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

PHYSICS 1004 :
PHYSICS I - ENVIRONMENTAL/LIFE SCIENCES

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 \( \varepsilon_0 = 8.85 \times 10^{-12} \, \text{F.m}^{-1}. \)

Permeability of free space \( \mu_0 = 1.26 \times 10^{-6} \, \text{T.m.A}^{-1}. \)

Elementary charge \( e = 1.6022 \times 10^{-19} \, \text{C}. \)

Electron volt \( \text{eV} = 1.602 \times 10^{-19} \, \text{J}. \)

Speed of light in vacuum \( c = 2.9979 \times 10^8 \, \text{m.s}^{-1}. \)

Planck constant \( h = 6.63 \times 10^{-34} \, \text{J.s} = 4.136 \times 10^{-15} \, \text{eV.s} \)

Rest mass of an electron \( m_e = 9.10939 \times 10^{-31} \, \text{kg} = 0.0005485799 \, \text{u}. \)

Rest mass of a neutron \( m_n = 1.67493 \times 10^{-27} \, \text{kg} = 1.0086649 \, \text{u}. \)

Rest mass of a proton \( m_p = 1.67262 \times 10^{-27} \, \text{kg} = 1.0072765 \, \text{u}. \)

Rest mass of a hydrogen atom \( m_H = 1.67353 \times 10^{-27} \, \text{kg} = 1.0078250 \, \text{u}. \)

Atomic mass unit \( u = 1.6605402 \times 10^{-27} \, \text{kg} = 931.502 \, \text{MeV.c}^{-2} \)

Boltzmann's constant \( k = 1.38 \times 10^{-23} \, \text{J.K}^{-1} = 8.61 \times 10^{-5} \, \text{eV.K}^{-1} \)
SECTION A
(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
A non-viscous liquid is flowing in a streamline manner in a horizontal pipe. At point A the cross-section is 3.0 m² and at point B it is 1.5 m².
(a) At which point is the pressure higher? State briefly the physical principles behind your answer.
(b) How will this change if the liquid is viscous?

(5 marks)

Question 3
A parallel plate capacitor is charged by connecting it to a battery. The battery is then disconnected. If the separation between the plates is increased, in what way do the following quantities change (if at all)? Provide brief justifications for your answers.
(a) The electric field between the plates.
(b) The energy stored in the capacitor.

(5 marks)

Question 4
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 5
(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 6
(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, γ ray)?

(5 marks)

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

Question 7
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.)

\[ \kappa_{\text{steel}} = 14 \text{ W m}^{-1} \text{ K}^{-1}, \quad L_V = 2256 \text{kJ kg}^{-1} \]

(10 marks)
Question 8

A 200 m long tunnel 7.2 m high and 5.8 m wide (with a flat roof) is to be constructed 40 m beneath the ground (see figure below). The tunnel roof is to be supported entirely by square steel columns, each with a cross-sectional area of 960 cm$^2$ (0.0960 m$^2$). The density of the ground material is 2800 kg m$^{-3}$. (Ultimate strength of steel $= 400 \times 10^6$ N.m$^{-2}$).

(a) What is the total weight that the columns must support?

(b) How many columns are needed to keep the compressive stress on each column at one-half of its ultimate strength? 

(10 marks)

Question 9

The electric eel has cells, called electroplaques, each of which generate an emf of 0.15 V with an internal resistance of 0.25 $\Omega$.

(a) If each row of electroplaques contains 5000 cells connected in series, what is the total emf and resistance of each row?

(b) If there are 140 such rows connected in parallel, what is the net emf and resistance of all the electroplaques?

(c) A circuit is created by the water presenting a resistance to the real emf source created by the eel's electroplaques. If the current through the water is 1 A, what is the resistance of the water?

(d) How much power is dissipated in each individual electroplaque? 

(10 marks)

Question 10

The time for a particle of mass $m$ and charge $q$ to circle once inside a medical cyclotron is given by $T = \frac{2 \pi m}{qB}$.

The magnetic field $B$ in this cyclotron is 1.5 tesla and the maximum radius to which ions can be accelerated is 0.8 m.
(i) What is the frequency of the accelerating electric field when the cyclotron is used to accelerate hydrogen (\(^1\text{H}\)) ions?

(ii) To what energy will this cyclotron accelerate hydrogen ions?

(iii) If the magnetic field is kept fixed how would the answers to (i) and (ii) differ if the cyclotron is used to accelerate deuterium (\(^2\text{H}\)) ions?

Assume that the energy of the ions is non-relativistic in answering this question.

(10 marks)

**Question 11**

The first four energy levels of an atomic system used in a laser are shown in the energy level diagram below.

(i) Copy (sketch) the diagram into your answer book and on it indicate the transitions important for laser action and explain why each is important.

(ii) What is the minimum excitation energy needed to produce laser action?

(iii) What is the energy of the resulting laser photons?

(iv) What is the wavelength of the laser light?

\begin{align*}
E1 & \quad \text{Ground state (0 eV)} \\
E2 & \quad \text{Metastable state (0.9 eV)} \\
E3 & \quad \text{Excited state (1.2 eV)} \\
E4 & \quad \text{Metastable state (1.5 eV)}
\end{align*}

(10 marks)

**Question 12**

An experiment uses a \(4.0 \times 10^6\) Bq \(^{137}\text{Cs}\) source. Each decay produces a 0.66 MeV gamma ray. A technician, mass 80 kg, standing nearby absorbs 30% of the gamma rays. The quality factor for gamma radiation is 0.9.

(a) How many decays occur per hour?

(b) Calculate the technician's absorbed dose in one hour?
(c) Calculate the biologically equivalent dose of this radiation?

(10 marks)

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