Answers to 2024 JC2 Preliminary Examination Paper 4 (H2 Physics)

Suggested Solutions

<table>
<tr><th>No.</th><th>Solution</th><th>Remark</th></tr>
<tr><td>1(b)</td><td>$x = \frac{15.0+15.0}{2} = 15.0$ cm

Period $T = \frac{20.8+20.7}{2\times 20} = 1.04$ s</td><td>[1]
- for correct measurements with units
- 1 d.p in cm
- repeat
- X should be within range of 14.0 cm to 16.0 cm

[1]
- Recorded no of oscillations, n
(can be deduced from working)
- 1 or 2 d.p in timing
- repeat
- T in 3 s.f. or 4 s.f. depending on the d.p. of t_1 and t_2
- $t \geq 10.0$ s</td></tr>
<tr><td>1(c)</td><td>
<table>
<tr><th>x/cm</th><th>N</th><th colspan="2">Time for N oscillation</th><th>Period T/s</th><th>T^4/s^4</th></tr>
<tr><th></th><th></th><th>t_1/s</th><th>t_2/s</th><th></th><th></th></tr>
<tr><td>11.0</td><td>25</td><td>24.2</td><td>24.1</td><td>0.966</td><td>0.871</td></tr>
<tr><td>13.0</td><td>25</td><td>25.1</td><td>25.2</td><td>1.01</td><td>1.04</td></tr>
<tr><td>15.0</td><td>20</td><td>20.8</td><td>20.7</td><td>1.04</td><td>1.17</td></tr>
<tr><td>17.0</td><td>20</td><td>21.4</td><td>21.6</td><td>1.08</td><td>1.36</td></tr>
<tr><td>19.0</td><td>20</td><td>22.1</td><td>22.2</td><td>1.11</td><td>1.52</td></tr>
<tr><td>21.0</td><td>20</td><td>22.9</td><td>22.8</td><td>1.14</td><td>1.69</td></tr>
</table>
</td><td>[1]
- headings and units
- 6 sets of data

<u>Note:</u> 20T is not accepted as time for 20 oscillations.

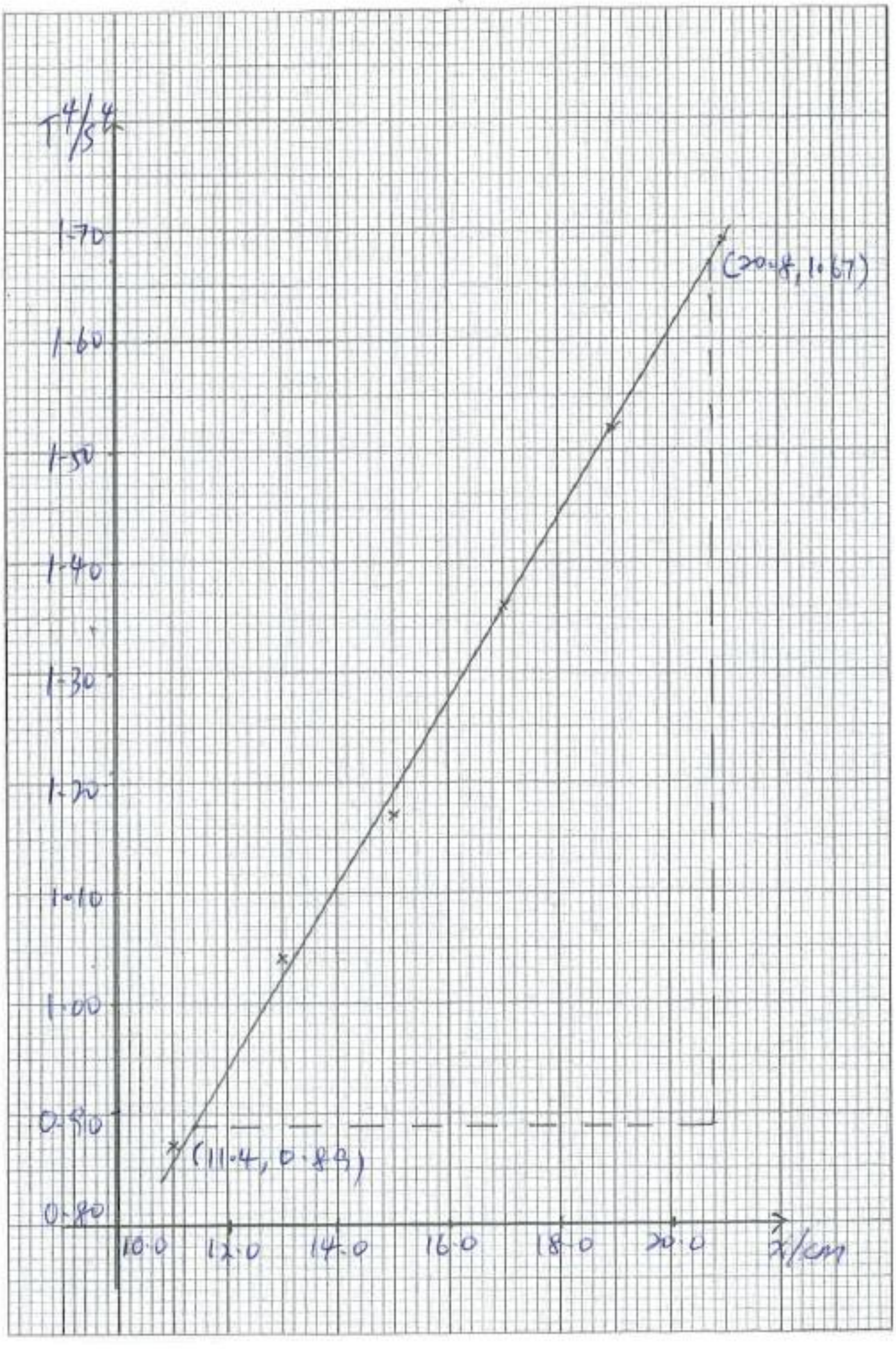
[1]
- d.p. of raw data
- $t \geq 10.0$ s with repeated measurement

