THE UNIVERSITY OF SYDNEY

FACULTIES OF ARTS, EDUCATION & SOCIAL WORK, ENGINEERING AND SCIENCE

PHYS1902 – PHYSICS 1B (ADVANCED)

NOVEMBER 2007

Time allowed: THREE Hours

MARKS FOR QUESTIONS ARE AS INDICATED
TOTAL: 90 marks

INSTRUCTIONS

- **All questions are to be answered.**
- **Use a separate answer book for each section.**
- **All answers should include explanations in terms of physical principles.**

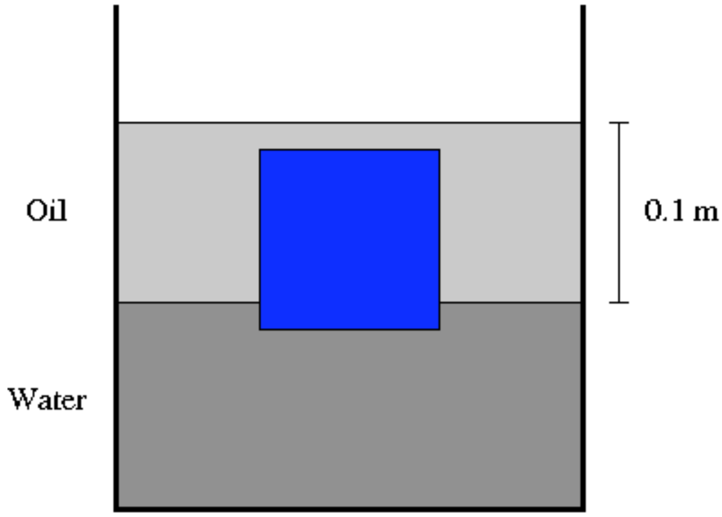
DATA

Density of water	ρ	=	1.00×10^{3} kg.m^{-3}
Density of air	ρ	=	1.20 kg.m^{-3}
Atmospheric pressure	1 atm	=	1.01×10^{5} Pa
Magnitude of local gravitational field	g	=	9.81 m.s^{-2}
Avogadro constant	N_A	=	6.022×10^{23} mol^{-1}
Permittivity of free space	ε_0	=	8.854×10^{-12} F.m^{-1}
Permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ T.m.A^{-1}
Elementary charge	e	=	1.602×10^{-19} C
Speed of light in vacuum	c	=	2.998×10^{8} m.s^{-1}
Planck constant	h	=	6.626×10^{-34} J.s
Rest mass of an electron	m_e	=	9.110×10^{-31} kg
Rest mass of a neutron	m_n	=	1.675×10^{-27} kg
Rest mass of a proton	m_p	=	1.673×10^{-27} kg
Rest mass of a hydrogen atom	m_H	=	1.674×10^{-27} kg
Boltzmann constant	k	=	1.381×10^{-23} J.K^{-1}
Atomic mass unit	u	=	1.661×10^{-27} kg
Rydberg constant	R	=	1.097×10^{7} m^{-1}

SECTION A

Question 1

A cubic block of wood, 0.10 m on a side, floats in equilibrium at the interface between oil and water, with its lower surface below the interface, as shown in the diagram. The oil is 0.10 m deep. The density of the oil is 800 kg.m^{-3}.



a) Draw a free-body diagram for the block.

b) Which direction does the buoyancy force on the block point? Why?

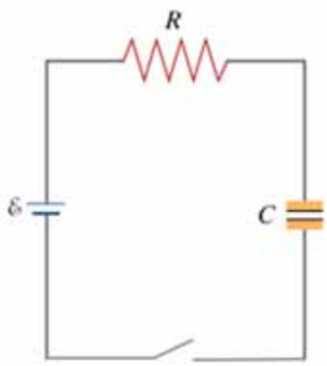
c) For the block shown in the diagram what can you say about the density of the block?

d) What would happen if the acceleration due to gravity were increased? Would the block float higher or lower, or remain at the same position?

