. The mass of an argon atom is 6.6×10^{-26} kg.

Show that the root mean square speed of the atoms is about 430 m s^{-1} .

$$\frac{1}{2} m \langle c^2 \rangle = \left(\frac{3}{2} \right) kT, \text{ so mean square speed } \langle c^2 \rangle = 3kT / m$$

$$\text{mean square speed} = 3 \times 1.38 \times 10^{-23} \times 298 / 6.6 \times 10^{-26}$$

$$= 1.87 \times 10^5 \text{ m}^2 \text{ s}^{-2}$$

$$c_{\text{rms}} = \sqrt{(1.87 \times 10^5)} = 432 \text{ m s}^{-1}, \text{ which is about } 430 \text{ m s}^{-1}$$

[3]

- (c) This part of the question considers how the behaviour of the gas changes if the piston is moved in quickly.

An argon atom moving at $+430 \text{ m s}^{-1}$ strikes the face of the piston which is moving at -1.5 m s^{-1} as represented in **Fig. 3.3**.

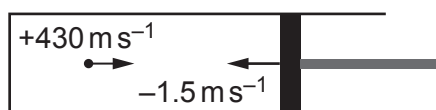


Fig. 3.3

- (i) The collision between the atom and the piston is elastic. Explain why the velocity of the gas atom is -433 m s^{-1} after the collision.

Relative velocity before = $430 - (-1.5) = +431.5 \text{ m s}^{-1}$

Elastic: relative velocity reversed, -431.5 m s^{-1} relative to piston

Velocity relative to cylinder = $-431.5 + (-1.5) = -433 \text{ m s}^{-1}$

[2]

- (ii) Describe and explain how the behaviour of the gas would change if the gas were compressed more quickly.

You may use equations and refer to your graphs in **Fig. 3.2a** and **3.2b** in your explanation.

The moving piston does work on the atoms: they gain k.e. (speed)

Increased mean k.e. of the atoms is a temperature increase

$pV = nRT$: smaller V gives a greater temperature rise, so p is greater

for a given volume and the p against $1/V$ line curves upwards

(increasing gradient)

More frequent collisions with walls: greater p at a given volume

[3]

SECTION B

- 4 **Fig. 4.1** shows apparatus that demonstrates standing waves in air. The two speakers, separated by about 2 metres, are connected to the same signal generator, producing coherent oscillations.

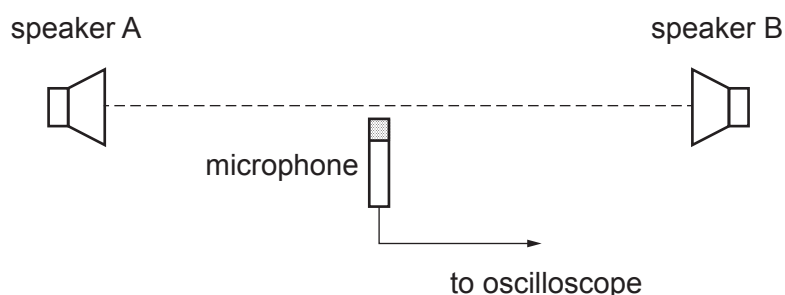


Fig. 4.1

- (a) Explain how standing waves are set up in between the two speakers and how this is observed.

Coherent waves from both speakers travel in opposite directions and
superpose.
Where they meet in phase an antinode forms: as the microphone is moved
along, the oscilloscope shows maximum amplitude.
In antiphase (180°) a node forms: minimum amplitude. [3]

- (b) (i) The signal generator vibrates the speakers at a frequency of 3.00 kHz. The microphone detects positions of minimum amplitude (nodes) separated by 5.60 cm.

Calculate the velocity of sound in air.

$$\text{node to node} = \lambda/2, \text{ so } \lambda = 2 \times 5.60 \text{ cm} = 11.2 \text{ cm} = 0.112 \text{ m}$$

$$v = f\lambda = 3000 \times 0.112$$

velocity of sound = 336 ms⁻¹ [1]

- (ii) A student suggests that a more accurate determination of the velocity of sound could be made if the distance between several nodes was measured instead of the distance between adjacent nodes. Explain the student's reasoning.