[1]
- s.f. of processed data
- correct calculation, allow 1 slip

[1] Range of x to be at least 10.0 cm

Don't accept x = 0 cm and x > 26 cm. These <u>will not</u> be considered one set of data.</td></tr>
<tr><td></td><td colspan="2">Note: Marks may be deducted for poor presentation:
• No table (including border must be drawn)
• Table lines not drawn using ruler
• Poor presentation of data in table (e.g. Show working in table)</td></tr>
<tr><td>1(d)</td><td>Refer to attached graph.</td><td>[1] axes: units, scale (1:1, 1:2 or 1:5 only)
[1] plotted points accurate to half of smallest division
[1] best fit line</td></tr>
<tr><td></td><td colspan="2">MC: For scale, students should use 1:1, 1:2 or 1:5 scale. In most cases, the data obtained would be able to accommodate the use of these scales which are easy to plot to half the smallest division.
• Students are allowed to <u>plot their graph in landscape</u> should they find that portrait does not allow for these scales. In general, the use of these</td></tr>
</table>

	scales would also save students some marks for the plotted points mark and the gradient calculations.	
1(d)	Given $T^4 = Px + Q$ Graph of T^4 vs x is plotted, where P is the gradient and Q is the y-intercept. Gradient= $\dfrac{1.67-0.89}{20.8-11.4}=0.0830$ P = 0.0830 $\text{s}^4\ \text{cm}^{-1}$ Substitute $(20.8, 1.67)$ into the equation, $1.67=(0.0830)(20.8)+Q$ $Q=-0.0564\ \text{s}^4$	[1] - linearization (statement) [1] - Big triangle - substitution of gradient coordinates accurate to half of smallest division. - P calculated correctly with units [1] Q calculated correctly with units



T^4/s^4
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
10.0
12.0
14.0
16.0
18.0
20.0
x/cm
(20.8, 1.67)
(11.4, 0.89)

[Total: 12]

<table>
<tr><th>No.</th><th>Solution</th><th>Remarks</th></tr>
<tr><td>2(a)(i)</td><td>$w = \dfrac{1.9 + 1.9}{2} = 1.9$ mm
$t = \dfrac{1.9 + 1.9}{2} = 1.9$ mm
$L_0 = \dfrac{7.5 + 7.5}{2} = 7.5$ cm</td><td>[1]
- Repeated w, t & L_0
- Recorded w and t to the nearest 0.01 mm with unit
- Value of w and t within the range 1.50 to 2.50 mm
- Recorded L_0 to the nearest mm with unit
- Value of L_0 within the range 7.0 to 9.0 cm</td></tr>
<tr><td>2(a)(ii)</td><td>Volume $V = (1.9\times10^{-3})(1.9\times10^{-3})(\mathbf{2}\times7.5\times10^{-2})$
$= 5.4 \times 10^{-7}$ m^3</td><td>[1]
- Correct calculation of V within range of 3.1×10^{-7} m^3 to 1.12×10^{-6} m^3
- Recorded to correct no. of s.f. and units</td></tr>
<tr><td>2(b)(i)</td><td>$L = \dfrac{8.8 + 8.8}{2} = 8.8$ cm

Extension $e = 8.8 - 7.5 = 1.3$ cm $= 0.013$ m

Force $F = 100\times10^{-3} \times 9.81 = 0.981$ N</td><td>[1]
- Correct calculation of e

- Recorded e to correct no. of d.p.
- $F = 0.981$ N (2 or 3 s.f.)

