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SCHOLARSHIP EXEMPLAR

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QUALIFY FOR THE FUTURE WORLD
KIA NOHO TAKATŪ KI TŌ ĀMUA AO!

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Scholarship 2021
Physics

Time allowed: Three hours
Total score: 32

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should answer ALL the questions in this booklet.

For all 'describe' or 'explain' questions, the answers should be written or drawn clearly with all logic fully explained.

For all numerical answers, full working must be shown and the answer must be rounded to the correct number of significant figures and given with the correct SI unit.

Formulae you may find useful are given on page 3.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–20 in the correct order and that none of these pages is blank.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Question	Score
ONE	
TWO	
THREE	
FOUR	
TOTAL	

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QUESTION ONE: NEUTRONS

Planck's constant	$= 6.63 \times 10^{-34}$ J s
Neutron mass	$= 1.67 \times 10^{-27}$ kg
Charge of an electron	$= -1.60 \times 10^{-19}$ C
Acceleration due to gravity	$= 9.81$ m s^{-2}

A research nuclear reactor is designed to produce a beam of neutrons. The neutrons are produced by the fission of uranium, with one of several possible reactions being described by the following equation:

$$ {}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3\,{}^{1}_{0}n $$

The neutrons released in these reactions have a wide range of energies, but can be slowed down by passing them through material of similar nuclear mass, to form a beam of "slow neutrons".

(a) Use the concept of binding energy to explain why fission reactions occur.

Binding energy is the energy ~~th~~ required to separate the atom into ~~nucleons~~ it's nucleons. The nucleons are binding by strong force. ~~the~~ However, ~~th~~ big atoms are less affected by this strong force and try to be stable by fission. As the fission ~~is no~~ results the ~~atom~~ ~~th~~ daughter atoms with stronger binding energy. ~~the energy that was~~ it means that it need more energy to separate ~~the~~ it's neucleons. This also means that the energy existed in the parents atom is released during fission. Therefore, the fission reactions occur with release of energy

(b) Particles such as neutrons also behave as if they have a wavelength, given by $\lambda = \frac{h}{p}$, where h is Planck's constant and p is the momentum of the particle.

Show that the wavelength of a slow neutron with a kinetic energy of 0.0400 eV is 1.43×10^{-10} m.

$p = mv, \quad E_k = \frac{1}{2}mv^2, \quad v = \sqrt{\frac{2E_k}{m}}$

$\therefore p = m \times \sqrt{\frac{2E_k}{m}} = \sqrt{2mE_k} \quad$ as $\frac{m}{\sqrt{m}} = \sqrt{m}$

$\therefore \lambda = \frac{h}{\sqrt{2mE_k}}, \quad \lambda = \frac{6.63 \times 10^{-34}}{(2 \times 1.67 \times 10^{-27} \times 0.0400 \times 1.60 \times 10^{-19})^{\frac{1}{2}}}$

$= 1.43400 \times 10^{-10}$

$= 1.43 \times 10^{-10}$ (3sf) m

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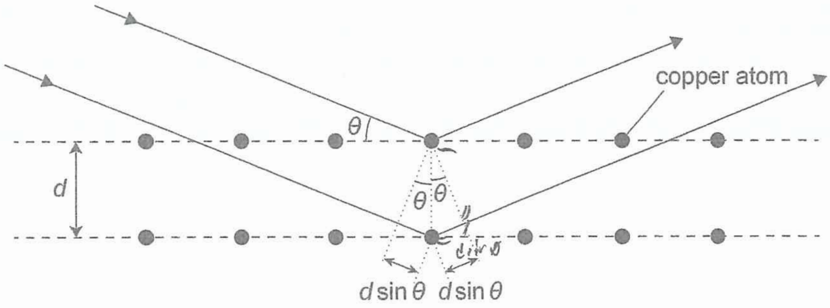
(c) Neutrons of energy 0.0400 eV can diffract from planes of atoms in crystalline copper, of spacing $d = 2.20 \times 10^{-10}$ m, as shown below.



