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For Supervisor's use only

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

Scholarship 2009
Physics

2.00 pm Tuesday 17 November 2009
Time allowed: Three hours
Total marks: 48

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.

Write all your answers 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 space for any answer, use the page(s) provided at the back of this booklet and clearly number the question.

Check that this booklet has pages 2–22 in the correct order and that none of these pages is blank.

You are advised to spend approximately 30 minutes on each question.

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

The formulae below may be of use to you.

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

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You have three hours to complete this examination.

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QUESTION ONE: ELECTRON STEW (8 marks)

Permittivity of free space = 8.85×10^{-12} F m^{-1}
Dielectric constant of air = 1.00
Charge on the electron = 1.60×10^{-19} C

(a) The Bohr model of the atom is based on several assumptions.

State these assumptions and discuss their significance.

(b) Electrons repel each other. Two wires carrying parallel currents attract each other. Therefore currents in wires cannot be due to the motion of electrons.

Comment.

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(c) Explain why there is a force of attraction between a charged rod and an uncharged, isolated metal sphere, and why this force increases when the sphere is earthed.

(d) Calculate the average distance between the excess electrons on one plate of a parallel plate capacitor for which the plates are separated by 1.00 mm of air, and have a potential difference between them of 1.00×10^3 V.

(8)

QUESTION TWO: AC CIRCUITS (8 marks)

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In an AC circuit, the RMS current and voltage are related to their peak values by the following two relations:

$$I_{\text{RMS}} = \frac{I_{\text{peak}}}{\sqrt{2}},\ V_{\text{RMS}} = \frac{V_{\text{peak}}}{\sqrt{2}}.$$

(a) Explain why RMS values are needed in AC electricity calculations, but not in DC.

(b) Explain why the expressions connecting RMS and peak values for current and voltage include a factor $\sqrt{2}$.

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An AC electric motor can be considered to be an ideal inductor, L, in series with a resistance, R. The motor is connected in series to a load, represented by a resistance, $R_{load} = 120\ \Omega$, and a power supply. The power supply has a frequency $f = 50$ Hz and RMS voltage $V_{source} = 240$ V.

When the RMS current through the motor is 0.50 A, the supply voltage leads the current by 40°.

(c) (i) Find the resistance, R, of the motor.

(ii) What is the total power generated in the load and in the resistance of the motor when the current is 0.50 A? How much power is supplied to the circuit? Discuss your answers to these questions using physical principles.

(d) An energy supply company requires large AC motors to be run with the current and voltage in phase with each other.

Explain how this might be achieved.

(8)

