

THE UNIVERSITY OF SYDNEY
FACULTIES OF ARTS, EDUCATION, ENGINEERING
AND SCIENCE

PHYSICS 1902: PHYSICS I (ADVANCED)

November 1998

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

Magnitude of local gravitational field	$g = 9.81 \text{ N.kg}^{-1}$.
Avogadro constant	$N_A = 6.023 \times 10^{23} \text{ mol}^{-1}$.
Universal gas constant	$R = 8.314 \text{ J.mol}^{-1}.\text{K}^{-1}$.
Permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F.m}^{-1}$.
Permeability of free space	$\mu_0 = 4 \times 10^{-7} \text{ T.m.A}^{-1}$
Elementary charge	$e = 1.6022 \times 10^{-19} \text{ C}$.
Electronvolt	$\text{eV} = 1.602 \times 10^{-19} \text{ J}$.
Speed of light in vacuum	$c = 2.9979 \times 10^8 \text{ m.s}^{-1}$.
Planck constant	$h = 6.626 \text{ } 07 \times 10^{-34} \text{ J.s.} = 4.136 \times 10^{-15} \text{ eV.s}$
Rest mass of an electron	$m_e = 9.109 \text{ } 39 \times 10^{-31} \text{ kg} = 0.511 \text{ MeV.c}^{-2}$
Rest mass of a neutron	$m_n = 1.674 \text{ } 93 \times 10^{-27} \text{ kg}$
Rest mass of a proton	$m_p = 1.672 \text{ } 62 \times 10^{-27} \text{ kg}$
Rest mass of a hydrogen atom	$m_H = 1.673 \text{ } 53 \times 10^{-27} \text{ kg}$
Rydberg constant	$R = 0.01097 \text{ nm}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J.K}^{-1} = 8.61 \times 10^{-5} \text{ eV.K}^{-1}$
Atomic mass unit	$u = 1.66 \times 10^{-27} \text{ kg} = 931.502 \text{ MeV.c}^{-2}$

SECTION A THERMAL PHYSICS (Please use a separate book for this section.)

Question 1

A mercury thermometer is laid out in direct sunlight.

- (a) Does it measure the temperature of the sun, the air, the mercury or something else?
- (b) Justify your answer using principles of physics.
- (c) Meteorological measurements of temperature are taken in the shade. Why is this so?

(5 marks)

Question 2

You are going on a picnic on a warm summer's day and you pack your insulated picnic box (esky) with plenty of ice at 0°C and warm lemonade which you have just picked up from the shop. You are intrigued by the notion of entropy having just heard about it in lectures and discuss it with your friends. What are your answers to the following:

After you put the room temperature lemonade into the esky with the ice

- (i) does the entropy of the lemonade increase, decrease or stay the same?
- (ii) does the entropy of the ice increase, decrease or stay the same?
- (iii) does the entropy of the system (lemonade + ice) increase, decrease or stay the same?

Give a justification of all your answers.

(5 marks)

Question 3

A pot with a steel bottom 0.01 m thick rests on a hot stove. The area of the bottom is 0.1 m^2 . The water inside the pot is at 100°C , and 0.05 kg is evaporated every 3 minutes.

- (a) Describe briefly two of the thermal processes that are taking place.
- (b) Find the temperature of the lower surface of the pot, which is in contact with the stove. (Assume that no heat is lost to the room.)

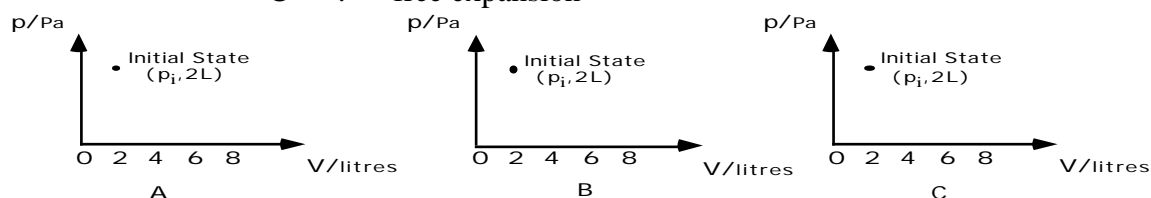
$k_{\text{steel}} = 14\text{ W m}^{-1}\text{ K}^{-1}, \quad L_V = 2256\text{ kJ kg}^{-1}$

(10 marks)

Question 4

Three cylinders A, B, C, each contain 5 moles of a monatomic gas ($\gamma = 5/3$) at temperature 300 K, and volume 2 litres. The gas in each cylinder is expanded to volume 6 litres, using a different process in each case:

- A : reversible isothermal
 B : reversible adiabatic
 C : free expansion



- (a) Copy these p - V diagrams into your answer book. Where possible, show on each diagram the final state of the system and the path taken by the system during the expansion process.
- (b) For each gas, calculate the final temperature, the heat added to the gas, and the change in entropy. Show your working, or state the reason for your answer, in every case. Present your answers in a table similar to the one below.

