93103

931030

# S

SUPERVISOR'S USE ONLY

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

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

# Scholarship 2018
# Physics

9.30 a.m. Friday 23 November 2018
Time allowed: Three hours
Total marks: 40

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 2.**

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 2–19 in the correct order and that none of these pages is blank.

You are advised to spend approximately 35 minutes on each question.

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

| Question | Mark |
|---|---|
| ONE | |
| TWO | |
| THREE | |
| FOUR | |
| FIVE | |
| TOTAL | /40 |

ASSESSOR'S USE ONLY

The formulae below may be of use to you.

$v_f = v_i + at$

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

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

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

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

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

$\Delta p = F\Delta t$

$\omega = 2\pi f$

$d = r\theta$

$v = r\omega$

$a = r\alpha$

$W = Fd$

$F_{net} = ma$

$p = mv$

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

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

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

$L = I\omega$

$L = mvr$

$\tau = I\alpha$

$\tau = Fr$

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

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

$\Delta E_p = mgh$

$\omega_f = \omega_i + \alpha t$

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

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

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

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

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

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

$F = -ky$

$a = -\omega^2 y$

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

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

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

$\Delta E = Vq$

$P = VI$

$V = Ed$

$Q = CV$

$C_T = C_1 + C_2$

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

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

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

$\tau = RC$

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

$R_T = R_1 + R_2$

$V = IR$

$F = BIL$

$\phi = BA$

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

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

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

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

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

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

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

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

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

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

$X_L = \omega L$

$V = IZ$

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

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

$n\lambda = d\sin\theta$

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

$E = hf$

$hf = \phi + E_K$

$E = \Delta mc^2$

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

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

$v = f\lambda$

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

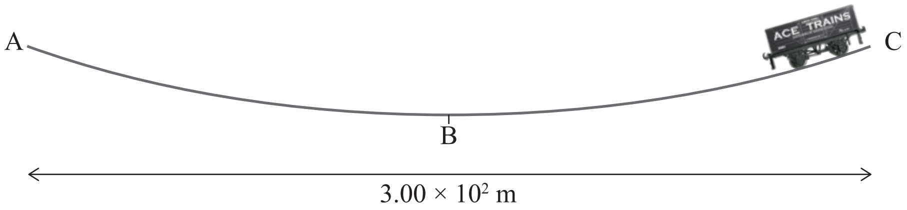
**This page has been deliberately left blank.**

ASSESSOR'S USE ONLY

## QUESTION ONE: THE RAILWAY WAGON

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

A railway wagon full of sand is released from rest at point C. The wagon oscillates on a vertically curved track between A and C with simple harmonic motion of period 60.0 s. The effects of friction can be ignored.




(a) (i) State the conditions that must apply for the motion to be simple harmonic motion.

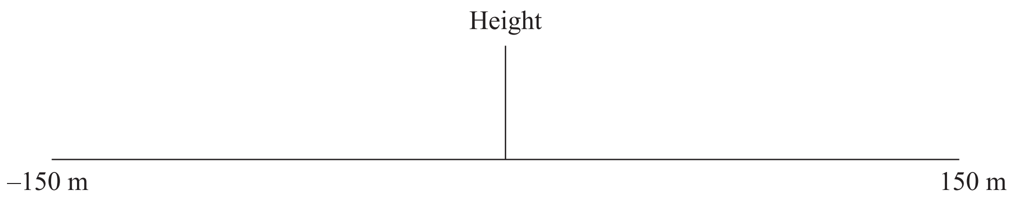
(ii) Show that the maximum speed attained is 15.7 m $s^{-1}$.

(b) When the wagon is halfway between B and C, calculate its approximate height above B.

(c) (i) The wagon has a small hole from which sand leaks onto the rail track at a steady rate.

Sketch a height profile of the sand on the graph below and explain the shape of the profile.

State any assumptions made.




(ii) When the wagon arrives back at C, the remaining sand is suddenly dumped from the wagon.

Explain what effect this removal of mass will have on the physical parameters of the wagon's motion.

(d) The track A to C is an arc of a circle.

By first calculating the radius of the circle, discuss whether the original assumption that this motion is simple harmonic motion is valid.

