

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE
NAME

SOLUTION

CLASS

TUTOR'S
NAME

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INDEX
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PHYSICS

9478/03

Paper 3 Longer Structured Questions

21 September 2026

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class, Centre number and index number in the spaces at the top of this page.

Write in dark blue or black pen on both sides of the paper.

You may use a HB pencil for any diagrams, graphs.

Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Section A

Answer **all** questions.

Section B

Answer **one** question only.

You are advised to spend one and a half hours on Section A and half an hour on Section B.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [] at the end of each question or part question.

For Examiner's Use	
Section A	
1	/ 7
2	/ 8
3	/ 7
4	/ 8
5	/ 9
6	/ 6
7	/ 10
Section B	
8	/ 20
9	/ 20
Total	/ 75

This document consists of **28** printed pages.

Data

speed of light in free space

permeability of free space

permittivity of free space

elementary charge

the Planck constant

unified atomic mass constant

rest mass of electron

rest mass of proton

molar gas constant

Avogadro constant

Boltzmann constant

gravitational constant

acceleration of free fall

$$c = 3.00 \times 10^8 \text{ m s}^{-1}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$$

$$\varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$$

$$\left(\frac{1}{4\pi\varepsilon_0}\right) = 8.99 \times 10^9 \text{ m F}^{-1})$$

$$e = 1.60 \times 10^{-19} \text{ C}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$u = 1.66 \times 10^{-27} \text{ kg}$$

$$m_e = 9.11 \times 10^{-31} \text{ kg}$$

$$m_p = 1.67 \times 10^{-27} \text{ kg}$$

$$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$$

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

$$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

$$g = 9.81 \text{ m s}^{-2}$$

Formulae

uniformly accelerated motion

$$s = ut + \frac{1}{2}at^2$$

work done on / by gas

$$v^2 = u^2 + 2as$$

pressure

$$W = p \Delta V$$

$$p = \frac{F}{A}$$

gravitational potential

$$\phi = -\frac{GM}{r}$$

temperature

$$T / K = T / ^\circ\text{C} + 273.15$$

pressure of an ideal gas

$$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$$

mean translational kinetic energy of an ideal gas particle

$$E = \frac{3}{2}kT$$

displacement of particle in s.h.m.

$$x = x_0 \sin \omega t$$

velocity of particle in s.h.m.

$$v = v_0 \cos \omega t = \pm \omega \sqrt{(x_0^2 - x^2)}$$

electric current

$$I = Anvq$$

resistors in series

$$R = R_1 + R_2 + \dots$$

resistors in parallel

$$1/R = 1/R_1 + 1/R_2 + \dots$$

capacitors in series

$$1/C = 1/C_1 + 1/C_2 + \dots$$

capacitors in parallel

$$C = C_1 + C_2 + \dots$$

energy in a capacitor

$$U = \frac{1}{2}QV = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2}CV^2$$

charging a capacitor

$$Q = Q_0 [1 - e^{-\frac{t}{\tau}}]$$

discharging a capacitor

$$Q = Q_0 e^{-\frac{t}{\tau}}$$

RC time constant

$$\tau = RC$$

electric potential

$$V = \frac{Q}{4\pi\epsilon_0 r}$$

alternating current / voltage

$$x = x_0 \sin \omega t$$

magnetic flux density due to a long straight wire

$$B = \frac{\mu_0 I}{2\pi d}$$

magnetic flux density due to a flat circular coil

$$B = \frac{\mu_0 NI}{2r}$$

magnetic flux density due to a long solenoid

$$B = \mu_0 nI$$

energy states for quantum particle in a box

$$E_n = \frac{h^2}{8mL^2} n^2$$

radioactive decay

$$x = x_0 e^{-\lambda t}$$

radioactive decay constant

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$$

Section A

Answer **all** the questions in the spaces provided.

- 1 Two spheres A and B of masses 3.7 kg and 2.7 kg respectively are attached to two light inextensible strings L_1 and L_2 each of length 0.50 m.

The combination of masses is made to swing in a vertical circle with both strings always in a straight line, as shown in Fig. 1.1.

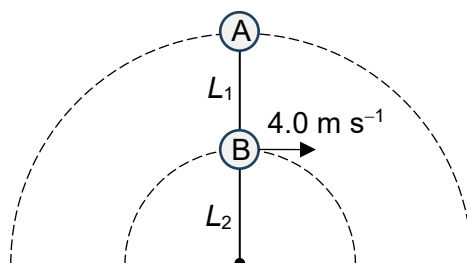


Fig 1.1

At the top of its motion, mass B is travelling at 4.0 m s^{-1} .

- (a) Determine the speed of mass A at this instant.

Both masses have the same angular velocity.

$$v = r\omega$$

$$\frac{v_A}{r_A} = \frac{v_B}{r_B} \Rightarrow \frac{v_A}{0.5 + 0.5} = \frac{4.0}{0.5} \quad [\text{M1}]$$

$$v_A = 8.0 \text{ m s}^{-1} \quad [\text{A1}]$$

speed of mass A = m s^{-1} [2]

- (b) Show that the tension in L_1 at this instant is 200 N.

$$W_A + T_A = \frac{mv^2}{r}$$

$$T_A = \frac{mv^2}{r} - W_A$$

$$= \frac{(3.7)(8.0)^2}{0.50 + 0.50} - (3.7)(9.81) \quad [\text{M1}]$$

$$= 200 \text{ N} \quad [\text{A0}]$$

[1]

(c) Hence or otherwise, determine the tension in L_2 at this instant.

$$\begin{aligned}
 W_B + T_B - T_A &= \frac{m_B v_B^2}{r_B} \\
 T_B &= \frac{m_B v_B^2}{r_B} - W_B + T_A \\
 &= \frac{(2.7)(4.0)^2}{0.50} - (2.7)(9.81) + 201 \quad [\text{M1}] \\
 &= 261 \text{ N} \quad [\text{A1}]
 \end{aligned}$$

Comments:

Always sketch FBDs to help visualise the forces. The addition of the forces will give rise to the net resultant force towards the center of the circular path.

tension in L_2 = N [2]

(d) At another instant in time, the combination of masses is at the bottom of its motion as shown in Fig. 1.2.

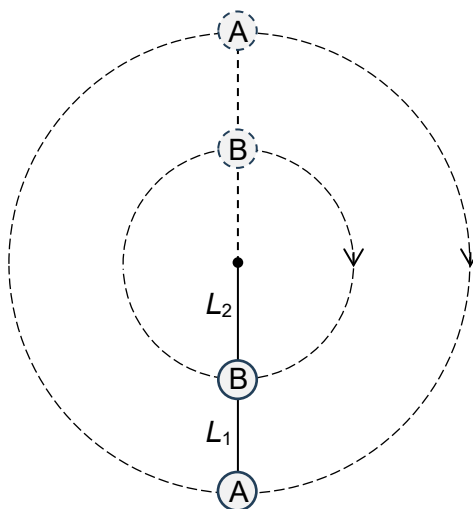


Fig 1.2

A student suggests that because the tensions in strings L_1 and L_2 change continuously during the motion, the total mechanical energy (i.e. kinetic and potential energy) of the system is not conserved.

With reference to tensions in the strings, state whether you agree with this statement and explain your reasoning.

