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TOP SCHOLAR

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QUALIFY FOR THE FUTURE WORLD
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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	

ASSESSOR'S USE ONLY

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The examination starts on page 4.

The formulae below may be of use to you.

$v_f = v_i + at$ $d = v_i t + \frac{1}{2}at^2$ $d = \frac{v_i + v_f}{2}t$ $v_f^2 = v_i^2 + 2ad$ $F_g = \frac{GMm}{r^2}$ $F_c = \frac{mv^2}{r}$ $\Delta p = F\Delta t$ $\omega = 2\pi f$ $d = r\theta$ $v = r\omega$ $a = r\alpha$ $W = Fd$ $F_{net} = ma$ $p = mv$ $x_{COM} = \frac{m_1x_1 + m_2x_2}{m_1 + m_2}$ $\omega = \frac{\Delta\theta}{\Delta t}$ $\alpha = \frac{\Delta\omega}{\Delta t}$ $L = I\omega$ $L = mvr$ $\tau = I\alpha$ $\tau = Fr$ $E_{K(ROT)} = \frac{1}{2}I\omega^2$ $E_{K(LIN)} = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$ $\omega_f = \omega_i + \alpha t$ $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ $\theta = \frac{(\omega_i + \omega_f)}{2}t$ $\theta = \omega_i t + \frac{1}{2}\alpha t^2$	$T = 2\pi\sqrt{\frac{l}{g}}$ $T = 2\pi\sqrt{\frac{m}{k}}$ $E_p = \frac{1}{2}ky^2$ $F = -ky$ $a = -\omega^2 y$ $y = A\sin\omega t$ $y = A\cos\omega t$ $v = A\omega\cos\omega t$ $v = -A\omega\sin\omega t$ $a = -A\omega^2\sin\omega t$ $a = -A\omega^2\cos\omega t$ $\Delta E = Vq$ $P = VI$ $V = Ed$ $Q = CV$ $C_T = C_1 + C_2$ $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ $E = \frac{1}{2}QV$ $C = \frac{\varepsilon_o \varepsilon_r A}{d}$ $\tau = RC$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ $R_T = R_1 + R_2$ $V = IR$	$F = BIL$ $\phi = BA$ $\varepsilon = -\frac{\Delta\phi}{\Delta t}$ $\varepsilon = -L\frac{\Delta I}{\Delta t}$ $\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $E = \frac{1}{2}LI^2$ $\tau = \frac{L}{R}$ $I = I_{MAX}\sin\omega t$ $V = V_{MAX}\sin\omega t$ $I_{MAX} = \sqrt{2}\,I_{rms}$ $V_{MAX} = \sqrt{2}\,V_{rms}$ $X_C = \frac{1}{\omega C}$ $X_L = \omega L$ $V = IZ$ $f_0 = \frac{1}{2\pi\sqrt{LC}}$ $v = f\lambda$ $f = \frac{1}{T}$ $n\lambda = \frac{dx}{L}$ $n\lambda = d\sin\theta$ $f' = f\frac{V_W}{V_W \pm V_S}$ $E = hf$ $hf = \phi + E_K$ $E = \Delta mc^2$ $\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$ $E_n = -\frac{hcR}{n^2}$

QUESTION ONE: NEUTRONS

ASSESSOR'S USE ONLY

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:

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

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 amount of energy required to separate a nucleus into its various nucleons. The more binding energy,* the more stable an atom is as it is harder to split apart its nucleus. The element with the highest binding energy per nucleon is Iron, which has a lower atomic number (so less protons) than Uranium. Hence Uranium, or other elements with atomic numbers greater than Iron, may often split in what is called a fission reaction to become a more stable element, releasing energy in the form of neutrons as part of the process.

* per nucleon.

(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.