ASSESSOR'S USE ONLY

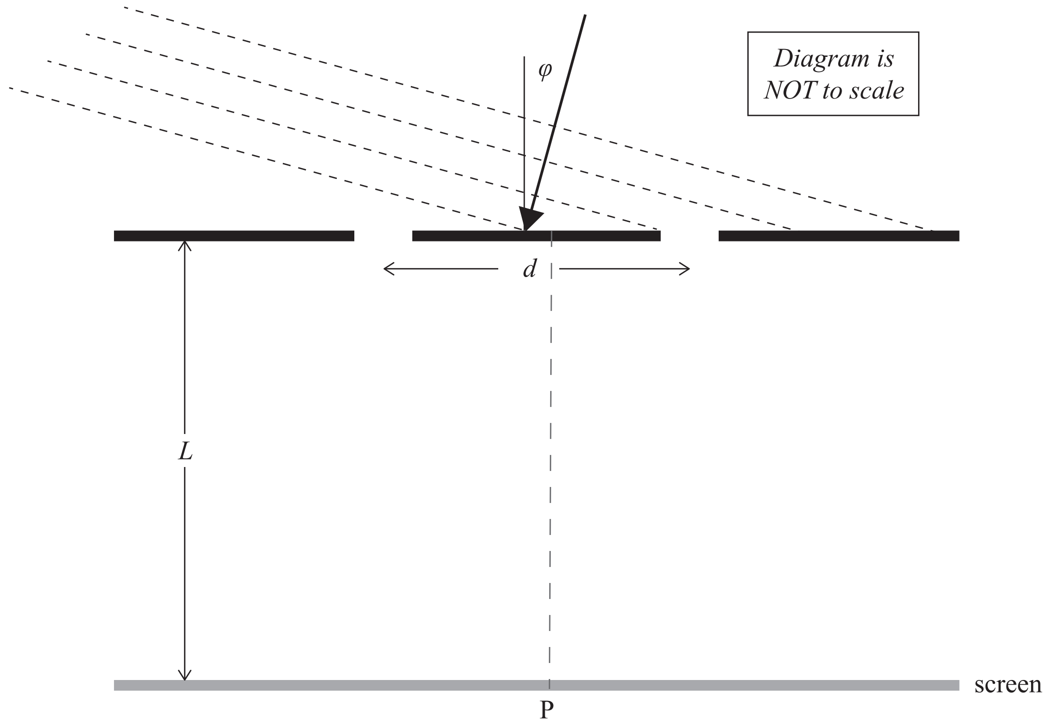
(8)

ASSESSOR'S USE ONLY

## QUESTION TWO: INTERFERENCE

(a) State the conditions for stationary interference fringes to be produced by two sources of light a distance *d* apart.

(b) Two narrow slits separated by a distance, *d*, are illuminated by light at an incident angle $\varphi$, as shown below. Light from the two slits produces an interference pattern on a screen a distance, *L*, away. Assume that *L* is much greater than *d*.

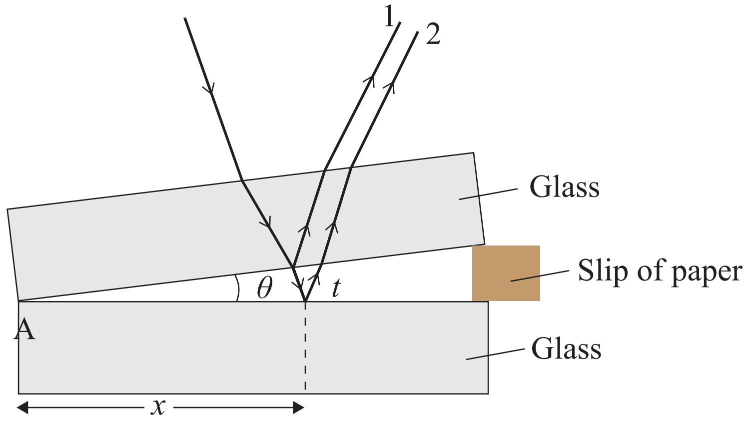



If $d = 1.00 \times 10^{-4}$ m, and the wavelength is 633 nm, calculate the smallest angle $\varphi$ that will give an intensity of zero at the point P on the screen as shown in the diagram.

ASSESSOR'S USE ONLY

Another way to produce an interference pattern is to illuminate a small wedge-shaped air gap as shown in the diagram below. When viewed from above, alternate bright and dark fringes are observed. The horizontal distance to the $n$th dark fringe is $x$, and at this point the thickness of the air gap is equal to $t$.

Note that when light travelling in air reflects off glass, it undergoes a 180 degree phase change.




(c) From directly above the position marked A on the diagram, a dark fringe is observed.

Explain why this occurs.

(d) Light of wavelength 550 nm is incident normally on an air gap of angle $3.5 \times 10^{-4}$ rad.

Calculate the number of dark fringes observed per metre.

(e) If the angle of the wedge-shaped air gap, $\theta$, becomes too large, no fringes are observed.

Explain.