*The distance measured across several nodes is larger,
but the absolute uncertainty in reading the positions stays the same,
so the percentage (fractional) uncertainty in the distance is smaller.
This gives a smaller (absolute) uncertainty in λ and so in the final
value of v .* [3]

- (c) The electron in a hydrogen atom can be modelled as a standing wave in a box of length equal to that of the diameter of the atom as indicated in Fig. 4.2.

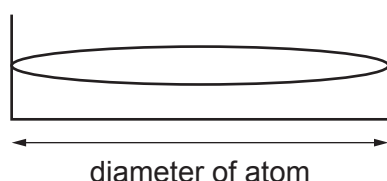


Fig. 4.2

- (i) Show that the momentum of an electron in a box of length $2.4 \times 10^{-10} \text{ m}$ is about $1.4 \times 10^{-24} \text{ kg m s}^{-1}$.

$$\lambda = 2 \times \text{box length} = 2 \times 2.4 \times 10^{-10} = 4.8 \times 10^{-10} \text{ m}$$

$$p = h / \lambda = 6.63 \times 10^{-34} / 4.8 \times 10^{-10} = 1.38 \times 10^{-24} \text{ kg m s}^{-1}$$

[1]

- (ii) Calculate the kinetic energy of the electron.

$$E_k = p^2 / 2m = (1.38 \times 10^{-24})^2 / (2 \times 9.11 \times 10^{-31})$$

$$\text{kinetic energy} = 1.0 \times 10^{-18} \text{ J} \quad [2]$$

- (iii) Calculate the potential energy of an electron at a distance of 1.2×10^{-10} m from a proton.

$$E_p = -kQq / r = -8.98 \times 10^9 \times (1.6 \times 10^{-19})^2 / 1.2 \times 10^{-10}$$

potential energy = -1.9×10^{-18} J [2]

- (iv) Use your answers to (ii) and (iii) to explain whether or not the electron would escape from the proton at this distance and explain how an estimate for the minimum size of a hydrogen atom can be calculated.

Total energy = $1.0 \times 10^{-18} + (-1.9 \times 10^{-18}) = -9.0 \times 10^{-19}$ J, which
is negative.
So the electron is bound to the proton and would not escape.
For a smaller box the k.e. rises ($\propto 1/d^2$) faster than the p.e. falls: the
minimum size is found where total energy = 0, i.e. k.e. = magnitude of
p.e. [3]

- 5 This question is about using alpha particles in radiotherapy. **Fig. 5.1** shows a graph of the number of ion-pairs formed by an alpha particle travelling through air. After 70 mm the alpha particle captures two electrons to become a helium-4 atom and ionisation stops.