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

$0.04 \times 1.6 \times 10^{-19} = \frac{1}{2} \times 1.67 \times 10^{-27} \times v^2$

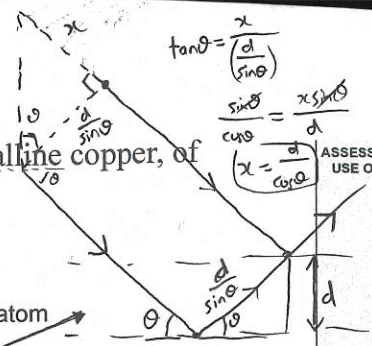
$v^2 = 7.66467 \times 10^{6}$

$v = 2.769 \times 10^{3}$ m s^{-1}

$\therefore \lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times 2.77 \times 10^{3}}$

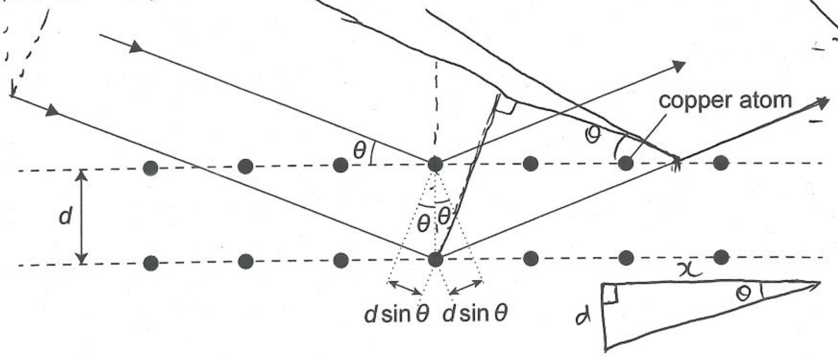
$= 1.434604 \times 10^{-10}$

$= 1.43 \times 10^{-10}$ m (3s.f.)



ASSESSOR'S USE ONLY

(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 $\theta = 19.0°$.

Suppose ~~path~~ the path difference is x. Then

$\tan\theta = \dfrac{d}{x}$

$x = \dfrac{d}{\tan\theta}$

Hence for a diffraction peak we require $x = n\lambda$. (where n is an integer)

$\dfrac{d}{\tan\theta} = n\lambda \Rightarrow n = \dfrac{d}{\lambda\tan\theta}$. When $\theta = 19.0°$, we have:

$n = \dfrac{2.2 \times 10^{-10}}{1.43 \times 10^{-10} \times \tan 19°}$

=

SEE BACK

(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.

From before, $v = 2.769 \times 10^3 \text{ m s}^{-1}$. Therefore

$t = \dfrac{d}{v} = \dfrac{100}{2.769 \times 10^3} = 0.03612$ s.

In that time, $d = v_i t + \frac{1}{2}at^2$

$= \frac{1}{2} \times 9.81 \times 0.03612^2$ (vertical velocity = 0 initially)

$= 0.00639949 = 6.40 \times 10^{-3}$ m (3s.f.)

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

As the neutron is a neutrally charged particle, placing it inside a uniform electric field will have no effect on its motion. Hence it cannot be used to compensate for the effect of gravity.

QUESTION TWO: STRINGS AND SPRINGS

ASSESSOR'S USE ONLY

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.

When two frequencies that are similar but not exactly the same are played at the same time, a phenomenon called beats can be heard, where the sound heard has a frequency equal to the average of the two frequencies but with its volume alternating between louder and quieter with a frequency equal to the difference in frequencies. SEE BACK