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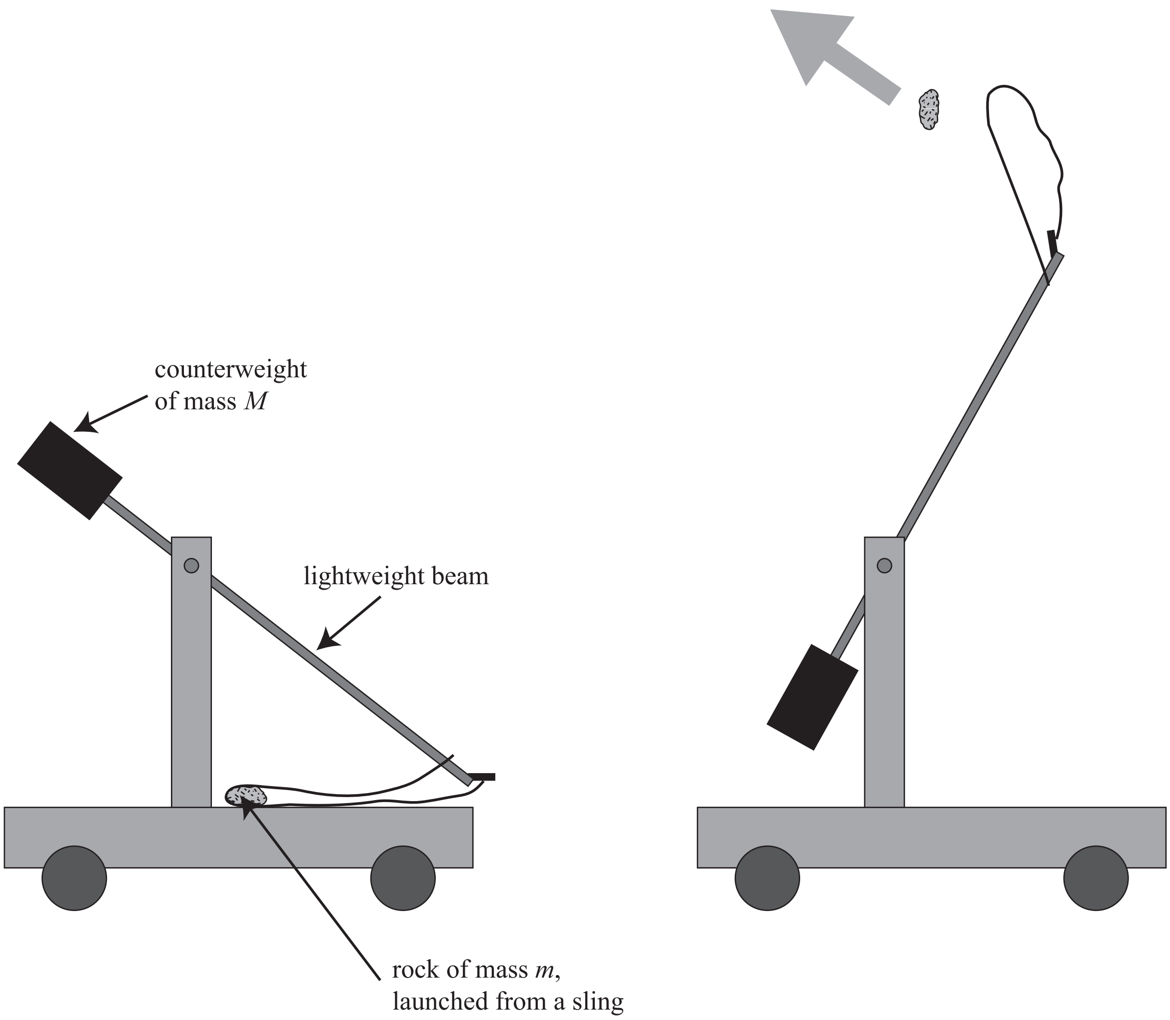
QUESTION THREE: THE TREBUCHET (8 marks)

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

The trebuchet is a medieval weapon for hurling rocks at fortifications.



(a) State the energy changes that take place when the machine fires the rock.

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(b) Assuming that the rock is released from ground level, show that the theoretical maximum range is:

$R = 2\frac{M}{m}h$, where M = mass of counterweight
m = mass of rock
h = height counterweight falls

(c) The maximum range can be increased by mounting the trebuchet on wheels (rather than fixing it to the ground).

Explain.

(d) If a trebuchet with a maximum range of 100 m on Earth were taken to the Moon (where the gravitational field strength is one sixth of that on the surface of the Earth), what would be its range?

Using physical principles, explain your answer.

(8)

QUESTION FOUR: LOOP THE LOOP (8 marks)

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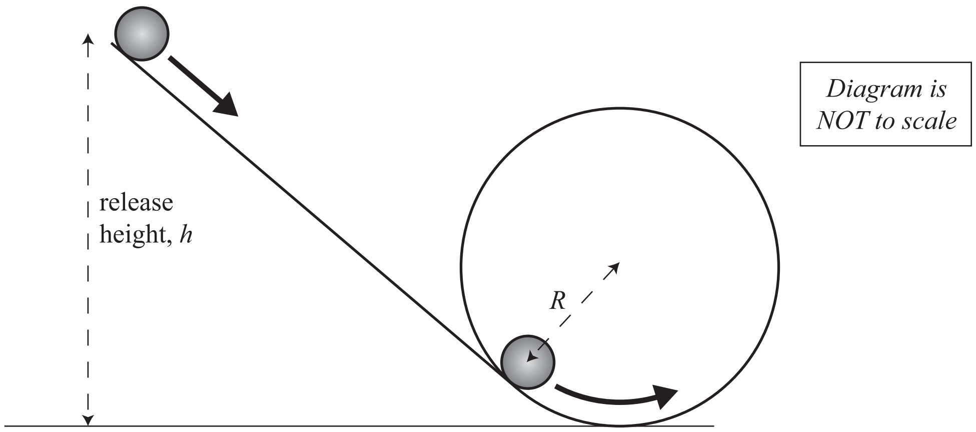
The rotational inertia of a solid sphere is $\frac{2}{5}mr^2$.

