THE UNIVERSITY OF BRITISH COLUMBIA

Physics 108

Sessional Examination

15 April 2003

TIME: $2\frac{1}{2}$ HOURS

FULL NAME: _____ STUDENT # : _____

SIGNATURE: _____

This Examination paper consists of 14 pages (including this one). Make sure you have all 14.

INSTRUCTIONS:

Write your name on every sheet.

One 1-page Summary Sheet is allowed.

Try every question — *easy* ones first! A *diagram* is usually a good start.

Read carefully!

MARKING:

Q1	/40	**Q4**	/12
Q2	/12	**Q5**	/12
Q3	/12	**Q6**	/12
TOTAL			/100

NAMES OF INSTRUCTORS: Jess H. Brewer

Q1 "QUICKIES" [40 marks — 5 each]

(*a*) Some butterflies have bright blue wings without any blue pigments. Explain briefly how this is possible.

(*b*) To which of the laws represented by Maxwell's Equations did Maxwell himself actually make a direct contribution, and what was his contribution?

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(*c*) If ϵ_0 and μ_0 are respectively the permittivity and the permeability of free space, what is the value (including *units*) of the quantity $(\mu_0\,\epsilon_0)^{-1/2}$ and *what does it represent*?

(*d*) In an LCR circuit driven by an AC voltage, the real current through the resistor is zero at any instant when [encircle *all* correct answers]

i) the charge on the capacitor is zero.

ii) the charge on the capacitor is largest.

iii) the voltage across the inductor is zero.

iv) the voltage across the inductor is largest.

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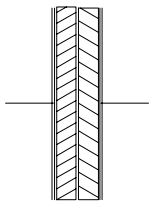
(e) In a hydrogen atom, the electrostatic force between the proton and electron is 2.3×10^{39} times greater than the gravitational force. If we can adjust the distance between the two particles, at what separation will the electrostatic and gravitational forces between them be equal in magnitude? *Explain.*

(f) A capacitor is made from two metal plates of area A separated by a distance d. The gap is filled with two dielectric slabs of equal thickness but with different dielectric constants κ_1 and κ_2. Calculate the *capacitance* in terms of the parameters given.



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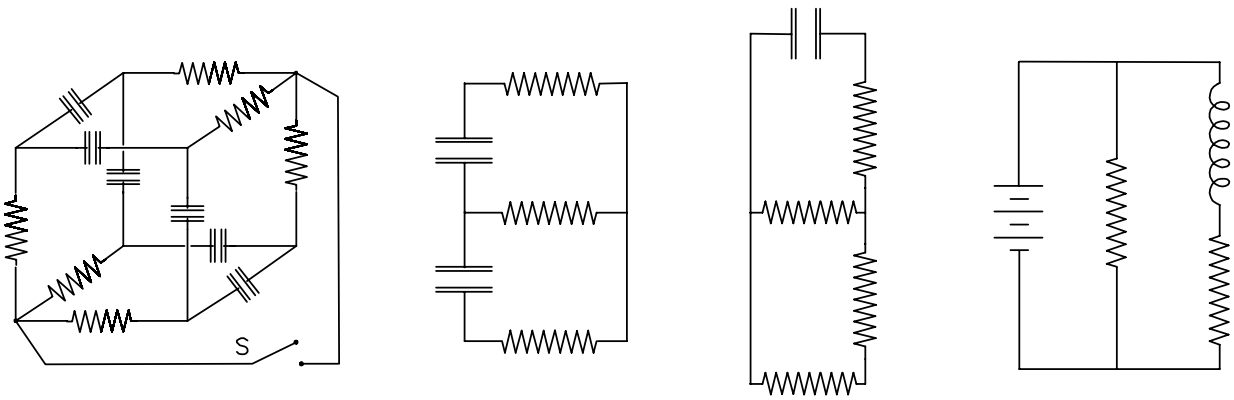
(g) Suppose you have a superconducting coil, a capacitor and a 1000 Ω resistor. First you charge up the capacitor and put it in series with the coil; this circuit oscillates at a frequency of $f = (1/2\pi)$ kHz. Next you charge up the same capacitor and discharge it through the resistor. (No coil in the circuit this time.) It takes 0.1 s for the charge on the capacitor to drop to $1/e$ of its original value. *What was the inductance of the coil?*

