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NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

Scholarship 2007
Physics

2.00 pm Friday 23 November 2007
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.

Answer ALL questions.

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 an 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 2–21 in the correct order.

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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QUESTION ONE: STANDING WAVES (8 marks)

Solar radius = 6.96×10^8 m

A pulsating variable star is a star whose intensity varies in a regular, periodic fashion. White dwarf stars are examples of such a star.

In one model, the period of a pulsating variable star may be estimated by considering the star to be executing radial pulsations in the fundamental standing wave mode. That is, the star's radius varies periodically with time, with a displacement antinode at the star's surface.

(a) Would the centre of the star be a displacement node or antinode? Explain.

(b) The pulsating variable star can be modelled as a pipe with one open end.

Explain how a standing wave can be formed in a pipe with one end open.

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(c) By analogy with a pipe with one open end, show that the period of the fundamental pulsation, T, of the variable star is given by, $T = \frac{4R}{v_{av}}$, where R is the equilibrium radius of the star, and v_{av} is the average speed of sound in the star.

(d) A typical white dwarf star is composed of material with a bulk modulus of 1.33×10^{22} Pa, density of 1×10^{10} kg m^{-3} and a radius equal to $9.0 \times 10^{-3} \times$ solar radius. The bulk modulus is a measure of the compressibility of the material – a high bulk modulus indicates a high degree of incompressibility.

It can be shown that in a fluid or gas, the average speed of sound is given by the following relationship, $v_{av} = \sqrt{\frac{\beta}{\rho}}$ where β = bulk modulus and ρ = density.

By using this relationship and that given in (c), calculate the pulsation period for a typical white dwarf star.

(8)

QUESTION TWO: ENVIRONMENTAL PHYSICS (8 marks)

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Radius of Earth = 6.4×10^6 m
Surface area of a sphere = $4\pi r^2$
Speed of light = 3.00×10^8 m s^{-1}

(a) Global warming could cause melting of floating ice (ice sheets) and land-based ice (ice caps) at the poles of the Earth. The volume of floating ice is estimated to be 6.6×10^{14} m^3 and the volume of land-based ice is estimated to be 3.2×10^{16} m^3.

Estimate the rise in sea-level if global warming causes all the ice to melt. State any assumptions you have made.

(b) If the polar ice melts, a large volume of water will be released into the ocean. This could cause the rotational period of the Earth about its axis to alter.

Using physical principles, discuss this statement.

(c) The use of nuclear power instead of gas- or coal-fired power stations is being suggested as one way of cutting back emissions of carbon dioxide, which causes global warming.

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(i) By referring to Albert Einstein's equation, explain the physical basis of nuclear power.

(ii) The reaction used in one type of nuclear reactor is:

$$^{239}_{94}\text{Pu} + ^{1}_{0}\text{n} \rightarrow ^{142}_{56}\text{Ba} + ^{93}_{38}\text{Sr} + 5^{1}_{0}\text{n}$$

The rest masses of the particles involved are:

239 plutonium:	$396.92935 \times 10^{-27}$ kg
142 barium:	$235.64216 \times 10^{-27}$ kg
93 strontium:	$154.27837 \times 10^{-27}$ kg
neutron:	1.67493×10^{-27} kg

In terms of energy production, calculate how many tonnes of coal are equivalent to 1 kg of plutonium. (1 tonne of coal produces 30 GJ of energy.)

(8)

QUESTION THREE: RESONANCE AND THE DOPPLER EFFECT (8 marks)

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Speed of sound in air = 340 m s^{-1}
Acceleration due to gravity = 9.80 m s^{-2}

Consecutive resonant frequencies in a tube will occur when an extra half-wavelength of the sound fits into the tube.