(8)

ASSESSOR'S USE ONLY

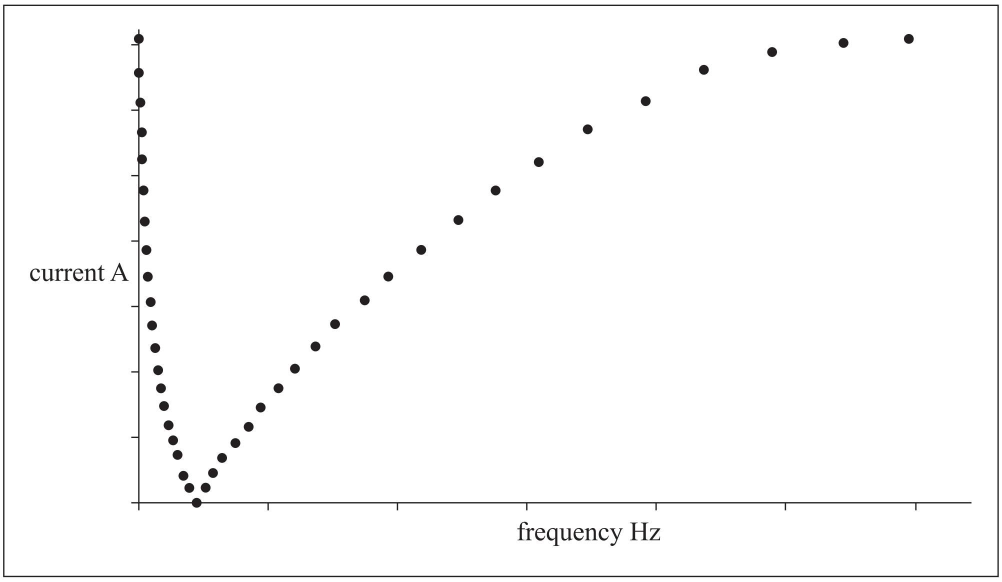
## QUESTION THREE: ELECTRONS EVERYWHERE

| | |
|---|---|
| Mass of the electron | $= 9.11 \times 10^{-31}$ kg |
| Charge on the electron | $= -1.60 \times 10^{-19}$ C |
| Universal gravitational constant | $= 6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$ |
| Coulomb's constant | $= 8.98 \times 10^{9}$ N m$^2$ C$^{-2}$ |

(a) Show that the force of gravitational attraction between a pair of electrons is about $10^{-43}$ times the force of electrostatic repulsion.

The force of electrostatic repulsion is given by the following equation: $F = \mathrm{k}\frac{q_1 q_2}{r^2}$, where k is Coulomb's constant, $q$ is the charge, and $r$ is the separation.

(b) An experimenter is given a black box with two electrical terminals. The experimenter knows that inside the box are exactly one inductor, one capacitor, and one resistor, but does not know the combination of parallel and series connections inside the box. Using an AC generator with variable frequency and fixed voltage, the experimenter measures the magnitude of the AC current as a function of frequency, and obtains the following graph:




Assuming that the circuit elements are ideal, describe how the three components are connected.

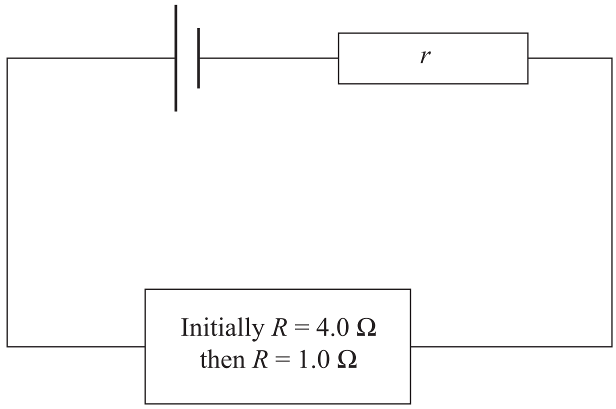
Explain your reasoning.

ASSESSOR'S USE ONLY

(c) A resistance of 4.0 Ω is connected across a cell of internal resistance *r*, as shown below.

The 4.0 Ω resistor dissipates energy at 16 W.

The 4.0 Ω resistor is replaced by a 1.0 Ω resistor, which also dissipates energy at 16 W.




Show that the source voltage must be 12 V.

(d) Explain in detail the key underlying physics of the emission spectra of the hydrogen atom.

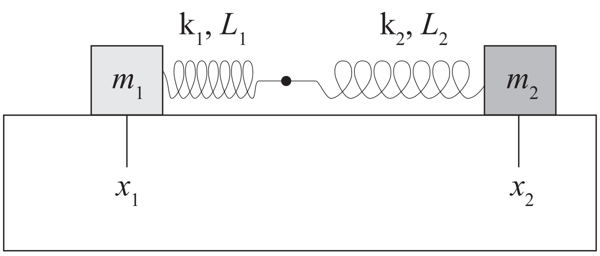
(8)

**QUESTION FOUR: SPRINGS**

ASSESSOR'S USE ONLY

(a) A spring of length $L$ and spring constant k is cut into two parts of lengths $L_1$ and $L_2$ with spring constants $k_1$ and $k_2$, respectively.

