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Candidate Code No

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NEW ZEALAND EDUCATION & SCHOLARSHIP TRUST

NZEST SCHOLARSHIP EXAMINATION 2002

PHYSICS

QUESTION AND ANSWER BOOKLET

Friday 8 November 2002, 2pm

Time allowed: Three hours

Notes to Candidates

1. The paper consists of:
   10 short-answer questions in Section A (worth 3 marks each)
   6 long-answer questions in Section B (worth 15 marks each).
   The total mark is 120.

2. To get full marks, you will need to show your working and your reasoning. In addition, up to **6 bonus marks** may be awarded in Section B (one mark per long question) for answers showing exceptional insight.

3. You should allocate your time in proportion to the question value: about one and a half minutes per mark.

4. To receive full marks for numerical questions your answers must be accompanied by the correct units and have an appropriate number of significant figures.

5. Answer all questions in this combined question/answer book.

6. Formulae and data are printed at the front of the book.

7. Page 24 is an extra answer page

DATA WHICH MAY BE REQUIRED

Acceleration of gravity	g	=	$9.80\ ms^{-2}$
Permittivity of free space	ε_0	=	$8.85 \times 10^{-12}\ F\ m^{-1}$
Permeability of free space	μ_0	=	$4\pi \times 10^{-7}\ H\ m^{-1}$
Electronic charge	e	=	$1.60 \times 10^{-19}\ C$
Coulomb-law constant	k	=	$8.99 \times 10^{9}\ N\ m^2\ C^{-2}$
Planck's constant	h	=	$6.63 \times 10^{-34}\ J.s$
Speed of light	c	=	$3.00 \times 10^{8}\ m\ s^{-1}$
Speed of sound in air		=	$340\ m\ s^{-1}$
Mass of electron	m_e	=	$9.11 \times 10^{-31}\ kg$

The following formulae may be of use to you:

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

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

$\Delta p = Ft$

$\omega = 2\pi f$

$d = r\theta$

$v = r\omega$

$a = r\alpha$

$W = Fd$

$F = ma$

$p = mv$

$v = v_i + at$

$v^2 = v_i^2 + 2ad$

$d = \frac{(v_i + v)t}{2}$

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

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

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

$L = I\omega$

$L = mvr_\perp$

$\tau = I\alpha$

$\tau = Fr$

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

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

$E_{GPE} = mgh$

$\omega = \omega_i + \alpha t$

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

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

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

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

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

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

$F = -ky$

$a = -\omega^2 y$

$y = A\sin\omega t$

$v = A\omega\cos\omega t$

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

$y = A\cos\omega t$

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

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

$\Delta E = Vq$

$P = VI$

$V = Ed$

$Q = CV$

$C_{TOT} = C_1 + C_2$

$\frac{1}{C_{TOT}} = \frac{1}{C_1} + \frac{1}{C_2}$

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

$C = \frac{\varepsilon_0\varepsilon_r A}{d}$

$\tau = RC$

$\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2}$

$R_{TOT} = R_1 + R_2$

$\phi = BA$

$\varepsilon = BAN\omega\sin\omega t$

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

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

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

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

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

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

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

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

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

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

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

$X_L = \omega L$

$V = IZ$

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

$n\lambda = d\sin\theta$

$f = |f_1 - f_2|$

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

$E = hf$

$hf = \phi + E_K$

$E = mc^2$

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

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

$\Delta E = |E_1 - E_2|$

$\upsilon = f\lambda$

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

Candidate Code No

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Section A: Guided Short-Answer [3 marks each]

*You must show your reasoning to gain the full three marks. Two marks are allocated for reasoning, one mark for making the correct choice (**T** or **F** for a True/False question; one of **a**, **b**, **c**, **d**, **e** for a multichoice question). A correctly chosen option without supporting working can earn no more than one mark.*

1. A car travelling at constant speed on a straight road drives past you. The angular momentum of the car, as measured in your reference frame, is constant. *True or false*?

2. When a sound wave passes from air into water it is refracted towards the normal. *True or false*?

3. Destructive interference of light waves is impossible as the energy carried by the original waves disappears when the troughs and crests cancel. *True or false*?

4. Because of the rotation of Earth, the effective acceleration due to gravity is less at the equator than at the South pole. *True or false*?

