THE UNIVERSITY OF SYDNEY

FACULTIES OF ARTS, EDUCATION, ENGINEERING AND SCIENCE

PHYS1902 – PHYSICS 1B (ADVANCED)

NOVEMBER 2005

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.**

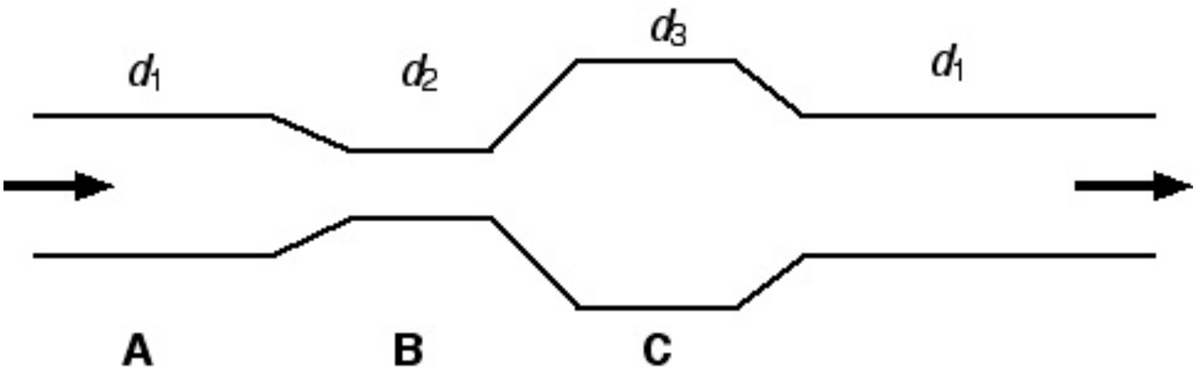
DATA

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 m^{-1}

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

Question 1

A non-viscous, incompressible fluid flows through a pipe of circular cross-section. The initial diameter of the pipe is d_1; the pipe then shrinks to a diameter $d_2 < d_1$, expands to a diameter $d_3 > d_1$, and then returns to its initial diameter d_1 before exiting to the atmosphere.



(a) A thief wants to drill a small hole so some fluid leaks out of the pipe before the exit. Will he be successful if he drills the hole at point A? Point B? Point C? Explain.

Hint: consider the pressure in the various parts of the pipe compared to air pressure.

(3 marks)

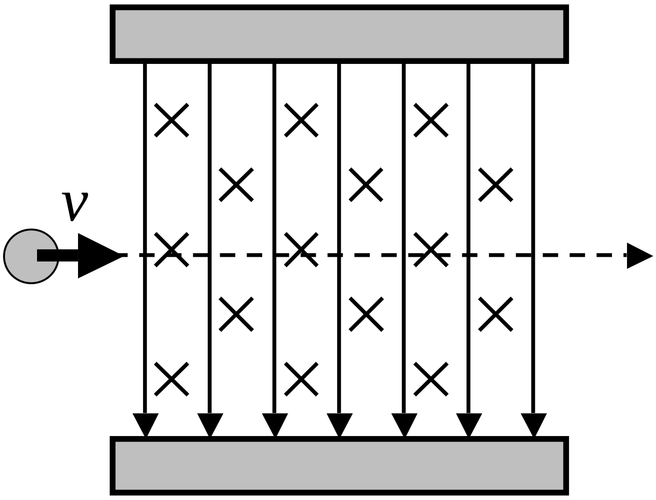
(b) Suppose the pipe contains alcohol, with a viscosity η = 2x10^{-3} Pa.s, and that the exit pipe has a diameter d_1 = 100 mm. If the speed of the flow as it exits is 0.1 m.s^{-1}, will the flow through the exit pipe be turbulent?

(2 marks)

(Total 5 marks)

Question 2

A charge *q* moves in a straight line with velocity *v* in a region with a uniform electric field *E* directed downwards, and a uniform magnetic field *B* directed into the page, as shown in the sketch below.



(a) Is the charge positive, negative, or is there insufficient information to determine its sign? Justify your answer.

(2 marks)

(b) Find an expression for the velocity *v* of the particle in terms of *q, E,* and *B*.

(3 marks)

(Total 5 marks)

Question 3

A capacitor C, and inductor L and a switch are connected in series. The capacitor initially has a charge Q. Assume all connecting wires have zero resistance.

(a) What happens to the charge when the switch is closed? Explain why this occurs.

(2 marks)

(b) Sketch the behaviour of current versus time.

(1 mark)

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

(2 marks)

(Total 5 marks)

Question 4

St Elmo's fire is a bluish flickering glow sometimes seen at tips of ships' masts when storm clouds are overhead, especially when the masts are wet. The masts appear to be 'on fire' but don't burn. Saint Erasmus (also known as Saint Elmo) became the patron saint of sailors who regarded the blue glow at their mastheads as a sign of Saint Erasmus' protection and thus a good omen. It isn't restricted to ships, having been seen at the top of tall church steeples etc.

Briefly describe the key points of physics you consider most likely to explain this electromagnetic effect.