I disagree with the statement, as tension is **always** acting perpendicular to the direction of motion of both masses [M1] Hence there is no work done by tension and hence total mechanical energy of the system is conserved. [A1] or

I disagree with the statement, as tension is **always** acting perpendicular to the direction of motion of both masses. [M1] Hence there is no work done by tension but there may be other resistive forces and hence mechanical energy is not conserved. [A1].....[2]

Comments:

[Total: 7]

Badly done.

The question is asking whether the changing tensions affect the conservation of energy between KE and GPE of the system. If you recall our treatment of non-uniform vertical circular motion, the normal contact forces always change but we still use COE to calculate the minimum speeds etc. Why? Because tension doesn't do work on the system.

When given new scenarios, always try to recall existing concepts/questions that have similarities and try to rationalise from there.

2 (a) Define gravitational potential at a point

The gravitational potential at a point is defined as the work done per unit mass [B1]
by an external force in bringing a small test mass from infinity to that point. [B1]

Comments:

It was entertaining to see gravitational potential about charges. That being said, it is a good sign that you save those 2 definitions in the same part of your brain. Just don't make that mistake again.

[2]

- (b) (i) The dwarf planet Ceres may be considered to be an isolated uniform sphere of mass 9.4×10^{20} kg and radius 4.7×10^5 m.

A particle is launched vertically upwards from the surface of the planet. Assuming negligible resistance from the planet's atmosphere, determine the minimum speed of this particle that will result in it escaping from the gravitational pull of the planet Ceres.

By conservation of energy,

Total GPE + KE at surface = Total GPE + KE at infinite distance away [C1]

$$\text{GPE}_{\text{surface}} + \text{KE}_{\text{surface}} = \text{GPE}_{r=\infty} + \text{KE}_{r=\infty}$$

$$-\frac{GMm}{r} + \frac{1}{2}mv^2 = 0 + 0$$

$$\frac{GM}{r} = \frac{1}{2}v^2$$

$$\frac{(6.67 \times 10^{-11})(9.4 \times 10^{20})}{4.7 \times 10^5} = \frac{1}{2}v^2 \quad [\text{C1}]$$

$$v = 520 \text{ m s}^{-1} \quad [\text{A1}]$$

Comments:

Majority marks loss is from careless mistakes. More concerning are the students who used $\frac{mv^2}{r}$. Nobody is circulating around anybody here. O yes, and 516.5 is rounded to 517 please.

speed = m s⁻¹ [3]

- (ii) Hydrogen may be assumed to be an ideal gas.
 The mass of a hydrogen molecule is 3.3×10^{-27} kg.

Calculate the root-mean-square (r.m.s.) speed of a hydrogen molecule in hydrogen gas that is at a temperature of 240 K.

$$\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$$

$$\frac{1}{2}(3.3 \times 10^{-27})c_{\text{rms}}^2 = \frac{3}{2}(1.38 \times 10^{-23})(240) \quad [\text{C1}]$$

$$c_{\text{rms}} = 1700 \text{ m s}^{-1} \quad [\text{A1}]$$

Comments:

- Starting with any of the following $\frac{1}{3}Nm\langle c^2 \rangle = PV = NkT = nRT$ is also acceptable.
- Some used avogadro's number somewhere. This indicates that either students didn't realise that 3.3×10^{-27} kg is mass of 1 molecule, or they didn't know that the magenta coloured m above is actually the mass of **ONE** molecule.

- (c) The surface of planet Ceres reaches temperatures of approximately 240 K when in direct sunlight.

Use your answers in (b)(i) and (b)(ii) to suggest a reason why Ceres does not have an atmosphere consisting of hydrogen.

Since r.m.s. speed of hydrogen molecules is more than the escape velocity on the surface of Ceres, the hydrogen molecules have sufficient kinetic energy to overcome the gravitational pull of the planet Ceres and escape to infinity.

[1]

Comments:
It was mostly well done.

[Total: 8]

3 A fixed amount of an ideal gas of mass 0.35 kg has pressure 2.0×10^5 Pa and volume 0.038 m^3 .

(a) In one process, the gas is heated at constant pressure so that its internal energy increases by 7600 J, volume increases by 0.025 m^3 and temperature increases by 56°C .

(i) Determine the thermal energy Q transferred to the gas.

$$W_{on} = -p\Delta V = -(2.0 \times 10^5)(0.025) \\ = -5000 \text{ J} \quad [\text{C1}]$$

$$\Delta U = Q + W_{on} \\ 7600 = Q + (-5000)$$

$$Q = 12600 \text{ J} \quad [\text{A1}]$$

Comments:

Generally well done.

$Q = \dots\dots\dots \text{ J} \quad [2]$

(ii) Calculate the specific heat capacity of the gas for this process. Give a unit with your answer.

$$Q = mc\Delta T \\ 12600 = 0.35c(56) \\ c = 640 \quad [\text{A1}] \text{ J kg}^{-1} \text{ K}^{-1} \quad [\text{A1}]$$

Comments:

- $\Delta T = 56^\circ\text{C} = (56 + 273)\text{K} - (0 + 273)\text{K} = 56 \text{ K}$
 $\Delta T \neq 56 + 273 \text{ K}$
- Units is not $\text{J kg}^{-1} \text{ C}^{-1}$. C is coulomb.

$\dots\dots\dots [2]$

(b) In another process, the gas is heated at constant volume so that the increase in internal energy of the gas is the same as in (a).

Use the first law of thermodynamics to explain whether the specific heat capacity of the gas for this process is less than, the same as, or greater than the answer in (a)(ii).

No change in volume means no work is done, $W = 0$. [B1]

By first law of thermodynamics, $\Delta U = Q + W$, since ΔU remains the same and $W = 0$ instead of being negative, Q will be lower. The same gain in internal energy, ΔU implies the same increase in temperature. [M1]

Less thermal energy Q needed for same temperature change means a lower specific heat capacity. [A1]

Comments:

- Many missed out that ΔT is the same. This cost them both the both the [M1] and [A1] mark.
- When explaining First Law in words, Q cannot be referred to as just "energy supplied". "Energy" is too general and refers to work done as well.
- Writing First Law as just $U = Q + W$ is also incorrect, as $U \neq \Delta U$.
- Some incorrectly thought $\Delta U = \Delta Q + \Delta W$. This led to them thinking that $\Delta W = 0$, thus incorrectly described it as "work done remained constant" instead of equals to zero.

- 4 (a) Fig. 4.1 shows a circular coil of 500 turns and radius 0.12 m.

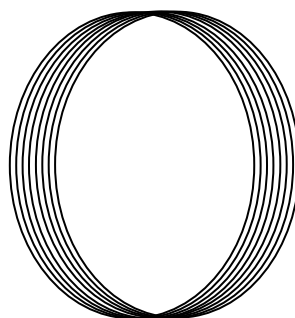


Fig. 4.1

A varying magnetic field is applied at right angles to the plane of the coil. Fig. 4.2 shows the variation with time t of this magnetic field of flux density B .