By first considering the path difference for neutrons scattered from adjacent planes, show that a diffraction peak will be observed at angle $\theta = 19.0°$.

the diffraction of neutrons will form the interference pattern and the peak will be observed when path difference between them is whole ~~number of λ~~ number and a half

$\therefore \frac{\lambda}{2} = d\sin\theta$, $\lambda = 1.43 \times 10^{-10}$ m, $d = 2.20 \times 10^{-10}$

$\frac{\lambda}{2} = d\sin\theta$, $\frac{7.15 \times 10^{-11}}{2.2 \times 10^{-10}} = \sin\theta$

$\sin\theta = 0.325$

$\theta = \sin^{-1}(0.325) = 18.965$,

$19.0°$ (3sf)

(d) Neutrons have mass, but zero charge. A neutron with kinetic energy of 0.0400 eV is initially travelling horizontally.

(i) Calculate the vertical deflection of the neutron due to gravity as it travels a horizontal distance of 1.00×10^2 m.

$E_k = 0.0400 \times 1.60 \times 10^{-19} = 6.4 \times 10^{-21}$ J, $E_k = \frac{1}{2}mv^2 = 6.4 \times 10^{-21}$

$100/2768.5 = 0.036$ sec, $V_f = V_i + at$, $V_{f\,ver} = 0.354\ ms^{-1}$ $v^2 = 7664670.6T$

$v_f^2 = v_i^2 + 2ad$, $0.354^2 = 0 + 2(9.8)d$, $d = 6.40 \times 10^{-3}$ m $v = \cancel{7668}\ 2768.5\ ms^{-1}$

100, 6.40x10^-3

$\tan\theta = \frac{6.40 \times 10^{-3}}{100}$, $\theta = \cancel{0.0}\ 3.666 \times 10^{-3}$, 3.67×10^{-3} (3sf) deflected

(degrees) OK

(ii) Explain whether or not a uniform electric field can be used to compensate for the effect of gravity on the neutron.

NO we cannot use electric field. As neutron doesnot have charge, it will not affected by energy change due to travelling distance in field. only proton and electron will have a change in energy and are able to compensate the effect.

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QUESTION TWO: STRINGS AND SPRINGS

A typical guitar has six strings. Two of these strings are tuned to the notes "A" and "D". When tuned correctly, the "A" string has a fundamental frequency of 110.0 Hz, and the 4th harmonic of the "A" string has the same frequency as the 3rd harmonic of the "D" string.

(a) (i) Explain how the principle of beats can be used to determine if the "D" string is at the correct frequency, if it is known that the "A" string already has the correct fundamental frequency of 110.0 Hz.

The Beat is created when the sound ~~that~~ waves that has slightly different frequency interfere each other, and creates repeatation of ~~sound~~ variation of loudness. Therefore, if the frequency of D is slightly different, the beat will produced. ~~Thus, we We can find correct frequency when the beat is not produced as the frequencies are identically. Hz~~ (extra paper)(continued)

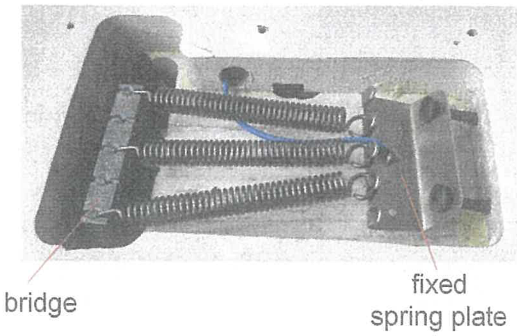
(ii) Calculate the fundamental frequency of the "D" string when it is correctly tuned.

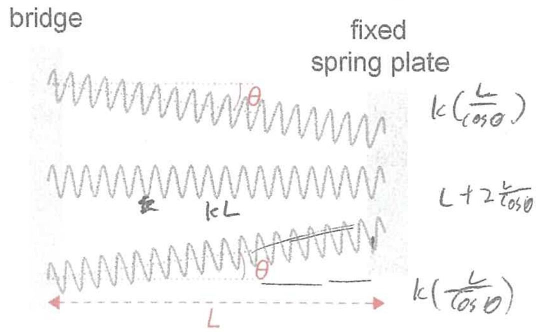
As the "D" is same frequency with 4th harmonic of "A" its frequency will be $4 \times 110.0 = 440.0$ Hz.