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

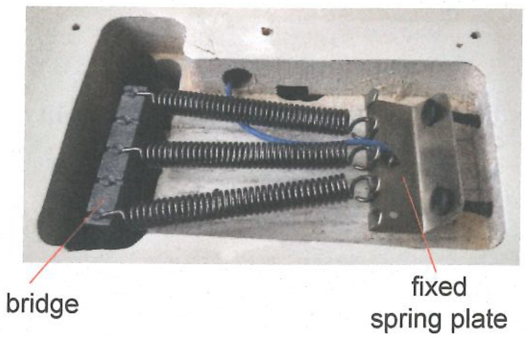
$f_A = 110.0$ Hz $\quad 4f_A = 3f_D$

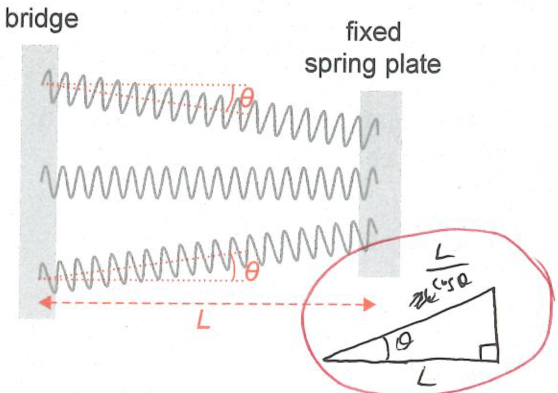
$f_D = \frac{4 \times 110}{3}$

$= 146.6667$

$= 147$ Hz (3s.f.)

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:

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

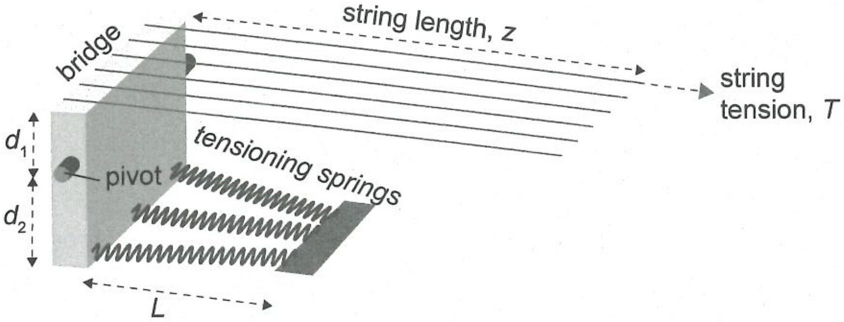
$F = kx$. The ~~middle~~ spring is stretched from L_0 to L, so its force is equal to $F = k(L - L_0)$. For the top and bottom springs, they are stretched from L_0 to $\frac{L}{\cos\theta}$ so $F = k\left(\frac{L}{\cos\theta} - L_0\right)$. Hence the total force is:

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

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

ASSESSOR'S USE ONLY

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: $v = \sqrt{\dfrac{T}{\mu}}$,

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:

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

Fundamental frequency occurs when length is exactly half a wavelength: $z = \frac{\lambda}{2}$. Thus $f = \frac{v}{\lambda} = \frac{v}{2z} = \sqrt{\frac{T}{\mu}} \cdot \frac{1}{2z} = \sqrt{\frac{T}{4\mu z^2}}$.

Now, using the pivot we know that $6Td_1 = Fd_2$ (equal torques)

$$T = \frac{Fd_2}{6d_1} = \frac{kd_2(3L - L_0(1+2\cos\theta))}{6d_1}$$

$$\therefore f = \sqrt{\frac{kd_2(3L - L_0(1+2\cos\theta))}{6d_1 \cdot 4\mu z^2}} = \sqrt{\frac{kd_2(3L - L_0(1+2\cos\theta))}{24\mu d_1 z^2}}$$

(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.

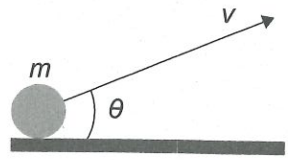
Since the tension in the strings before was the same for all the strings, this must still be the case*. ~~However,~~ Therefore the tension in each string is $\frac{6T}{5} = 1.2T$. Now, the tension in the A string has increased by a factor of $1.2\times$ and $f \propto v \propto \sqrt{T}$ so the fundamental frequency must increase by a factor of $\sqrt{1.2} = 1.095$. Hence the new fundamental frequency of the A string is $110 \times 1.095 =$ 120.5 Hz (4 s.f.)

* after the D string snaps

ASSESSOR'S USE ONLY

QUESTION THREE: ABOUT A BALL

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

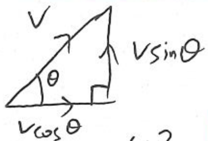


A ball with mass, *m*, is launched at a speed, *v*, at an angle, *θ*, to the horizontal, as shown. The projectile lands at the same height that it was launched from.

