

SUPERVISOR'S USE ONLY

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Draw a cross through the box (X) if you have NOT written in this booklet

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Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Scholarship 2025 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 2–28 in the correct order and that none of these pages is blank.

Do not write in the margins (✂). This area will be cut off when the booklet is marked.

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

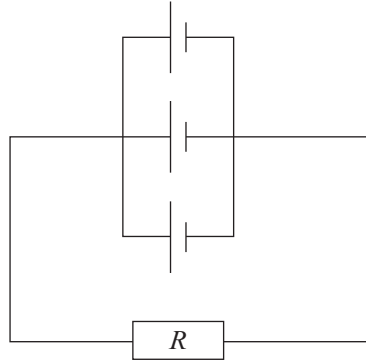
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The assessment starts on page 4.**

The formulae below may be of use to you.

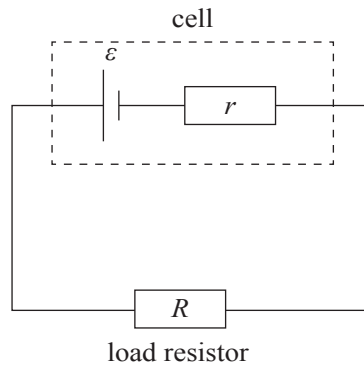
$v_f = v_i + at$ $d = v_i t + \frac{1}{2} at^2$ $d = \frac{v_i + v_f}{2} t$ $v_f^2 = v_i^2 + 2ad$ $F_g = \frac{GMm}{r^2}$ $F_c = \frac{mv^2}{r}$ $\Delta p = F \Delta t$ $\omega = 2\pi f$ $d = r\theta$ $v = r\omega$ $a = r\alpha$ $W = Fd$ $F_{\text{net}} = ma$ $p = mv$ $x_{\text{COM}} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$ $\omega = \frac{\Delta\theta}{\Delta t}$ $\alpha = \frac{\Delta\omega}{\Delta t}$ $L = I\omega$ $L = mvr$ $\tau = I\alpha$ $\tau = Fr$ $E_{K(\text{ROT})} = \frac{1}{2} I\omega^2$ $E_{K(\text{LIN})} = \frac{1}{2} mv^2$ $\Delta E_p = mg\Delta h$ $\omega_f = \omega_i + \alpha t$ $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ $\theta = \frac{(\omega_i + \omega_f)}{2} t$ $\theta = \omega_i t + \frac{1}{2} \alpha t^2$	$T = 2\pi\sqrt{\frac{l}{g}}$ $T = 2\pi\sqrt{\frac{m}{k}}$ $E_p = \frac{1}{2} ky^2$ $F = -ky$ $a = -\omega^2 y$ $y = A \sin \omega t \quad y = A \cos \omega t$ $v = A\omega \cos \omega t \quad v = -A\omega \sin \omega t$ $a = -A\omega^2 \sin \omega t \quad a = -A\omega^2 \cos \omega t$ $\Delta E = Vq$ $P = VI$ $Q = CV$ $C_T = C_1 + C_2$ $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ $E = \frac{1}{2} QV$ $C = \frac{\epsilon_0 \epsilon_r A}{d}$ $\tau = RC$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ $R_T = R_1 + R_2$ $V = IR$ $F = BIL$ $V = BvL$ $F = Bqv$ $F = Eq$ $E = \frac{V}{d}$	$\phi = BA$ $\epsilon = -\frac{\Delta\phi}{\Delta t}$ $\epsilon = -L \frac{\Delta I}{\Delta t}$ $\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $E = \frac{1}{2} LI^2$ $\tau = \frac{L}{R}$ $I = I_{\text{MAX}} \sin \omega t$ $V = V_{\text{MAX}} \sin \omega t$ $I_{\text{MAX}} = \sqrt{2} I_{\text{rms}}$ $V_{\text{MAX}} = \sqrt{2} V_{\text{rms}}$ $X_C = \frac{1}{\omega C}$ $X_L = \omega L$ $V = IZ$ $f_0 = \frac{1}{2\pi\sqrt{LC}}$ $v = f\lambda$ $f = \frac{1}{T}$ $n\lambda = \frac{dx}{L}$ $n\lambda = d \sin \theta$ $f' = f \frac{V_W}{V_W \pm V_S}$ $E = hf$ $hf = \phi + E_K$ $E = \Delta mc^2$ $\frac{1}{\lambda} = R \left(\frac{1}{S^2} - \frac{1}{L^2} \right)$ $E_n = -\frac{hcR}{n^2}$
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A battery can be made by connecting a number of individual cells together. The cells can be connected either in series or in parallel.