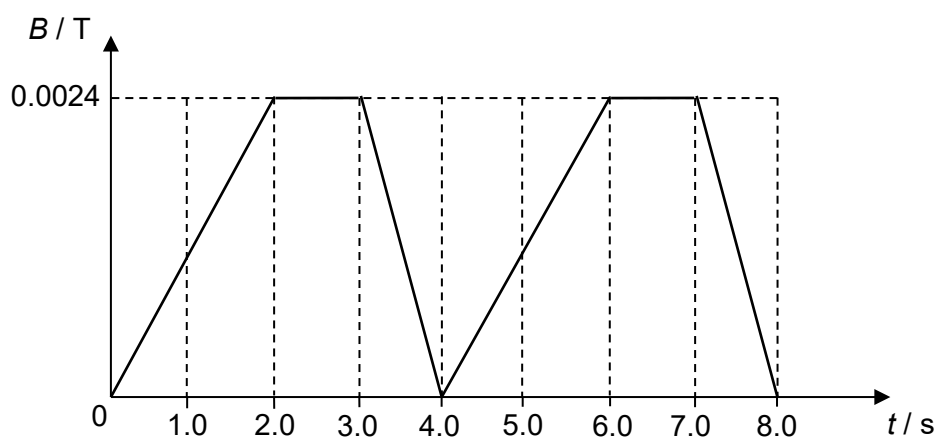


Fig. 4.2

- (i) On Fig. 4.3, sketch a graph to show the variation with time t of the induced e.m.f. E in the coil. Include values on the y axis.

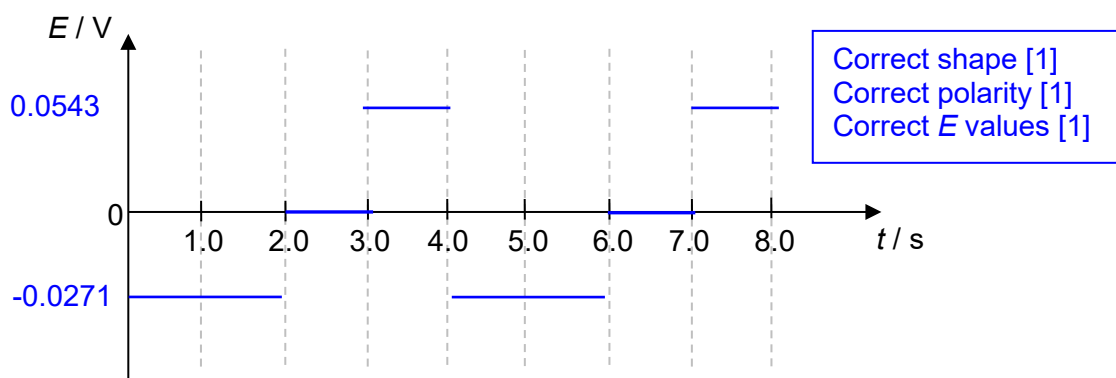


Fig. 4.3

[3]

- (ii) Hence, determine the r.m.s value of the induced e.m.f.

$$\begin{aligned} \text{r.m.s.} &= \sqrt{\frac{(0.0271^2 \times 2) + (0.0543^2 \times 1)}{4}} \quad \text{M1} \\ &= 0.0332\text{A} \quad \text{A1} \end{aligned}$$

r.m.s. value of induced e.m.f. = V [2]

- (iii) The e.m.f. source that you have sketched in Fig. 4.3 is now connected in series with a resistor R and an ideal diode as shown in Fig. 4.4.

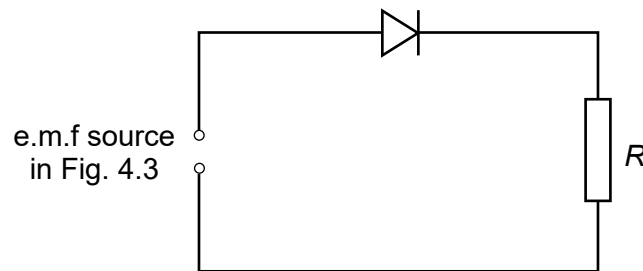


Fig. 4.4

State and explain the potential difference across R when the ideal diode has maximum potential difference across it.

When diode has maximum p.d. across it, it is reverse bias / not conducting / has infinite resistance. [M1].

The sum of the p.d. across R and diode must equal to the e.m.f. of the supply. [M1]

Since resistance of R is insignificant compared to that of diode, p.d. across R is zero. [3]

[A1]. OR The total resistance of the circuit is infinite and the current in the circuit is zero. [Total: 8]

zero. [M1] Since there is no current in R , p.d. across R is zero. [A1]

No credit is given for simply writing "by potential divider rule" without stating how it is used and the values of the resistances and the p.d.s.

- 5 (a) A straight rigid conducting wire of mass 0.14 kg and length 0.40 m is placed horizontally on a frictionless plastic plane. The plane is at an angle of 20° to the horizontal and is placed in a region of upwards uniform vertical magnetic field as shown in Fig. 5.1 and Fig. 5.2.

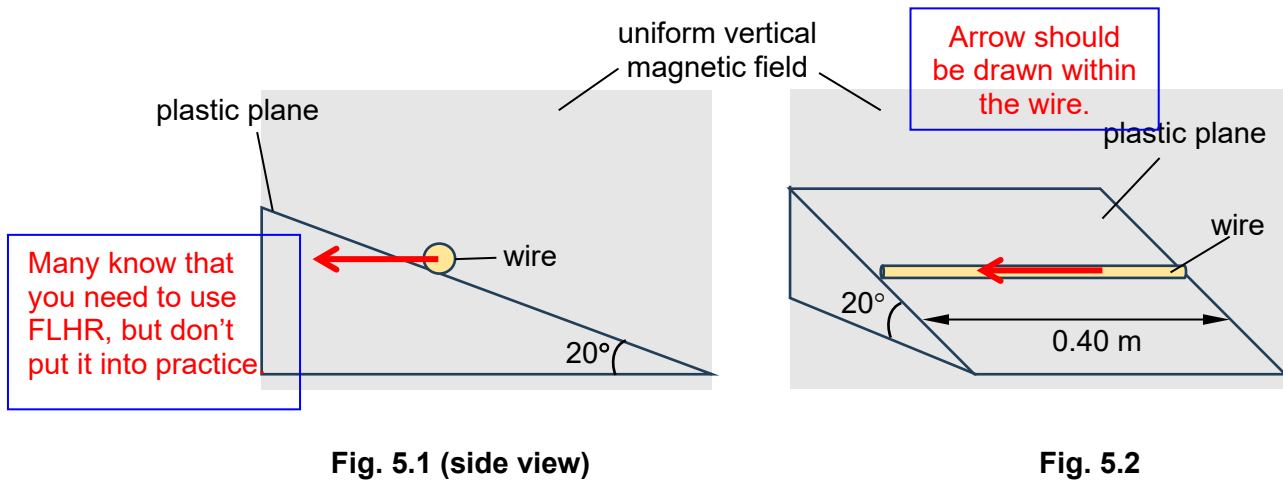


Fig. 5.1 (side view)

Fig. 5.2

To prevent the wire from sliding down the plane, a steady current I is passed through the wire so that it remains stationary on the plastic plane.

- On Fig. 5.1, draw an arrow to show the direction of the magnetic force acting on the wire. [1]
- On Fig. 5.2, draw an arrow to show the direction of the current I in the wire. [1]
- With reference to forces acting on the wire, explain why the wire remains stationary.

The direction of current I is perpendicular to the magnetic field/ flux density B and by Flemings left hand rule, experiences a force perpendicular to both I and B , acting leftwards. (Fig. 5.1) [B1] The wire remains stationary when the component of the magnetic force upwards along the plane balances the component of weight downwards along the plane. [2]

[2]

Comments:

The process use to deduce the direction of the force is needed to be see (and correct) for credit. Please write 'by Fleming's left hand rule'.

There is NO horizontal components of weight! Please learn to use proper terms. COMPONENT of weight along the plane etc. You need to work on terminology.

The best way for such questions is to always sketch a free body diagram!

