THE UNIVERSITY OF SYDNEY

FACULTIES OF ARTS, EDUCATION, ENGINEERING AND SCIENCE

PHYS1902 – PHYSICS 1B (ADVANCED)

NOVEMBER 2003

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

Question 1

(a) Mercury is a very poisonous substance. Give two reasons why it is used in barometers (instruments to measure pressure) rather than water, which is much safer.

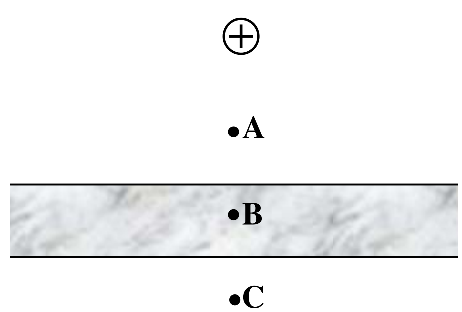
(b) A cylinder floating vertically in a tank of liquid can be used to determine the density of that liquid. This is called a hydrometer. For comparison, the cylinder can be floated in water.

Find an expression for the density ρ of the unknown liquid, in terms of depth h to which the cylinder sinks in the liquid, the depth h_w it sinks in water and the density of water ρ_w.

(c) Explain what else you would need to measure to find the density of the unknown liquid if the cylinder sank to the bottom of the tank.

(5 marks)

Question 2



The diagram shows a cross-sectional view of a positive point charge near a large neutral sheet of conducting material.

(a) Copy the diagram and *carefully* draw representative field lines showing the electric field, clearly indicating any regions where the field is zero.

(b) At which, if any, of the points A, B and C is the electric potential zero? Why? You should follow the usual definition that points at infinity are at zero potential.

(5 marks)

Question 3

(a) In static situations the electric field satisfies

$$\oint \boldsymbol{E} \cdot d\boldsymbol{l} = 0.$$

Assuming this equation holds, give a short argument to show that electric field lines cannot form closed loops.
(Hint: Use proof by contradiction).

(b) Briefly give an argument for the existence of 'Displacement Current'(the extra term added by Maxwell to Ampere's Law). Your answer should be descriptive only (do NOT derive the formula).

(5 marks)

Question 4

The electric and magnetic fields that you observe depend on your frame of reference. With this in mind, consider the experiment in which current is induced in a solenoid when it moves relative to a permanent magnet.

(a) Briefly describe what is happening, as viewed in the frame of reference of the solenoid.

(b) Also give a description as viewed in the frame of reference of the magnet.

(5 marks)

Question 5

In an experiment, light of wavelength 700 nm shines on a clean metallic surface causing electrons to be ejected from the surface. The maximum kinetic energy of the electrons is 0.78 eV.

(a) What is the work function of the metal? Give your answer in electron volts.

(b) What would be the minimum kinetic energy of the electrons? Briefly (i.e. in no more than about five lines) justify your answer.

(c) What is the cutoff frequency for the metal?

(5 marks)

Question 6

A collimated beam of electrons, accelerated through a potential difference of 600 V, passes through a thin aluminium foil onto a photographic plate.

(a) Draw a neat sketch showing the pattern observed on the photographic plate after several thousand electrons have passed through the foil.

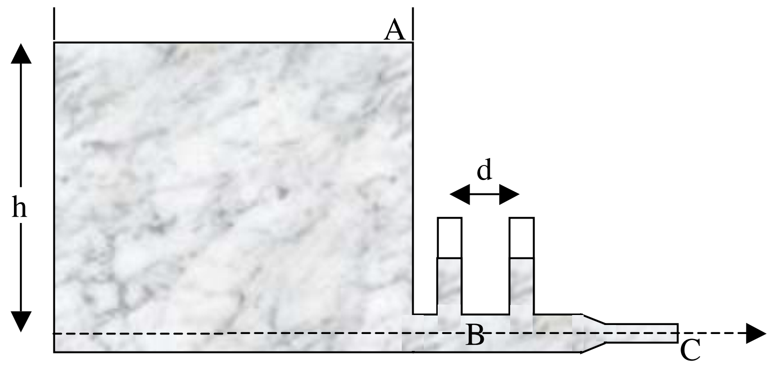
(b) Briefly explain why the observed pattern is observed.

(c) What would happen to the pattern if the total exposure were the same but the intensity of the beam were reduced to the stage where on average there was only one electron at a time passing through the foil? Why? What does this reveal about the nature of electrons?

(d) What would happen to the pattern if the accelerating voltage were increased to 1200 V? Briefly explain your answer.

(5 marks)

Question 7



A very large tank is open to the atmosphere. It has a horizontal tube (with circular cross section) leading out of the tank such that the axis of the exit pipe is $h = 0.80$ m below the surface of the liquid in the tank. The first part of the horizontal pipe tube has two vertical tubes set into it, open to the atmosphere and separated by $d = 0.20$ m. The cross-sectional area of the section of the horizontal pipe next to the tank is 1.0×10^{-4} m^2. As shown in the figure, the pipe narrows to a cross sectional area of 3.0×10^{-5} m^2 where the liquid exits the pipe. You can assume that the level of water in the tank (position A) does not change.

(a) Assuming the liquid in the tank is ideal (having zero viscosity) and a density $\rho = 1000$ kg.m^{-3}, answer the following questions:

(i) What is the volume flow rate as the liquid exits the smaller pipe? (position C)

(ii) What is the speed of the liquid in the larger portion of the horizontal pipe at position B?

(iii) What is the height of the liquid in the two open vertical tubes?