(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.



Considering vertical velocity: $v_i = v\sin\theta = \frac{\sqrt{2}}{2}v$, $a=-g$, $d=0$, $t=?$

$d = v_i t + \frac{1}{2}at^2$

$0 = \frac{\sqrt{2}}{\cancel{2}}vt + \frac{1}{\cancel{2}}\cdot -g \cdot t^2$

$gt^2 - \sqrt{2}vt = 0$

$t(gt - \sqrt{2}v) = 0$

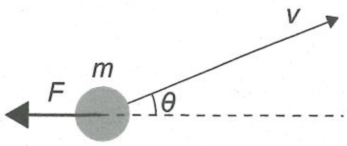
$t = 0$ or $t = \frac{\sqrt{2}v}{g}$

~~Obviously~~ The ball is launched at $t=0$ so it must land at $t = \frac{\sqrt{2}v}{g}$.

Now, considering horizontal velocity: $v = v\cos\theta = \frac{\sqrt{2}}{2}v$, $t = \frac{\sqrt{2}v}{g}$, $d=?$

Velocity is constant so $d = vt = \frac{\sqrt{2}}{\cancel{2}}v \cdot \frac{\sqrt{2}v}{g} = \frac{v^2}{g}$

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.



(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:

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

The vertical component of the ball's velocity is unaffected by the drag force so as above we must have:

$v_i = v\sin\theta$, $a=-g$, $d=0$, $t=?$

$d = v_i t + \frac{1}{2}at^2$

$0 = v\sin\theta\, t + \frac{1}{2}\cdot -g\cdot t^2$

$gt^2 - 2v\sin\theta\, t = 0$

$t(gt - 2v\sin\theta) = 0$

SEE BACK

ASSESSOR'S USE ONLY

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

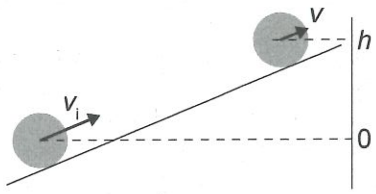
Describe more realistic assumptions about the drag force, and explain how these would affect the horizontal distance travelled by the ball.

The assumptions about the drag force in part (b) are not very realistic and are ~~done~~ made to simplify the scenario. Rather than being only in the horizontal direction, the drag force would actually be in the exact opposite direction to the velocity of the ball.* Also, rather than being of constant magnitude, the size of the drag force would also be proportional to the velocity of the ball.

*at any one time

SEE BACK

(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:

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

At $h=0$, the energy of the ball (i.e. the total energy of the system) is given by $E_{total} = \frac{1}{2}mv_i^2 + \frac{1}{2}I\omega^2$

$$= \frac{1}{2}mv_i^2 + \frac{1}{\cancel{2}} \cdot \frac{\cancel{2}}{5}m\cancel{R^2} \cdot \left(\frac{v_i}{\cancel{R}}\right)^2$$

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

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

Then, at height h, and by the conservation of energy:

$$\frac{7}{10}mv_i^2 = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + mgh$$

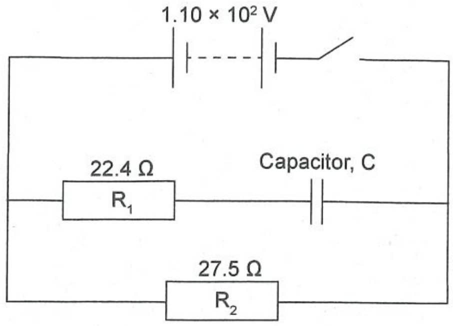
SEE BACK

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

$\cancel{m}gh = \frac{7}{10}\cancel{m}v_i^2$ (all energy is gravitational potential energy)

