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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!

Scholarship 2016
Physics

2.00 p.m. Wednesday 16 November 2016
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

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The formulae below may be of use to you.

$F_g = \frac{GMm}{r^2}$ $F_c = \frac{mv^2}{r}$ $\Delta p = F\Delta t$ $\omega = 2\pi f$ $d = r\theta$ $v = r\omega$ $a = r\alpha$ $W = Fd$ $F_{net} = ma$ $p = mv$ $x_{COM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$ $\omega = \frac{\Delta\theta}{\Delta t}$ $\alpha = \frac{\Delta\omega}{\Delta t}$ $L = I\omega$ $L = mvr$ $\tau = I\alpha$ $\tau = Fr$ $E_{K(ROT)} = \frac{1}{2}I\omega^2$ $E_{K(LIN)} = \frac{1}{2}mv^2$ $\Delta E_p = mgh$ $\omega_f = \omega_i + \alpha t$ $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ $\theta = \frac{(\omega_i + \omega_f)t}{2}$ $\theta = \omega_i t + \frac{1}{2}\alpha t^2$	$T = 2\pi\sqrt{\frac{l}{g}}$ $T = 2\pi\sqrt{\frac{m}{k}}$ $E_p = \frac{1}{2}ky^2$ $F = -ky$ $a = -\omega^2 y$ $y = A\sin\omega t$ $y = A\cos\omega t$ $v = A\omega\cos\omega t$ $v = -A\omega\sin\omega t$ $a = -A\omega^2\sin\omega t$ $a = -A\omega^2\cos\omega t$ $\Delta E = Vq$ $P = VI$ $V = Ed$ $Q = CV$ $C_T = C_1 + C_2$ $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ $E = \frac{1}{2}QV$ $C = \frac{\varepsilon_o \varepsilon_r A}{d}$ $\tau = RC$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ $R_T = R_1 + R_2$ $V = IR$ $F = BIL$	$\phi = BA$ $\varepsilon = -\frac{\Delta\phi}{\Delta t}$ $\varepsilon = -L\frac{\Delta I}{\Delta t}$ $\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $E = \frac{1}{2}LI^2$ $\tau = \frac{L}{R}$ $I = I_{MAX}\sin\omega t$ $V = V_{MAX}\sin\omega t$ $I_{MAX} = \sqrt{2}\,I_{rms}$ $V_{MAX} = \sqrt{2}\,V_{rms}$ $X_C = \frac{1}{\omega C}$ $X_L = \omega L$ $V = IZ$ $f_0 = \frac{1}{2\pi\sqrt{LC}}$ $n\lambda = \frac{dx}{L}$ $n\lambda = d\sin\theta$ $f' = f\frac{V_W}{V_W \pm V_S}$ $E = hf$ $hf = \phi + E_K$ $E = \Delta mc^2$ $\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$ $E_n = -\frac{hcR}{n^2}$ $v = f\lambda$ $f = \frac{1}{T}$

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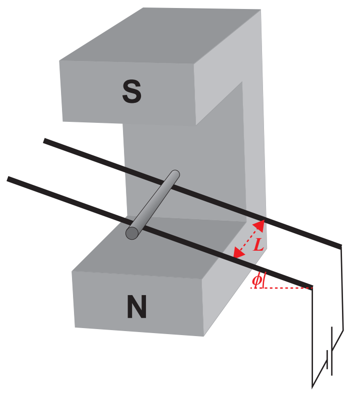
QUESTION ONE: THE MAGNETIC ROLLER

A pair of parallel, conducting metal rails are connected to a voltage source, as shown in the diagram. The fixed rails slope down at angle ϕ to the horizontal between the poles of a large magnet. The force on a current carrying conductor in a magnetic field is given by the relationship $F = BIL$. The voltage induced when a conductor moves through a magnetic field is given by $V = BvL$. Both of these relationships apply in the case where the magnetic field and the conductor are at right angles to each other, and when the velocity is at right angles to both.



(a) Show that a conducting roller can be placed across the rails and remain stationary in the position shown, if the magnetic field strength is given by $B = \dfrac{mg\tan\phi}{IL}$,

where m = mass of the roller, I = current through the roller, and L = the separation of the rails.

(b) The voltage source is now replaced with a small-valued resistor, of resistance R. The metal roller moves down the rails and enters the magnetic field. It slows down and continues at a constant velocity while it is inside the magnetic field.

Explain why this occurs.

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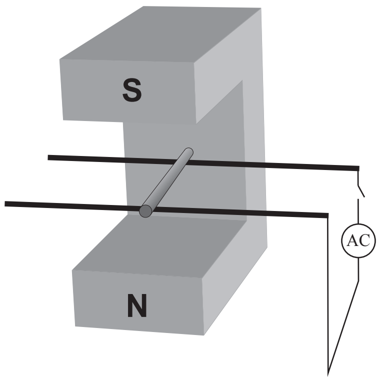
(c) Show that the constant velocity achieved by the roller through the magnetic field is given by:

$$v = \frac{mgR\tan\phi}{B^2L^2\cos\phi}$$

(d) With the rails now horizontal, they are connected to an AC (50 Hz) power supply, as shown in the diagram. When the switch is closed, the motion of the roller may be any one of a variety of different motions.