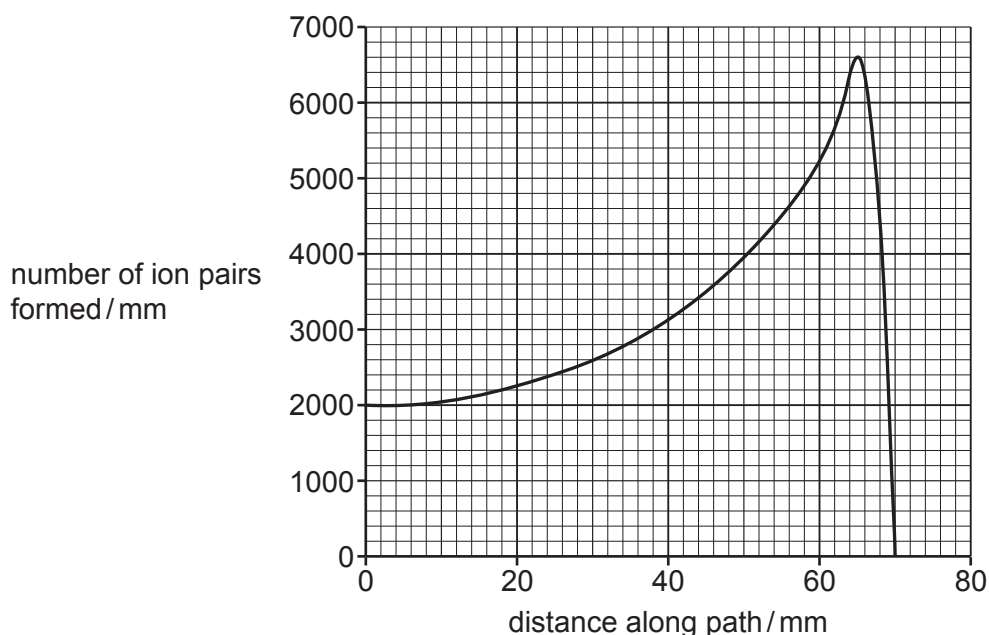


Fig. 5.1

- (a) (i) State how the graph shows that an alpha particle produces about 240 000 ion pairs along its track.

The area under the line gives the total number of ion pairs formed.

[1]

- (ii) It takes about 30 eV to produce an ion-pair. Estimate the kinetic energy of the alpha particle when it is ejected from a nucleus. Explain your reasoning.

Reasoning: *Each ionisation transfers about 30 eV from the alpha particle's k.e., until all of it is transferred.*

$$k.e. = 240\,000 \times 30 \text{ eV} = 7.2 \times 10^6 \text{ eV}$$

kinetic energy = *7.2* MeV [2]

- (iii) Explain why beta particles have a longer range in air than alpha particles of the same initial energy.

Beta particles are less ionising (interact less often with air molecules), so fewer ionisations per mm: they travel further before losing all their energy.

[2]

- (b) (i) $^{224}_{88}\text{Ra}$ (radium-224) is an alpha emitter that can be used in radiotherapy. It decays as shown:



Assuming that the radium nucleus is stationary when it emits an alpha particle, use the principle of conservation of momentum to calculate the percentage of the kinetic energy released in the decay transferred to the alpha particle.

momentum conserved: $0 = m_{\alpha}v_{\alpha} - m_{\text{Rn}}v_{\text{Rn}}$, so $4v_{\alpha} = 220v_{\text{Rn}}$

$v_{\alpha} / v_{\text{Rn}} = 220 / 4 = 55$

$k.e. = p^2/2m$; same p , so $k.e._{\alpha} / k.e._{\text{Rn}} = 220 / 4 = 55$

$k.e. \text{ of alpha} / \text{total } k.e. = 55 / (55 + 1) = 55/56 = 0.98$

proportion of kinetic energy transferred to alpha particle = ...**98**..... % [2]

- (ii) Alpha emitters can be implanted into body tissue. The range of alpha particles in the tissue is typically about 0.1 mm.

State why the range is smaller in tissue than in air.

...Tissue is denser: atoms are closer together, so there are more.....

...ionisations per mm..... [1]

- (iii)* Use the data below to calculate the energy of an alpha particle released when a nucleus of radium decays. Use this figure to calculate the effective dose delivered to a group of cells of total mass 0.004 kg over two hours, a period much shorter than the half-life of radium. State and explain any assumptions you make in the calculation and whether you think they are reasonable.

mass of radium nucleus = 223.97191 u

mass of radon nucleus = 219.9642 u

mass of alpha particle = 4.00150 u

quality factor of alpha radiation = 20

activity of alpha source = 18 kBq

density of tissue = 990 kg m⁻³

$$\text{Mass defect} = 223.97191 - (219.9642 + 4.00150) = 6.21 \times 10^{-3} \text{ u}$$

$$= 6.21 \times 10^{-3} \times 1.66 \times 10^{-27} = 1.03 \times 10^{-29} \text{ kg}; E = mc^2 = 1.03 \times$$

$$10^{-29} \times (3.00 \times 10^8)^2 = 9.28 \times 10^{-13} \text{ J per decay.}$$

$$\text{The alpha takes 98\% of this (from (b)(i)): } 0.98 \times 9.28 \times 10^{-13} =$$

$$9.11 \times 10^{-13} \text{ J.}$$

$$\text{Decays in 2 hours} = 18 \times 10^3 \times 7200 = 1.30 \times 10^8, \text{ so energy} =$$

$$1.30 \times 10^8 \times 9.11 \times 10^{-13} = 1.18 \times 10^{-4} \text{ J.}$$

$$\text{Dose} = 1.18 \times 10^{-4} / 0.004 = 0.0295 \text{ Gy; effective dose} = 20 \times$$

$$0.0295 = 0.59 \text{ Sv.}$$

Assumption 1: the activity stays constant at 18 kBq over the two hours. Reasonable, as the half-life is much longer than two hours.