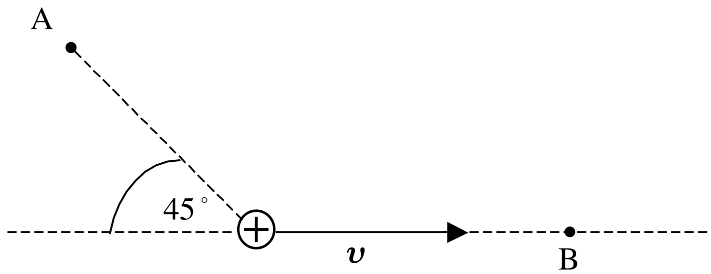
(b) The liquid is replaced by a viscous liquid with density $\rho = 800$ kg.m^{-3} and viscosity coefficient $\eta = 0.0060$ Pa.s. If the liquid now leaving the tube has the same volume flow rate as in part (a):

(i) What is the difference in the levels of the liquid in the two vertical tubes?

(ii) In a few sentences explain why you expect the two levels to be different.

(10 marks)

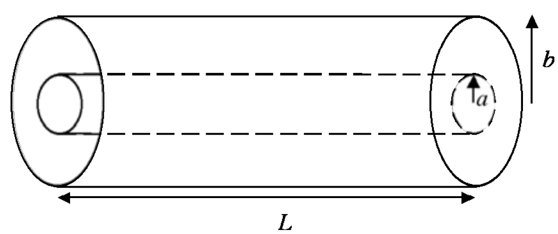
Question 8



The diagram shows a positive charge q moving to the right with velocity $\boldsymbol{v}$ (much less than the speed of light). At the instant shown in the diagram, the charge is a distance r from the two points A and B. At each of the points A and B, what is the magnitude and direction of the magnetic field?

(10 marks)

Question 9



Consider two long concentric *hollow* conducting cylinders with radii a and b (where $a < b$). Assume that they are very thin and are long enough that end effects can be ignored. Positive charge is spread uniformly along the inner cylinder and an equal amount of negative charge is spread uniformly along the outer cylinder, so that they have linear charge densities of $+\lambda$ and $-\lambda$ respectively.

(a) Sketch the electric field and calculate its magnitude as a function of the distance r from the central axis. Be sure to consider the three regimes: $r < a$, $a < r < b$ and $r > b$.

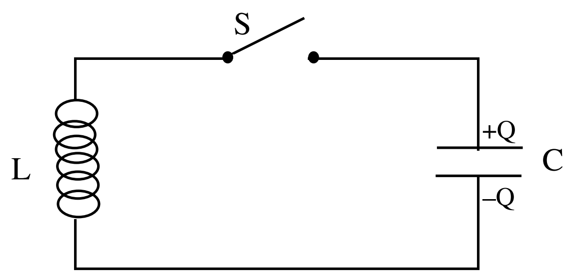
(b) Show that the potential difference between the two cylinders is $\dfrac{\lambda}{2\pi\varepsilon_0} \ln\left(\dfrac{b}{a}\right)$.

(c) Calculate the capacitance per unit length of the pair of cylinders.

(d) Calculate the total electrical potential energy stored in the system.

(10 marks)

Question 10



The circuit shown below contains a switch S; an inductor L and a capacitor C. The capacitor has an initial charge of Q. Assume all connecting wires have zero resistance.

(a) Describe the current in the circuit *immediately* after the switch is closed in terms of the values given. Briefly explain why the current has this value.

(b) Write an expression for the sum of potential differences across the components in the circuit.

(c) Using this expression, show that the variation in charge on the capacitor as a function of time is governed by the equation $\frac{d^2q}{dt^2} + \frac{1}{LC} q = 0$.

(d) If a solution to this equation can be expressed in the form $q = Q \cos \omega t$, express ω in terms of the values given.

(e) Draw a graph to indicate how the current changes with time. Label all important values of current and time *in terms of the values given*.

(f) Explain what happens to the energy initially stored in the capacitor.

(10 marks)

Question 11

(b) Draw a labelled diagram showing the essential features of the apparatus for a Compton scattering experiment. Indicate the scattering angle on your diagram. *(A diagram which is carelessly drawn or difficult to interpret will not be marked.)*

(b) List the key assumptions used in the derivation of the theoretical formula for the Compton shift.

The incident X-rays in a Compton experiment have a wavelength of 71.1 pm. The scattering angle is 65°.

(c) What is frequency of the scattered X-rays?

(d) What is the kinetic energy of the recoiling electron?

(e) What is the magnitude of the momentum of the electron? You may use non-relativistic mechanics.

(f) What is the corresponding de Broglie wavelength of the electron?

(10 marks)

Question 12

An electron is located in an infinitely deep one-dimensional square potential well. The width of the well is 1.00 nm.

(a) Sketch the wave function for the electron in the n = 2 state, clearly indicating the positions of the edges of the well.

(b) Where is the electron in the n = 2 state most likely to be found and why?

(c) Sketch an energy level diagram showing the energies of the n = 1, 2 and 3 states and indicate the energy of the bottom of the well.

(d) Calculate the energy for each of these three states.

(e) Light is shone on the electron causing it to jump from the ground state to the n = 3 state. What is the wavelength of the light?

(f) What would happen if light with wavelength twice that calculated in part f were shone on the electron in its ground state?

(g) Suppose that the width of the potential well were made much narrower. Describe qualitatively how this would affect the ground state energy of the electron. How is this related to the Heisenberg Uncertainty Principle?

(10 marks)