(Total 5 marks)

Question 5

(a) An electron, a neutron and an alpha particle (He nucleus) all have the same kinetic energy. State the de Broglie hypothesis and rank the particles in order of increasing wavelength.

(2 marks)

(b) A beam of helium atoms travelling in space is slowed down by collisions with photons. What is the velocity they have to be reduced to in order for them to have a wavelength of 1cm?

(2 marks)

(c) Explain briefly how the exclusion principle forces one of the electrons in Lithium (atomic number 3) to enter a 2s state.

(1 mark)

(Total 5 marks)

Question 6

An electron is confined between two walls that act as very high potential barriers. The x axis is drawn perpendicular to the walls. One wall is located at x=0 and the other is at x=d.

(a) Write down and explain in a paragraph the Heisenberg position/momentum uncertainty principle as it applies to the motion of the particle in the x direction.

(2 marks)

(b) Apply this form of the Heisenberg uncertainty principle to the situation above and find the uncertainty in the momentum of the particle in the x direction in terms of the wall separation.

(1 mark)

(c) Calculate the uncertainty in the kinetic energy of the electron as a result of its momentum in the x direction if the walls are 0.1 nm apart. Express your answer in electron volts.

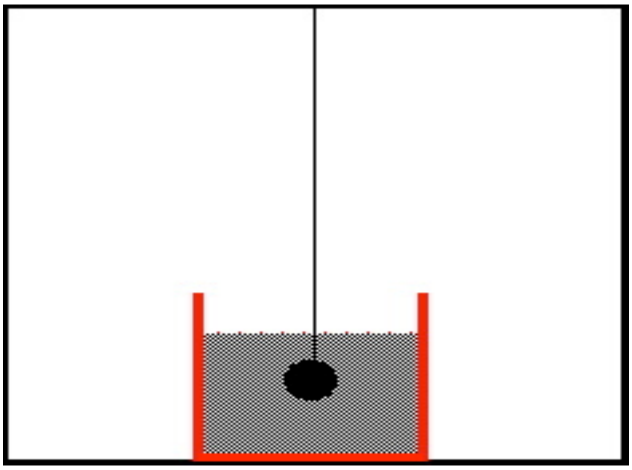
(2 marks)

(Total 5 marks)

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

Question 7

A rock with mass m = 3.00 kg is suspended from the roof of an elevator by a light cord. The rock is totally immersed in a bucket of water that sits on the floor of the elevator, but the rock doesn't touch the bottom or sides of the bucket.



(a) When the elevator is at rest, the tension in the cord is 21.0 N.
- (i) Draw a diagram showing all the forces on the rock.
- (ii) Calculate the buoyancy force exerted on the rock.

(4 marks)

(b) (i) Show that the tension in the cord T when the elevator and all its contents are accelerating *upward* with an acceleration of magnitude a is given by

$$T = (m - m_w)(g + a)$$

where m_w is the mass of water displaced by the rock.

(3 marks)

(ii) Calculate the tension when $a = 2.50\,m.s^{-2}$ upward.

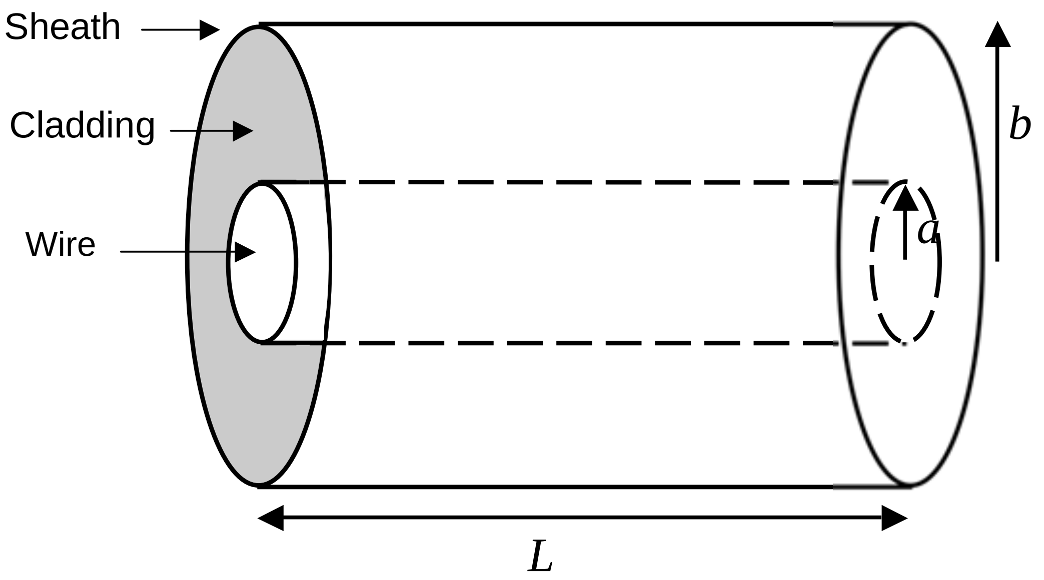
(1 mark)

(c) What is the tension when the elevator is in free fall with a downward acceleration equal to g? Explain your reasoning.