- (iv) Suggest and explain whether the wire will eventually slide up, remain stationary or slide down the plane if an alternating current of root-mean-square value of I is passed through the wire instead.

The current I will alternate between positive and negative values, and the component of magnetic force ($\propto I$) will alternate between acting upwards and downwards along the plane.

Since the average I and hence magnetic force between cycles is zero, it cannot balance the component of weight downwards along the plane. Hence the rod will slide down the plane.

Or?

The current I will alternate between positive and negative values, and the component of magnetic force ($\propto I$) will alternate between acting upwards and downwards along the plane. [2]

Since $I_{\text{rms}} = 0.707 I_0$, the time duration at which the a.c current causes a **net** upward force along plane (when upward $F_{\text{m}\parallel} > W_{\parallel}$ to slope downwards) is shorter than when there is a net downward force. Hence the rod will slide down the plane.

Comments:

Alternating a.c. means at the force also changes directions. This point was not explicitly stated in most scripts. Recall that it was the force that enabled the wire to remain stationary on the plane.

The I_{rms} value = I . Many claimed that I_{rms} is now smaller which is untrue. It is an AC circuit so there will be instances that the ac current is at a value that is larger than I !

The rod will not be stationary, there are instances that the net force is upwards along the slope and at other times downwards and this was not clearly stated. Many only mentioned only the portion where the force is towards the right which was insufficient.

- (b) The current in (a) is disconnected, and the magnetic field is removed. The wire is now given a uniform net positive charge of $+2.0 \times 10^{-6} \text{ C}$.

- (i) To keep the wire stationary in the same position on the frictionless plane, a uniform electric field of strength E is applied in the horizontal direction.

Determine the magnitude of E .

The electric force must be acting leftwards for wire to be stationary. $\sum F_{\parallel} = 0$

$$F_{E\parallel} = W_{\parallel}$$

$$qE_{\parallel} \cos \theta = mg \sin \theta \quad [\text{C1}]$$

$$E_{\parallel} = \frac{mg}{q} \tan \theta$$

$$= \frac{(0.14)(9.81)}{2.0 \times 10^{-6}} \tan 20^\circ \quad [\text{M1}]$$

$$= 2.5 \times 10^5 \quad [\text{A1}]$$

$$E = \dots\dots\dots \text{N C}^{-1} \quad [3]$$

[Total: 9]

Comments:

Many many errors on vector resolution. Main reason being that you don't have the habit to sketch your FBDs!.

- 6 The pick-up on an electric guitar produces an electrical signal from the vibrations of the guitar string. The pick-up consists of a small coil of insulated wire wound round a small cylindrical magnet as shown in Fig. 6.1.

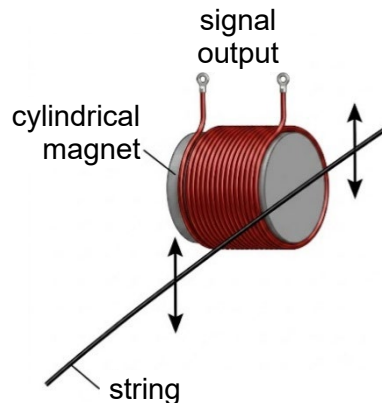


Fig. 6.1

The strings of the guitar are made of steel, which is a conductor. When a string vibrates, an electrical signal is generated between the terminals of the coil.

- (a) Use Faraday's Law to explain why an electrical signal is generated.

The string is magnetised by the magnet and becomes a temporary magnet. B1

As the string vibrates, it produces a varying magnetic field and hence the coil experiences a rate of change of magnetic flux linkage. B1

Faraday's law states that induced emf is directly proportional to the rate of change of magnetic flux linkage, B1 thus an emf is induced and a signal in the coil. [3]

No credit is given if only 'change in magnetic flux linkage' and 'e.m.f. induced' are stated without associating it to the coil.

- (b) Suggest why

- (i) the electrical signal needs to be amplified before connection to a loudspeaker,

The amplitude of the vibration is small / the strength of the magnetic field due to the string is weak, hence the induced e.m.f. is small. B1 [1]

- (ii) the design of the pick-up would be inappropriate for use on a guitar with nylon strings.

Nylon is non-magnetic material and thus cannot be magnetised. B1

Hence it is unable to produce any rate of change of magnetic flux linkage in the coil and thus no signal generated. B1

The string needs to be of a magnetic material to produce a magnetic field – it is not connected to an electrical circuit, as many candidates imagined. [2]

[Total: 6]

- 7 (a) An electron is confined inside a one-dimensional potential well of length 0.50 nm with infinitely high potential barriers at $x = 0$ and $x = 0.50$ nm.

Within the well, the potential energy $U(x) = 0$, and outside the well, $U(x) = \infty$.

- (i) By considering the de Broglie wavelength of the electron trapped in this well, explain why the electron has specific allowed energy levels.

The wavefunction of the electron must be a standing wave due to the infinite potential boundaries, thus its de Broglie wavelength can have only certain values and satisfy the condition $n\frac{\lambda}{2} = L$. [B1] As momentum determines wavelength ($p = \frac{h}{\lambda}$) and kinetic energy is dependent on momentum as $KE = \frac{p^2}{2m}$, [B1] the kinetic energy of the electron can have only certain values. [2]

Comments: The reason why the wavelength is specific needs to be stated. Cannot just give a vague description. In addition, many gives the energy of a photon which is wrong. All expressions must be written down.

- (ii) The electron emits a single photon when it transitions from the second excited state to the ground state.

Determine the wavelength of the photon.

$$\Delta E = \frac{h^2}{8mL^2}(3^2 - 1^2) = \frac{(6.63 \times 10^{-34})^2}{8 \times 9.11 \times 10^{-31} \times (0.50 \times 10^{-9})^2}(3^2 - 1^2) \text{ [B1]} = 1.93 \times 10^{-18} \text{ J}$$

$$= \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{\lambda} \text{ [B1]}$$

$$\lambda = 1.03 \times 10^{-7} \text{ m [A1]}$$

Comments: Common error is the use of factor 2 to represent second excited state.

wavelength = m [3]

- (iii) Explain, with reference to the Heisenberg Uncertainty Principle, why the ground state energy of the electron cannot be zero.

As the electron is confined to the well, the maximum uncertainty in its displacement is L . [B1] Thus by the Heisenberg Uncertainty Principle, the minimum uncertainty in its momentum cannot be zero. [B1] Since there must be at least some uncertainty in its momentum, the electron cannot be at rest. NOT $E = pc = hc/\lambda$. Ignore any symbols [2]
if not defined clearly.

Examiner's comments: If any symbols are used and are not defined in the question, these must be stated clearly in words, for e.g. Δx refers to the uncertainty in position. There were occasions where x was incorrectly referred to as displacement or uncertainty in displacement. There were also many misconceptions stating that the energy of an electron is given by $E=pc=hc/\lambda$. Students must apply the HUP and not give its definition without answering to the context of the question.

(b) An electron bound within a hydrogen atom has allowed energy levels shown in Fig. 7.1.