(5 marks)

Question 2

A capacitor C and a resistor R are connected in series in a simple RC circuit to a source of emf ε. The capacitor is initially uncharged when the switch is closed.



a) Draw a sketch to show the current in this circuit as a function of time, starting from $t = 0$ (when the switch is first closed).

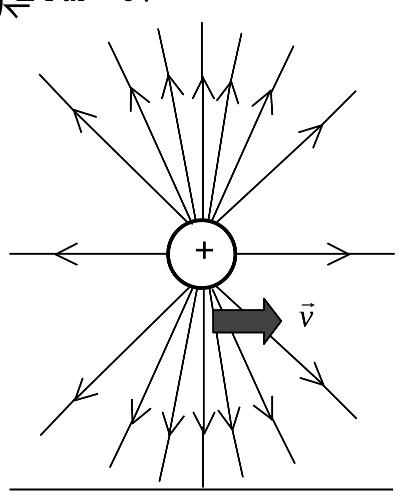
b) How long will it take for the capacitor to reach a charge equal to half of its maximum charge? Express your answer in terms of R, C, and ε.

c) To reduce the time it takes to charge *this* capacitor to half of its maximum value, what should be changed in the circuit?

(5 marks)

Question 3

a) The electric field from a single charge that is moving at high speed is not radially symmetric, as shown in the figure below. Show that this field is not conservative, i.e. it does not satisfy $\oint \mathbf{E} \cdot d\mathbf{l} = 0$.



b) Consider the equation $\oint \mathbf{B} \cdot d\mathbf{A} = 0$, which is one of Maxwell's equations.

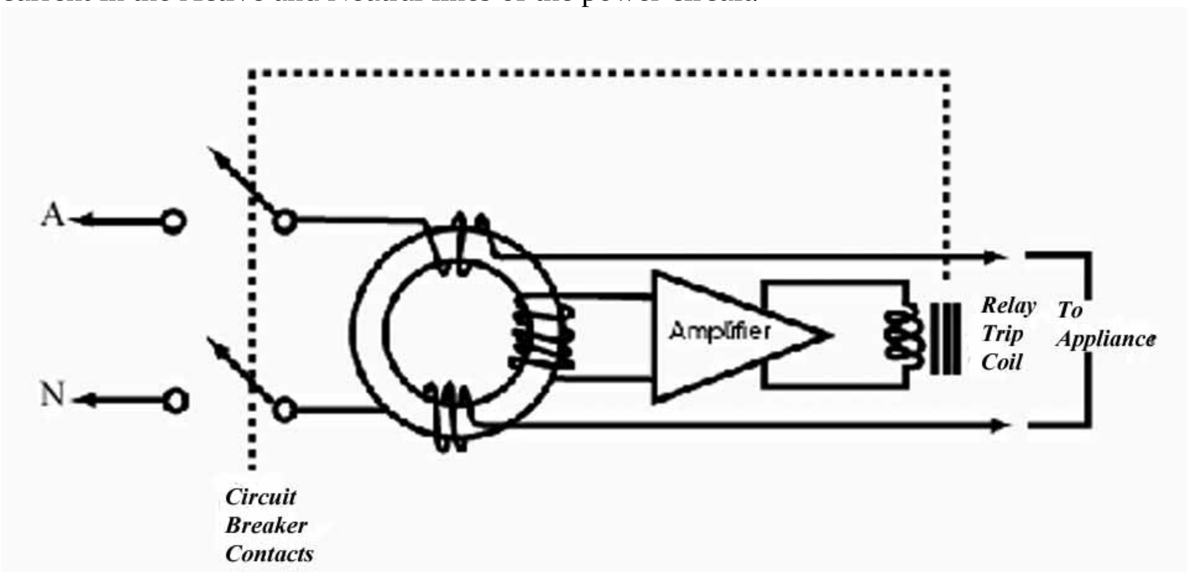
i. Briefly explain what this equation tells us about the flux of a magnetic field.

ii. Briefly explain why the discovery of magnetic monopoles would violate this equation.