Explain how this is possible.



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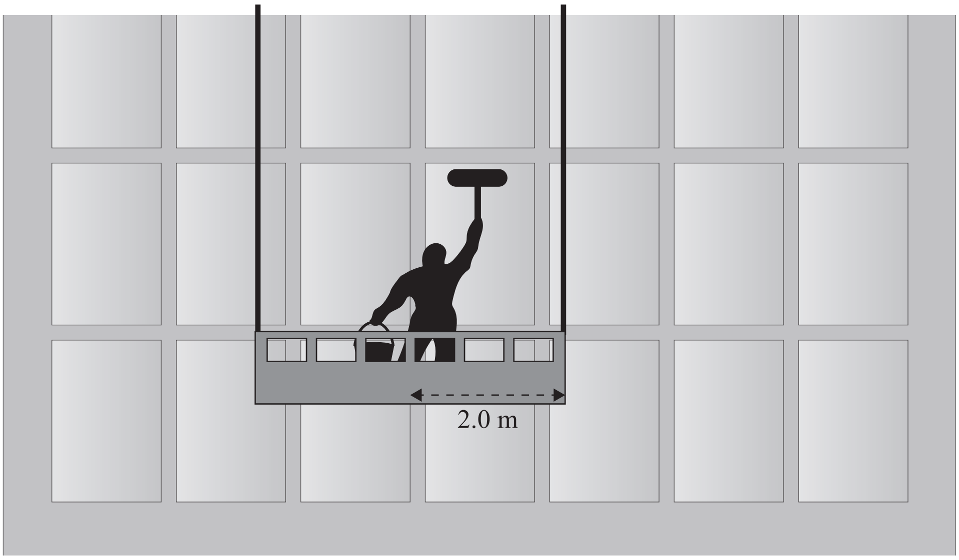
QUESTION TWO: VIBRATING WIRES

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

Long wires, stretched between two points, can vibrate when a steady wind blows past them. Engineers, in dealing with the problems caused by these vibrations, have found it useful to define the Strouhal number, St, as $\mathrm{St} = f\frac{r}{v_\mathrm{w}}$, where f is the frequency of vibration, r is the radius of the wire, and v_w is the wind speed.

(a) Show that the Strouhal number is dimensionless.

A window-washing cradle of width 4.0 m is suspended from two cables of equal length.



A steady wind of 10 m s^{-1} causes the cables to vibrate with a frequency of 200 Hz. In this situation, a Strouhal number of 0.20 is typical. The wave speed in a wire is given as $v = \sqrt{\frac{T}{\mu}}$, where T is the tension and μ is the mass / unit length.

(b) Explain, using physical principles, why the wave speed in a wire depends on the tension and the mass / unit length.

(c) The cradle has a mass of 100 kg and the window washer, who is standing in the middle of the cradle, has a mass of 75 kg (including his mop and bucket).

Given that the density of the cable material is 8.0×10^3 kg m^{-3}, show that the wave speed in the cables is 18 m s^{-1}.

(d) The window washer moves from the centre of the cradle to a position 1.0 m from the centre.

(i) Compare the wavelengths of the vibrations in the two cables.

(ii) In this scenario, the window washer does not hear beats.

Explain the physical conditions required for him to hear beats from vibrations in the wires when he is standing in the window-washing cradle.

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QUESTION THREE: SATELLITES

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Universal Gravitational Constant = 6.67×10^{-11} N m^2 kg^{-2}
Mass of the Earth = 5.98×10^{24} kg
Radius of the Earth = 6.37×10^{6} m
Acceleration due to gravity = 9.81 m s^{-2}

A satellite, in a circular orbit around the Earth, has a rotational period of 2.00 hours. The satellite is orbiting above the Equator, and is moving in the same rotational direction as the Earth.

(a) All satellites, at any height, are said to be weightless.

Explain.

(b) Calculate the height, above the Earth's surface, of the satellite.

(c) Calculate the angular velocity of the satellite relative to the Earth.

(d) Calculate the angle, measured with respect to the centre of the Earth, through which the satellite will be visible to the observer at the Equator.

(e) There are limits to the largest and smallest periods of an Earth satellite.

Discuss this statement.

