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NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

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

Tick this box if you have NOT written in this booklet

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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This page has been deliberately left blank.
The examination starts on page 4.

The formulae below may be of use to you.

$v_f = v_i + at$

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

$d = \frac{v_i + v_f}{2}t$

$v_f^2 = v_i^2 + 2ad$

$F_g = \frac{GMm}{r^2}$

$F_c = \frac{mv^2}{r}$

$\Delta p = F\Delta t$

$\omega = 2\pi f$

$d = r\theta$

$v = r\omega$

$a = r\alpha$

$W = Fd$

$F_{net} = ma$

$p = mv$

$x_{COM} = \frac{m_1x_1 + m_2x_2}{m_1 + m_2}$

$\omega = \frac{\Delta\theta}{\Delta t}$

$\alpha = \frac{\Delta\omega}{\Delta t}$

$L = I\omega$

$L = mvr$

$\tau = I\alpha$

$\tau = Fr$

$E_{K(ROT)} = \frac{1}{2}I\omega^2$

$E_{K(LIN)} = \frac{1}{2}mv^2$

$\Delta E_p = mg\Delta h$

$\omega_f = \omega_i + \alpha t$

$\omega_f^2 = \omega_i^2 + 2\alpha\theta$

$\theta = \frac{(\omega_i + \omega_f)}{2}t$

$\theta = \omega_i t + \frac{1}{2}\alpha t^2$

$T = 2\pi\sqrt{\frac{l}{g}}$

$T = 2\pi\sqrt{\frac{m}{k}}$

$E_p = \frac{1}{2}ky^2$

$F = -ky$

$a = -\omega^2 y$

$y = A\sin\omega t$ $\quad$ $y = A\cos\omega t$

$v = A\omega\cos\omega t$ $\quad$ $v = -A\omega\sin\omega t$

$a = -A\omega^2\sin\omega t$ $\quad$ $a = -A\omega^2\cos\omega t$

$\Delta E = Vq$

$P = VI$

$V = Ed$

$Q = CV$

$C_T = C_1 + C_2$

$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$

$E = \frac{1}{2}QV$

$C = \frac{\varepsilon_o\varepsilon_r A}{d}$

$\tau = RC$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

$R_T = R_1 + R_2$

$V = IR$

$F = BIL$

$\phi = BA$

$\varepsilon = -\frac{\Delta\phi}{\Delta t}$

$\varepsilon = -L\frac{\Delta I}{\Delta t}$

$\frac{N_p}{N_s} = \frac{V_p}{V_s}$

$E = \frac{1}{2}LI^2$

$\tau = \frac{L}{R}$

$I = I_{MAX}\sin\omega t$

$V = V_{MAX}\sin\omega t$

$I_{MAX} = \sqrt{2}\,I_{rms}$

$V_{MAX} = \sqrt{2}\,V_{rms}$

$X_C = \frac{1}{\omega C}$

$X_L = \omega L$

$V = IZ$

$f_0 = \frac{1}{2\pi\sqrt{LC}}$

$v = f\lambda$

$f = \frac{1}{T}$

$n\lambda = \frac{dx}{L}$

$n\lambda = d\sin\theta$

$f' = f\frac{V_W}{V_W \pm V_S}$

$E = hf$

$hf = \phi + E_K$

$E = \Delta mc^2$

$\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$

$E_n = -\frac{hcR}{n^2}$

QUESTION ONE: NEUTRONS

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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:

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

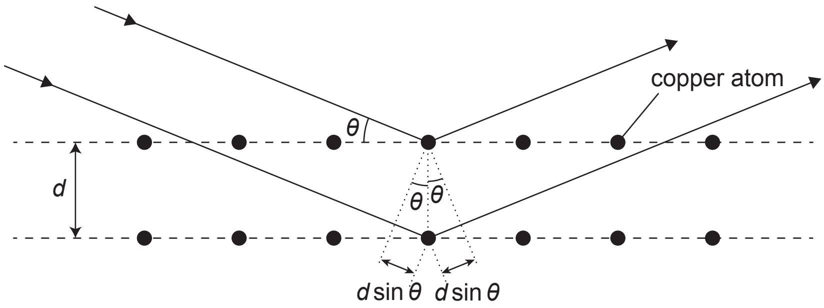
The neutrons released in these reactions have a wide range of energies, but can be slowed down by passing them through material of similar nuclear mass, to form a beam of "slow neutrons".