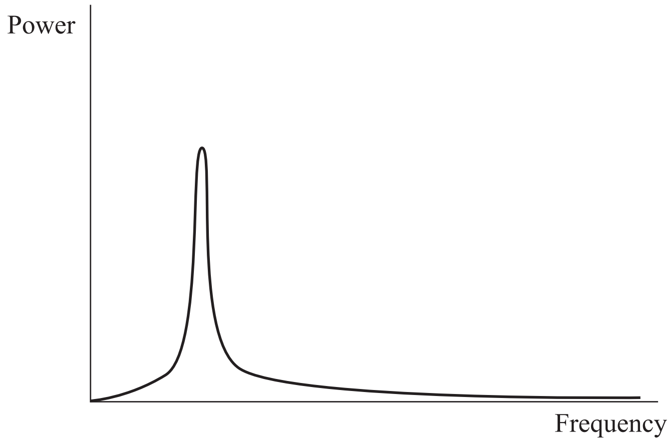
(a) The depth of a well can be measured using a frequency generator. Successive resonances are observed at frequencies of 99.2 Hz and 127.5 Hz.

Calculate the depth of the well.

(b) On a second deeper well, a different technique is used to measure the depth. A small object that emits a constant frequency of 530 Hz is dropped down the well. The observer, at the top of the well, hears the frequency decreasing as the object drops into the well. Just before the object hits the bottom of the well the observed frequency is 500 Hz.

Calculate the depth of the well.

(c) Resonance is also observed in electrical circuits. The power dissipated in an RLC circuit depends on the frequency as shown in the graph below.



Discuss this curve in terms of the electrical response of the inductor, capacitor and resistor to the AC voltage.

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QUESTION FOUR: THE SLIDING TOY (8 marks)

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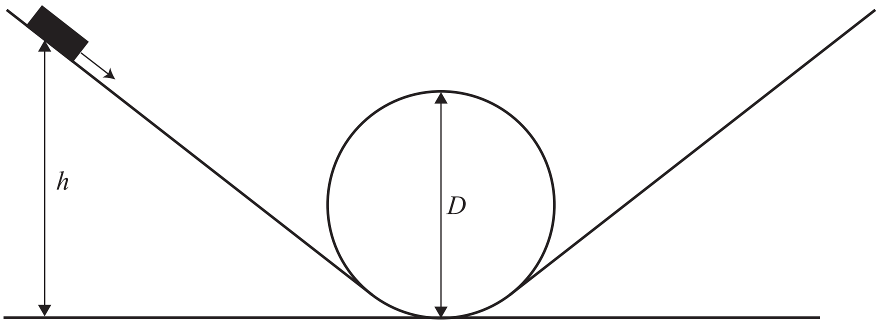
Acceleration due to gravity = 9.80 m s^{-2}

Benjamin is playing with his toy slider and track. The track has a circular loop of diameter, *D*, as shown in the diagram. Friction between the slider and the track is negligible.



(a) Explain the physical conditions under which the slider can travel around the loop without losing contact with the track.

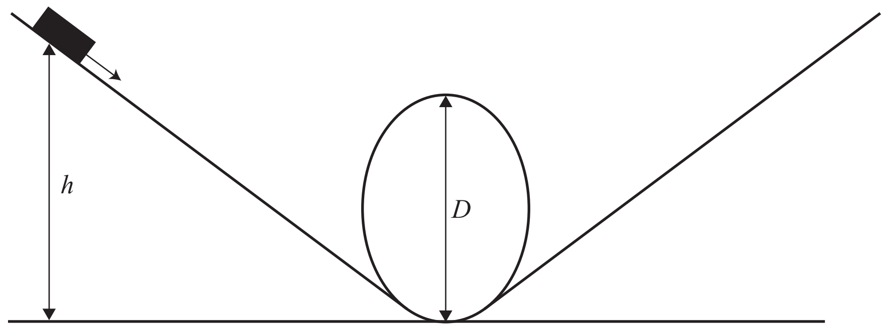
(b) If Benjamin releases the slider from rest, derive an expression for the minimum height, *h*, so that the slider does not lose contact with the track.

