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NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

Scholarship 2011
Physics

2.00 pm Wednesday 16 November 2011
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.

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 2–22 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.

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

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You have three hours to complete this examination.

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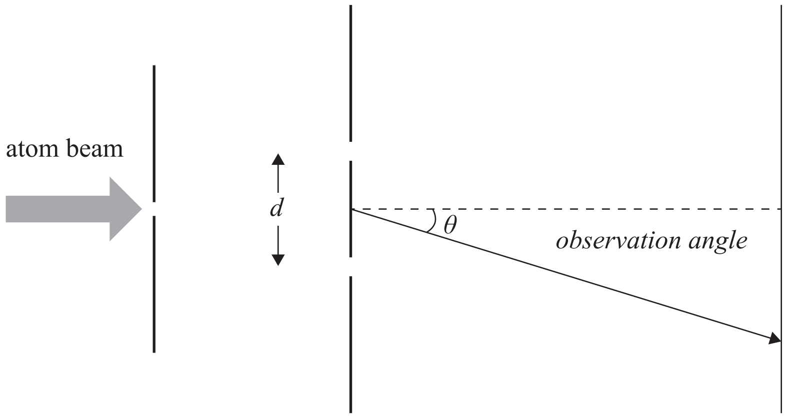
QUESTION ONE: WAVE / PARTICLE DUALITY (8 marks)

Matter, as well as light, can demonstrate wave-like behaviour and particle-like behaviour. The de Broglie relationship $\lambda = \frac{\text{h}}{p}$, where λ is the wavelength, p is the momentum and h is Planck's constant, can be verified by the experimental observation of the diffraction of atoms.

In the experiment below, a beam of atoms is incident on a double slit with slit separation d.



(a) Show that the de Broglie wavelength of an atom of mass m is related to its kinetic energy, E, by the following expression $\lambda = \frac{\text{h}}{\sqrt{2mE}}$.

(b) (i) Starting from $d \sin\theta = n\lambda$, derive an expression for the intensity maxima of the atom waves diffracted through the double slit, as a function of kinetic energy.

(ii) State the corresponding expression for the intensity minima.

One experimental difficulty is that the incident atoms have a range of kinetic energies. Assume that they have a range of energies distributed between $E + \Delta E$ and $E - \Delta E$, so that the mean energy is E.

(c) Explain why a range of energies will lead to poorly defined intensity maxima.

(d) The atom beam is incident on a diffraction grating. If the energy range $2\Delta E$ is too large, the interference fringe of the first order maximum will overlap the second order maximum.

Derive an expression for ΔE such that the first and second fringes have no overlap.

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QUESTION TWO: GRAVITY (8 marks)

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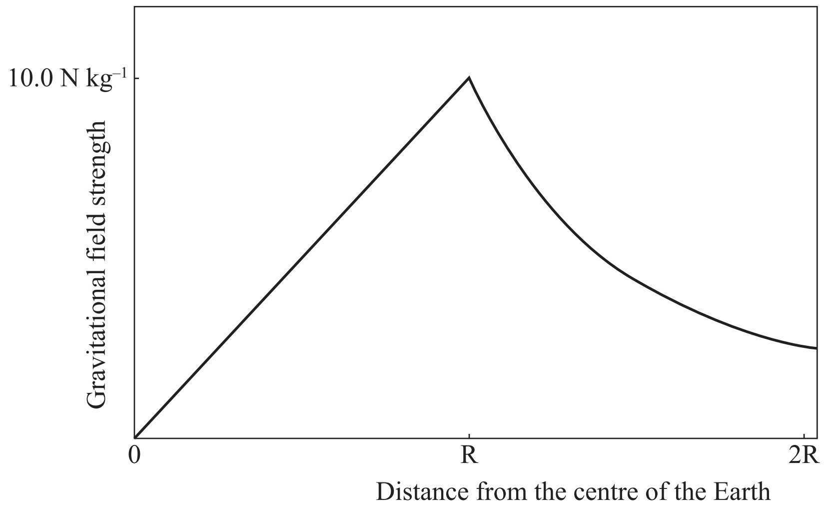
Some text books show the change in gravitational field strength (g) as one moves outwards from the centre of the Earth, by using a graph, such as the one following, where R is the radius of the Earth.



(a) Explain, using physical principles, why the gravitational field strength (g) is zero at the centre of the Earth.

(b) An object within a hollow sphere experiences no gravitational force from the mass of that sphere.

Use this result, and Newton's law of gravitation, to show that g increases linearly as one moves from the centre of the Earth outwards to the surface.

Note: volume of sphere $= \frac{4}{3}\pi r^3$ and density $= \frac{\text{mass}}{\text{volume}}$.