A ball of mass *m* rolls, without being slowed by friction, down a ramp leading to a vertical circular track. *R* is the distance from the centre of the track to the centre of mass of the ball. The radius of the ball, *r*, is much less than *R*.



(a) Explain what will happen to the ball for a release height, $h \leq R$.

(b) Show that the ball will "loop the loop" (stay in contact with the track for the full circle) if the ball is released from a height, $h \geq 2.7\ R$.

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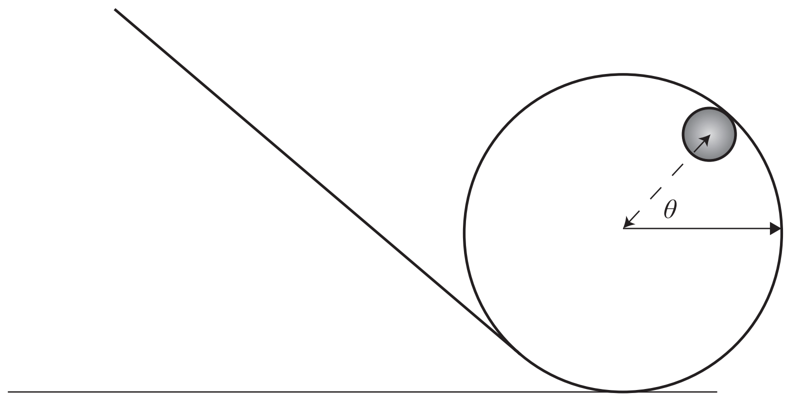
(c) If the ball is released at a height greater than R but less than $2.7R$, it will lose contact with the track at an angle θ, as shown in the diagram below.



Derive an expression (in terms of θ) for the velocity of the ball at the time it loses contact with the track.

Explain your reasoning.

(d) For a release height, $h \leq R$, the solid ball is replaced by a frictionless sliding block of the same mass and similar size.

Explain any similarities or differences from the motion for the rolling ball in part (a) of this question.

(8)

QUESTION FIVE: DIFFRACTION (8 marks)

Assessor's use only

(a) When light is incident on a pair of slits (Young's slits), the light can undergo diffraction. The diffracted waves might then interfere with each other.

Explain what conditions are needed for diffraction and interference to take place.

(b) The formulae $n\lambda = \frac{dx}{L}$ and $n\lambda = d\sin\theta$ can both be used in interference calculations.

What are the limitations on the use of these formulae?

(c) Light of wavelength of 632 nm is incident on a double slit diffraction grating. The distance between the slits is 2.00×10^{-5} m. The diffraction pattern is observed on a screen at a distance of 1.20 m from the diffraction grating.

Calculate how far the second order dark fringe is from the central maximum.

(d) When a particular line spectrum is examined using a diffraction grating of 300 lines per mm with the light coming in along the normal, it is found that a line at 24.46º contains both red (640 to 750 nm) and blue / violet (360 to 490 nm) components.

Are there any other angles at which both red and blue / violet components are observed?

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(8)

QUESTION SIX: SNOWBOARDING (8 marks)