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

QUESTION FOUR: DC CIRCUITS

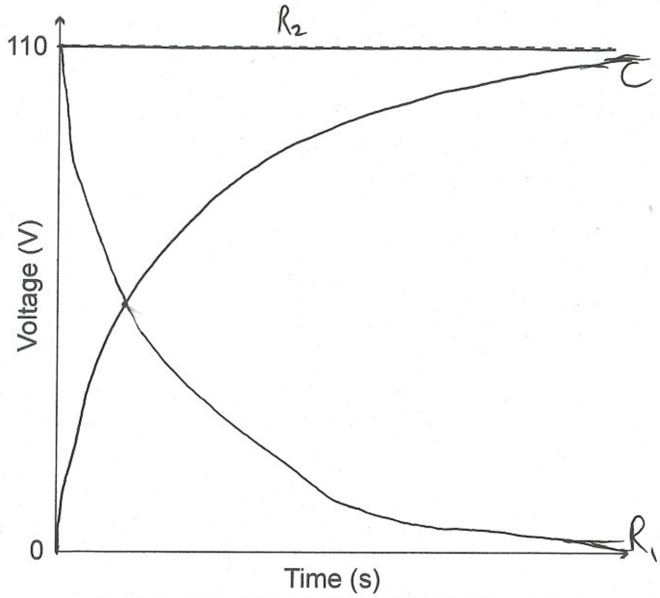


A parallel circuit is connected to a 1.10×10^2 V DC supply and a switch, as shown.

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.



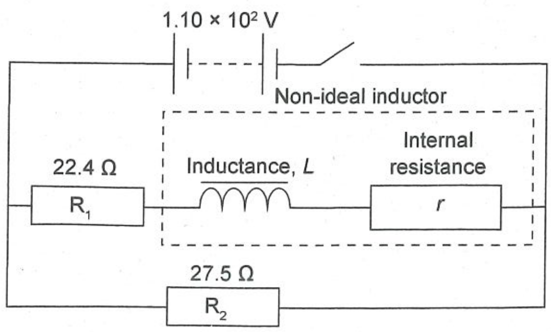
If you need to redraw your response, use the axes on page 12.

In a parallel circuit, each branch receives the same voltage but the current is split. Therefore the voltage across R_2 will be 110 V ~~there~~ from when the switch is closed as it is the only component in its branch. As for the capacitor, it will charge up over time, initially storing 0 V and eventually storing 110 V. This is quick at first, but the rate of increase of voltage slows over time as it becomes harder for similar charges to accumulate on either side of the capacitor's plates. Finally, the voltage across R_1 is simply $110 - V_c$ where V_c is the voltage across the capacitor, as per Kirchhoff's voltage law. 4

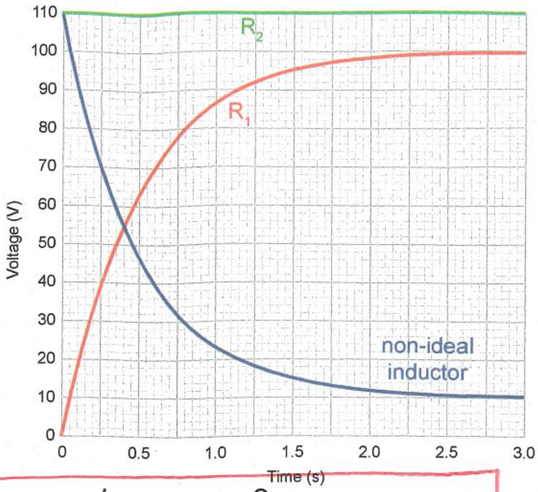
The capacitor is removed from the circuit and replaced with a non-ideal inductor.

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.



As in the previous question, R_2 maintains a constant 110 V due to being in a parallel branch. An inductor resists the change in current. It does this by producing a back emf.* Immediately when the switch is closed, the ~~ind~~ current changes ~~from 0~~ very quickly so a large emf is produced. ~~As this is 110 V, there is momentarily~~ However, the ~~current is~~ ~~decreasing~~ rate of change of current slows over time and hence so too does the voltage across the inductor. SEE BACK

* proportional to the rate of change of current

ASSESSOR'S USE ONLY

(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.