Circuit 3



- (b) A real cell produces an emf ε and has internal resistance r . The cell is connected to a load resistor with resistance R .



- (i) Show that the power dissipated by the load resistor is given by the expression:

$$P_R = \frac{\varepsilon^2 R}{(r + R)^2}$$

- (ii) For a cell with constant ε and constant r , the power dissipated by the load resistor is maximum when $R = r$.

Use appropriate physics concepts to explain why the power dissipated by the load resistor is small at extremely large and at extremely low values of R .

All voltages and currents referred to in parts (c) and (d) of this question are rms values.

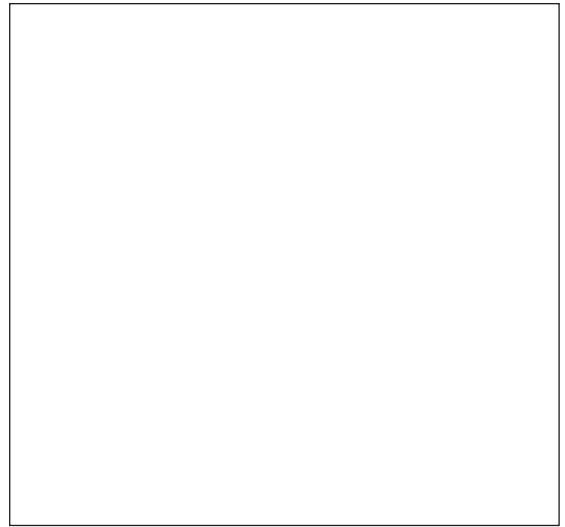
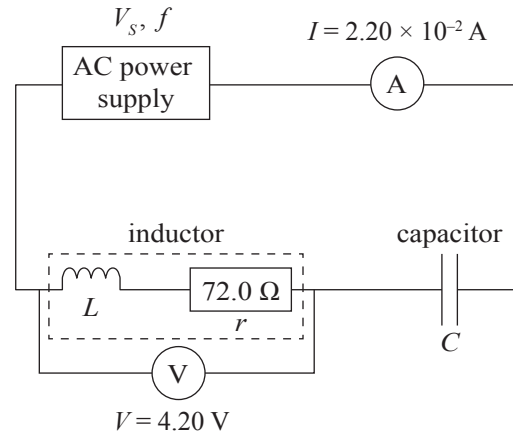
- (c) A real inductor has both inductance L and internal resistance r .

A real inductor with internal resistance $r = 72.0 \, \Omega$ is connected in series with a capacitor to an AC power supply with voltage V_S and frequency f .

Assume that both the capacitor and the power supply are ideal.

The current in the circuit is $I = 2.20 \times 10^{-2} \, \text{A}$. An AC voltmeter, connected as shown, measures the combined voltage of both the inductance and internal resistance of the real inductor as $V = 4.20 \, \text{V}$. The voltage V across the real inductor leads the voltage of the AC power supply V_S by 120° .

Sketch a phasor diagram for the voltages, and use it to calculate the value of the power supply voltage V_S .



- Describe the conditions required for both V_L and V_C to exceed V_S .
Explain the energy transfers occurring in the circuit under these conditions.

(a) Te kō is a traditional Māori musical instrument that consists of a single string connected between the ends of a bent stick. The string is struck with a second stick to produce a sound.

(continued)

Describe TWO separate changes that could be made to the design to increase the frequency of the sound produced.

Explain how each of these changes alters fundamental parameters that result in a higher frequency sound.

- (b) A pōrutu is a traditional Māori musical wind instrument that is carved from wood or bone. A pōrutu is a hollow pipe that is open at both ends. It is played in a similar way to a flute, by blowing across one of the open ends and covering small holes with the fingers.



<https://collection.nelsonmuseum.co.nz/objects/G30429/porutu-long-flute>

Harmonic frequencies in a pipe occur when sound waves travelling along the pipe reflect from the end and interfere, forming a standing wave.