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

(b) Particles such as neutrons also behave as if they have a wavelength, given by $\lambda = \frac{\text{h}}{p}$, 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.

(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 $\theta = 19.0°$.

(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.

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

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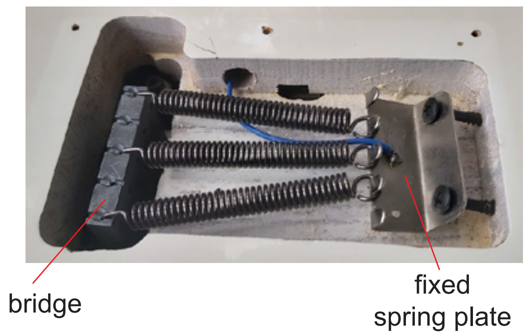
QUESTION TWO: STRINGS AND SPRINGS

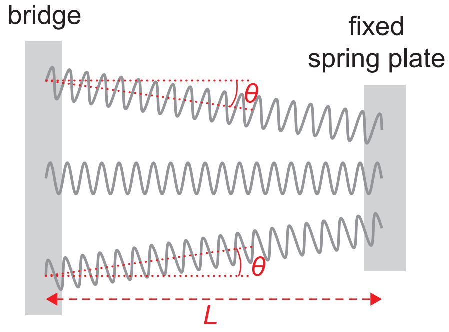
A typical guitar has six strings. Two of these strings are tuned to the notes "A" and "D". When tuned correctly, the "A" string has a fundamental frequency of 110.0 Hz, and the 4th harmonic of the "A" string has the same frequency as the 3rd harmonic of the "D" string.

(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.

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

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:

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

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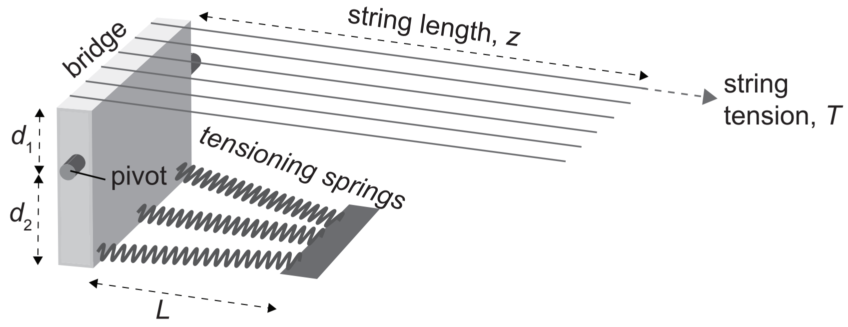
The bridge is where the strings connect to the body of the guitar. Some guitars have a "floating bridge" design, where the springs are attached to the bottom and the strings to the top of the pivoted bridge, as shown below.



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

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:

$$f = \sqrt{\frac{\mathrm{k}d_2\left(3L - L_0\left(1 + 2\cos\theta\right)\right)}{24\mu d_1 z^2}}$$

(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.

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QUESTION THREE: ABOUT A BALL

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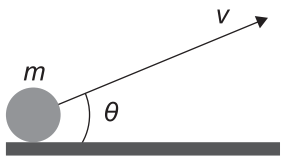
$2\sin\theta\cos\theta = \sin 2\theta$

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.

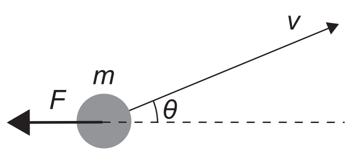


(a) The horizontal distance travelled, d, is maximum when $\theta = 45°$.

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.

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:

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

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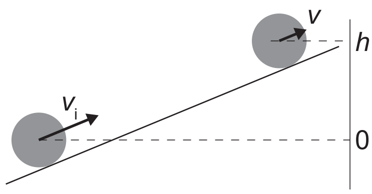
(c) Discuss the validity of the assumptions about the drag force in part (b).