(5 marks)

Question 4

An earth-leakage circuit breaker (see the circuit diagram below) is now installed in many houses as extra protection against electrocution. It operates by detecting an imbalance in the current in the Active and Neutral lines of the power circuit.



Explain in detail the operation of the earth-leakage circuit breaker. Your answer should concentrate on the physics of how the device works and not just a description of the circuit diagram.

(5 marks)

Question 5

When X-rays are incident on matter some X-rays are scattered. In 1923 Arthur Compton and others discovered that some of the scattered X-rays undergo a change in wavelength. This is known as the Compton Effect.

a) Carefully draw a diagram showing the essential features of the apparatus for a Compton scattering experiment. Clearly label your diagram, including an indication of the scattering angle.

b) What does the Compton experiment tell us about the properties of electromagnetic radiation?

c) The spectrum of the scattered radiation usually includes radiation centred around two wavelengths. What is the origin of two distinct peaks in the spectrum?

(5 marks)

Question 6

Energetic electrons accelerated through a potential difference of 50 kV are incident on a metal target and produce X-rays.

a) The spectrum of X-rays produced shows both line and continuum emission. Briefly explain the origin of each.

b) What is the shortest wavelength X-ray produced?

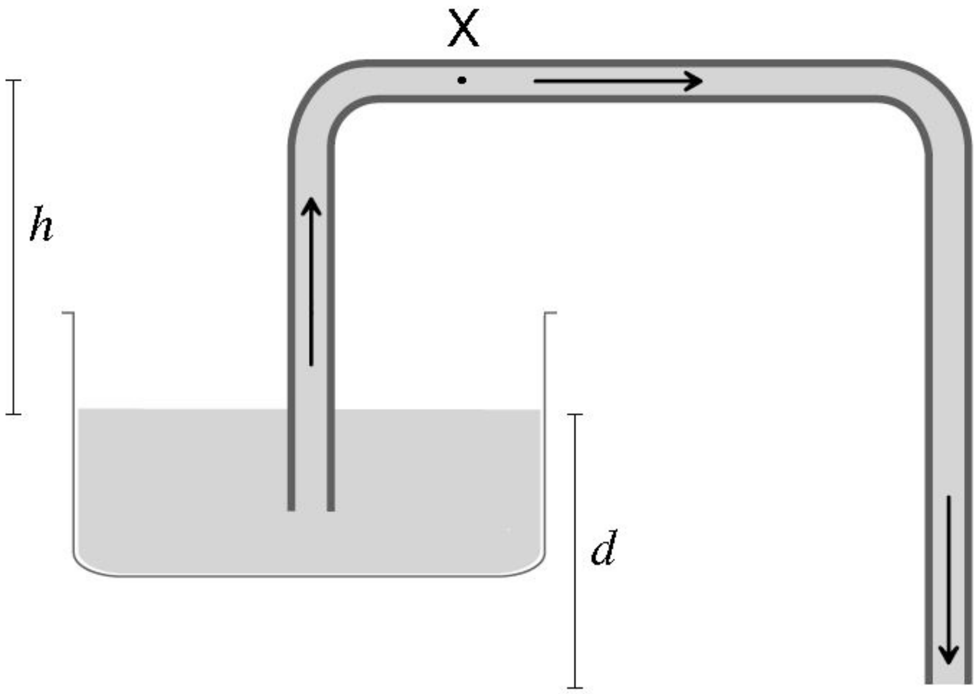
c) When different metals are used as the target, the peak frequency of a line in the spectrum is found to vary in proportion to $(Z-1)^2$, where Z is the atomic number of the metal. Briefly explain this result.