A simple model of this situation assumes that an antinode always occurs at an open end of a pipe.

Explain how a sound wave reflects from an open end of a pipe, and how this results in an antinode being formed.

- Sketch a trend line on the axes below to show how you expect the trend to continue if the pipe radius is increased significantly beyond the range tested.
- Use relevant physics concepts to explain why you expect the trend to behave in this way.

QUESTION THREE: X-RAY PHOTOELECTRON SPECTROSCOPY

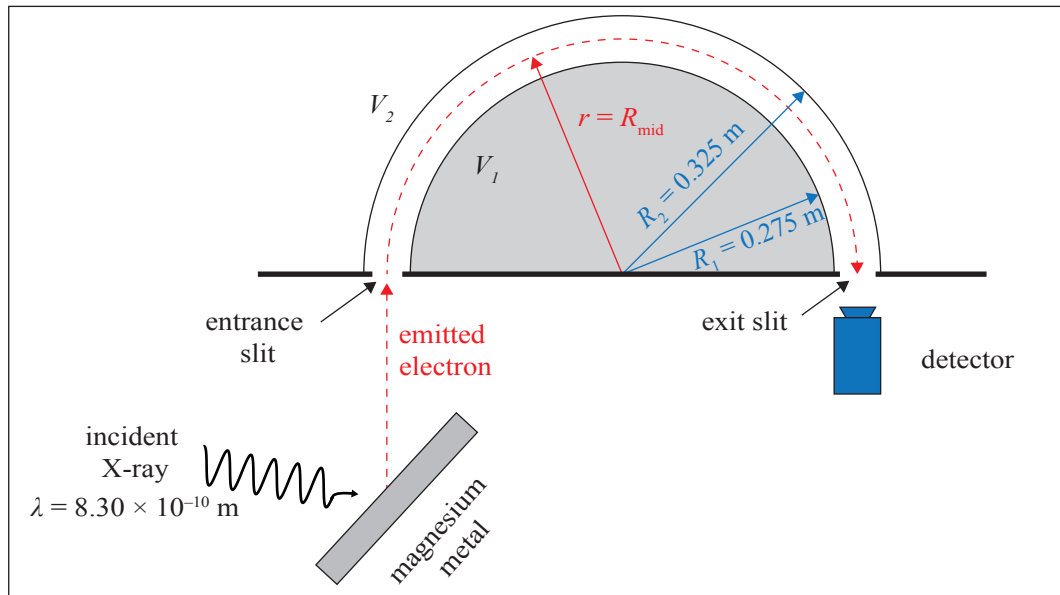
Charge of an electron = $-1.60 \times 10^{-19} \text{ C}$

Planck's constant = $6.63 \times 10^{-34} \text{ J s}$

Speed of light = $3.00 \times 10^8 \text{ m s}^{-1}$

X-ray photoelectron spectroscopy (XPS) is a technique used to determine the energy of electrons emitted by a material when it is illuminated with X-rays.

Electrons emitted by the illuminated material enter a hemispherical electron energy analyser, which consists of two concentric metal hemispheres with a narrow gap between them. The hemispheres have a potential difference of $V_2 - V_1$ between them, as shown in the diagram below.



In an experiment to measure the energy of electrons in magnesium, a sample of magnesium metal is illuminated by X-rays with a wavelength of $8.30 \times 10^{-10} \text{ m}$.

A narrow opening at the entrance ensures that the electrons enter the gap between the hemispheres midway between their surfaces, and that they enter at a tangent to the hemispheres. At the exit, on the other side of the analyser, a detector records any electrons that successfully travel around the semicircular path from the entrance to the exit.

The radii of the inner and outer hemispheres are $R_1 = 0.275 \text{ m}$ and $R_2 = 0.325 \text{ m}$ respectively. The potential difference between the hemispheres is varied, and the rate of electrons received by the detector is observed. Electrons are observed at the detector when the potential difference between the analyser plates is set to 60.0 V .