5. On humid days, electrostatic experiments are difficult to perform as charge 'leaks' from charged objects. *True or false*?

6. In your body the ratio of neutrons to protons is:

(a) less than 1 (b) exactly 1 (c) greater than 1

7. A length of elastic has mass M and is stretched between two points a distance D apart with a tension force T. Which of the following is the correct formula for the speed v of a transverse wave along the elastic?

(a) $v = T/(MD)$ (b) $v = \sqrt{DT/M}$ (c) $v = D^2/(MT)$

(d) $v = D\sqrt{T/M}$ (e) $v = \sqrt{T/M}$

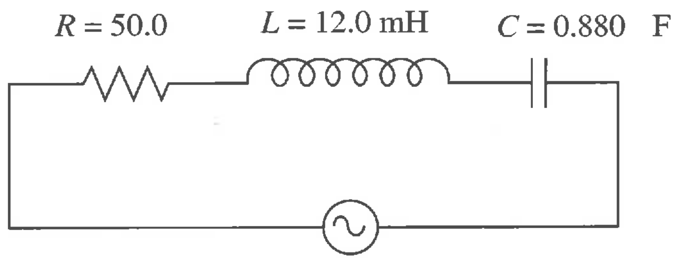
8. A bird in a cage is placed in a large box, which is then placed on a weighing balance. Relative to the weight when the bird is sitting on its perch, the weight when the bird is flying about its cage is:

(a) larger,
(b) smaller,
(c) the same.

9. Consider a collision between elementary particles: a negative pion (which has the same charge as an electron but is about 200 times more massive) and a deuteron (which is a nucleus consisting of one proton and one neutron). If the pion enters from the left and collides with the deuteron at rest, which of the following results is possible (all post-collision particles are described):

(a) 2 electrons were emitted to the right and a proton to the left.
(b) A proton was emitted upwards and to the right, and an electron was emitted upwards and to the left.
(c) A neutron was emitted upwards and to the right, and a second neutron was emitted downwards and to the right.
(d) A proton was emitted upwards and to the right, and a neutron was emitted downwards and to the right.
(e) The pion reflected off the deuteron, which stayed at rest.

10. What is the resonant frequency of the ac series circuit shown below?



(a) 973 Hz (b) 1.55 kHz (c) 6.11 kHz (d) 9.73 kHz (e) 61.1kHz

SECTION B: LONG QUESTIONS [15 marks each]

QUESTION B1:

(a) A martial arts instructor strikes a wooden board with her fist as part of a demonstration. The board will break when its central deflection is 18mm, and you may treat the bending of the board as elastic, with effective spring constant $k = 4.0 \times 10^4$ Nm^{-1}. The board has a mass of 0.15 kg, and the mass of the instructor's hand is 0.67 kg.

(i) Determine the energy that is stored in the board just prior to it breaking. **[1 mark]**

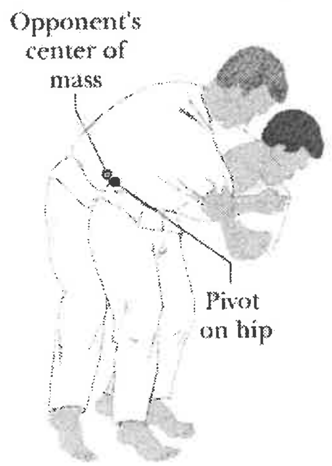
(ii) Give a reason why the collision between the fist and the board is inelastic. **[1 mark]**

(iii) Write down a relation between the speed of the instructor's fist just before impact and the speed of the board just after impact. **[1 mark]**

(iv) Show that the instructor's fist must be travelling faster than 4.9 ms^{-1} before the impact in order to break the board. **[2 marks]**

(v) If the collision between the instructor's fist and the board lasts for 0.02 s, estimate the average force on the instructor's hand. **[2 marks]**

(b) The instructor next demonstrates a hip throw. She backs into her opponent, grabs his arm and bends forward. This lifts his feet off the floor and puts his centre of mass next to her hip, which she uses to pivot him (see figure). She then applies a force ***F*** to his arm in order to throw him.