(5 marks)

SECTION B
(Please use a separate booklet for this section)

Question 7

A siphon is simply a tube used to remove fluids from containers. To establish the flow, the tube must be initially filled with fluid. For the siphon shown in the diagram below assume that the tube has constant cross-sectional area and that the fluid has a density of ρ.



a) If the lower (exit) end of the siphon is at a distance *d* below the free surface of the liquid in the container, what is the velocity of the fluid as it flows out of the lower end of the siphon? Assume the container has a large area compared to the tube cross-section, and ignore viscosity.

b) What is the pressure at point X at the top of the tube?

c) What is the greatest height *h* that point X can have for the siphon flow to still occur?

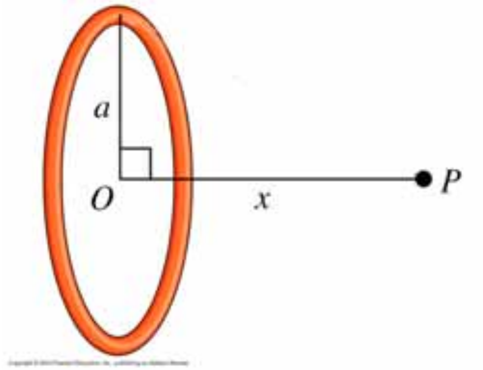
d) If the liquid in the siphon is mercury (density 13.6×10^3 kg.m^{-3}), what is the greatest height *h* for the siphon?

e) Compare the height that a mercury siphon could reach on Venus (atmospheric pressure 9.3 MPa, surface gravity 8.9 m.s^{-2}) and Mars (atmospheric pressure 0.8 kPa, surface gravity 3.7 m.s^{-2}). Ignore temperature effects.

(10 marks)

Question 8

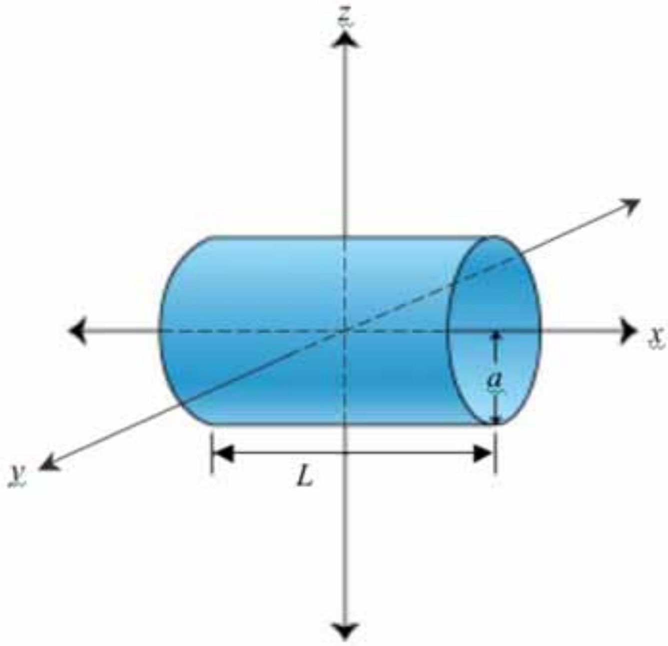
a) An electric charge q is distributed uniformly around a thin ring of radius a as shown in the diagram below.



Show that the electric potential at a point P on the axis of the ring, at a distance x from the centre of the ring, is given by

$$V = \frac{1}{4\pi\,\varepsilon_o}\frac{q}{\sqrt{x^2 + a^2}}$$

b) Now consider a hollow cylinder of length L and radius a, with a charge Q uniformly distributed across its surface. Assume the orientation as shown in the diagram.



Using the result from part (a), or otherwise, show that the electric potential at the centre of the uniformly charged cylinder is

$$V = \frac{Q}{2\pi\,\varepsilon_o\,L}\ln\left(\frac{L}{2a} + \sqrt{1 + \frac{L^2}{4a^2}}\right)$$

(Hint: You may need to use the following integral $\int \frac{da}{\sqrt{a^2 + b^2}} = \ln\left(\frac{a}{b} + \sqrt{1 + \frac{a^2}{b^2}}\right)$)

(10 marks)

Question 9

Consider a very long *solid* metal cylinder with radius R. A current I flows along the cylinder and the current density is uniform across the cylinder.

a) Using Ampere's law, derive an expression for the magnitude of the magnetic field at a point inside the cylinder at a radius $r < R$.