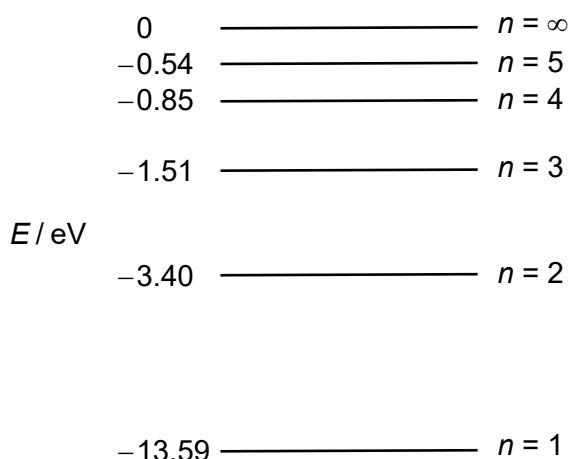


Fig. 7.1

- (i) Suggest one reason why the energy levels of this electron are different from those of the electron in (a).

The electron of a hydrogen atom has potential energy [B1] due to the electrostatic forces by the nucleus. Difference must be insightful and not stating the obvious, for e.g. one is bounded in an atom while the other is bounded in a potential well. [1]

Examiner's comments: Challenging question. There were many reasons which restated the question or explained the process of de-excitation or whether the electron can escape or not. There were many answers that compared the length of the potential well to the length of the atom, or that one was 1D and the other was 3D. Note that the question specifically required the difference to be made with reference to the energy levels.

- (ii) The electron emits a single photon when it transitions from the second excited state to the ground state. Determine the wavelength of the photon.

$$\Delta E = (-1.51 - (-13.59)) = 12.08 \text{ eV} = 1.933 \times 10^{-18} \text{ J} \text{ [B1] ecf from previous part if used } n = 2$$

$$= \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{\lambda}$$

$$\lambda = 1.029 \times 10^{-7} \text{ m [A1]}$$

wavelength = m [2]

[Total: 10]

Examiner's comments: Generally well done. Common mistakes were using the energy difference from $n = 2$ to $n = 1$ and forgetting to convert to joules from eV. There were occasional calculation errors.

Section B

Answer **one** question from this section in the spaces provided.

- 8 (a) A small steel sphere is oscillating vertically on a spring, as shown in Fig. 8.1.

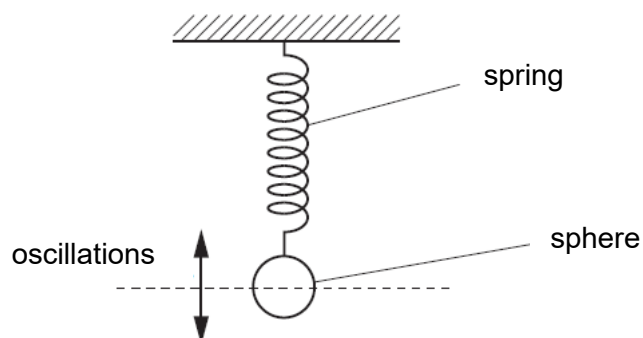


Fig. 8.1

Fig. 8.2 shows the variation with displacement x of the energy E of the oscillations.

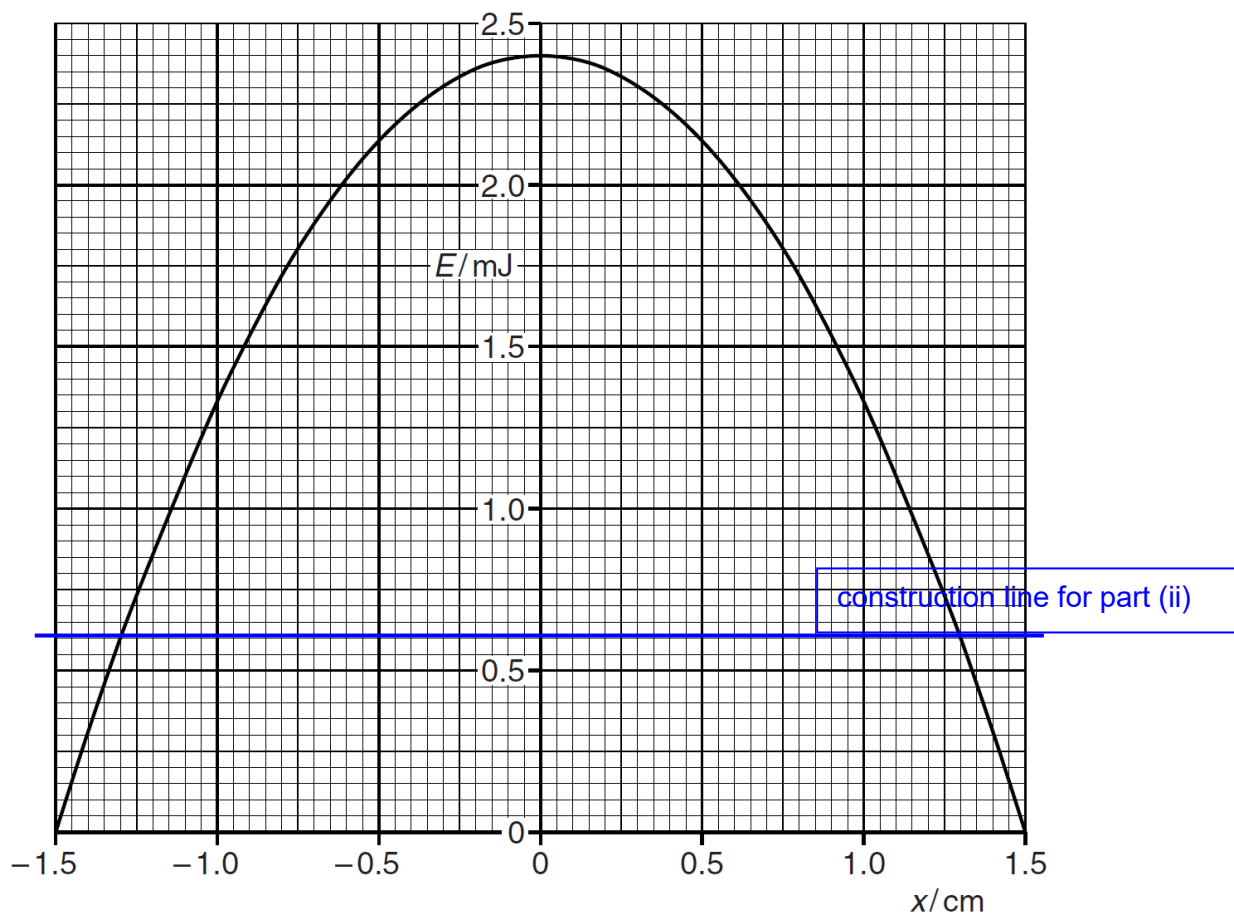


Fig. 8.2

- (i) State whether the energy E represents the total energy, the potential energy or the kinetic energy of the oscillations.

Kinetic energy [B1][1]

- (ii) The amplitude of the oscillations reduces over a long period of time. After many oscillations, the maximum value of E decreases **by** 0.60 mJ.

Without further calculation, use Fig. 8.2 to determine the new amplitude of the oscillations. Show your construction.

suitable line that shifts the x-axis up by 0.60 mJ to intersect the original curve [M1]

→ new amplitude (intersection) of 1.3 cm [A1]

Comments: Many use calculation which means they ignore the question. Students should not construct a curve freehand when a graph grid is provided.

new amplitude = cm [2]

- (b) The steel sphere is held between two fixed points A and B by two identical springs, as shown in Fig. 8.3.