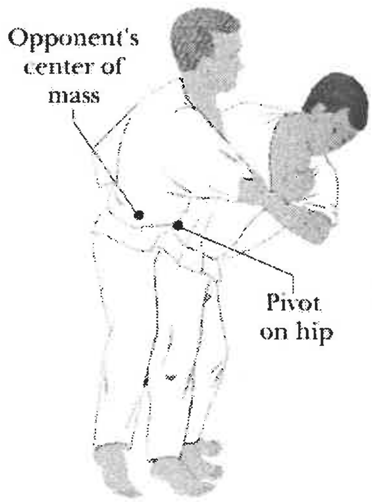


(i) On the diagram above draw all the forces acting on the opponent. **[2 marks]**

(ii) Calculate the magnitude of the force ***F*** she needs to apply in order to give her opponent an angular acceleration of 5.5 rad s^{-2}. You should take the perpendicular distance between the force ***F*** and the pivot point to be 27 cm, and the moment of inertia of her opponent to be 15 kg m^2, and his mass to be 80 kg. **[2 marks]**

(iii) Estimate the time it takes her opponent to fall to the floor, assuming that the torque is constant throughout the motion. **[2 marks]**

If the instructor forgets to bend her opponent forward she will have to apply a much larger force in order to throw him (see figure).



(iv) If the opponent's centre of mass is now 12 cm behind her hip, determine the magnitude of the force now required to give him an angular acceleration of 5.5 rad s^{-2}. **[2 marks]**

QUESTION B2:

(a) State, both in words and mathematically, the quantum condition used in the Bohr model of the Hydrogen atom. **[2 marks]**

(b) The attractive Coulomb force between a proton and an electron is $F(d)=\frac{ke^2}{d^2}$ where e is the magnitude of the charge on both the proton and electron, and d is the distance between them. If the electron orbit is a circle of radius r, show that the angular momentum of the electron about the proton is $L=\sqrt{ke^2mr}$. **[2 marks]**

(c) Use the Bohr quantum condition and the result of (b) to show that the radius of the electron orbit is $r=n^2\frac{h^2}{4\pi^2ke^2m}$. **[2 marks]**

(d) Calculate the numerical value of $\frac{h^2}{4\pi^2ke^2m}$ and give its correct (SI) units. **[2 marks]**

(e) If, instead of orbiting a proton, the electron were orbiting a nucleus of charge Ze, what would be the radius of the orbit? **[1 mark]**

(f) It is observed that all neutral atoms (in their lowest energy states) have approximately the same size. Give an explanation of this observation. **[2 marks]**

(g) The Hydrogen atom in the n^{th} quantum state has energy $E_n = -\frac{13.6\text{eV}}{n^2}$. Calculate the wavelength of light emitted when the atom makes a transition from the $n = 5$ level to the $n = 2$ level. **[3 marks]**

(h) By shining white light from a broadband source on Hydrogen gas at room temperature, we can observe the absorption spectrum of the gas i.e. the wavelengths that are absorbed by the gas. Give a reason why the wavelength you found in (g) is not seen in the absorption spectrum of Hydrogen. **[1 mark]**

QUESTION B3:

(a) Describe (in words) the Doppler effect. **[1 mark]**

Bats navigate and find prey using ultrasonic waves. A certain species of bat emits ultrasonic waves at a frequency f_B, which is about 80 kHz.

(b) Consider a moth flying directly towards a stationary bat with speed v_M.

(i) If the speed of sound in air is v, write down the speed of propagation of the ultrasonic waves relative to the moth. **[1 mark]**

(ii) Hence show that the frequency of ultrasonic waves detected by the moth is

$$f_M = f_B \frac{v + v_M}{v}$$ **[2 marks]**

(iii) If the bat is emitting ultrasound at 80.0 kHz and the moth is flying directly away from the bat at 2.9 m s^{-1}, determine the frequency of ultrasound detected by the moth. **[1 mark]**

(iv) The bat now sets off in search of the moth. It flies at 3.6 m s^{-1} directly towards the moth, which is still flying away from the bat at 2.9 m s^{-1}. The bat continues to emit ultrasound at 80.0 kHz. Show that the frequency of ultrasound detected by the moth is 80.2 kHz. **[3 marks]**

(v) Determine the frequency of the echo from the moth that the bat detects. **[2 marks]**

(vi) How does the bat determine the distance between itself and the moth using only the ultrasound echo? **[1 mark]**

(c) Some stars are observed to *pulsate*, that is their radius varies periodically with time. We can consider the pulsations to be radial longitudinal oscillations in the fundamental standing wave mode with the star's surface being a displacement antinode.