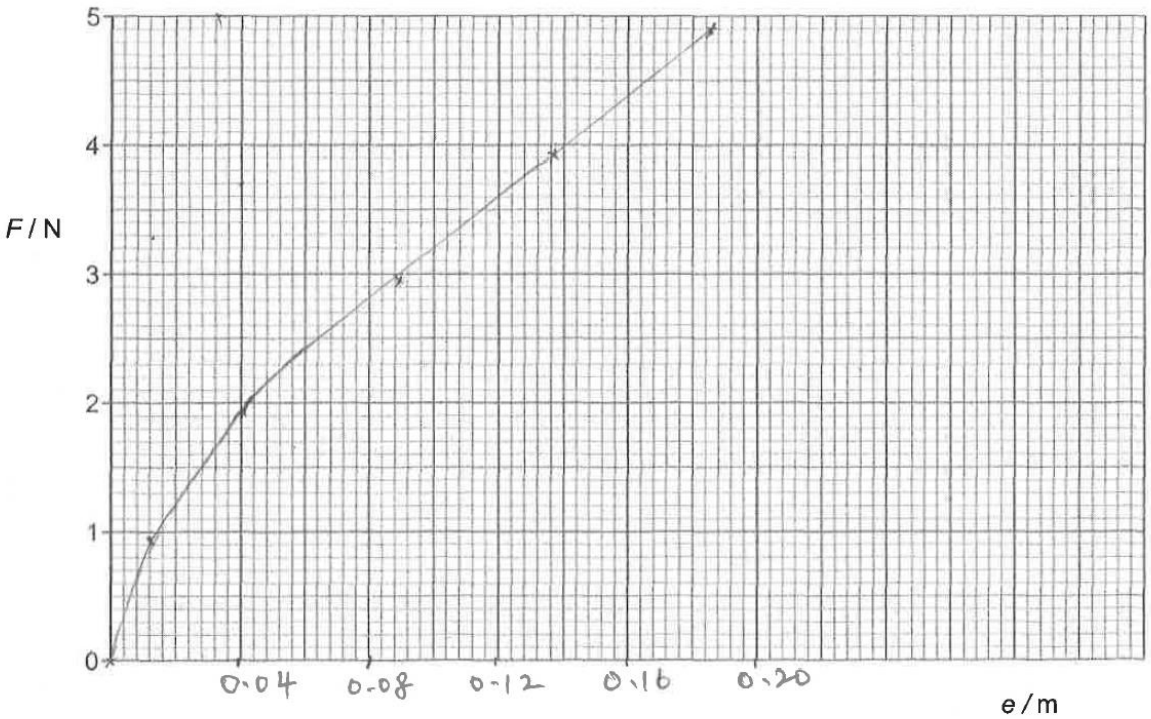
- repeat measurement for L</td></tr>
<tr><td>2(b)(ii)</td><td>
<table>
<tr><th>m/kg</th><th>L/m</th><th>e/m</th><th>F/N</th></tr>
<tr><td>0.000</td><td>0.075</td><td>0.000</td><td>0.000</td></tr>
<tr><td>0.100</td><td>0.088</td><td>0.013</td><td>0.981</td></tr>
<tr><td>0.200</td><td>0.116</td><td>0.041</td><td>1.96</td></tr>
<tr><td>0.300</td><td>0.165</td><td>0.090</td><td>2.94</td></tr>
<tr><td>0.400</td><td>0.212</td><td>0.137</td><td>3.92</td></tr>
<tr><td>0.500</td><td>0.261</td><td>0.186</td><td>4.91</td></tr>
</table>
</td><td>[1]
- headings and units
- at least 5 sets of data (excluding 0)

Do not accept masses such as 150g, 250g, 350g as no 50g mass were provided.

[1]
- d.p. of raw data
- m in 3 d.p

[1]
- correct calculation, allow 1 slip
- s.f of processed data</td></tr>
<tr><td></td><td colspan="2">MC: Candidates tend to forget that “0” is also considered a data point/set when included in the table. Hence it should be recorded to the appropriate precision.</td></tr>
<tr><td>2(b)(iii)</td><td>Refer to attached graph.</td><td>[1]
- plotted points accurate to half of smallest division
- best fit curve / line
- No marks awarded if best fit curve / line does not pass through origin</td></tr>
</table>

2(b)(iv)	When the extended length is $2L_0$, the extension e is L_0 = 0.075 m and force F is 2.7 N. Energy stored = area under the graph $= \frac{1}{2}(0.013)(0.981) + \frac{(0.981+1.96)(0.028)}{2}$ $+ \frac{(1.96+2.7)(0.034)}{2}$ = 0.127 J	[1] correct calculation **OR** estimate via counting squares
	MC: Inaccurate read-offs from the graph were a common error. Another common error was taking the area under the graph from L = 0 m to $L = 2L_0$ Some candidates who managed to obtain a curve estimated the area under the graph using the area of a triangle which tends to be an underestimate and hence were penalized.	
2(b)(v)	Energy stored per unit volume $= \frac{0.127}{5.42 \times 10^{-7}}$ $= 2.34 \times 10^{5}$ J m^{-3}	[1] correct calculation



[1]

<table>
<tr><th>No.</th><th>Solution</th><th>Remarks</th></tr>
<tr><td>3(a)</td><td>$D_Y = \frac{4.5 + 4.5}{2} = 4.5$ cm

Diameter $d_Y = \frac{0.30 + 0.30}{2} = 0.30$ mm</td><td>[1]
- correct measurement for D_Y.
Accept 4.0 cm to 5.5 cm
- repeat

[1]
- correct measurement for d_Y.
Accept 0.22 mm to 0.35 mm
- repeat</td></tr>
<tr><td>3(b)(i)</td><td>There are 13 turns on cardboard tube Y.