Assumption 2: all alpha energy is absorbed by the cells. Reasonable:

$$\text{volume} = 0.004/990 = 4.0 \times 10^{-6} \text{ m}^3, \text{ a sphere of radius } 9.9 \text{ mm,}$$

much bigger than the 0.1 mm range in tissue.

Assumption 3: the energy is spread evenly through all the cells. Not

likely, because the very short range means cells near the source get a

much larger dose and distant cells almost none.

[6]

- 6 **Fig. 6.1** shows wavefronts produced by a very small object. The wavefronts are approaching a converging lens.

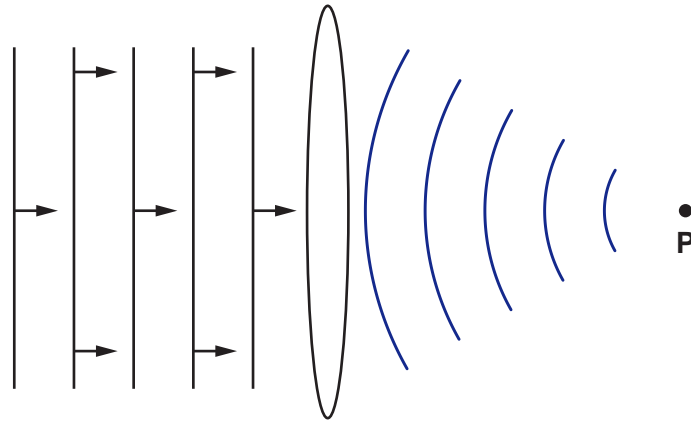


Fig. 6.1

- (a) (i) What feature of **Fig. 6.1** shows that the object producing the wavefronts is a long way from the lens?

The wavefronts are plane (zero curvature), not diverging...... [1]

- (ii) Add wavefronts to the right of the lens which focus at point P.

[1]

- (iii) The lens adds curvature of +1.8D to the waves. Calculate the distance from the lens to point P. Explain your reasoning.

$$\text{curvature in} = 1/u = 0 \text{ (} u \text{ very large)}$$

$$\text{curvature out} = 0 + 1.8 = +1.8 \text{ D}$$

$$\text{distance} = 1 / \text{curvature} = 1 / 1.8$$

$$\text{distance to P} = 0.56 \dots \text{ m}$$

Reasoning: *waves from a distant object have zero curvature,*.....

$$\text{so } 1/v = 1.8 \text{ D after the lens and } v = 1/1.8 = 0.56 \text{ m} \dots [2]$$

- (b) Simple lenses can produce chromatic aberration, resulting in different lens-powers for different colours. This happens because different wavelengths of light travel through glass at different speeds.

- (i) Complete the table below of the refractive index from air to glass for different wavelengths of light.

velocity of all wavelengths in air = $3.00 \times 10^8 \text{ m s}^{-1}$

wavelength/nm	velocity of light in glass / m s^{-1}	refractive index
410	$1.81 \times 10^8 \text{ m s}^{-1}$	1.66
710	$1.85 \times 10^8 \text{ m s}^{-1}$	1.62

[2]

- (ii) Explain why the power of the lens will be greater for shorter wavelength light and the effect this will have on the focal length of the lens for light of different wavelengths.

..Shorter wavelengths are slower in glass, so higher refractive index:.....

..greater change of direction of wavefronts (greater added curvature), so

..greater power.....

..So longer wavelengths have longer focal lengths..... [2]

(c) Fig. 6.2 shows a highly simplified diagram of the eye.