(i) Explain why the centre of the pulsating star acts as a displacement node. **[1 mark]**

(ii) Sketch a diagram of the standing wave mode. **[1 mark]**

(iii) Show that the average speed of sound in the pulsating star is given by $v = \frac{4R}{T}$ where T is the period the pulsations and R is the equilibrium radius of the star. **[2 marks]**

Candidate Code No

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QUESTION B4:

(a) Certain stovetops are able to heat pans yet remain cool to touch. A physics student investigates such a stovetop and finds that it has a coil of wire beneath the glass top. Describe how the stovetop works. **[3 marks]**

(b) A loudspeaker has a permanent magnet with a uniform field *B* in the annular gap between the poles (see diagram). A coil with 1500 turns and radius 1.0 cm is wound on a thin cardboard cylinder which slides smoothly over the inner pole of the magnet. The coil is mechanically connected to the loudspeaker cone.

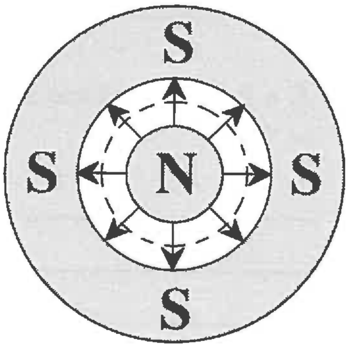

Figure 1

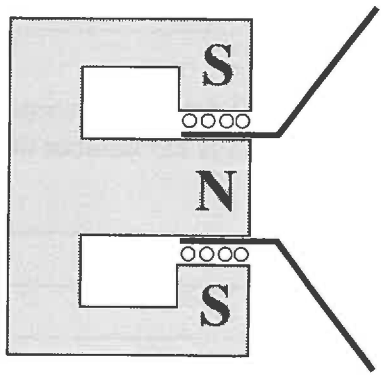

Figure 2

(i) If the field has a magnitude of 0.075 T, determine the force exerted on the speaker cone when there is a steady current of 1.0 A in the coil. **[2 marks]**

(ii) If the current in the coil is an ac current $I(t) = I_0 \sin \omega t$, the speaker cone will oscillate in SHM. Find the amplitude of the cone's oscillations if the effective mass of the coil and cone is 135 g, the peak current is 1.0 A, and the frequency is 1200 Hz. You may ignore air resistance. **[3 marks]**

The loudspeaker can also be used as a microphone. If the coil moves perpendicular to the field with velocity v, an electric field $E = vB$ is induced in the coil.

(iii) If the coil is moved into the page in Figure 1 above, is the induced electric field in the clockwise or anticlockwise sense? **[2 marks]**

(iv) Show that the emf generated in the coil is $\mathcal{E} = 2\pi RnvB$ where R is the radius of the coil, and n is the number of turns. **[2 marks]**

(v) A sound wave incident on the cone causes the coil to move in the annular gap of the magnet with displacement given by $y(t) = A \sin \omega' t$ where the amplitude of the motion A is 1×10^{-6} m and the frequency ω' is 3.0 kHz.
Find an expression for the induced emf in the coil as a function of time. **[3 marks]**

Candidate Code No

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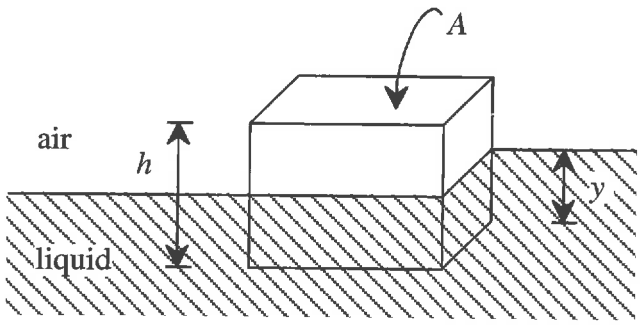
QUESTION B5:

Archimedes' Principle states that for a body submerged in a fluid, the buoyancy force on the body is directed upward and has magnitude equal to the weight of the fluid that has been displaced by the body.

An object of uniform composition, with mass M, height h and uniform cross-section A is partially submerged in a liquid of density ρ (see figure).