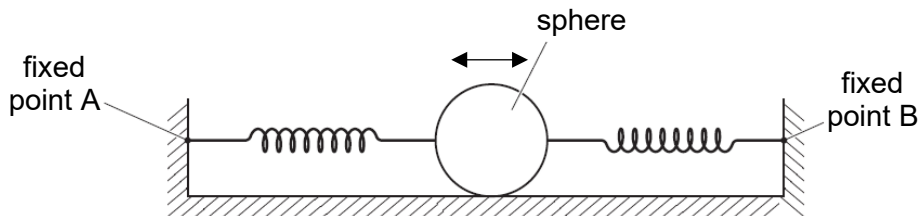


Fig. 8.3

The sphere is displaced from its equilibrium position and then released so that it is free to oscillate horizontally along the line AB. During the oscillations, the springs remain extended and do not exceed their limits of proportionality.

The resultant force acting on the sphere is given by

$$F = -2kx$$

where k is the spring constant and x is the displacement of the sphere from equilibrium position.

- (i) Explain how the equation shows that the oscillations of the sphere are simple harmonic.

• k is a (positive) constant so F is (directly) proportional to x M1

• Negative sign means F is directed opposite of x M1

Since F is (directly) proportional and in the same direction as acceleration a , then a is proportional and directed opposite to x , hence simple harmonic motion. A0

Comments: The question is asking which features and how they show SHM and not just by stating the properties of SHM. [2]

(ii) Show that the frequency f of the oscillations is given by

$$f = \frac{1}{2\pi} \sqrt{\frac{2k}{m}}$$

where m is the mass of the sphere.

By Newton's 2nd Law

$$F = ma$$

$$-2kx = ma$$

$$a = -\left(\frac{2k}{m}\right)x \quad [\text{M1}]$$

$$\omega^2 = \frac{2k}{m} \text{ leading to } \omega = \sqrt{\frac{2k}{m}} \text{ and } \omega = 2\pi f \quad [\text{M1}]$$

$$\text{so } f = \frac{1}{2\pi} \sqrt{\frac{2k}{m}}$$

Comments: Newton's 2nd Law must be stated

[2]

The variation of the acceleration a of the sphere with its displacement x from the equilibrium position is shown in Fig. 8.4.

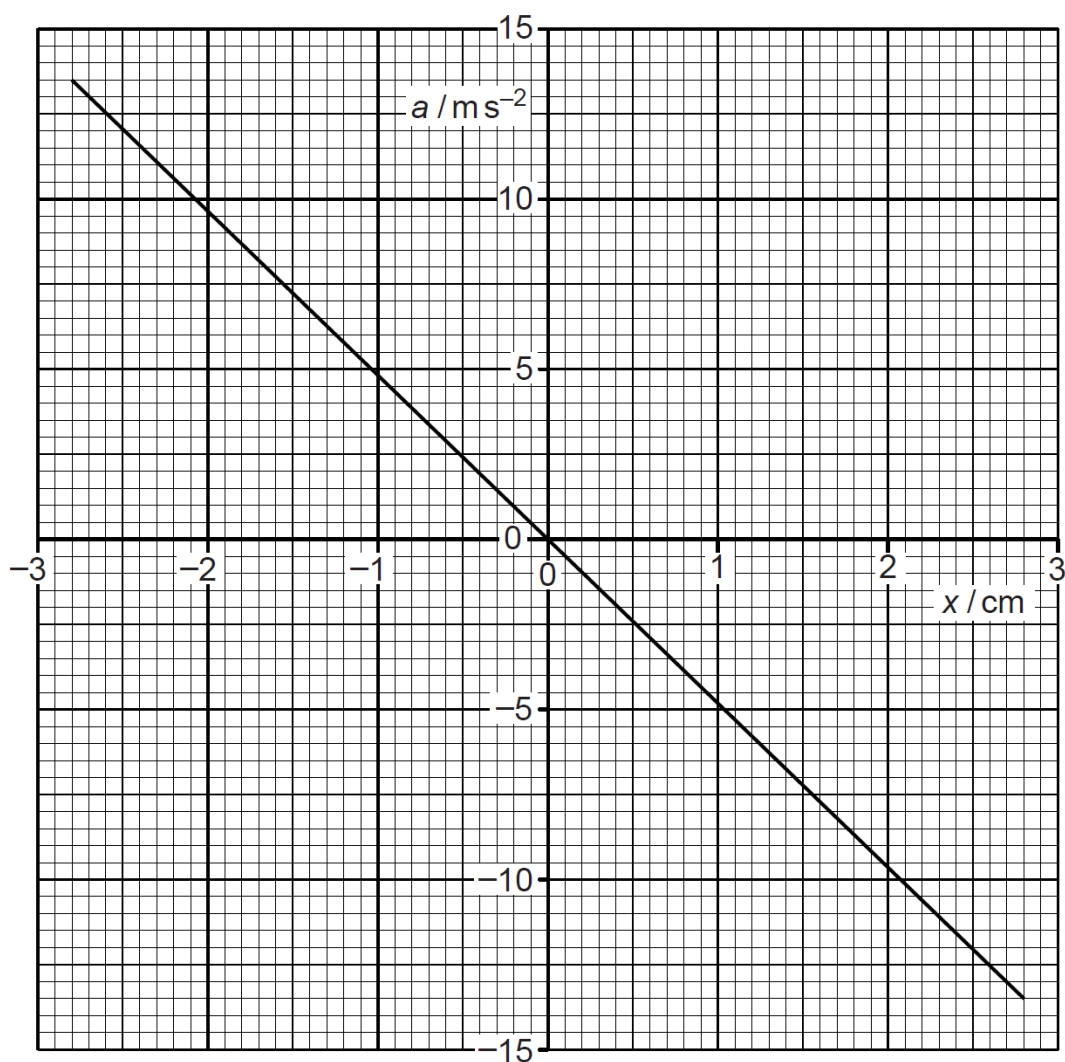


Fig. 8.4

(iii) Use Fig. 8.4. to determine the frequency of oscillations of the sphere.

$$\text{gradient} = -\omega^2 \quad [\text{C1}]$$

$$\omega^2 = -\frac{-13.5 - 13.5}{2.8 \times 10^{-2} - (-2.8 \times 10^{-2})} = 482$$

$$\omega = 22.0 \text{ rad s}^{-1} \quad [\text{C1}]$$

$$f = \frac{22.0}{2\pi} = 3.5 \text{ Hz} \quad [\text{A1}]$$

Comments: Common error is missing out that x is in cm.

Must use gradient and not single point to calculate.

$$f = \dots\dots\dots \text{ Hz} \quad [3]$$

(iv) State **one** way how the period of oscillations of the sphere can be reduced.

Use a sphere of lighter mass (reduce m) OR use a stiffer spring (increase k) [B1]

NOT damping or increasing the amplitude [1]

Examiner's comments: A larger amplitude implies a larger acceleration ($a \propto x$). Whilst a larger acceleration tends to make the period shorter, a larger amplitude means the mass must travel further, so the effect exactly cancels out $\rightarrow T = \frac{2\pi}{\omega}$ which is independent of amplitude. Damping increases the period.