Assume now that the current density J is not constant, but rather varies according to the relationship $J = \alpha r$, where α is a constant.

b) If the total current flowing along the cylinder is I, show that α in terms of I and R is given by:

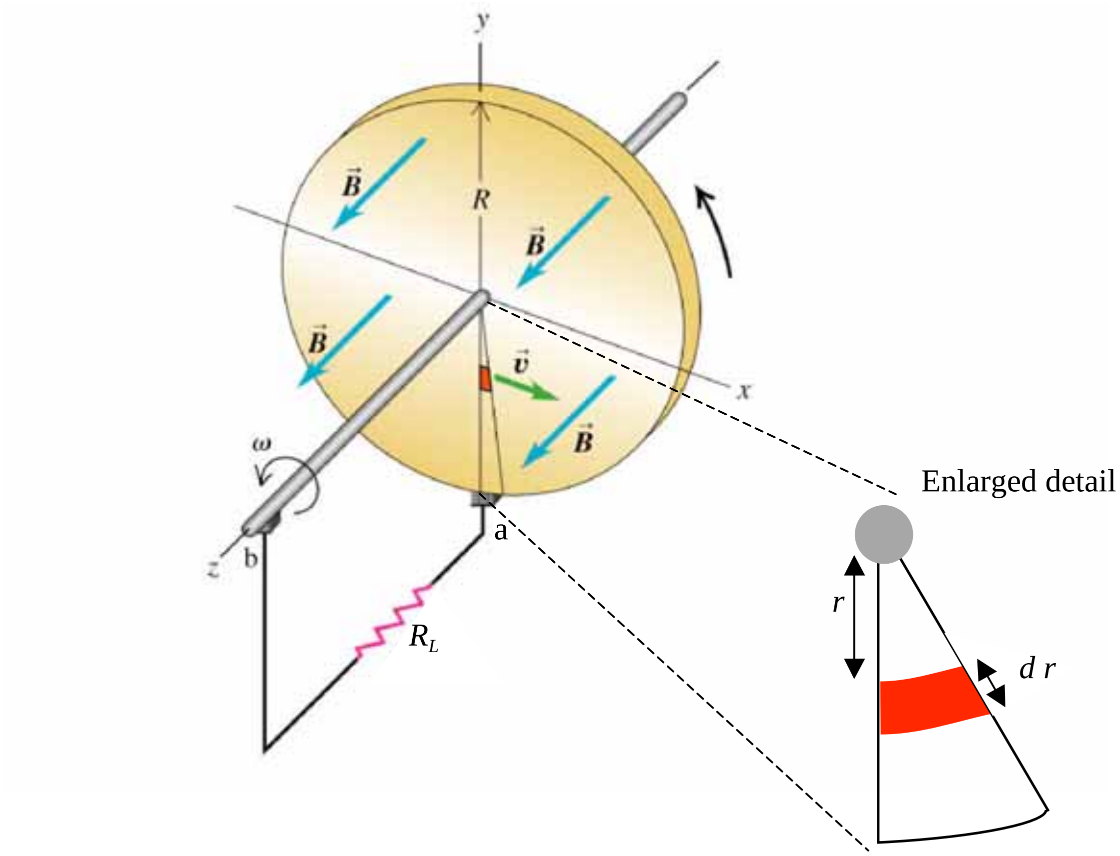
$$\alpha = \frac{3I}{2\pi R^3}$$

c) Using Ampere's law and this new current density, derive an expression for the magnitude of the magnetic field at a point inside the cylinder, at a radius $r < R$. Express your answer in terms of r, R, I, and μ_0.