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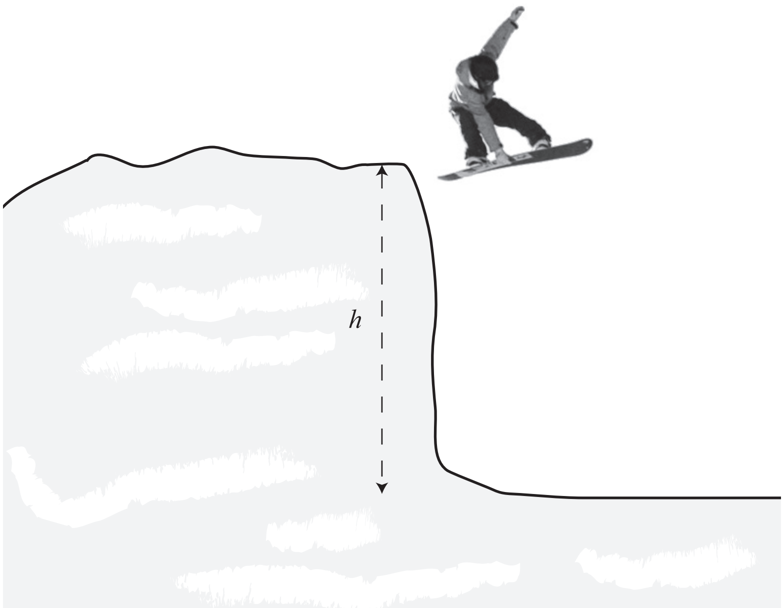
A snowboarder of mass *m* rides over an icy ledge onto a horizontal surface below.
The snowboard leaves the ledge at 0 m s^{-1} in the vertical direction and at only a very small horizontal velocity.



(a) Assuming that the centre of mass drops by a distance *b* (through the bending of the knees) on impact, show that the average reaction force acting on the snowboarder is

$$F_R = mg\left(1 + \frac{h}{b}\right)$$

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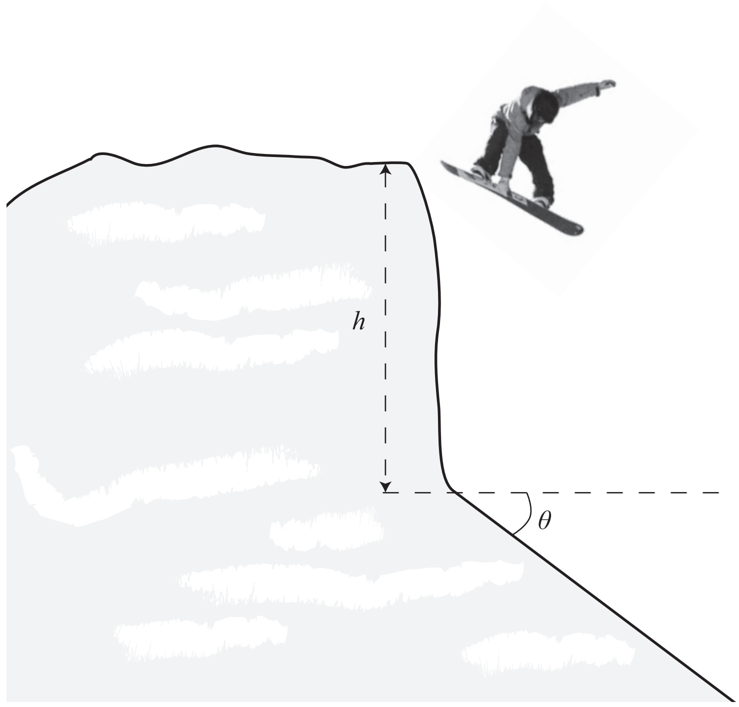
(b) By using a height, h, of 3 m and a reasonable estimate of b, calculate the size of the average reaction force experienced by the snowboarder. Comment on how the actual force might differ from the average force.

(c) Show that the time to come to a stop is given by $t = b\sqrt{\frac{2}{gh}}$ and discuss the effect of landing on soft snow (a sample calculation is required).

Question Six (d) is on the following page.

(d) Having survived his first fall, the intrepid snowboarder makes sure his next fall is onto a surface sloping at angle θ to the horizontal, as shown.



It can be shown that $F_R = mg\left(1+\frac{h}{b}\right)\cos\theta$.

Explain, using physical principles, the effect of the slope on the force experienced by the snowboarder.

(e) For snowboarders approaching the ledge with a non-zero velocity, the slope can be made so that the reaction force on landing is zero.

Discuss what shape of the slope would be required and why.

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(8)

Extra paper for continuation of answers if required.
Clearly number the question.

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