The fundamental frequency of "D" will be 1/3 of 3rd harmonic

∴ $440.0/3 = 146.67$ Hz, 146.7 Hz (4sf)

Some guitars use a set of three identical springs to apply tension to the strings. The three springs all have spring constant, k, and an unstretched length, L_0. They are then stretched and connected between the bottom side of a pivoted metal plate called the bridge and a fixed spring plate, as shown.





(b) Show that the net force, F, applied to the bridge by the three stretched springs is given by:

$F = \mathrm{k}(3L - L_0(1 + 2\cos\theta))$

$F = kx$, ∴ for middle, $x = L - L_0$ ∴ $F_t = k(L - L_0)$

for two springs, $x = \frac{L}{\cos\theta} - L_0$ $F_t = k(\frac{L}{\cos\theta} - L_0)$

However, the pulling force from string is horizontal component

∴ $F_{t\ horizontal} = k(\frac{L}{\cos\theta} - L_0)\cos\theta = k(L - L_0\cos\theta)$

∴ $F_{Total} = k(L - L_0) + 2k(L - L_0\cos\theta) = k(L - L_0 + 2L - 2L_0\cos\theta)$
$= k(3L - L_0(1 + 2\cos\theta))$

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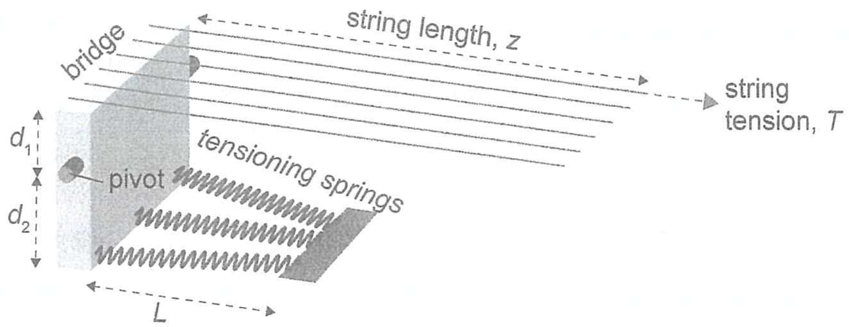
The bridge is where the strings connect to the body of the guitar. Some guitars have a "floating bridge" design, where the springs are attached to the bottom and the strings to the top of the pivoted bridge, as shown below.



The speed of a transverse wave in a string is given by: $v = \sqrt{\frac{T}{\mu}}$,

where T is the tension in the string, and μ is the linear density of the string.

(c) Assuming that all strings have equal tension, T, and length, z, show that the fundamental frequency of a string is given by:

$$f = \sqrt{\frac{kd_2\left(3L - L_0\left(1 + 2\cos\theta\right)\right)}{24\mu d_1 z^2}}$$

$\frac{d_2}{6d_1}$

$v = f\lambda$, $f = \frac{v}{\lambda}$, $\lambda = 2z$, $f\lambda = \sqrt{\frac{T}{\mu}}$

$f = \frac{1}{2z} \times \sqrt{\frac{T}{\mu}} = \sqrt{\frac{T}{4z^2\mu}}$

T of the string spring $\xleftarrow{d_2}$ O $\xrightarrow{d_1}$ strings pivot , torque will be equal magnitude

$\therefore T_{sp} d_2 = d_1 T_{str} \times 6$, $6T_{str} = \frac{d_2}{d_1} T_{sp}$, as $T_{sp} = k(3L - L_0(1+2\cos\theta))$

$T_{str} = \frac{d_2}{6d_1} k(3L - L_0(1+2\cos\theta))$

$\therefore f = \sqrt{\frac{T_{str}}{4z^2\mu}} = \sqrt{\frac{\frac{d_2}{6d_1}k(3L-L_0(1+2\cos\theta))}{4z^2\mu}}$

$= \sqrt{\frac{kd_2(3L-L_0(1+2\cos\theta))}{24z^2\mu d_1}}$

(d) If the "D" string on a guitar with a floating bridge snaps, explain how the fundamental frequency of the "A" string will be affected, and state the new fundamental frequency of the "A" string.