(c) Explain how the minimum height changes for the following three different cases:

(i) Benjamin pushes the slider as he releases it.

(ii) Benjamin replaces the slider with one that has greater mass, but is otherwise identical.

(iii) Benjamin replaces the loop with an elliptical one with the same height as the circular one, as shown in the diagram.



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QUESTION FIVE: THE ASTRONAUT (8 marks)

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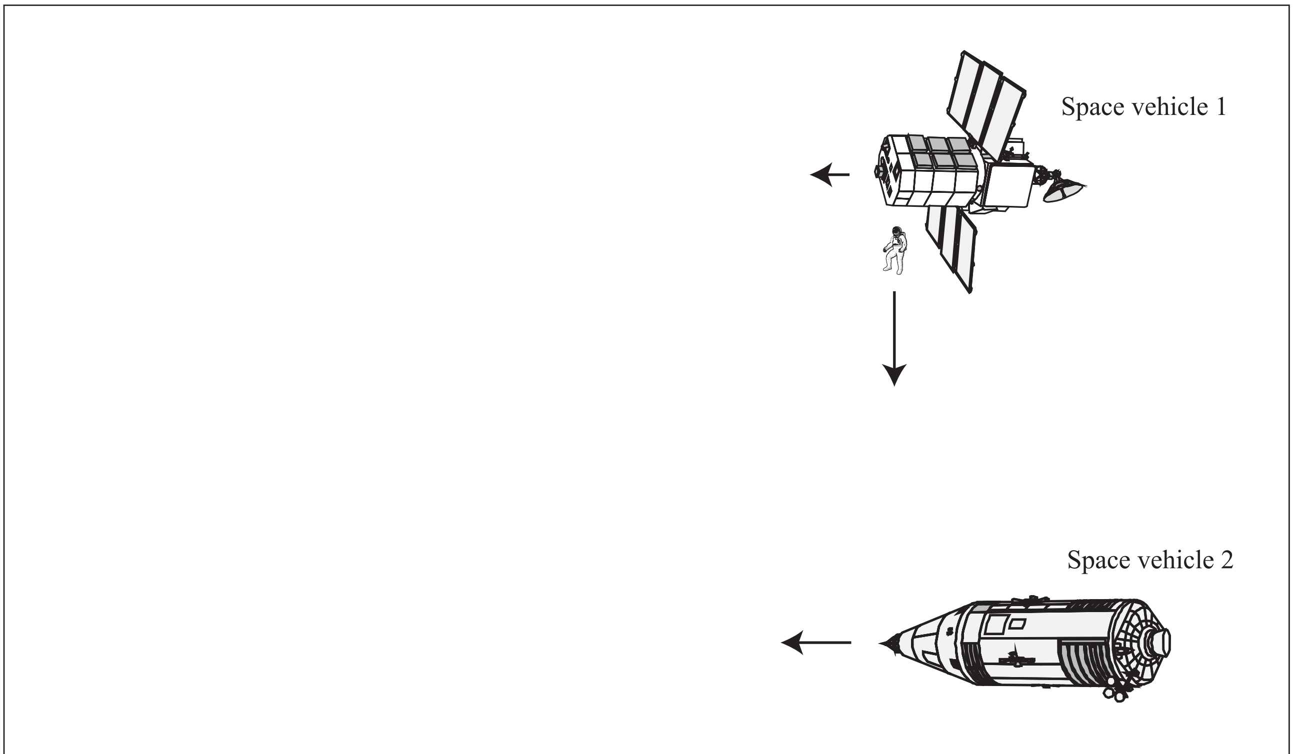
Nicole, an astronaut, is assigned to make external repairs to a second space vehicle which is travelling in a direction parallel to her own, but with a greater relative velocity of 2.6 m s^{-1}. The second space vehicle is 85 m in length. Nicole launches herself directly towards the nose of the vehicle with a speed of 6.0 m s^{-1} in a direction perpendicular to the motion of the second space vehicle. At this point, the vehicles are separated by a distance of 200 m. As a safety measure, Nicole is equipped with a launcher that fires a magnetic puck. The magnetic puck is attached to a 4 m length of rope, the other end of which is tied to Nicole. The magnetic puck can only be fired in the direction in which Nicole is travelling. The magnetic puck has a mass equal to 1% of Nicole's mass, but only 0.004% of the mass of the second space vehicle that she is heading towards.