$L_Y = 13 \times D_Y \times \pi + 2(5)$
$= 13 \times 4.5 \times \pi + 2(5)$
$= 194$ cm</td><td>[1]
- Estimated Ly using circumference × no of turns

[1]
- Added length of tail ends and value of Ly within the range 180 to 220 cm recorded to correct s.f.</td></tr>
<tr><td>3(b)(ii)</td><td>$L_Y = 13\pi D_Y + 2L_{tail}$
$\Delta L_Y = 13\pi \Delta D_Y + 2\Delta L_{tail}$
$\frac{\Delta L_Y}{L_Y} = \frac{13\pi \Delta D_Y + 2\Delta L_{tail}}{L_Y}$
$\frac{\Delta L_Y}{L_Y} \times 100\% = \frac{13\pi(0.2) + 2(0.2)}{194} \times 100\% = 4.4\ \%$</td><td>[1] for correct percentage uncertainty
(1 or 2 s.f.)</td></tr>
<tr><td>3(c)</td><td>$R = 15\ \Omega$
$I = 140.6 \times 10^{-3}$ A</td><td>[1]
- Record R as 15 Ω
- Record I to 0.1 x 10^{-3} or 0.0001 A
- Value of I within the range of 0.1350 to 0.1550 A</td></tr>
<tr><td>3(d)</td><td><table>
<tr><th>R / Ω</th><th>I / A</th><th>IR / V</th></tr>
<tr><td>15</td><td>0.1406</td><td>2.1</td></tr>
<tr><td>18</td><td>0.1329</td><td>2.4</td></tr>
<tr><td>22</td><td>0.1227</td><td>2.7</td></tr>
<tr><td>27</td><td>0.1148</td><td>3.1</td></tr>
<tr><td>33</td><td>0.1128</td><td>3.7</td></tr>
</table></td><td>[1]
- headings and units
- 5 sets of data

[1]
- d.p, units of raw data

[1]
- correct calculation
- s.f of processed data</td></tr>
</table>

<table>
<tr><td>3(e)</td><td>Gradient=$\dfrac{3.4-2.2}{30-16}=0.0857$
$G=0.0857$ A

Substitute $(30,3.4)$ into the equation,
$3.4=(0.0857)(30)+H$
$H=0.829$ V

$X_Y=\dfrac{H}{G}=\dfrac{0.829}{0.0857}=9.67\ \Omega$</td><td>[1]
- points plotted correctly
- best fit line drawn

[1]
- value of G calculated correctly (with or without unit)

[1] value of X_Y calculated correctly in 2 or 3 sig. fig</td></tr>
<tr><td>3(f)(i)</td><td>$D_Z=\dfrac{4.5+4.5}{2}=4.5$ cm

Diameter $d_Z=\dfrac{0.20+0.20}{2}=0.20$ mm
(0.14 to 0.25 mm)

$L_Z=\dfrac{3L_Y}{4}=\dfrac{3(194)}{4}=146$ cm</td><td>[1]
- correct measurement for D_Z
- Accept 4.0 cm to 5.0 cm
- (repeat)

- correct measurement for d_Z
- Accept 0.15 mm to 0.25 mm
- (repeat)

- correct calculation for L_z</td></tr>
<tr><td>3(f)(ii)</td><td><table><tr><td>R/Ω</td><td>I/A</td><td>IR/V</td></tr><tr><td>15</td><td>0.1258</td><td>1.9</td></tr><tr><td>18</td><td>0.1165</td><td>2.1</td></tr><tr><td>22</td><td>0.1079</td><td>2.4</td></tr><tr><td>27</td><td>0.1001</td><td>2.7</td></tr><tr><td>33</td><td>0.0972</td><td>3.2</td></tr></table>
Gradient=$\dfrac{3.05-2.0}{31.5-16.5}=0.0700$
$G=0.0700$ A

Substitute $(31.5,3.05)$ into the equation,
$3.05=(0.0700)(31.5)+H$
$H=0.845$ V

$X_Z=\dfrac{H}{G}=\dfrac{0.845}{0.0700}=12.1\,\Omega$</td><td>[1]