(v) ~~The variation of the displacement of the sphere with time is sinusoidal. The variation of the velocity of the sphere with time is also sinusoidal.~~

1. State the phase difference between the displacement and the velocity of the sphere.

$$\text{phase difference} = \boxed{90^\circ} [\text{B1}] \dots\dots\dots^\circ \quad [1]$$

2. The sphere is released from its maximum positive displacement at time $t = 0$.

Calculate the magnitude of the velocity of the sphere at time $t = \frac{T}{12}$, where T is the period of oscillations.

$$x = x_0 \cos \omega t$$

$$x = (2.8 \times 10^{-2}) \cos\left(\frac{2\pi}{T} \times \frac{T}{12}\right) \quad [\text{M1}]$$

$$x = 0.0242 \text{ m}$$

$$v = \omega \sqrt{x_0^2 - x^2}$$

$$= 22 \sqrt{(2.8 \times 10^{-2})^2 - 0.0242^2} \quad [\text{M1}]$$

$$= 0.31 \text{ m s}^{-1} \quad [\text{A1}]$$

If degree mode is used, $x = 0.02799 \text{ m}$ leading to $v = 0.0165 \text{ m s}^{-1}$ scores 2m max.

If $x = x_0 \sin \omega t$ used leading to $x = 0.014 \text{ m}$, $v = 0.533 \text{ m s}^{-1}$ scores 1m max.

Examiner's comments: Generally doable. Common mistakes were starting from the wrong expression for displacement, powers-of-ten (POT) errors of not converting to metres, reading off the wrong amplitude, and not using radian mode during the calculation.

$$\text{velocity} = \dots\dots\dots \text{ m s}^{-1} \quad [3]$$

- (vi) The microscopic structure of a solid crystal can be pictured as planes of atoms, as shown in Fig. 8.5. The distance between the centres of neighbouring atoms is indicated.

Examiner's comments: Somewhat challenging question but there were some good attempts. Common answers were to state that the atoms were colliding with each other even though the interatomic restoring forces would not allow them to do so.

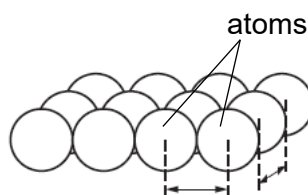


Fig. 8.5

Suggest why the spring-sphere system in Fig. 8.3 provides a simple model for the motion of an atom in a solid crystal.

Sphere can be modelled as an atom oscillating between adjacent atoms in the crystal, where the (restoring) spring forces resemble the attractive and repulsive interatomic forces when the atom is displaced slightly further apart or closer to adjacent atoms, respectively [B1] [1]

- (c) The fixed point B is now replaced with an oscillator that causes horizontal oscillations of the sphere, as shown in Fig. 8.6. Both springs remain extended within the limit of proportionality.

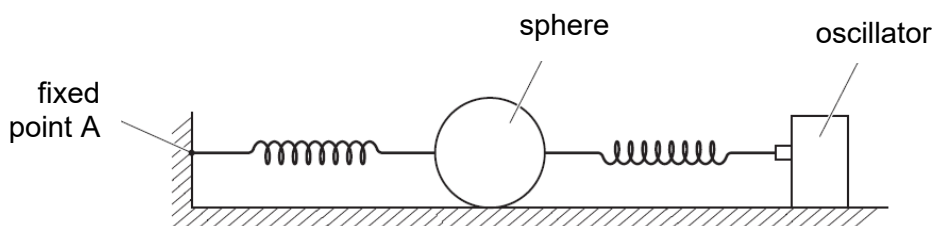


Fig. 8.6

The oscillator is switched on. The amplitude of vibration of the oscillator is constant. The frequency f of vibration of the oscillator is varied.

The variation of the amplitude x_0 of the oscillations with frequency f of the oscillator is shown in Fig. 8.7.

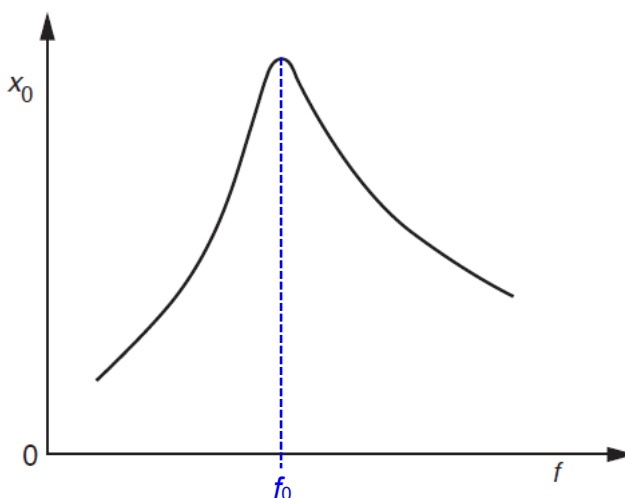


Fig. 8.7

(i) Explain why there is a peak in Fig. 8.7 and state the frequency at which the peak occurs.

The peak suggests that resonance occurred since the sphere is under forced oscillations

 where the oscillator's driving frequency is equal to the natural frequency of the system [B1]

idea of resonance explained adequately

The frequency at which the peak occurs = 3.5 Hz OR ecf their value of f [B1] [2]

(ii) State and explain **one** modification to the setup in Fig. 8.6 to reduce the amplitude of the oscillations in Fig. 8.7.

- EITHER idea of increased damping by a sensible method (e.g. attaching a light card

 with large surface area to increase air resistance, sprinkling sand on the surface to

 increase friction) [B2]

- OR reduce amplitude of vibration of oscillator to reduce energy input to system (B2) [2]

[Total: 20]

Examiner's comments: The safest answer to reduce the amplitude of oscillations is to increase damping or reduce the amplitude of the driving force. Modifications that varied the frequency instead; for e.g. changing the mass or spring constant only reduce the amplitude if they move the natural frequency farther away from the driving frequencies, particularly so that the natural frequency does not lie within the range of driving frequencies. Students should note the flow of the question and factors affecting f was already tested previously in part (b). Some modifications defied common sense although they are not technically incorrect, for e.g. immersing the whole set up in oil or water (assuming the oscillator still functions after being submerged in oil or water).

- 9 (a) In a circuit, a 4.0 V battery with internal resistance is connected in series to a thermistor and a coaxial resistor.

The coaxial resistor has a cylindrical core of length 0.020 m. The core is made of material A and is surrounded by material B as shown in Fig. 9.1. In the circuit, the direction of the current passing through the coaxial resistor is parallel to its length. The physical dimensions of the coaxial resistor are fixed.

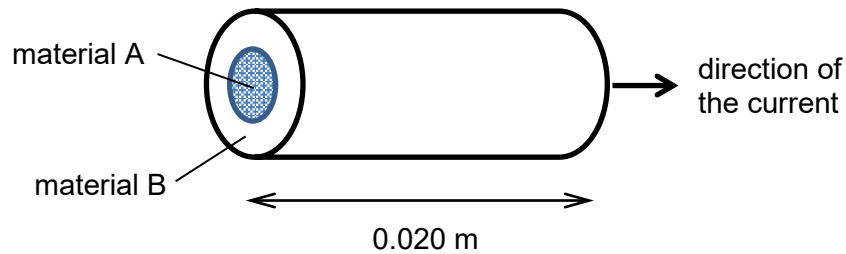


Fig. 9.1

- (i) Draw a complete circuit diagram of the circuit in the space below.

Represent the coaxial resistor as two separate resistors A and B, one for each material respectively.

thermistor B1

parallel B1

4.0 V battery with internal resistance B1

[3] **Comments: Most can solve this part.**

- (ii) Fig. 9.2 shows the variation of the current I in the thermistor with temperature T of the thermistor.

Fig 9.3 shows the variation of I in the thermistor with voltage V across the thermistor.