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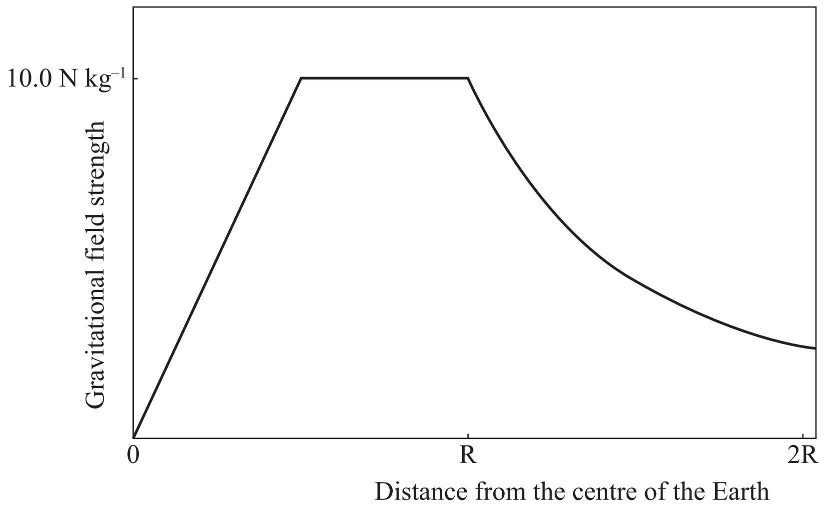
(c) Explain why g decreases as shown, when one moves outwards from the Earth's surface.

(d) In fact, the variation in g is more accurately shown in this graph.



What does this graph tell us about the Earth's interior structure?

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QUESTION THREE: CLARINETS AND FLUTES (8 marks)

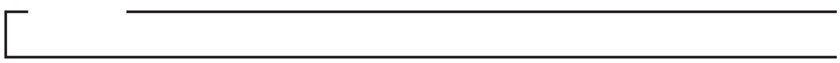
Clarinet

www.life123.com/arts-culture/musical-instruments/clarinets/history-of-the-clarinet.shtml

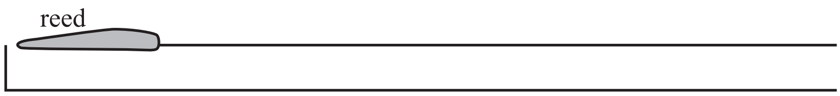
Flute

http://miami.olx.com/flute-lessons-are-dynamic-excellent-results-iid-26298197

The flute is played by blowing air over a large opening.

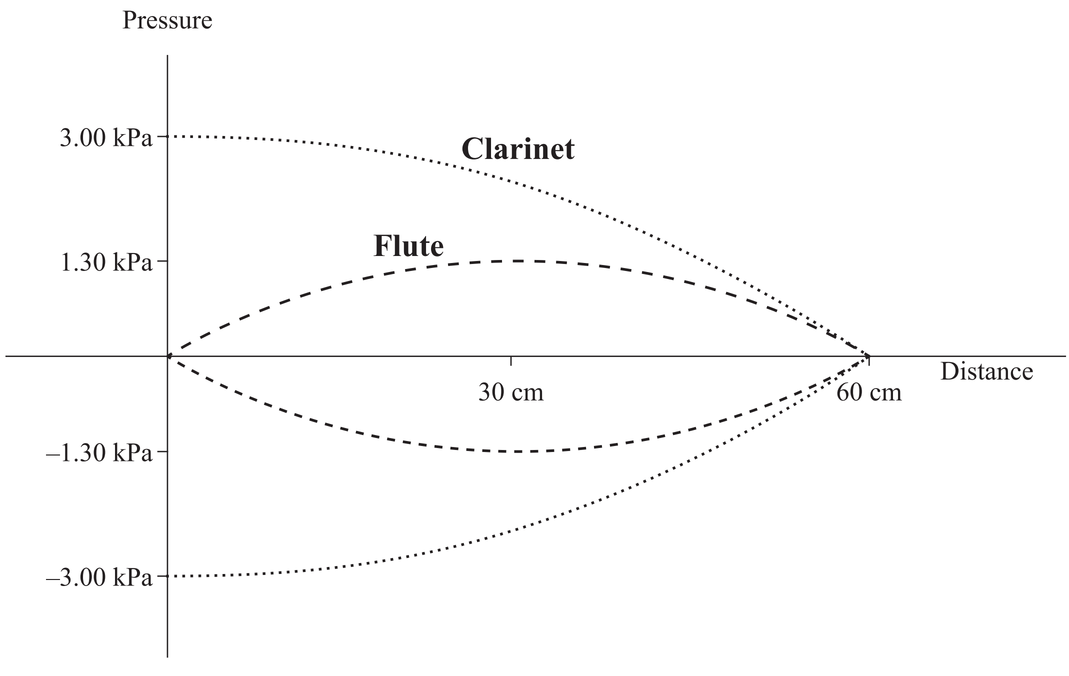


The clarinet is played by blowing air through a small opening covered by a vibrating reed.



The "acoustic pressure" in these wind instruments is the difference between the air pressure inside the instrument and the atmospheric pressure outside.