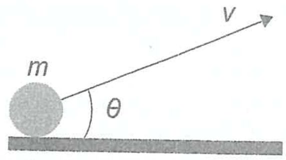
Assume that the string length, z, is constant.

~~As the D string is snaps, the bridge is oscillating with the frequency of 146.67 Hz~~ If the "D" string is snaps, the tension that is provided to the string "A" will be increased as ~~providing ten~~ tension from spring is constant and there are less number of strings. As the $v = \sqrt{\frac{T}{\mu}}$, the velocity of wave through string A will be increased. Since $v = f\lambda$, the frequency of ~~waves~~ wave through string A ~~will also be~~ increased. As there are now only 4 strings, the tension will be increased by $\frac{5}{4}$ times.

ASSE USE

QUESTION THREE: ABOUT A BALL

$$2\sin\theta\cos\theta = \sin 2\theta$$

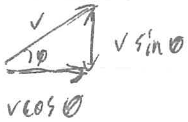


A ball with mass, m, is launched at a speed, v, at an angle, θ, to the horizontal, as shown. The projectile lands at the same height that it was launched from.

(a) The horizontal distance travelled, d, is maximum when $\theta = 45°$.

By considering components of the velocity, v, show that the maximum horizontal distance travelled, d, is given by: $d = \frac{v^2}{g}$.

Assume that drag is negligible for this part of the question.



$d = vt$, $v_{(\text{vertical})} = v\sin\theta$

$V_{f\,\text{vert}} = V_{i\,\text{vert}} + at$, $v\sin\theta = -v\sin\theta + gt$

$t = \frac{2v\sin\theta}{g}$

$d = vt$, $V_h = v\cos\theta$

$d = \frac{v\cos\theta\left(\frac{2v\sin\theta}{g}\right)}{g}$

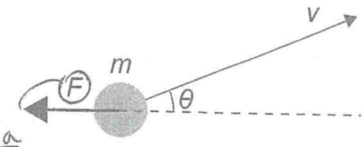
$= \frac{2\cos\theta\sin\theta\, v^2}{g}$, $2\sin\theta\cos\theta = \sin 2\theta$,

$= \frac{\sin 2\theta \times v^2}{g}$, $\sin 2(45) = 1$

$= \frac{v^2}{g}$

horizon

A more accurate model of the situation includes a drag force, F, that acts on the ball. This force changes the motion of the ball as it moves through the air. A simple assumption would be that the drag force, F, is constant in magnitude, and acts only in the horizontal direction as the ball moves through the air, as shown.



$F = m \times a$

(b) Show that in the case of a constant, horizontal drag force, F, the horizontal distance travelled, d, by a ball launched at speed, v, at an angle, θ, to the horizontal, is given by the expression:

$$d = \frac{v^2}{g}\left(\sin 2\theta - \frac{2F}{mg}\sin^2\theta\right)$$

As F_{drag} is horizontal, ~~the~~ time will be constant, $t = \frac{2v\sin\theta}{g}$

$V_f = V_i + at$ ~~$V_f^2 = V_i^2 + 2ad$~~, $V_f = 0$, (horizontal) $V_i = v\cos\theta$, $F_{drag} = ma$, $a_{drag} = -\frac{F}{m}$, negative as opposite direction

~~$V_f = v\cos\theta +$~~ ~~$0 = v^2\cos^2\theta - 2\frac{2F}{m}d$~~ $V_f = v\cos\theta \mp \frac{F}{m}\cdot\frac{2v\sin\theta}{g} = v\cos\theta \mp \frac{2Fv\sin\theta}{mg}$