	A	B	C
Final temperature			
Heat added			
Entropy Change			

(10 marks)

SECTION B

ELECTROMAGNETISM

(Please use a separate book for this section.)

Question 5

Two different circuits are shown below. S is a switch, E is an emf device generating a potential difference V , R is a resistor, C is a capacitor which is initially uncharged, and L is an inductor. The switch S is closed at time $t = 0$ and each circuit then responds, eventually reaching a steady state.



- (i) Draw two graphs to indicate how the current changes with time. The time axis of your graph should start at $t = 0$ and extend over an interval of time many times greater than the time constant of the circuit.
- (ii) On each of your graphs, indicate clearly values of initial and final current. Where possible express these values in terms of V , R , C and L .

(5 marks)

Question 6

A magnet dropped through a hollow copper pipe is observed to fall very slowly. By considering what happens as the magnet moves past a fixed point P on the pipe, carefully explain this observation.

Your explanation should include a diagram and be given in terms of physical principles but without using equations. Your answer should be less than half a page long, not including the diagram.

For convenience, assume the magnet falls without spinning, with its north pole downwards.

(5 marks)

Question 7

A solenoid of length 20 cm and diameter 4 cm is constructed with 400 turns of wire. The resistance of the wire can be neglected. A current i is supplied to the solenoid in such a way that i increases from zero to 0.5 A at a uniform rate over 2 seconds. The current then stays constant at 0.5 A. Calculate:

- (a) the inductance of the solenoid,
- (b) the maximum magnetic field in the solenoid,

- (c) the potential difference across the solenoid during the time when the current is increasing,
- (d) the potential difference across the solenoid during the time when the current remains constant,
- (e) the emf induced in a single circular loop of wire during the time when the current is increasing. Assume the loop has diameter 10 cm and is placed around the solenoid in such a way that the axis of the loop coincides with the axis of the solenoid.

(10 marks)

Question 8

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. Let r be the distance from the axis of the cylinder.

- (a) Using Ampere's Law or otherwise, derive an expression for the magnitude of magnetic field outside the cylinder ($r > R$). State all the steps in the argument.
- (b) Show that the magnitude of magnetic field inside the cylinder is

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

- (c) Now consider a segment of the cylinder of length L . Show that the total energy stored in the magnetic field inside this segment of the cylinder is independent of R .

Hint: First find the energy in a thin cylindrical shell of radius r and thickness dr .

(10 marks)

SECTION C QUANTUM

(Please use a separate book for this section.)

Question 9

- (a) In the wave theory of light, intensity is associated with the squares of the amplitude of the electric and magnetic fields. In the particle theory of light, what determines the intensity?

- (b) Electrons are ejected from a surface when light of a certain frequency is incident upon the surface. Does the maximum kinetic energy of ejected electrons increase, decrease or stay the same if
- ((i) the frequency of the incident light is doubled?
 - (ii) the intensity of the incident light is doubled?
 - (iii) the exposure time is doubled?

(5 marks)**Question 10**

- (a) Draw a careful, labelled energy level diagram of a hydrogen atom.
- (b) A hydrogen atom is in its second excited state (ie $n = 3$). It emits light with the shortest possible wavelength. Draw on your diagram an arrow to represent this transition.
- (c) In what frequency range does the emitted light fall (eg microwave, visible, radio, ultraviolet, x ray, ray)?

(5 marks)**Question 11**

Schrodinger's equation for the wave function of a particle in one dimension is

$$\frac{d^2}{dx^2} + \frac{2m}{\hbar^2} [E - V(x)] \psi = 0$$

where x is the position, $\psi(x)$ is the wave function, E is the total mechanical energy of the particle, and $V(x)$ is the potential energy distribution of the force which confines the particle.

Derive the normalised eigenfunctions and eigen-energies corresponding to a potential of the form

$$V(x) = 0 \quad 0 \leq x \leq L$$

$$V(x) = \infty \quad \text{elsewhere}$$

- Hints:*
1. A suitable trial function might be $\psi(x) = A \sin(kx) + B \cos(kx)$.
 2. $\psi(x)$ must be zero at $x = 0$ and $x = L$.
 3. The normalisation condition is $\int_0^L |\psi|^2 dx = 1$.

(10 marks)**Question 12**

- (a) Give a clear argument to show that in a solid, an energy band which is completely full of electrons cannot conduct an electric current. Use this fact with an appropriate energy band diagram to discuss the electrical conductivity of a metal, an insulator and a semiconductor.
- (b) Show that the average velocity v of an electron, mass m and charge e released at zero velocity and accelerated by an electric field E for a time t is given by

$$v = \frac{eE}{m}$$

- (c) Define resistivity in terms of current density and electric field. Using the result of (b), show that the resistivity of a metal or semiconductor having n electrons per unit volume is given by

$$= \frac{m}{e^2 n}.$$

- (d) Both metals and superconductors can conduct electricity well. Compare the two cases by listing the most important differences between their electron systems.
- (c) Calculate the energy gap of the semiconductor which is required to construct a blue light emitting diode which produces photons with a wavelength of 410 nm.

(10 marks)

- - - - - This is the end of your questions. - - - - -