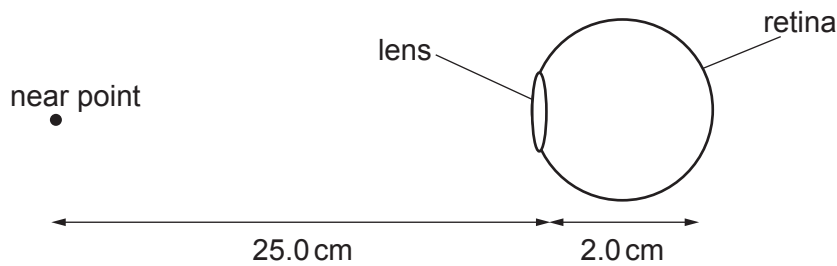


Fig. 6.2 (not to scale)

The distance between the lens and the retina, the surface on which the image is formed, is 2.0 cm.

The curvature of the eye lens increases as it focuses on nearby objects. The nearest point an object can be brought to focus by a person with normal vision is 25 cm. This is called the near-point.

- (i) This letter **X** is approximately 4 mm high. Calculate the height of the image of the **X** on the retina of a person with normal vision when viewed from the near point of 25 cm.

$$\text{image height} = \text{object height} \times v/u$$

$$= 4 \text{ mm} \times (2.0 / 25) = 0.32 \text{ mm}$$

$$\text{image height} = \dots 3.2 \times 10^{-4} \dots \text{ m [2]}$$

If an individual is unable to focus as close as 25 cm they can use a converging lens to bring the image into focus.

- (ii) Calculate the power of a lens required to allow a person with a near point of 50 cm to focus an object at a distance of 25 cm.

$$\text{power to focus at 25 cm} = 1/0.25 + 1/0.020 = 4 + 50 = +54.0 \text{ D}$$

$$\text{power eye has (near point 50 cm)} = 1/0.50 + 1/0.020 = 2 + 50 = +52.0 \text{ D}$$

$$\text{lens power} = 54.0 - 52.0$$

$$\text{lens power} = \dots +2.0 \dots \text{ D [2]}$$

(d) Here are some data about two materials used for spectacle lenses.

material	density / kg m^{-3}	refractive index
high-index glass	3.2×10^3	1.70
plastic (polycarbonate)	1.2×10^3	1.59

Explain why high-index glass might be chosen for more powerful spectacle lenses whereas polycarbonate might be a better choice for lower power lenses. Make your reasoning clear.

Higher refractive index adds more curvature for a given lens shape, so
 high-index glass gives thinner lenses for a given power.
 This matters most for high power lenses, as the curvature of the lens is
 greater (they would be very thick).
 For low power lenses, polycarbonate (lower density) gives lighter, more
 comfortable lenses. [3]

SECTION C

This section is based on the **Advance Notice Article**.

- 7 This question is about a simple generator (lines 19–27). **Fig. 7** shows how the flux through a square coil varies with time as the coil rotates in a uniform magnetic field.