~~$\frac{v\cos^2\theta\, m}{2F} = d$~~ $V_{f\,\text{horizontal}}^2 = V_{i\,\text{horizontal}}^2 + 2ad$

$\left(v\cos\theta + \frac{2vF\sin\theta}{mg}\right)^2 = v^2\cos^2\theta + \frac{2F}{m}d$, $\therefore d = -\frac{2vF\sin^2\theta}{mg^2} + \frac{v^2\sin 2\theta}{g}$

$= \frac{v^2}{g}\left(-\frac{2F}{mg}\sin^2\theta + \sin 2\theta\right)$

$v^2\cos^2\theta + \frac{4v^2F^2\sin^2\theta}{m^2g^2} - \frac{4vF\sin\theta\cos\theta}{mg} = v^2\cos^2\theta + \frac{2F}{m}d$, $\frac{4v^2F^2\sin^2\theta}{m^2g^2} + \frac{2vF\sin 2\theta}{mg} = \frac{2F}{m}d$

(c) Discuss the validity of the assumptions about the drag force in part (b).

Describe more realistic assumptions about the drag force, and explain how these would affect the horizontal distance travelled by the ball.

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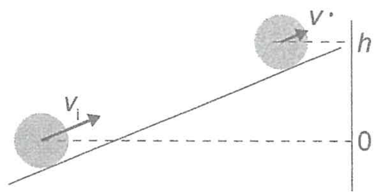
The drag force also ~~a~~ affect to ~~the~~ vertical ~~when the ball~~ as the ball also has ~~fall~~ rising / falling motion. The drag force will be generated from air resistance ~~between with~~ ball acting to ball. As the drag force acts in ~~other~~ opposite direction of applied force (acceleration), the ball will ~~not~~ have less time in the air due to decreasing of ~~acc~~ vertical acceleration from drag force. This causes the ball to travel shorter horizontal distance while it is in the air.

(d) After receiving an initial push, the solid ball begins rolling up a slope, as shown on the right.



The ball has mass m, radius R, and moment of inertia $I = \frac{2}{5}mR^2$.

When it is at height = 0, the centre of mass of the ball has velocity v_i. When it has reached height = h, the centre of mass of the ball has velocity v.

(i) Assuming that drag is negligible in this situation, show that the velocity of the centre of mass of the ball, v, when it has reached height, h, is given by:

ms^{-1} $\quad 2R\pi/v = T$

$$v = \sqrt{v_i^2 - \frac{10gh}{7}}$$

$E_{rot\,final} + E_{k\,final} + E_p$ gravitational potential energy $= E_{k\,initial} + E_{rot}$

$\frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 + mgh = \frac{1}{2}mv_i^2 + \frac{1}{2}I\omega^2$, $\quad \omega = \frac{2\pi}{T}$, as $v = ms^{-1}$, diameter $= 2R\pi$, $2R\pi/v = T$

$\therefore \omega = 2\pi / (2R\pi/v) = \frac{v}{R}$

$\therefore \frac{1}{2}I\omega^2 = \frac{1}{2}\cdot\frac{2}{5}mR^2 \cdot \frac{v^2}{R^2}$

$= \frac{1}{5}mv^2$

$\frac{1}{5}mv^2 + mgh = \frac{1}{2}mv_i^2 + \frac{1}{5}mv_i^2$, cancel m

$\frac{1}{5}v^2 + \frac{1}{2}v^2 + gh = \frac{1}{2}v_i^2 + \frac{1}{5}v_i^2$

$\frac{7}{10}v^2 + gh = \frac{7}{10}v_i^2$

$\frac{7}{10}v^2 = \frac{7}{10}v_i^2 - gh$

$v^2 = v_i^2 - \frac{10gh}{7}$

$\therefore v = \sqrt{v_i^2 - \frac{10gh}{7}}$

(ii) Give an expression for the maximum height reached by the ball as it rolls up the ramp.