When the acoustic pressure is measured inside a flute and inside a clarinet, the maximum and minimum pressures are found to vary along the length of the instruments, as shown in the following graph. (Both the flute and the clarinet are 60 cm long, with the opening at 0 cm.)



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(a) Explain why, at each point inside the instruments, the pressure is recorded as having both a positive and a negative value.

(b) At the left hand end (where the reed is positioned) of the clarinet pipe, the acoustic pressure is a maximum.

Explain why there is a displacement node at this end of the clarinet.

(c) It is possible to blow some wind instruments harder so that the sound is **double** the frequency of the fundamental.

Explain why this is possible with a flute and is not possible with a clarinet.

(d) When the wind instrument is being played, the air inside can warm up and the notes played become sharper (have a slightly higher frequency).

Explain why this happens.

(e) Explain how standing sound waves can occur in open pipes.

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QUESTION FOUR: CAPACITORS (8 marks)

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(a) A capacitor with air between the plates has a capacitance of 3.0×10^{-6} F.

Calculate the capacitance when wax of dielectric constant 2.8 is placed between the plates. State your assumptions.

(b) Dielectric materials can increase the capacitance of a capacitor.

Explain how a dielectric material creates an increase in capacitance.

A capacitor is made of two parallel plates with air between them. A student is attempting to determine the work lost or gained when the two plates are moved apart. The plates, each of area A, are connected to a battery of potential difference V.

The student sets the initial separation of the plates to d_1, and they are to be moved further apart to a separation d_2.

(c) Show that the work done in changing the separation from d_1 to d_2 is $\frac{V^2 \varepsilon_0 A}{2}\left(\frac{d_2 - d_1}{d_1 d_2}\right)$.

(d) Explain, using physical principles, what happens to the stored energy and charge as the plate separation increases.

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(e) The plates are brought back to the original separation d_1. The battery is now disconnected.

Derive an expression for the work done to, once again, increase the separation to d_2.

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QUESTION FIVE: THE PENDULUM (8 marks)

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A pendulum bob (mass M) is released from the horizontal position shown in the diagram ($\theta = 0°$) and swings down to the vertical position ($\theta = 90°$).

(a) Explain why the motion of this pendulum will not be a simple harmonic motion.

(b) Show that the tension in the cord (which was originally zero) has increased to $3Mg$, as the bob passes through the lowest point.

(c) The pendulum cord is replaced with a thinner string, and is again released from rest when $\theta = 0°$.

If the string breaks when the tension is twice the weight of the bob, at what angle does it break?

(d) The bob of a pendulum is given a positive charge and oscillates with a small amplitude above a large, earthed, metal plate.

Explain how the period differs from the case where the metal plate is absent.

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QUESTION SIX: COLLISIONS (8 marks)

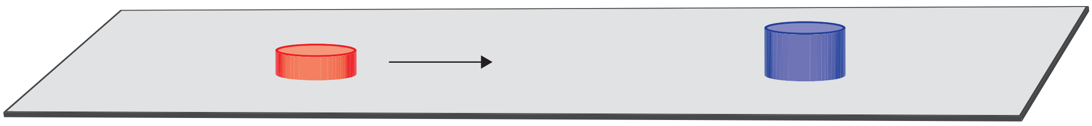
A red puck of mass 2.0×10^{-3} kg is set moving along a long, frictionless track towards a blue puck of mass 4.0×10^{-3} kg. The red puck has a velocity of 21 m s^{-1}, while the blue puck is at rest, but free to move. Both pucks carry a positive charge of 1.5×10^{-6} C. The pucks meet along the line of their centre of mass in an elastic interaction.

The charges cause an electrostatic force between the two pucks.

When they are separated by a distance r, the repulsive force is given by $F = \dfrac{kQ_1Q_2}{r^2}$.

The electric potential energy is given by $E_p = \dfrac{kQ_1Q_2}{r}$.

Q_1 and Q_2 are the two charges and k is a constant ($= 9.0 \times 10^9$ N m^2 C^{-1}).



- 2.0×10^{-3} kg
- 21 m s^{-1}
- +1.5 μC

- 4.0×10^{-3} kg
- +1.5 μC

(a) Describe (without calculations) the motion of each puck as it interacts with the other.

(b) At the instant of closest approach, both pucks have the same velocity.

Explain why this is so, and show that the velocity is 7.0 m s^{-1}.

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(c) If the pucks are initially 10 m apart, show that the electrostatic potential energy at this separation is negligible compared with the kinetic energy of the moving puck.

(d) By considering the kinetic and electrostatic energies, calculate the distance of closest approach.

(e) Calculate the final velocities of the pucks (when they are a long distance apart).

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Write the question number(s) if applicable.

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Question	Mark
ONE	(8)
TWO	(8)
THREE	(8)
FOUR	(8)
FIVE	(8)
SIX	(8)
TOTAL	(48)