(h) Encircle any of the following circuits which are "*simple*" (can be reduced to an equivalent series R and/or C and/or L and/or $\mathcal{E}$ circuit). The wires in the leftmost circuit are along the edges of a 3-dimensional cube. Assume that all similar circuit elements are identical.



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Q2 TWO-STATE SYSTEM [12 marks]

A simple organism has only two possible microstates: "asleep" with zero energy or "awake" with energy $\varepsilon = 0.01$ eV. It is in thermal equilibrium with its environment.

(a) [3 marks] At what *temperature* is the organism $1/e$ times as likely to be awake as to be asleep? ($e = 2.718\cdots$)

(b) [3 marks] At what temperature does it have an *equal* probability of being asleep or awake?

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TWO-STATE SYSTEM *(continued from previous page)*

In the space below, *sketch*

(*c*) [3 marks] The probability of being awake as a function of $\tau \equiv k_{\mathrm{B}}T$ for a fixed "waking" microstate energy ε.

(*d*) [3 marks] The probability of being awake as a function of the "waking" microstate energy ε for a given τ.

(Include axis labels and vertical scales on your sketches.)

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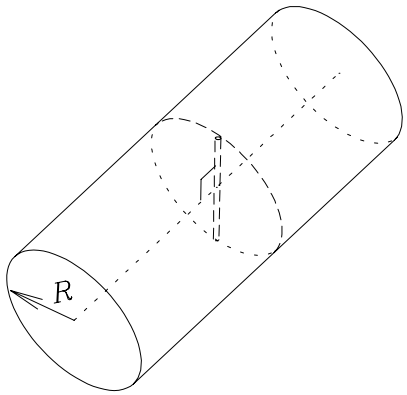
Q3 CYLINDER OF CHARGE [12 marks]



A long solid insulating cylinder of radius R is uniformly charged with a positive charge density ρ [charge per unit volume]. A small hole is drilled straight through the cylinder at right angles to its axis, as shown. Assume that the hole is very far from the ends of the cylinder.

(a) [6 marks] Show that the electric field in the hole is proportional to the distance from the cylinder axis.

(b) [6 marks] Show that a negatively charged particle dropped straight into the hole will execute simple harmonic motion as long as it doesn't hit the sides of the hole.

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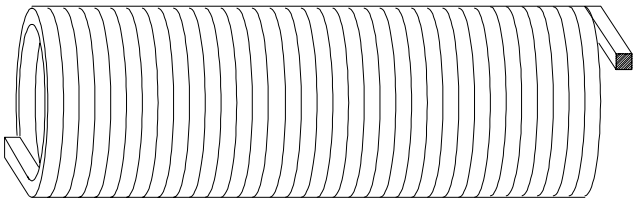
Q4 SOLENOID DESIGN [12 marks]



You are given a certain *volume* V of copper from which to make *wire* with a square cross section. The wire you make is then used to wind a *one-layer solenoid* as shown. (Ignore the practical necessity for insulation between the wires and pretend that they can be wound so that the distance between turns is exactly the width of the wire.)

Your goal is to generate the highest possible magnetic field at the centre of the solenoid.

(*a*) [6 marks] For wire of a given cross section and for a given *current* I in the wire, should you make the *inside diameter* of the solenoid large or small? Explain.

(*b*) [6 marks] For a given inside diameter and for a given *voltage* $\mathcal{E}$ applied to the solenoid, should you make the wire *long and thin* or *short and thick*? Explain.