Show that $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$.




Consider the situation shown above with two springs of spring constants $k_1$ and $k_2$ connected together and linking masses $m_1$ and $m_2$, which sit on a frictionless surface. The equilibrium lengths of the springs are $L_1$ and $L_2$, respectively, and the centre of mass of $m_1$ lies at $x_1$ and the centre of mass of $m_2$ lies at $x_2$.

(b) Mass $m_1$ is held fixed while a force $F_0$ is applied to mass $m_2$ in the direction of $m_1$.

Using the result of part (a), show that the change of position for mass $m_2$ is $\Delta x_2 = F_0 \frac{k_1 + k_2}{k_1 k_2}$

ASSESSOR'S USE ONLY

Both masses are now released simultaneously. The values for the masses and spring constants are $m_1 = 2.0$ kg, $k_1 = 5.0$ N m$^{-1}$, $m_2 = 3.0$ kg, $k_2 = 10$ N m$^{-1}$, and the force $F_0 = 2.0$ N. Assume the mass of the springs is negligible compared to $m_1$ and $m_2$.

(c) Describe in detail the resulting motions of masses $m_1$ and $m_2$.

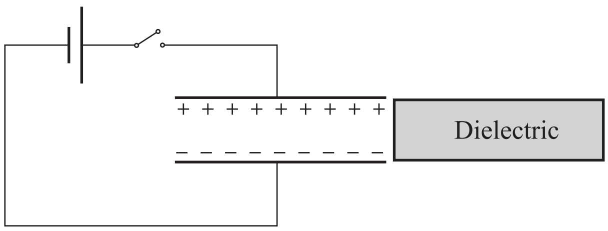
(d) Show that the maximum velocity reached by mass $m_2$ is = 0.40 m s$^{-1}$.

(e) Explain how the motion of the system would be altered if the mass of the springs was not negligible compared to $m_1$ and $m_2$.

(8)

## QUESTION FIVE: CAPACITORS AND DIELECTRICS

(a) Describe the electrical properties required for a material to act as a dielectric.



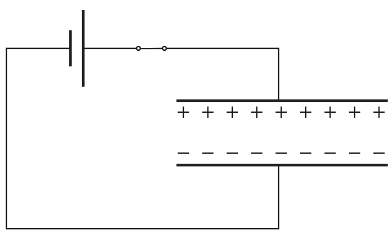

(b) A capacitor containing a dielectric is initially charged and then disconnected from a battery. The capacitor then has its dielectric removed, as in the diagram above.

(i) Show that the minimum work required to remove the dielectric is $\frac{1}{2}C_F V_F^{\,2}\left(\frac{\varepsilon_r - 1}{\varepsilon_r}\right)$

where $C_F$ is the capacitance of the capacitor with the dielectric removed, $V_F$ is the final potential difference, and $\varepsilon_r$ is the dielectric constant.

(ii) Explain why work has to be done to remove the dielectric.

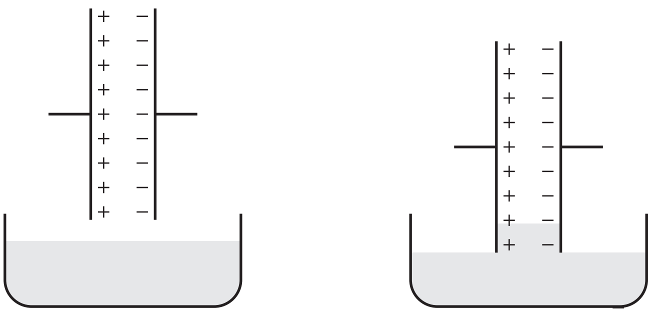
(c) If the capacitor is still connected to the battery when the dielectric is removed, as in the diagram below, the energy stored in the capacitor will decrease.



Despite this reduction in energy, work must still be done to withdraw the dielectric.

Explain this apparent contradiction.

(d) If the charged capacitor is held just touching the surface of a liquid dielectric, the dielectric will be drawn up into the capacitor.



(i) Explain why the capacitor voltage decreases when this phenomenon takes place.

(ii) Explain why the liquid dielectric is drawn up into the charged capacitor.

ASSESSOR'S USE ONLY

(8)

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

QUESTION NUMBER

ASSESSOR'S USE ONLY

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

QUESTION NUMBER

ASSESSOR'S USE ONLY

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

QUESTION NUMBER

ASSESSOR'S USE ONLY

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

QUESTION NUMBER

ASSESSOR'S USE ONLY

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

QUESTION NUMBER

ASSESSOR'S USE ONLY

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

QUESTION NUMBER

ASSESSOR'S USE ONLY

93103