(a) Show that the vertical distance from the surface of the liquid to the bottom of the floating object at equilibrium is $y = \frac{M}{\rho A}$ **[2 marks]**

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(b) If a downward force F acts on the floating object, the object will be displaced by $\Delta y = \frac{F}{\rho g A}$ (assume that the object does not become fully submerged). Argue that when the force is suddenly removed, the object will oscillate in simple harmonic motion with period $T = 2\pi\sqrt{\frac{M}{\rho g A}}$. **[3 marks]**

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(c) If the object has density ρ_S, find an expression for the period of the motion in terms of ρ_S and h. **[1 mark]**

(d) A group of physics students decides to determine the density of ice. They prepare a number of samples of ice, each of rectangular cross-section and of varying length. Each of the samples in turn is placed in a large beaker of pure water, and set into SHM. The time for 5 oscillations of each ice sample is recorded. The experiment is done inside a refrigerator at 4°C. The density of pure water at this temperature is 1000 kgm^{-3}.

The students' data are given below

Height of ice sample (cm) ± 0.1 cm	2.0	4.0	6.0	10.0	15.0
Time for 5 oscillations (s) ± 0.025 s	1.25	1.90	2.35	3.05	3.75

(i) Plot an appropriate linear graph of the students' experimental data with the height of the ice sample as the independent variable on the graph paper on the next page. **[4 marks]**

Candidate Code No

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(ii) From the slope of your linear graph estimate the density of ice. Use the uncertainty in the slope to give an appropriate uncertainty in the density. **[3 marks]**

(iii) A criticism of this experiment is that it ignores the viscous drag between the ice and the water. Describe the effect of this force on the period of the oscillations, and state whether this effect increases or decreases the experimental value of the density relative to the actual value. **[2 marks]**

Candidate Code No

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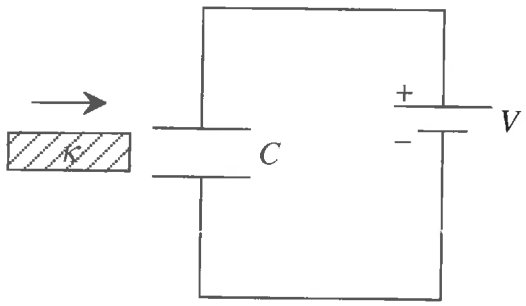
QUESTION B6:

(a) A certain parallel plate capacitor has air between its plates. The capacitor is connected to a battery, and after some time a steady state is reached. A dielectric slab with dielectric constant κ is now slipped between the plates, as in the diagram below.



Describe qualitatively what happens to the:

(i) capacitance **[1 mark]**

(ii) electric field **[1 mark]**

(iii) stored energy **[1 mark]**

(iv) If in (iii) you said that the stored energy changes, explain where the extra energy comes from or goes to. If in (iii) you said that the stored energy does not change, explain why this is so. **[1 mark]**

(b) A medical defibrillator is required to deliver a large amount of energy (200 J) to a patient's heart in a relatively short time (2 ms).

(i) Write down the average power required to operate the defibrillator. **[1 mark]**

(ii) Suggest a reason why a charged capacitor is used in the defibrillator instead of the mains power supply. **[1 mark]**

(iii) The discharge circuit of the defibrillator can be considered as a capacitor in series with a resistance (the portion of the patient's body between the 'paddles' of the defibrillator plus the contact resistances between the patient's body and the paddles). The time constant of the circuit is to be 2.0 ms, after which time the circuit is automatically opened. If the resistance in the circuit is 90 Ω, determine the necessary capacitance of the circuit. **[2 marks]**

(iv) If the contact resistance between the patient's body and each of the paddles of the defibrillator is 30 Ω, what proportion of the energy stored in the capacitor is discharged in the patient's body? **[1 mark]**

Candidate Code No

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(v) Show that a fully charged capacitor discharges approximately 86% of the stored energy in a time equal to the time constant of the discharging circuit. **[3 marks]**

(vi) From your answers to (d) and (e) determine the total energy that is needed to be stored in the capacitor if 200 J is to be discharged in the patient's body in 2 ms. **[1 mark]**

(vii) Determine the potential to which the capacitor must be charged. **[2 marks]**

-End of Examination-

Please complete the backflap of this answer booklet

Candidate Code No

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Extra answer page

Please clearly indicate which question(s) you are answering and ensure you have written '*continued*' in the space provided for your answer.