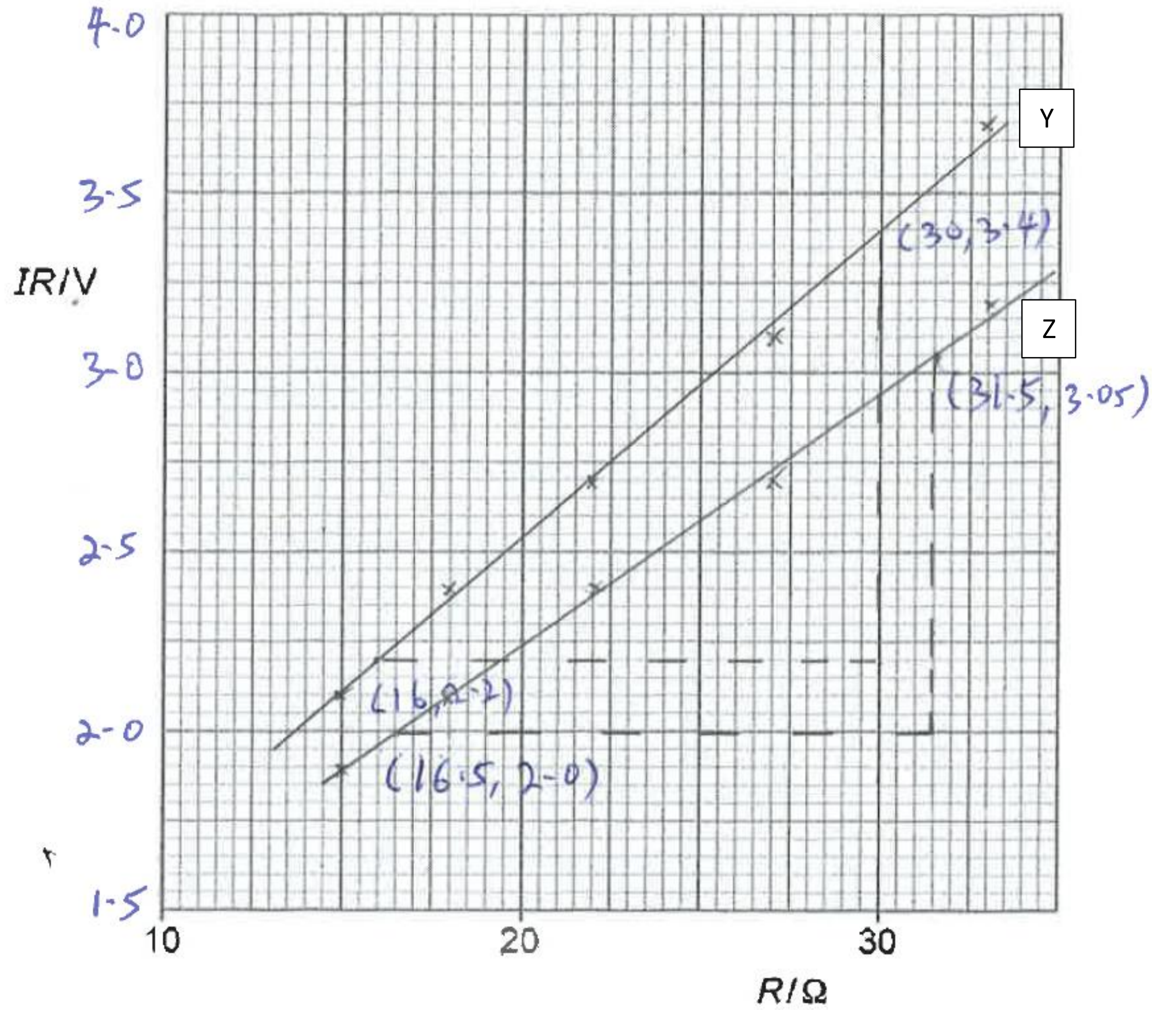
- headings and units

- 5 sets of data

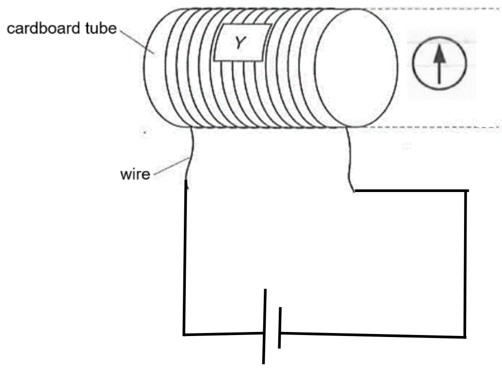
- d.p, units of raw data

- s.f of processed data

[1] value for X_Z calculated correctly</td></tr>
</table>


4.0
3.5
3.0
2.5
2.0
1.5
IR/V
10
20
30
R/Ω
Y
Z
(30, 3.4)
(31.5, 3.05)
(16, 2.2)
(16.5, 2.0)