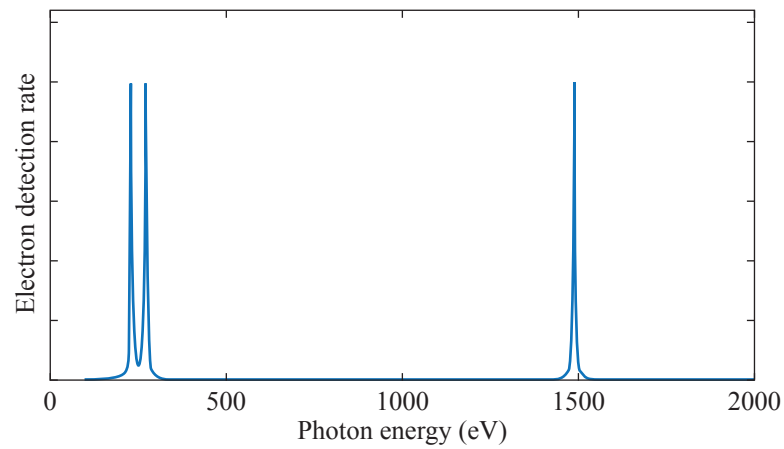
- (a) Explain whether the potential difference $V_2 - V_1$ should be negative or positive.

- (c) In this experiment, the magnesium must be electrically connected to ground.

Explain why this is necessary, and discuss how the kinetic energy of a photoemitted electron would be affected if the magnesium was not electrically connected to ground.

- (d) In this experiment, the photon wavelength can be varied to change the photon energy. The graph below shows the rate at which electrons are observed at the detector as photon energy is varied. The count rate displays three clear peaks.

Explain what this implies about the energy of the electrons inside the magnesium metal.



QUESTION FOUR: PENDULUMS AND SPRINGS

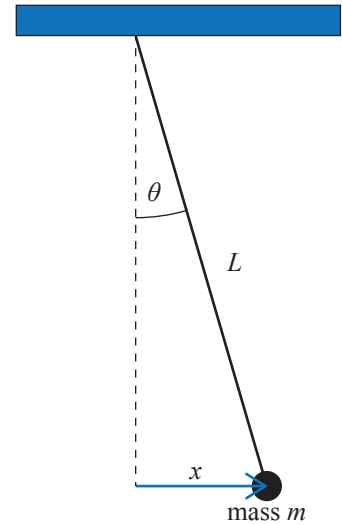
Acceleration due to gravity = 9.81 m s^{-2}

A simple pendulum, with a string of negligible mass, that is oscillating with a small angle θ , can be approximated as moving with simple harmonic motion.

- (a) (i) By considering the forces acting, show that the acceleration of the pendulum is given by the expression:

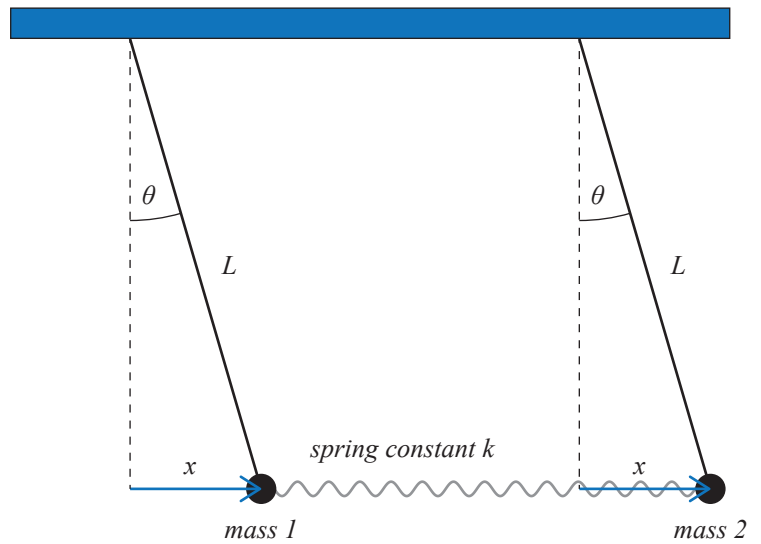
$$a = -\frac{gx}{L}$$

- (ii) Explain how this expression shows that when the angle θ is small, the motion of a simple pendulum can be approximated as simple harmonic motion.



- (b) Two identical pendulums are independently suspended from a fixed beam and connected by a spring with negligible mass. The spring has spring constant k , and the natural unstretched length of the spring is the same as the distance between the two points from which the pendulums are suspended.