The emf ε generated is given by the equation

$$\varepsilon = \text{maximum flux linkage} \times 2\pi f \sin(2\pi ft)$$

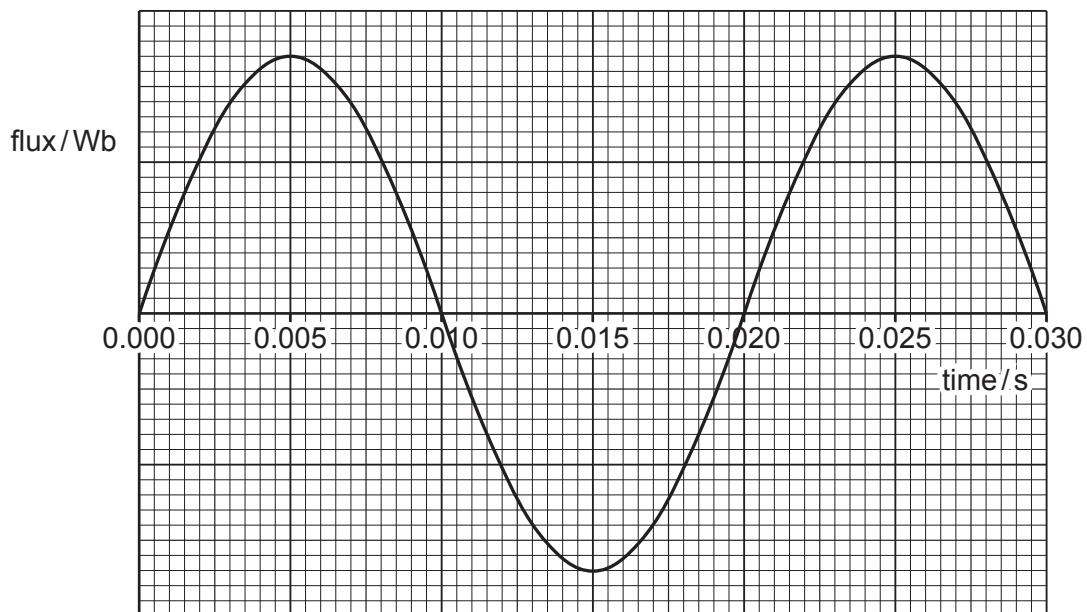


Fig. 7

The maximum e.m.f. induced in the coil is 24.0 V.

- (a) (i) Calculate the maximum flux linkage in the coil.

From Fig. 7, $T = 0.020$ s, so $f = 50$ Hz

$$24.0 = 2\pi f \times \text{max flux linkage} = 100\pi \times \text{max flux linkage}$$

$$\text{max flux linkage} = 24.0 / 100\pi$$

$$\text{maximum flux linkage} = \underline{0.076} \dots \text{ Wb turns [2]}$$

- (ii) The coil has sides of length 12 cm. It has 400 turns. Calculate the flux density B of the magnetic field.

$$\text{flux linkage} = NBA$$

$$0.076 = 400 \times 0.12^2 \times B$$

$$B = 0.0764 / 5.76$$

$$\text{flux density } B = \underline{0.013} \dots \text{ T [2]}$$

- (b) Suggest and explain two modifications to the generator that would increase the e.m.f. induced without changing the frequency of the rotor. You may refer to equations in your explanations.

1. Increase the number of turns N on the coil: this increases the flux linkage $N\Phi$ for the same flux, and $\varepsilon = N\Phi \times 2\pi f \sin(2\pi ft)$, so the maximum e.m.f. increases.

2. Reduce the air gap between rotor and stator (or decrease the length of the magnetic circuit): this increases the permeance of the magnetic circuit, so the flux Φ increases.

With greater flux the rate of change of flux linkage is greater, so by Faraday's law $\varepsilon = -d(N\Phi)/dt$ the e.m.f. is larger at the same frequency.

..... [4]

8 This question is about the output power from a wind farm (lines 29–41).

- (a) Use the concept of the kinetic energy of a volume of air moving with velocity v to show that the power of the wind striking area A is given by

$$P = \frac{1}{2} \rho A v^3$$

where ρ is the density of the air.

In time t the air moving at v travels a distance vt through area A .

volume of air = Avt , so mass = ρAvt

mass transferred per second = ρAv

k.e. = $\frac{1}{2} m v^2$

power = k.e. transferred per second = $\frac{1}{2} (\rho Av) v^2$

$P = \frac{1}{2} \rho A v^3$

[2]

(b)* Here are some data about a wind farm:

efficiency = 43%
 turbine height = 90 m
 blade diameter = 120 m
 number of turbines = 85
 density of air = 1.2 kg m^{-3}
 output power = 900 MW.

Use the data above and the equations in the article to estimate the wind speed at a height of 10 m required to produce this power. Explain your method.

Total input power = output / efficiency = $900 \text{ MW} / 0.43 = 2093 \text{ MW}$

Input power per turbine = $2093 / 85 = 24.6 \text{ MW}$

Swept area $A = \pi r^2 = \pi \times 60^2 = 1.13 \times 10^4 \text{ m}^2$; use $P = \frac{1}{2} \rho A v^3$ to find the wind speed at turbine height (90 m).