(10 marks)

Question 10

A conducting disk with radius R, as shown below, lies in the xy-plane and rotates with a constant angular velocity ω about the z-axis. The disk is in a uniform, constant magnetic field $\boldsymbol{B}$ directed parallel to the z-axis. Sliding contacts at points a and b in the diagram below allow current through the resistor R_L.



a) Consider a small segment of radial extent dr located at radius r from the axis of rotation at the centre of the disk. Calculate the contribution $d\varepsilon$ of this segment to the total induced emf.

b) Integrate over the radius to find the total induced emf ε_T between the axis and the outer edge.

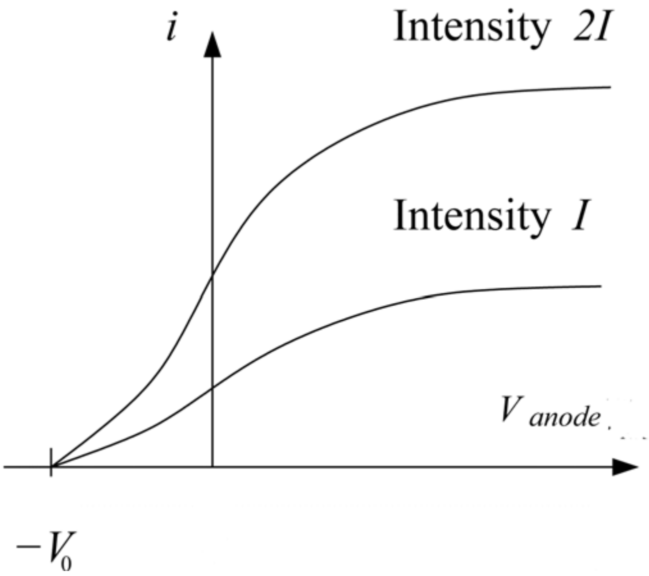
c) Use Lenz's law to identify the direction of current through the resistor R_L, i.e. does the current flow from point a to b, or b to a?

d) Write an expression for the power required to maintain the constant angular velocity of the disk.

(10 marks)

Question 11

A cathode and anode are enclosed in a vacuum and light of frequency f is incident on the cathode. The anode is held at a potential V_{anode} with respect to the cathode by means of an external circuit. A current i flows in the external circuit. The figure above shows how i varies as V_{anode} is varied, when the intensity of light is I, and when the intensity is $2I$.



a) Briefly explain why a current flows, given that there is a gap in the circuit between the cathode and anode.

b) Briefly explain why the current is zero when $V_{anode} = -V_0$, and derive an expression for V_0 in terms of ϕ, the work function of the cathode, and f.

c) Briefly explain why the current becomes constant for large V_{anode}

d) Briefly explain why the current at large V_{anode} is doubled when the intensity is doubled.

e) If the frequency of incident light is changed to $2f$, determine the value of V_{anode} for which the current is zero, in terms of V_0 and ϕ.

f) Briefly explain one way in which the above diagram is incompatible with classical physics.

(10 marks)

Question 12

The Bohr model for the Hydrogen atom assumes that the orbital angular momentum of the electron is quantised, i.e.

$$m v_n \, r_n = \frac{n h}{2\pi},$$

where m is the electron mass, v_n is the orbital speed of the electron, r_n is the orbital radius of the electron, $n = 1, 2, 3, \ldots$ is the principal quantum number, and h is Planck's constant.

a) Briefly explain why Bohr made the assumption that angular momentum is quantised.

b) Show that the radii of the Bohr orbits obey

$$a_n = n^2 a_0$$

where

$$a_0 = \frac{\varepsilon_0 \, h^2}{\pi \, m \, e^2}$$

is the Bohr radius.

c) Show that the total energy of the Bohr atom obeys

$$E_n = -\frac{m e^4}{8 \varepsilon_0^2 \, h^2} \frac{1}{n^2}.$$

d) Briefly explain why the result in (c) was considered a success of the model.

e) Is Bohr's value for the orbital angular momentum of the ground state ($n = 1$) of the Hydrogen atom correct? Briefly explain.

(10 marks)

This is the end of your questions