3(f)(iii)	Difference: The calculated value is 12.1 Ω and the measured value is 21.6 Ω. Reason: Contact resistance of crocodile clip is not accounted for in the calculated value. Since *R* is proportional to length for a given resistivity and cross-sectional area, measured *R* is greater than the calculated value **OR** The coil heats up due to the current passing through it and the resistance of the coil increases with increase in the temperature of the coil.	[1] - Measured value is higher than the calculated value - appropriate reason
3(g)(i)	Given $X = \frac{kL}{d^2} \Rightarrow k = \frac{Xd^2}{L}$ First value of *k* (for wire Y) $k_Y = \frac{9.67(0.30\times10^{-3})^2}{1.84}$ = 4.7×10^{-7} Ω m Second value of *k* (for wire Z) $k_Z = \frac{12.1(0.20\times10^{-3})^2}{1.38}$ = 3.5×10^{-7} Ω m	[1] - correct calculation of value of both *k*. - correct unit (Ω cm or Ω m) and recorded to correct sf.
3(g)(ii)	Percentage difference $= \frac{(4.73-3.51)\times10^{-7}}{3.51\times10^{-7}}\times100\% = 35\%$ The percentage difference of 35% between the two *k* values are higher than the percentage uncertainties of L_Y at 4.4%. As such, the result of my experiment does not support the suggested relationship.	[1] valid evaluation based on comparing percentage difference with percentage uncertainties of L_Y
	- Calculated correctly **%*k* difference** $= \frac{\Delta k}{k_{ave}}$ x 100% **OR** **%*k* difference** $= \frac{\Delta k}{k_{smaller}}$ x 100% - $\Delta k = \lvert k_1 - k_2 \rvert$ **OR** $\Delta k = \lvert k_1 - k_2 \rvert / 2$ - Use the percentage uncertainty of **(b)(ii)** as the criterion - Concluded that results do not support the suggestion if **%*k* difference** > percentage uncertainty of **(b)(ii)** OR - Concluded results support the suggestion if **%*k* difference** ≤ percentage uncertainty of **(b)(ii)**	
3(h)(i)	From the equation *B* = *CnI*, magnetic flux density *B* at each end of the tube depends on *n,* number of turns of wire per unit length, and the current in the wire, *I*. Since wire wound on tube Y has a larger current passing through it compared to the wire wound on tube Z (deduce from gradient of graph in Fig. 3.3) **and** tube Y has greater	

	number of turns of wire per unit length on it than tube Z (inspect the tubes Y and Z), **tube Y** has greater magnetic flux density at its ends.	[1] explanation
3(h)(ii)	 **Fig. 1**	[1] Diagram to show - battery connected directly across the coil - compass placed beside on end of the tube
	 **Fig. 2** Set up the circuit as shown in Fig. 1 for both tube Y and Z, keeping the circuit open and compass at fixed distance from one end. The needle of the compass points due north when there is no current flowing in the coil. Tube Y and Z should also be arranged in the East-West direction. [1] Count the number of turns of wires, N and measure the length of the tube l and determine $n = \frac{N}{l}$. The deflection of the needle of the compass as shown in Fig. 2 gives the direction of the resultant magnetic flux density due to the Earth magnetic flux density and the magnetic flux density at the end of the tube. Close the switch and measure the angle of deflection using a protractor. The angle of deflection of the compass needle is used to determine the relative field strength. By comparing the angle of deflection of compass needle for both tube Y and Z will conclude whether tube Y or tube Z has a greater magnetic flux density at its end.	[1] - Distance between compass and coil Y and Z must be constant [1] compare angle of deflection to determine the relative field strength Max: 3

Answers and Marker's Comments to
2024 DHS Preliminary Examination
Paper 4 - Planning

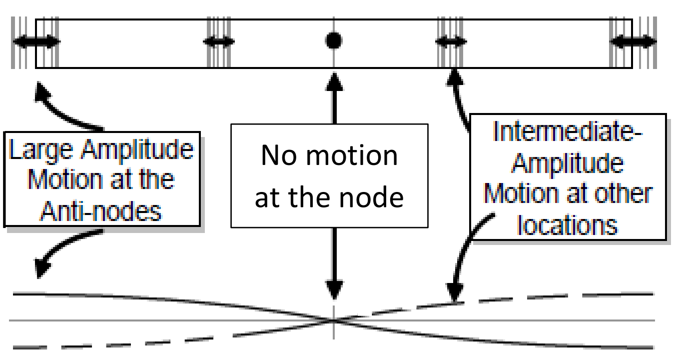
Diagram	
Labelled diagram of workable experiment including: • rod supported at its middle by a clamp (indicate $L/2$ correctly) • clamp attached to stand, with stand on bench	**D1**
• microphone connected to cathode ray oscilloscope (c.r.o.) • microphone is positioned at the end of the open pipe that has no applied impulse (e.g. due to dropped slotted mass)	**D2**

CKW MC:

- Several candidates suggested using instruments like a stroboscope or a high-speed camera. However, they can observe transverse oscillations in a rod and are unsuitable for this scenario because the question mentioned a *stationary sound wave within the rod* that *oscillate at a fundamental frequency f*, which is the driver of the progressive sound wave that needs to be detected by a microphone connected to a cathode ray oscilloscope (c.r.o.) discussed in Learning Outcome (j): *determine the frequency of sound using a calibrated oscilloscope* of the topic of "Wave Motion".

QR code for YouTube video demonstrating transverse and longitudinal waves in a rod

Actual longitudinal oscillations of particles in rod



Transverse **Representation** of Wave Motion

The damping from the clamp positioned firmly in the middle of the rod will cause a node to occur there.

The intensity of the driven progressive sound wave is largest near the ends of the rod.