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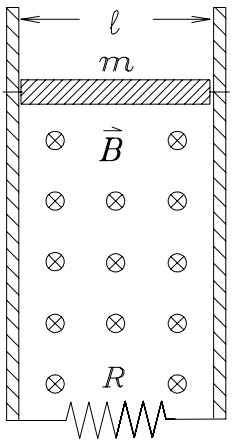
Q5 FALLING BAR [12 marks]



A horizontal bar of mass m is free to slide without friction down the vertical rails of a conducting frame, as shown. The combined resistance of the bar and the frame is negligible compared to R, the resistance placed in series with this circuit. What is the *terminal speed* of the bar as it falls under the influence of gravity (at the surface of the Earth) through a uniform horizontal magnetic field $\vec{\boldsymbol{B}}$ directed perpendicular to the plane of the frame? (Give your answer in terms of m, B, ℓ, R, g and other fundamental constants.)

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Q6 3-SLIT GRATING [12 marks]

Most gratings have a very large number of "slits" — but picture one that has only *three* 25 μm wide slits, uniformly spaced 100 μm apart (center to center). This grating is uniformly illuminated with greenish blue light of wavelength $\lambda = 500$ nm incident normal to the plane of the grating, producing an interference pattern on a screen 1 m away, oriented parallel to the plane of the grating.

(*a*) [4 marks] *Make a detailed sketch of the resulting interference pattern* (intensity as a function of position on the screen). You may plot the intensity in arbitrary units, but please include units and dimensions on the position axis. Show at least the range from the central maximum out to the first diffraction minimum on each side.

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3-SLIT GRATING *(continued from previous page)*

(*b*) [4 marks] Ignoring diffraction due to the finite width of the individual slits, *sketch the phasor diagram* for the position in the interference patterm where the *intensity* first drops to one ninth (**1/9**) of its value at the central maximum.

(*c*) [4 marks] Suppose that light of a slightly different colour (wavelength $\lambda + \Delta\lambda$) shines on the grating in the same way at the same time. What is the *smallest* wavelength difference $\Delta\lambda$ that can just barely be resolved at the first principal maximum?

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(spare page for scratch work)

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Constants and Conversion Factors. (You may not need all of these!)

Exchange Rate (05 Mar 2003)	\$1.00 CAD	=	0.619965 EUR (Euro)
Universal Gravitational Constant	G	=	6.672×10^{-11} m^3 kg^{-1} s^{-2}
Mass of the Earth	M_E	=	5.974×10^{24} kg
Mean radius of the Earth	R_E	=	6367 km
Planck's constant	h	=	6.6262×10^{-34} J-s $= 4.1357 \times 10^{-15}$ eV-s
Permittivity of free space	ϵ_0	=	0.8854×10^{-11} C^2/N-m^2 [or F/m]
constant in Coulomb's Law	$k_E = \dfrac{1}{4\pi\epsilon_0}$	=	8.988×10^9 N-m^2/C^2
Permeability of free space	μ_0	=	1.2566×10^{-6} N/A^2 [or H/m]
constant in Biot-Savart Law	$k_M = \dfrac{\mu_0}{4\pi}$	=	10^{-7} T-m/A
Electric charge of a proton	e	=	1.602×10^{-19} C
Speed of light in vacuum	c	=	2.99792458×10^8 m/s
Avogadro's number	N_0	=	6.022×10^{23} molecules per mole
Proton rest mass	M_p	=	1.673×10^{-27} kg
Neutron rest mass	M_n	=	1.675×10^{-27} kg
Electron rest mass	m_e	=	9.11×10^{-31} kg
Boltzmann constant	$k_{\rm B}$	=	1.3807×10^{-23} J/K
electron volt	1 eV	=	1.602×10^{-19} J $=$ $k_{\rm B} \times 11,600$ K
Atmospheric pressure:	1 atm	=	760 torr $=$ 1.013×10^5 pascal [N/m^2]

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