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

(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:

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

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

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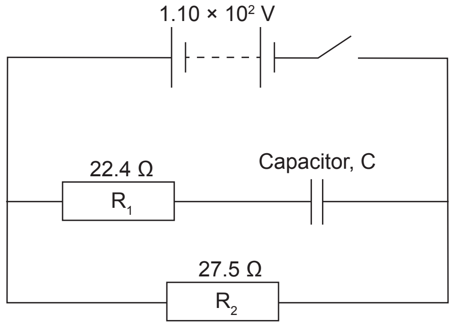
QUESTION FOUR: DC CIRCUITS

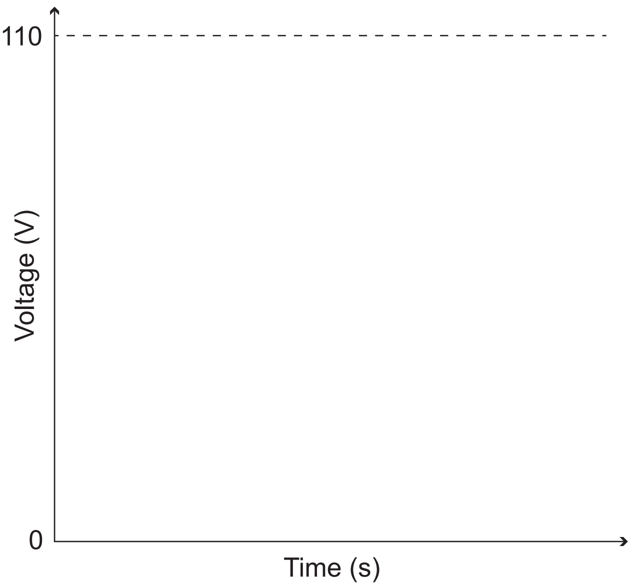


A parallel circuit is connected to a 1.10×10^2 V DC supply and a switch, as shown.

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.

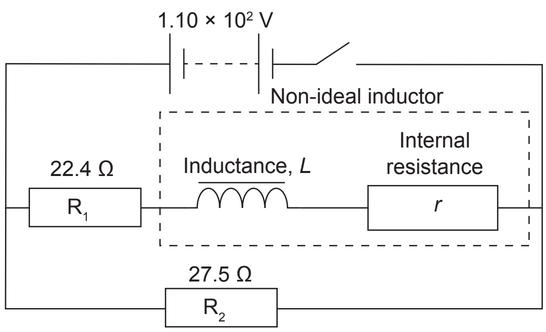


If you need to redraw your response, use the axes on page 12.

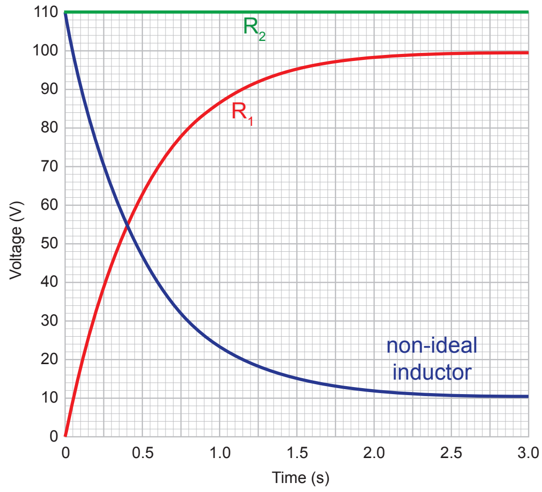
The capacitor is removed from the circuit and replaced with a non-ideal inductor.

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.



(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.

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

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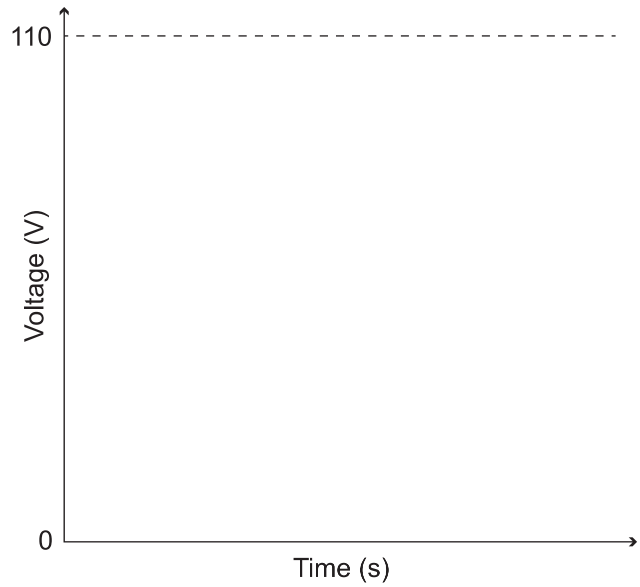
SPARE DIAGRAM

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.



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