Defining the problem	
Dependent Variable (DV): fundamental frequency of (a stationary sound wave) in **thin** rod *f* Independent Variables (IVs): • Experiment ONE: Length of rod *L* • Experiment TWO: Density of rod ρ	**V1**

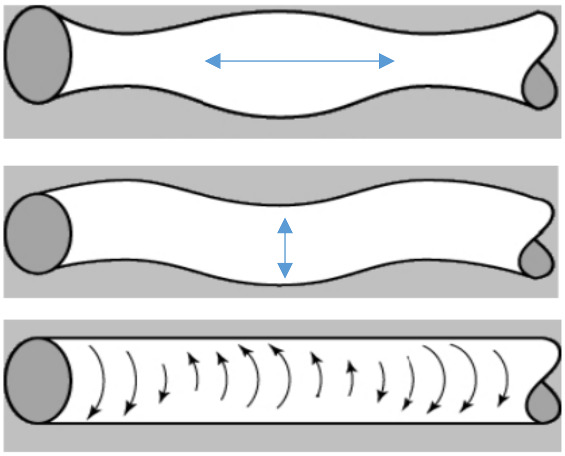
CKW MC:

- The DV and IVs should be stated clearly in words with the correct symbols used in the question.

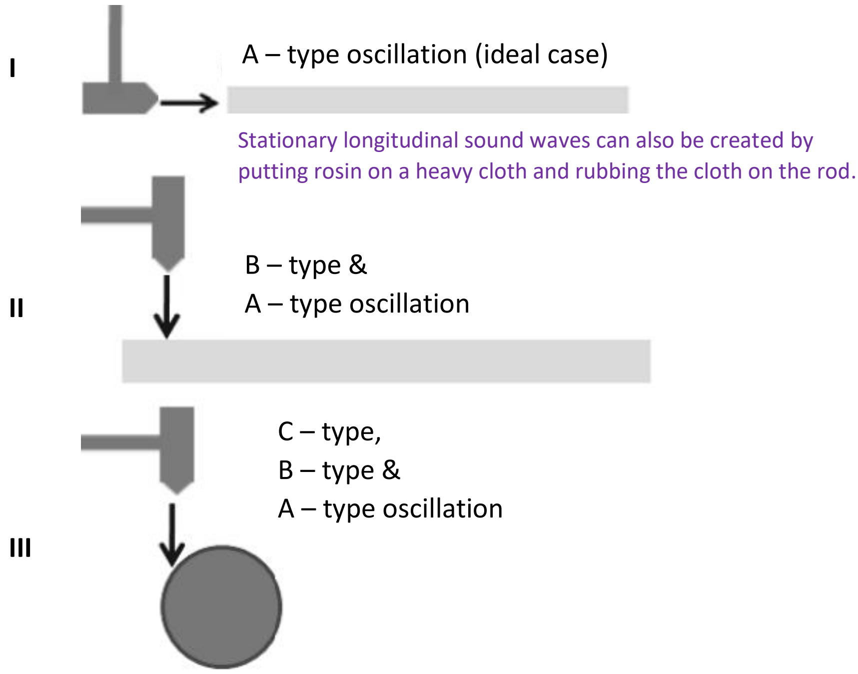
- When a hammer strikes a **hollow** metal tube, the impulse primarily causes vibrations in the metal of the tube, which damps quickly, rather than in the air inside, due to the more efficient transfer of energy between the solid hammer and the metal. Consider the difference between swinging a hammer in the air to create a sound wave versus using a tuning fork; the latter, designed to resonate at specific frequencies, is significantly more effective for purposefully resonating the air within a hollow structure.

- Thus, the rod is **solid**, not hollow, and can exhibit three possible fundamental modes of oscillation: longitudinal, transverse, and torsional, as shown in Fig. A, B and C respectively.

- The objective of the experiment is specifically to investigate the fundamental frequency of oscillation in the longitudinal mode.



- The three main ways an object, e.g. a hammer, can be used to interact with the **solid** rod to cause oscillation is shown in the diagram:



Controlled Variables (CV) for both experiments: (Any **significant one** from)

- Impulse applied at one end of the rod
  - Method to ensure consistency: drop a slotted mass (e.g. 50 g) from a fixed height (e.g. 5.0 cm) above one end of the rod **V2**
- Distance from each end of rod to the clamp
  - Method to ensure consistency: use to ruler to measure and ensure that both distances are constant i.e. $L/2$ **V3**

CKW MC:

- Minor variation in diameter of a *thin* rod will not have significant effect on the fundamental frequency of (a stationary sound wave) in the thin rod. The phrasing of the question is similar to Q5 from the [9702/52 paper of the February/March 2024 session].

- Many candidates proposed employing a hammer to impart an impulse to a rod, thereby initiating oscillatory motion either through the mechanism of dropping the hammer or manually striking the rod's end. However, there was a prevalent oversight in addressing the requisite consistency of this method, particularly in terms of delivering a constant impulse. Discussions lacked depth in articulating strategies to ensure that the hammer strikes the same part of the rod with the same force, time duration and angle in each trial. Moreover, candidates neglected to consider dynamics, such as the hammer's centre of gravity being near its metal end, which could cause it to rotate if dropped from a height in the presence of air resistance. There are alternative methods, as suggested in the Mark Scheme, to cause a rod to oscillate at its fundamental frequency without relying on a hammer or manual striking.