(a) Show that the magnetic puck allows Nicole to attach herself to the second space vehicle.

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(b) Nicole can control the speed at which she fires the puck, from 10 m s^{-1} to 750 m s^{-1} relative to herself.

If Nicole fires the magnetic puck when she is 4 m away from the second space vehicle:

(i) Discuss the effect of the puck velocity on the success of the mission.

(ii) Discuss the effect of the puck velocity on the second space vehicle, for the full range of puck velocities.

(8)

QUESTION SIX: ELECTROMAGNETIC INDUCTION (8 marks)

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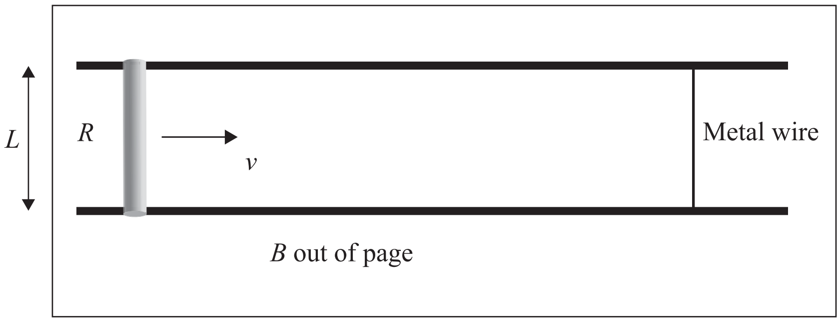
A metal roller of resistance *R* is placed on two long metal rails, which are connected via a metal wire. The whole system is placed in a uniform magnetic field, as shown in the diagram below. Initially the metal roller is given a small impulse towards the right.

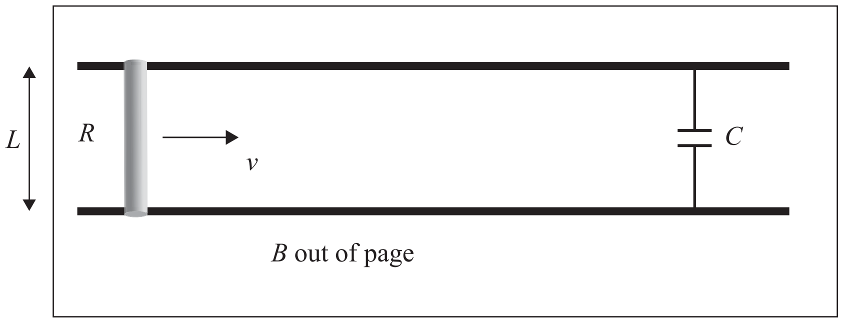


(a) Explain physically why the metal roller cannot continue to move with constant velocity towards the metal wire.

(b) By applying a constant force to the right, the roller can be made to move with constant velocity.

By applying Faraday's Law, derive a relationship for the voltage across the roller.

The metal wire is replaced by a capacitor, as shown below. The roller is again given a small impulse to the right.



(c) Explain why the roller eventually travels at a constant velocity.

(d) Derive an expression for the charge on the capacitor when the roller has reached constant velocity. Show that the expression you have derived is dimensionally correct.

(e) Explain what would be the effect of initially charging the capacitor before releasing the roller onto the rails.

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(8)

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

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Question Number	Marks
Q1	(8)
Q2	(8)
Q3	(8)
Q4	(8)
Q5	(8)
Q6	(8)
TOTAL	(48)

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