when it is at maximum, $E_{potential}$ = initial E_k + initial E_{rot}

$mgh = \frac{1}{2}mv_i^2 + \frac{1}{5}mv_i^2$

$gh = \frac{7}{10}mv_i^2$

$h = \frac{7mv_i^2}{10g}$

QUESTION FOUR: DC CIRCUITS

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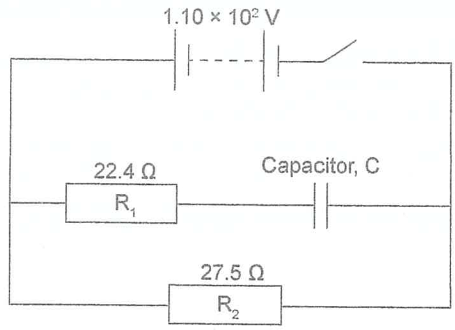
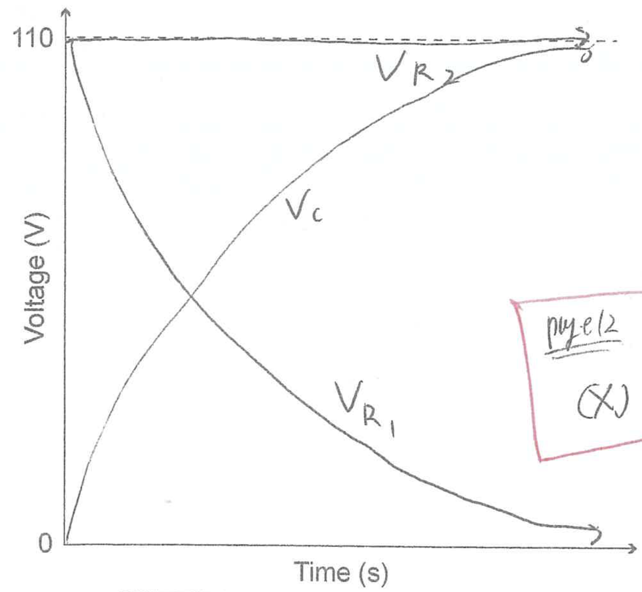
A parallel circuit is connected to a 1.10×10^2 V DC supply and a switch, as shown.

One branch of the circuit has a 22.4 Ω resistor, R_1, and an uncharged capacitor, C, in series. The other branch has only a 27.5 Ω resistor, R_2.



(a) Sketch clearly labelled lines/curves on the axes on the right to show how the voltage across each component, R_1, R_2, and the capacitor, C, will change when the switch is closed at $t = 0$ s.

Explain why the voltage across each component changes in this way.



page 12

(X)

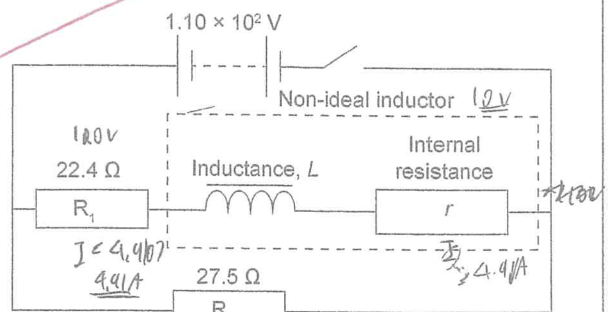
If you need to redraw your response, use the axes on page 12.

As the circuit is parallel, the voltage across three component will be same with 110V at t=0. ~~However, the Voltage across~~ R1 and capacitor will be decreased as the charge is being stored on the plate of capacitor and repel the approaching ~~car~~ charges. the time constant that voltage decreased by its 63% value will be, T = RC, ~~22.4x~~ then ~~it will the~~ the voltage across the R1 and Capacitor will be zero ~~on the~~ after 5 time constant is passed. The voltage across the R2 will be constantly 110V ~~as~~ because the current across the R2 will change as ~~the total resistance of circuit also will also change as due to the change~~ the ~~current~~ current across the R1 is charged. The capacitor will be charged up, so voltage across it will be increased.