$I = \frac{V}{R}$ so $I_2 = \frac{110}{27.5} = 4$ A. ~~Therefore~~ The current through R_1 is given by $I_1 = \frac{V_{R_1}}{R_1}$ so $V_{R_1} = 4 \times 22.4 = 89.6$ V. Therefore, looking at the graph we can estimate that the current through R_1 and R_2 are equal at about time ~~t=1.1s~~ $t = 1.15$ s.

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

The voltage across the inductor appears to be approaching 10 V, so we can assume this is the voltage a long time after the switch has been closed. Then we know that $V_{R_1} = 100$ V, so

$$I = \frac{V_{R_1}}{R_1} = 4.4643 \text{ A.}$$ (in this branch with the inductor)

Hence $r = \frac{V_L}{I} = \frac{10}{4.4643} = 2.24\ \Omega$

Also, the time constant τ is given by $\tau = \frac{L}{R}$ and we know that after one time constant, the current** will rise to ~~drop~~ 63% of its maximum value

$I_{max} = 4.4643$ A so $I_{(after\ 1\tau)} = 0.63 \times 4.4643 = 2.8125$ A.

Now, $I = \frac{V_{R_1}}{R_1}$ so we want to find t when $V_{R_1} = 2.8125 \times 22.4 = 63$ V.

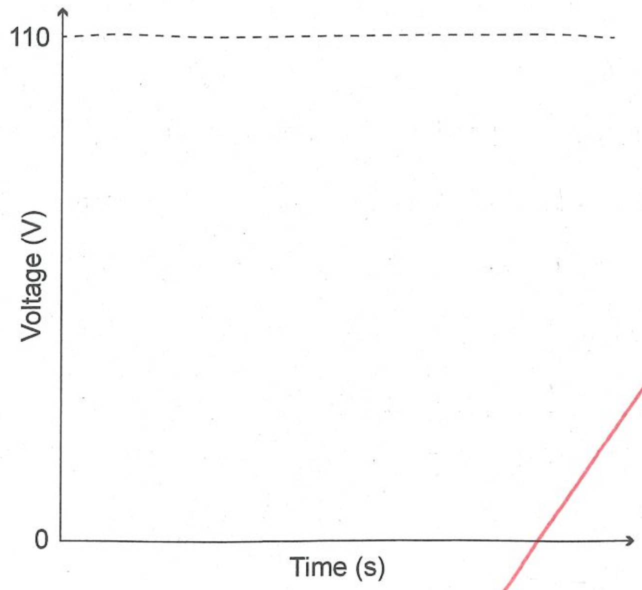
This occurs when $t = 0.5$ s. Hence $\tau = 0.5$ s and $L = \tau R = 0.5(22.4 + 2.24)$

** across the inductor only (ignoring internal resistance) $= 12.3$ H (3 s.f.)

SPARE DIAGRAM

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.

ASSESSOR'S USE ONLY



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

QUESTION NUMBER

ASSESSOR'S USE ONLY

Q3b) $t=0$ or $t=\frac{2v\sin\theta}{g}$

Now, in the horizontal direction we also need to use the kinematic equations as the velocity is no longer constant:

$v_i = v\cos\theta$, $a=\frac{-F}{m}$, $t=\frac{2v\sin\theta}{g}$, $d=?$

$$d = v_i t + \frac{1}{2}at^2$$

$$= v\cos\theta \cdot \frac{2v\sin\theta}{g} + \frac{1}{2}\cdot\frac{-F}{m}\cdot\left(\frac{2v\sin\theta}{g}\right)^2$$

$$= \frac{2v^2\sin\theta\cos\theta}{g} + \frac{-F}{\cancel{2}m}\cdot\frac{\cancel{4}^{2}v^2\sin^2\theta}{g^2}$$

$$= \frac{v^2\sin 2\theta}{g} - \frac{2Fv^2\sin^2\theta}{mg^2}$$

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

// seen.

Q3c) As well as slowing the horizontal component of the ball's velocity, it would also reduce the vertical component of the ball's velocity, so the ball would spend less time in the air and therefore not travel as far. //

seen.