The two pendulums can be independently moved either to the left or to the right before being released to investigate the motion of the pendulums with different initial conditions.



For the first investigation, the two pendulums are both moved to the right with the same initial displacement x , as shown in the diagram above. The pendulums are released at the same time so that they oscillate in phase.

The pendulums are set up with the following values:

- pendulum length = 0.560 m
- pendulum mass = 50.0 g
- initial displacement = 2.50 cm
- spring constant = 13.0 N m⁻¹

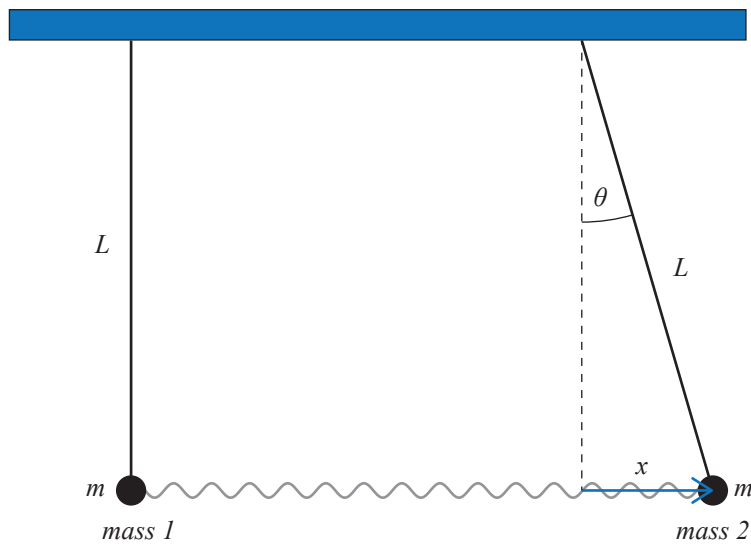
Calculate the period of the pendulums in this system.

Use appropriate reasoning to justify your answer.

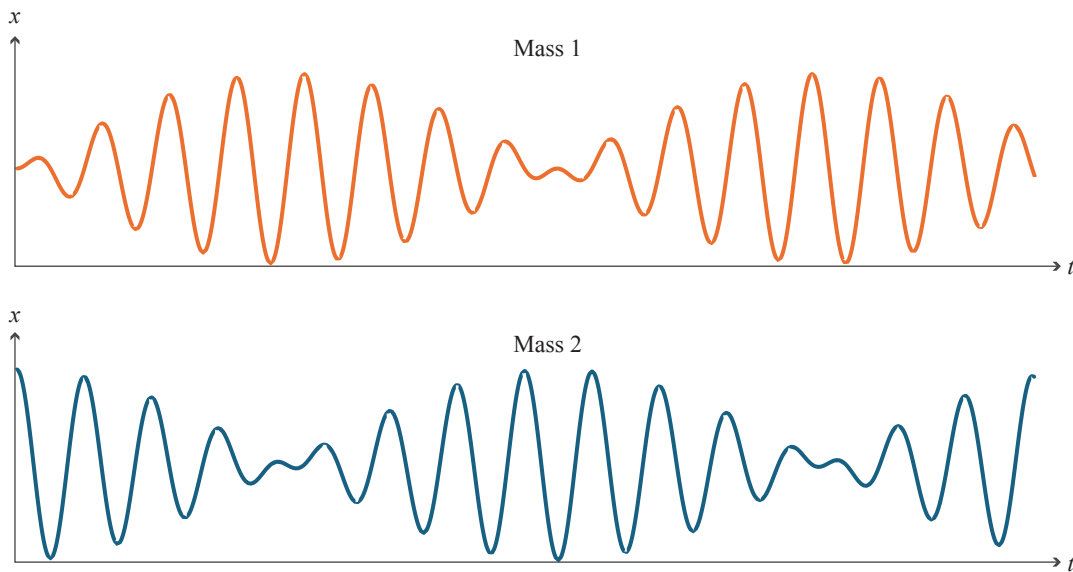
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*Question Four continues
on the following page.*

- (d) For the third investigation, mass 1 is held at its equilibrium position, while mass 2 is displaced to the right, as shown below.



Both masses are released at the same time. The two pendulums oscillate with varying amplitude, and are neither purely in phase nor in opposite phase with each other. The displacement of the two masses over time is shown below.



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