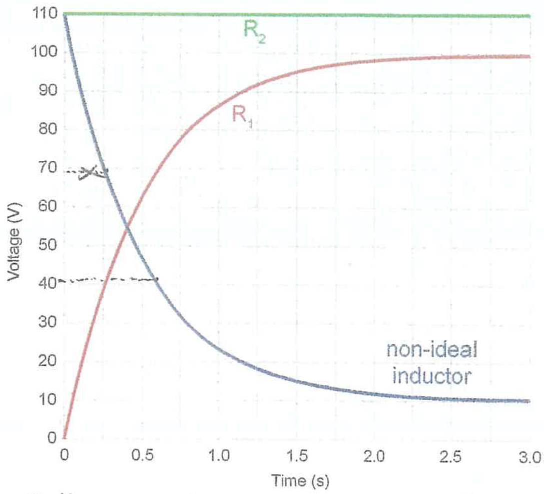
The capacitor is removed from the circuit and replaced with a non-ideal inductor.

The non-ideal inductor has both inductance, L, and internal resistance, r.

At $t = 0$ s, the switch is closed. The voltage across each component, R_1, R_2, and L, is measured for 3.00 s, and plotted on the graph on the facing page.



(b) Using physics principles, explain why each of the three lines on the graph has the shape it does.



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when the ~~current~~ switch is closed, ~~there~~ ~~is~~ The inductor is induced by the changing of current. As the change of current was maximum at t=0, the Induced voltge is maximum according to Faraday's law ($\varepsilon = L\frac{\Delta I}{\Delta t}$) This makes the potential difference across path that contains R_1 and inductor be zero, so initially, the voltge across R_1 becomes 0. However, as the time flow, the ~~chg~~ rate of change of current will decrease and reach to steady current gradually. As the voltge induced on inductor is decreased, the voltge across the R_1 increase gradually. The R_2 will receieve same voltge as ~~B~~ the circuit is parallel.

(c) Use information from the graph to estimate the time at which the current through R_1 and the current through R_2 are equal.

The time ~~when~~ when current across R_1 and R_2 ~~be~~ be equal is the time when voltge ~~ind~~ induced on inductor become zero. The inductor is considered to be ~~zero~~ induced ~~to zero~~ fully and have 0V after 5τ. ~~T is~~ Time constant τ is the time taken to be reduced by 63% of its voltge value. ∴ τ for this inductor is approximately ~~0.25~~ 0.60 second. ∴ ~~5 × 0.25~~ 5 × 0.60 = ~~1.25~~ sec 3.0 sec

(d) Using information from the graph, calculate the value of the inductance, L, and internal resistance, r, of the non-ideal inductor.

τ of inductor = $\frac{L}{R}$, $R = R_1 + r$

∴ ~~R~~ $L = \tau(R_1 + r)$, τ = about 0.60

$L = 0.60(R_1 + r)$, $R_1 = 22.4\,\Omega$

$L = 0.60(22.4 + r)$

∴ ~~110V is induced to non-ideal inductor, terminal voltge = 110V,~~

~~from Kirchoff's rule,~~ ~~110 = 22.4~~ From graph, voltge ~~induced~~ across R_1 = 100V

∴ V across r = 10V, as ~~the~~ r and R_1 is in same path, $I_{R_1} = I_L$

$I_{R_1} = 4.464$, ~~4.46 A (3sf)~~ $\frac{100}{22.4}$

~~10 =~~ 10 = 4.46 × r, r = 2.24 Ω, ∴ $L = 0.60(22.4 + 2.24)$

$= 0.60(24.64)$

$= 14.784$ ~~H~~ ≒ 14.8 H (3sf)