- Mechanical or robotic arms are typically expensive and may not be readily available in all laboratory settings. This makes them impractical for experiments where simpler, more cost-effective methods can achieve similar results.

Methods of data collection

Reasoned method to determine

- frequency from c.r.o, e.g.
  T = time-base x (horizontal) length (of one periodic waveform) **and** $f = 1/T$ **C1**
  - Use theory to verify that the frequency is fundamental e.g.

    $$f_{\text{type A}} = \frac{v_{\text{sound in metal}}}{2L} \approx f_{\text{expt}}$$ **C2**

- Density of rod ρ, e.g. $\rho = \dfrac{4m}{\pi d^2 L}$ $\left[\text{Not just } \rho = \dfrac{m}{V}\right]$ **C3**

Method to measure

- L, e.g. use a metre rule
- mass (m) (of metal rod), e.g. use an electronic weighing machine
- diameter (d) of *thin* rod e.g. use a micrometer / calipers **C4**

CKW MC:

- $v_{\text{sound in metal}}$ is dependent on the density of the rod. The speed of sound in air is ~330 m s^{-1} while the speed of sound in aluminium is ~5000 m s^{-1}. Some candidates quote the speed of sound as 3 x 10^8 m s^{-1}, confusing it with the speed of electromagnetic radiation in a vacuum.

- Some candidates suggested using a measuring cylinder to determine the volume of the metal rod. Measuring cylinders are generally wide and shallow, designed for precise volume measurements of liquids. The range of lengths of the rod required for this experiment is such that the longer rods (up to 1 m and above) cannot be fully submerged in a standard measuring cylinder.

• Although a Fourier Transform can be utilized to analyze a generated sound wave and determine its frequency components, as suggested by a candidate, the specialized software, hardware, and techniques required for such analysis extend beyond the H2 syllabus. Candidates are advised to refrain from citing advanced experimental methods without providing sufficient elaboration or justification for their necessity.	
Method of Analysis	
$f = k\rho^x L^y$ $\lg f = \lg k + x\lg\rho + y\lg L$ [Full linearisation required]	
Experiment ONE (IV: L, CV: ρ) (Use rods of same density but different lengths): Plot a graph of lg f against lg L (or equivalent), gradient is y and vertical intercept is $\lg(k\rho^x)$	**A1**
Experiment TWO (IV: ρ, CV: L) (Use rods of same length but different densities): Plot a graph of lg f against lg ρ (or equivalent), gradient is x and vertical intercept is $\lg(kL^y)$	**A2**
2 experiments, 1 for each independent variable, with clearly described procedures	**A3**
Additional details for accuracy Any **one** from:	
Repeat measurements of diameter along the length of rod / around the rod **and** average diameter	**P1**
Perform experiment in • a quiet room to reduce background noise • an anechoic chamber to prevent distortion of signals received by c.r.o. due to reverberation	**P2** **P2S**
Reasoned method to obtain measurable signal from the microphone, e.g. • use a cone to increase the intensity of sound detected by the microphone • increase the amplitude of oscillation of the rod by increasing the impulse of the hammer	**P3**
Method to reduce uncertainties e.g. • use large values of L to reduce (percentage) uncertainty in L • adjust time-base to display one complete periodic waveform	**P4** **P5**
Conduct a preliminary trial to determine the appropriate range of ρ and L that will produce frequencies within the human audible range, specifically between 20 Hz and 20 kHz.	**P6**
Use a hacksaw to cut the rods of different density to the same length measured by e.g. a metre rule.	**P7**
Use a thermostat to maintain room temperature so that the sound of sound in air and in the metal rod is constant.	**P8**
To precisely determine the (horizontal) length of one periodic waveform on a c.r.o., utilize a high-speed camera to record the CRO's screen and analysing the footage frame-by-frame since the sound wave produced by an oscillating rod in air is transient and damped.	**P9**

CKW MC: • A similar question has appeared in IYPT 2010 problem 13 • There are **22** available marking points, each with specific criteria for awarding credit. • A notable observation was that many candidates included a section for safety precautions that were not credited for this question. • Many candidates did not adhere to the prescribed template or effectively utilize information about apparatus, such as the CRO, as found in the DHS notes on planning, when constructing their answers for Question 4.
In summary, identifying and analysing the keywords in the question is crucial for candidates to develop a relevant planning report that aligns with the required objectives of the experiment “to verify the relationship ($f = k\,\rho^x\,L^y$) and determine the values of x and y (and not *k*)”. Other key phrases such as • “a thin cylindrical metal rod,” • “struck with a hammer” (indicating the method to induce vibrations), • “clamped at its middle,” • “stationary sound wave,” • “fundamental frequency of the rod” and • “accuracy of the experiment” only provide essential context and areas of focus.