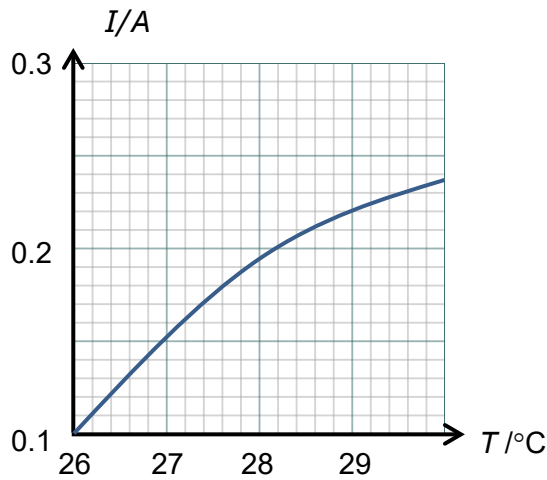


Fig. 9.2

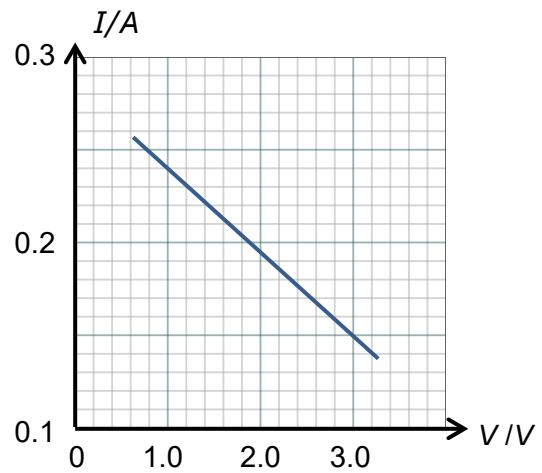


Fig. 9.3

Determine the resistance of the thermistor at 27 °C.

Reading from the graph, at 27°C, $I = 0.15$ A

And pd across resistor = 3V C1

Hence resistance of thermistor = $\frac{3}{0.15} = 20 \Omega$ A1

Comments: Accuracy is important here.

resistance = Ω [2]

- (iii) Describe and explain what will happen to the potential difference across resistors A and B in the circuit when the temperature of the thermistor increases.

By potential divider rule, $V_A = \frac{R_{\text{eff}A,B}}{\text{Total resistance}} \times E$ M1

Since temperature of thermistor increases and thus its resistance drop, total resistance drop, V_A and hence V_B increases since they are in parallel and $R_{\text{eff}A,B}$ is constant. A1

Comments: Many just merely state potential divider rule without the equation. [2]

- (b) (i) Two identical lamps are connected to a d.c. and a.c. supply as shown in Fig. 9.4a and Fig. 9.4b respectively.

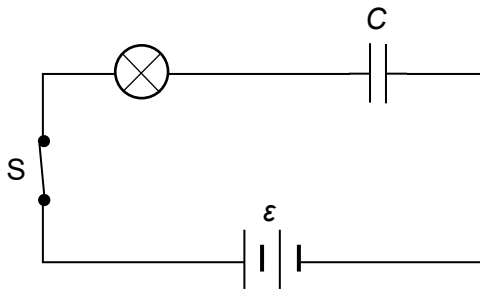


Fig 9.4a

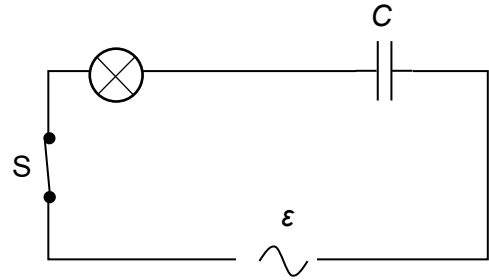


Fig 9.4b

State and explain which lamp will be turned on for a longer period of time. Assume that the time constant is large.

In 9.4a, the lamp will be on when the capacitor is charging. At full charge, the lamp will be off B1

In Fig 9.4b, the capacitor is constantly charged and discharged because of the periodic nature of the a.c. as the pd across capacitor can be larger or smaller than the ac emf B1

Hence a continuous supply of ac passes through the lamp to light it and it will stay lit for a longer period of time. B1 [3]

Comments: Most compare the value of current in both cases which are not correct. Many did not understand that there is no current in (a) once the capacitor is fully charged.

- (ii) The charged capacitor of capacitance C is being discharged through a resistor of resistance R , as shown in Fig. 9.5. At time $t = 0$ s, the capacitor is fully charged.

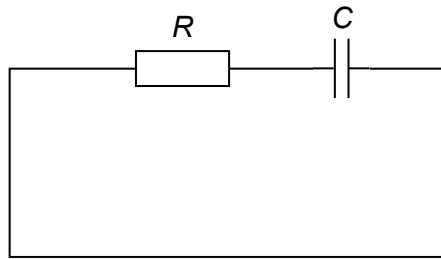


Fig. 9.5

The energy stored in the capacitor decreases with time as the capacitor discharges. Determine the time t , in terms of R and C , it takes for this stored energy to be discharged by 75% of its initial value.

$$\text{Energy} = \frac{q^2}{2C}$$

$$= \frac{Q^2}{2C} e^{-\frac{2t}{RC}} \quad \text{B1 (if took as } 3/4 \text{ can get method mark for this)}$$

$$= U_0 e^{-\frac{2t}{RC}}$$

$$\text{Hence } \frac{1}{4} U_0 = U_0 e^{-\frac{2t}{RC}} \quad \text{M1}$$

$$t = \frac{1}{2} RC \ln 4 = 0.693 RC \quad \text{A1}$$

$$t = \dots\dots\dots [3]$$

Examiner's comments: Poorly done despite a similar question tested before. Common errors were not realising that the final value is 25% of the initial value and not recalling that $E \propto Q^2$ or V^2 .

- (c) After a long time, the capacitor in Fig. 9.5 is fully discharged and a battery of e.m.f E of negligible internal resistance is used to recharge the capacitor in a circuit as shown in Fig. 9.6.

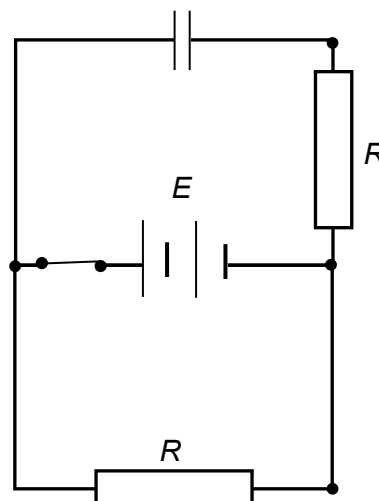


Fig. 9.6

- (i) Determine the current, in terms of E and R , in the battery immediately after the switch is closed.

$$R_{\text{eff}} = \frac{R}{2} \quad \text{M1}$$

$$I = \frac{E}{2R} \quad \text{A1}$$

current = [2]

- (ii) Determine the current, in terms of E and R , in the battery a long time after the switch is closed.

When the capacitor is fully charged, there is no current in the resistor in series with it. M1

Hence $I = \frac{E}{R}$ A1

current = [2]

- (iii) Hence suggest an expression for the time constant, in terms of R and C .

Explain your reasoning.

The capacitor and its resistor (the one in series with it) are parallel to the lower resistor.

B1 Hence, the pd across the lower resistor is always E and thus (will not affect) can

be removed without affecting the charging process. M1 Hence, only the resistor in

series with it will affect the charging process and thus the time constant is RC . A1

[3]

Examiner's comments: Challenging question. Many answers relied on mathematical workings (which end up incorrect) rather than explaining in words.

[Total: 20]

END OF PAPER