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QUESTION FOUR: NUCLEAR PHYSICS

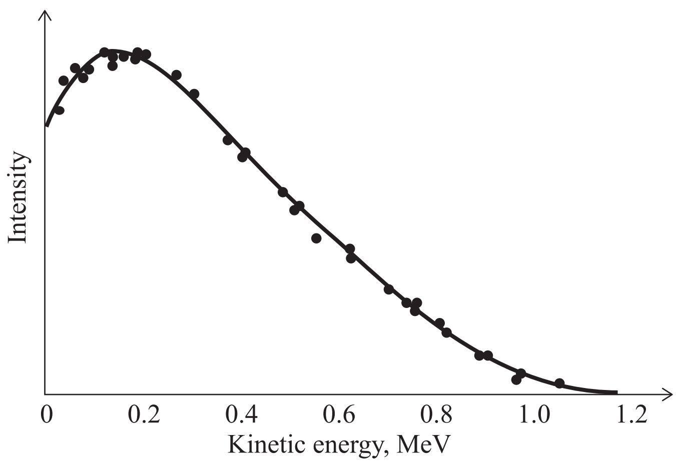
Speed of light	$= 3.00 \times 10^{8}$ m s^{-1}	**Rest masses:**
Charge on the electron	$= -1.60 \times 10^{-19}$ C	Rn = 222.017578 u
1 u	$= 1.66 \times 10^{-27}$ kg	Ra = 226.025410 u
		He = 4.002603 u

A radium nucleus, initially at rest, undergoes alpha decay according to the following:

$$^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

(a) Show that the energy liberated is 4.88 MeV.

(b) Using appropriate conservation laws, calculate the kinetic energy of the alpha particle, and explain why most of the energy released in the decay goes to the lighter particle. Relativistic effects can be ignored.



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(c) The graph on the previous page shows the range of kinetic energies observed in the electrons released in a typical beta decay. There is a distribution that cuts off at some maximum kinetic energy. Initially, researchers concluded that the products of beta decay were simply the daughter nucleus and a fast moving electron (beta particle). Wolfgang Pauli used the above graph to conclude that there was some additional particle involved in the beta decay.

Explain how this conclusion can be reached.

(d) The rest mass of a deuteron (one proton, one neutron) is $3.34358372 \times 10^{-27}$ kg. If the proton and neutron are separated, then the sum of the rest masses is $3.34754925 \times 10^{-27}$ kg, i.e., more than the original value. By contrast, if a rocket ship separates itself from a planet by burning fuel to escape the gravitational pull, then the total mass of the rocket on the launch pad is significantly more than the mass of the rocket after escape.

Compare and contrast these situations.

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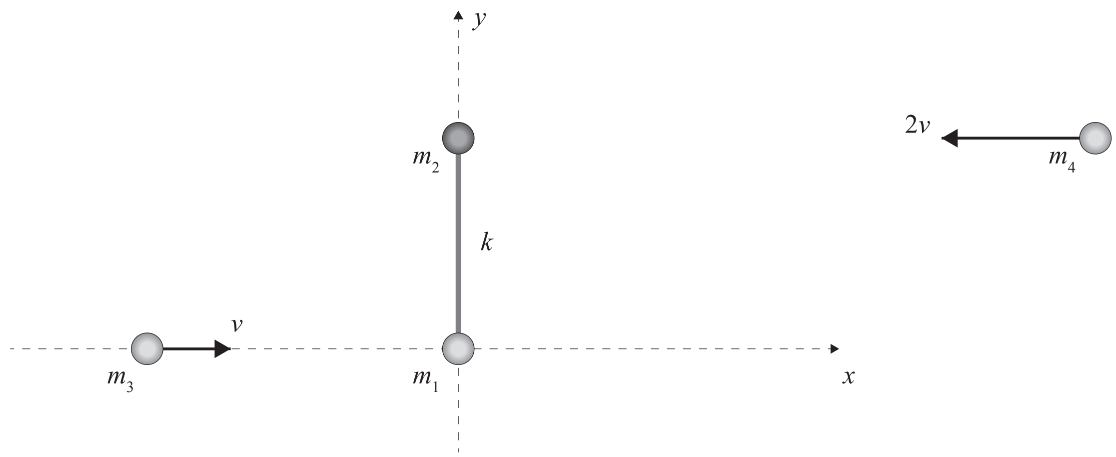
QUESTION FIVE: A SPINNING DUMBBELL



The diagram shows two masses, m_1 and m_2, initially at rest, connected by a rigid, massless rod of length k. Initially m_1 is located at the origin [coordinates $(x,y) = (0,0)$], and m_2 is located at coordinates $(x,y) = (0,\text{k})$. Two additional masses, m_3 and m_4, travel towards the rod with speeds v and $2v$, respectively, along the trajectories shown. Mass m_3 strikes mass m_1 at the same time as mass m_4 strikes mass m_2, and both stick to their respective targets after the collision.

m_1, m_3, and m_4 all have the same mass m, while m_2 has mass $2m$.

(a) Show that the (x,y) coordinate of the centre of mass of the system, immediately after the collisions, is $\left(0, \frac{3k}{5}\right)$.

(b) Show that, after the collisions, the rotational inertia of the system about an axis perpendicular to the x-y plane passing through the centre of mass is given by:

$$I = \frac{6}{5}mk^2$$

(c) Calculate the angular velocity of the system, after the collisions, about the same axis defined in part (b).

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(d) If $m = 2.0$ kg, $v = 2.0$ m s^{-1}, and $k = 1.0$ m, calculate the (x,y) coordinates of the combined mass $(m_2 + m_4)$ at a time 0.50 seconds after the collisions.

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Extra space if required.
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