Q3di) $\frac{7}{10}mv_i^2 = \frac{1}{2}mv^2 + \frac{1}{2}\cdot\frac{2}{5}mR^2\cdot\left(\frac{v}{R}\right)^2 + mgh$

$\frac{7}{10}mv_i^2 = \frac{1}{2}mv^2 + \frac{1}{5}mv^2 + mgh$

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

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

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

seen

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

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Q4b) In an ideal conductor, the current would eventually reach its maximum at which point there would be no change of current so no voltage measured across the inductor. However, as this is a non-ideal conductor the internal resistance means that even when the current has settled on a steady value ~~the~~ we still measure a voltage across the inductor, equal to Ir. Finally, as in the previous question $R_1 = 110 - V_L$ where V_L is the voltage across the inductor. This is why the curve for R_1 has the same shape as for V_L but flipped upside-down. // seen

Q2ai) This can be used to tune the guitar: by playing the 4th harmonic of the A string ~~and the~~ (which is known to be in tune) and the third harmonic of the D string (which should be the same frequency) simultaneously, beats will be heard if the frequencies are almost the same, so the D string can be adjusted until there is no beats heard, at which point ~~the string~~ it will be at the correct frequency. // seen.

Q2b)
$$F = k\left(\frac{L\cos\theta - L_0\cos\theta + 2L - 2L_0\cos\theta}{\cos\theta}\right)$$

$$= k\left(\frac{L(2+\cos\theta) - 3L_0\cos\theta}{\cos\theta}\right)$$

seen

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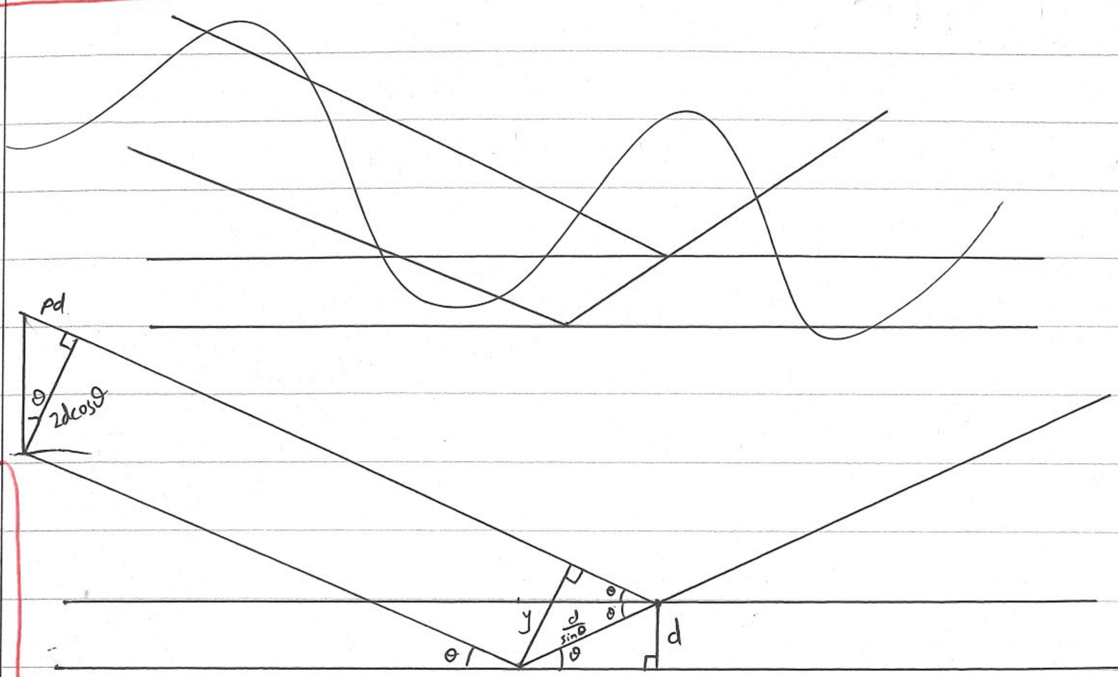
Q1 c)