(2 marks)

(Total 10 marks)

Question 8



A length of coaxial cable consists of a central wire of radius *a* surrounded by an insulating plastic cladding and a woven flexible metal sheath (essentially a cylinder) of radius *b*. The plastic cladding has a *dielectric constant* $K = 4$ (See hint below). Assume that the cable is long enough so that end effects can be ignored.

Positive charge is spread uniformly along the central wire and an equal amount of negative charge is spread uniformly along the cylindrical sheath, so that they have linear charge densities of $+\lambda$ and $-\lambda$ respectively.

Hint: The presence of the dielectric means that ε_o is replaced in the equations by $K\varepsilon_o$.

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

(4 marks)

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

(2 marks)

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

(2 marks)

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

(2 marks)

(Total 10 marks)

Question 9

Consider a very long *solid* metal cylinder with radius R. A current i flows along the cylinder to the left with uniform current density.

(a) Using Ampere's Law, derive expressions for the magnitude of the magnetic field $B(r)$ in the range $r > R$. State all the steps in the argument.

(4 marks)

(b) Show that the magnitude of the magnetic field inside the cylinder ($r < R$) is

$$B(r) = \frac{\mu_0 i r}{2\pi R^2}$$

(2 marks)

A hollow cylindrical shell of radius $2R$ is now placed around this same cylinder, such that they share the same axis. A current i flows along this outer shell to the *right*, opposite in direction to the current in the inner cylinder.

(c) Calculate the magnetic field of this new configuration outside this shell ($r > 2R$).

(1 mark)

(d) Has the magnetic field in the region $R<r<2R$ changed from that given in part (a)? Justify your answer.

(1 mark)

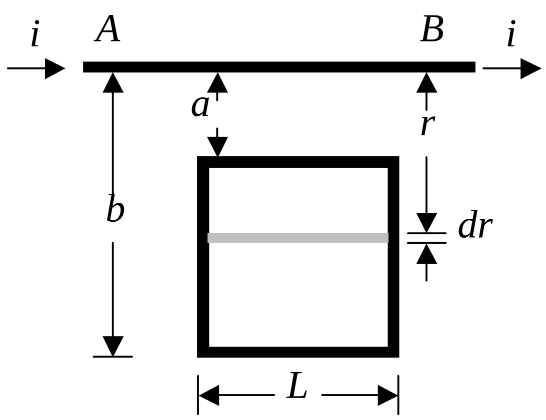
(e) In a drawing, sketch the magnetic field lines (including direction) in all regions ($r< R$, $R<r<2R$, and $r>2R$).

(2 marks)

(Total 10 marks)

Question 10

The current in the long, straight wire *AB* as shown in the sketch below is directed to the right, and is increasing steadily at a rate *di/dt*.



(a) At an instant when the current is i, use Ampere's Law to determine the magnetic field $\vec{B}$ (both magnitude and direction) at a distance r below the wire.
(2 marks)

(b) What is the flux $d\Phi_B$ through the narrow, shaded strip with width dr?
(2 marks)

(c) Show that the total flux through the loop is

$$\Phi_B = \frac{\mu_0 i L}{2\pi}\ln\left(\frac{b}{a}\right)$$

(2 marks)

(d) What is the magnitude of the induced emf in the loop in terms of di/dt, L, a, b, and μ_0?
(2 marks)

(e) What is the direction of this emf? Justify your answer using Lenz's Law.
(2 marks)

(Total 10 marks)

Question 11

Wien's displacement law reads $\lambda_m T = 0.0029$ m·K.

(a) Explain the symbols and briefly discuss the meaning and significance of this result.

(3 marks)

(b) Explain why the explanation of the blackbody radiation spectrum is inconsistent with classical physics and how quantum mechanics resolves this issue.

(3 marks)

(c) Calculate the relation between the wavelength and the temperature at which the photon energy hf equals the average translational thermal energy of a particle 3kT/2.

(2 marks)

(d) Compare your result with Wien's displacement law and comment.

(2 marks)

(Total 10 marks)

Question 12

An 'atom laser' is made by bunching atoms together so that they have closely similar momenta and positions. This is usually done by confining the atoms laterally and slowing them down to a common velocity in the remaining dimension. One way of slowing atoms down is to arrange for them to absorb photons.

(a) What is the momentum of a photon of wavelength λ?

(1 mark)

(b) Explain what is meant by the Balmer series of spectral lines of hydrogen and calculate the wavelength of the longest wavelength spectral line in this series using the Rydberg formula $\frac{1}{\lambda} = R_H\left(\frac{1}{{n_{lower}}^2} - \frac{1}{{n_{upper}}^2}\right)$

(3 marks)

(c) Calculate the change in velocity of a hydrogen atom moving at 2000 m/s if it absorbs a photon travelling in the opposite direction. (Proceed through conservation of momentum). Having the same wavelength as the longest wavelength in the Balmer series

(4 marks)

(d) Explain why the photon would need to have a slightly shorter wavelength than the answer to (c) if it is to be absorbed by the atom.

(2 marks)

(Total 10 marks)

This is the end of your questions