Then use the article's height relationship to scale the speed at 90 m down to 10 m.

$$24.6 \times 10^6 = \frac{1}{2} \times 1.2 \times \pi \times 60^2 \times v^3$$

$$v^3 = 24.6 \times 10^6 / 6790 = 3.62 \times 10^3, \text{ so } v = 15.4 \text{ m s}^{-1} \text{ at } 90 \text{ m}$$

$$\text{speed at height } h: v_h = v_{10} \times (h / 10)^{1/7}$$

$$15.4 = v_{10} \times (90 / 10)^{1/7} = v_{10} \times 1.37$$

$$v_{10} = 15.4 / 1.37 = 11.2 \text{ m s}^{-1}$$

wind speed = 11 m s⁻¹ [6]

- 9 This question is about a small hydroelectric turbine. Water flows down a penstock from a head height of 195 m. (See Figs 4 and 5 in the article.)

The output power of the turbine is 94.5 kW.

Flow rate of water = 55 kg s^{-1} .

- (a) Calculate the efficiency at which the potential energy of the water is transferred to energy output.

$$\text{change in p.e. per second} = (m/t)gh = 55 \times 9.81 \times 195 = 1.05 \times 10^5 \text{ W}$$

$$\text{efficiency} = 94.5 \text{ kW} / 105 \text{ kW} \times 100\% = 0.90 \times 100\%$$

$$\text{efficiency} = \dots 90 \dots \% \quad [2]$$

- (b) (i) Consider water flowing from a pipe of cross-sectional area $7.9 \times 10^{-3} \text{ m}^2$.

Water flows out of the pipe at a rate of $55 \times 10^{-3} \text{ m}^3 \text{ s}^{-1}$. Show that the velocity of the water leaving the pipe is about 7 m s^{-1} .

$$v = \text{volume flow rate} / \text{area} = 55 \times 10^{-3} / 7.9 \times 10^{-3} = 6.96 \text{ m s}^{-1} \approx 7 \text{ m s}^{-1}$$

[1]

The water strikes a surface and divides as shown in **Fig. 9**. The horizontal velocity of the water reduces to zero when it strikes the surface.

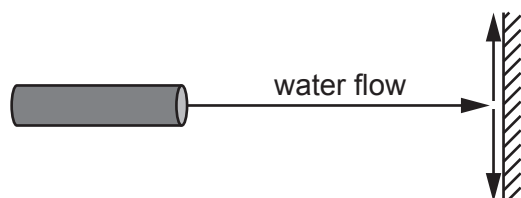


Fig. 9

- (ii) Calculate the magnitude of the force exerted on the surface.

density of water = 1000 kg m^{-3}

$$F = \text{rate of change of momentum} = (m/t)(v - u)$$

$$= 1000 \times 55 \times 10^{-3} \times 6.96 = 383 \text{ N}$$

$$\text{force} = \dots 383 \dots \text{ N} \quad [2]$$

- (iii) Maximum power is extracted from a Pelton turbine when the velocity of the turbine vane is half that of the water jet.

Calculate the maximum power that can be transferred to the generator when the water in the situation described in (b)(i) strikes a surface moving to the right with a velocity of 3.5 m s^{-1} .

velocity of the vane relative to the water = $6.96 - 3.5 \approx 3.5 \text{ m s}^{-1}$,

half the jet speed, so the force is half the value in (b)(ii):

$$F = 383 / 2 = 191.5 \text{ N}$$

$$P = Fv = 191.5 \times 3.5 = 670 \text{ W}$$

$$\text{power} = \underline{670} \dots\dots\dots \text{ W [2]}$$

- (iv) Describe and explain how the design of the vane increases the power output of the Pelton turbine (see Fig. 7 in the article).

*The cup-shaped vane turns the water round, so the 'reflected' water
leaves with velocity in the opposite direction to the incoming jet.
The change in velocity of the water is therefore larger than in (b)(ii),
where it only fell to zero (up to twice as large),
giving a greater change in momentum per second for the same mass of
water per second,
so the force F on the vane is greater and $P = Fv$ is greater for the
same vane speed. The split (double cup) shape sends the water out to
the sides so it does not interfere with the incoming jet.* [4]

END OF QUESTION PAPER

[illegible]

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