$$\sin 2\theta = \frac{y}{\left(\frac{d}{\sin\theta}\right)}$$

$$y = \frac{d}{\sin\theta} \cdot \sin 2\theta = 2d\cos\theta$$

$$\tan\theta = \frac{pd}{2d\cos\theta}$$

$$\frac{\sin\theta}{\cancel{\cos\theta}} \cdot 2d\,\cancel{\cos\theta} = pd$$

$$\boxed{pd = 2d\sin\theta} \rightarrow$$

$$2 \times 2.2 \times 10^{-10} \sin\theta = 1 \times 1.43 \times 10^{-10}$$

$$\sin\theta = 0.325$$

$$\theta = 18.96557$$

$$= 19.0^\circ \text{ (3s.f.)}$$

Require $pd = n\lambda$

$$2d\sin\theta = n\lambda$$

$$n = \frac{2d\sin\theta}{\lambda}$$

When $\theta = 19^\circ$:

$$n = \frac{2 \times 2.2 \times 10^{-10} \times \sin 19^\circ}{1.43 \times 10^{-10}}$$

$$= 1.00 \text{ (3s.f.)}$$

Hence there is a diffraction peak at $\theta = 19.0^\circ$

seen

Extra space if required.
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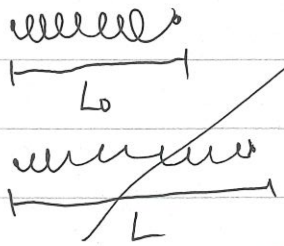
~~$F = k(3L - L_0(1+2\cos\theta))$~~

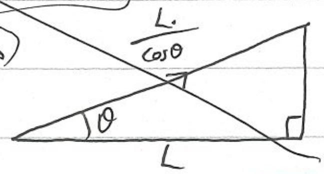
~~↓~~

~~$k(L - L_0)$ $\quad k(L - \cancel{2}\cos\theta L_0)$ $\quad k(L - \cos\theta L_0)$~~



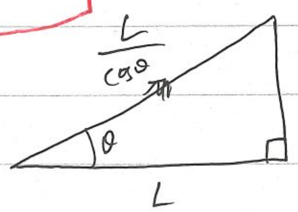
~~$L - \cos\theta L_0$?~~

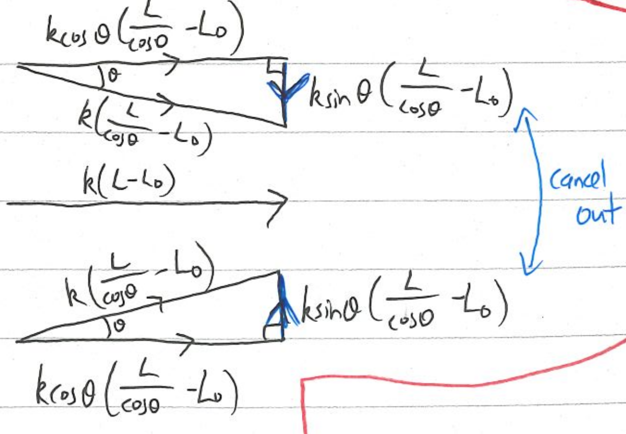
~~$= \cos\theta\left(\frac{L}{\cos\theta} - L_0\right)$~~



Q2b) The middle spring is stretched from L_0 to L, so its force is $F = k(L_{\cancel{0}} - L_0)$ (using $F = kx$). The other two springs stretch from L_0 to $\frac{L}{\cos\theta}$, but this force is applied at an angle of $\pm\theta$ so the ~~force~~ vertical components cancel out * leaving a total of $F = 2k\cos\theta\left(\frac{L}{\cos\theta} - L_0\right) = 2k(L - \cos\theta L_0)$. Hence the total force is:

$$F_{net} = k(L_{\cancel{0}} - L_0) + 2k(L - \cos\theta L_0)$$
$$= k(L_{\cancel{0}} - L_0 + 2L - 2\cos\theta L_0)$$
$$= \boxed{k(3L - L_0(1 + 2\cos\theta))}$$





* (as they are in opposite directions and have the same magnitude)

seen.

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