SPARE DIAGRAM

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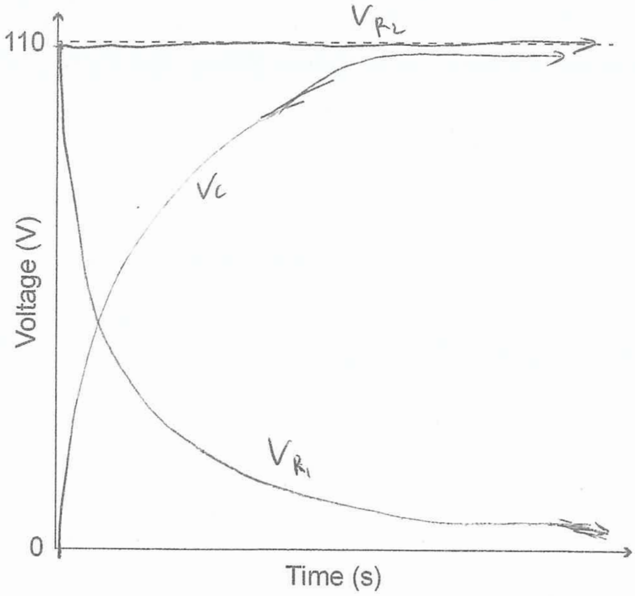
If you need to redraw your response to Question Four (a), use the diagram below. Make sure it is clear which answer you want marked.



seen

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

ASSESSOR'S USE ONLY

Q2 (a)(i)

Thus ~~the~~ we can check If the string D is tuned correctly or not by checking th frequency of beat produced ~~in the~~ when plucking two strings together. If the string D is tuned correctly, the ~~3rd~~ ~~h~~ ~~fu~~ fundamental ~~frequ~~ harmonic of string D will ~~so~~ produce $\frac{4}{3}$ of fundamental frequency of "A". ~~Th~~ As frequency of ~~string~~ beat $= |f_1 - f_2|$, the beat ~~of~~ thathas frequency of $\frac{4}{3}f_A - f_A = \frac{1}{3}f_A$ will be heard.

or As the fundamental frequency ~~is~~ of 'D' is $\frac{4}{3}$ of fundamental frequency of "A", we can make the tension of string A ~~increase~~ be increased to "A" has $\frac{4}{3}$ times of its own frequency. ~~So~~ This will not ~~make~~ ~~the beat~~ ~~not~~ created the beat as their frequency will be same and just enhance eachother

seen

~~k~~ ~~L_0~~ ~~2L cos~~

$(2L_0\cos\theta - L_0)$

$\cos\theta = \frac{L}{x}$

$L = x\cos\theta$

$x = \frac{L}{\cos\theta}$

~~KE~~ $x = L - L_0$

~~$x = \frac{L}{\cos\theta}$~~ stregthed $= \frac{L}{\cos\theta}$, ~~2L~~

$\frac{L}{\cos\theta} - L_0$

$k\left(\frac{L}{\cos\theta} - L_0\right)$ ~~+k~~$(L - L_0)$

$k\left(\frac{L}{\cos\theta} - 2L_0 + L\right)$

$k\left(\frac{L}{\cos\theta} - L_0\right) \times \cos\theta$

$2k(L - L_0\cos\theta$

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Q2 (d)

from $v = \sqrt{\frac{T}{\mu}}$, as T increased by $\frac{5}{4}$

v increased by $\sqrt{\frac{5}{4}}$, $\frac{\sqrt{5}}{2}$

seen

since $v = f\lambda$, as ~~λ~~ λ is constant, f will be increased by $\frac{\sqrt{5}}{2}$ as well.

$\therefore$ The new fundamental frequency will be $110 \times \frac{\sqrt{5}}{2}$

$= \cancel{50}\ 55\sqrt{5}$ Hz

$= 122.98$,

123.0 Hz (4sf)

Scholarship exemplar 2021

Subject:	Physics	NZS standard:	93103	Total score:	21

Q	Score	Annotation
1	6	Scholarship level understanding of binding energy shown. Indifferent grasp of interference phenomena resulting in a grade just below outstanding
2	7	Outstanding understanding of force components as well as torque, equilibrium and the frequency relationship with tension. Only marred by a small mathematical error in the last part.
3	5	Demonstrates scholarship level of understanding of dynamics calculations. Inferior layout and incomplete explanations prevented an outstanding performance.
4	3	Only a rudimentary grasp of the operation of capacitors and inductors has been demonstrated. This is below scholarship level.