King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/1490 Structure of Matter

Summer 1996

Time allowed: THREE Hours

Candidates must answer SIX parts of SECTION A, and TWO questions from SECTION B.

Separate answer books must be used for each Section of the paper.

The approximate mark for each part of a question is indicated in square brackets.

You must not use your own calculator for this paper.
Where necessary, a College Calculator will have been supplied.

TURN OVER WHEN INSTRUCTED

Physical Constants:

Acceleration due to gravity g = 9.806 ms^{-2}
Avagadro's number $N_A = 6.022 \times 10^{23}$ **mol^{-1}**
Electronic charge e $= 1.602 \times 10^{-19}$ **C**
Mass of 1 atomic mass unit u $= 1.661 \times 10^{-27}$ **kg**
Speed of light in a vacuum c = 2.998 $\times 10^{8}$ **m s^{-1}**
Boltzman's constant k = 1.381 $\times 10^{-23}$ **JK^{-1}**

SECTION A – Answer any SIX parts of this section

1.1) i) What is meant by the term "ideal gas"?
ii) The energy (E) of an ideal gas is given by E $= E = \frac{3}{2}kT$, where k is Bolzman's constant and T is the temperature in degrees Kelvin. How is this expression modified to describe the energy of a gas made from diatomic molecules?

[7 marks]

1.2) The Thomson model of the atom envisaged electrons embedded in a cloud of positive charge. Describe one piece of experimental evidence which is not consistent with this model and state a different experimental result that lead to the nuclear model of the atom.

[7 marks]

1.3) To a good approximation, the mass of an atom can be calculated by multiplying the atomic mass number by one atomic mass unit. State two reasons why this method does not yield values which are in exact agreement with the measured values.

[7 marks]

1.4) Give a brief explanation of how a nuclear fission reactor functions.

[7 marks]

1.5) A mass of 1kg is suspended on a nylon wire which has a free length of 1m and has a cross-section of 1mm^2. Young's modulus for the wire is 2 $times 10^9$ N/m^2. Calculate the length of the wire under load and the strain energy stored in the wire.

[7 marks]

1.6) i) Show with the aid of a diagram that an x-ray beam of wavelength λ will show a strong reflection from crystal planes which are separated by a distance d when the angle of incidence is θ, such that

$$n\lambda = 2\ d\ Sin(\theta)$$

ii) State once process that leads to x-ray production when a metal target is bombarded by electrons which have some tens of kilo volts of energy.

[7 marks]

1.7) i) State the four fundamental forces of nature.
ii) Place these forces in order of strength when considered between two protons separated by: 1 Fermi (1×10^{-15}m)
ii) Place two of these forces in order of strength when the separation is 1×10^{-6}m. .

[7 marks]

1.8) 1g of ^{2}35U undergoes fission in a nuclear reactor and releases an amount of energy in the process. The fusion of 1g of hydrogen in the sun produces a greater amount of energy. Explain why this is so.

[7 marks]

SECTION B – Answer any TWO questions

2)

a) Explain with the aid of a sketch why most materials expand when heated.

[8 marks]

b) The potential $V(r)$ of a diatomic molecule held together by van der Walls forces can be described by the Lennard-Jones 6-12 potential, i.e.

$$V(r) = \epsilon \left[\left(\frac{a_0}{r} \right)^{12} - 2 \left(\frac{a_0}{r} \right)^{6} \right]$$

where ϵ is the binding energy, r is the distance between the centres of the atoms and a_0 is the equilibrium separation.

Show that the force acting on the molecule is zero when $r = a_0$.

[9 marks]

c) When considering the potential of an ion in an ionic crystal, nearest neighbour interactions only need be accounted for in the repulsive term. Why is this not so for the Coulomb term?

[4 marks]

d) The potential of an ion in an NaCl ionic crystal can be described by the sum of a repulsive term and a Coulomb term. Derive an expression for the Coulomb term only of the potential of an ion in such an ionic crystal.

[9 marks]

3)

a) Electrons can be considered as particles or waves. Briefly describe an experiment which demonstrates *particle* behaviour or describe an experiment which demonstrates *wave* behaviour.

[6 marks]

b) Draw a labelled diagram of Thomson's apparatus for measuring the charge to mass ratio of the electron. Explain how the value of the charge to mass ratio may be obtained from its use.

[12 marks]

c) The electron gun in Thomson's apparatus is replaced by a radioactive source which emits alpha particles with an energy of 0.1MeV. In the absence of electric and magnetic fields, a bright spot is seen on the centre of the flourescent screen.

i) If the source is located 1m from the fluorescent screen, calculate the velocity of the alpha particle, and the time taken to travel from the source to the screen.

[4 marks]

ii) If the α source were replaced by β^- source of similar energy, and a magnetic field of 0.1 Tessla is applied at right angles to the direction of motion of the β^- particles for the last 3cm of their path to the screen, describe what would be observed at the fluorescent screen.

[8 marks]

4)

a) Bhör postulated the concept of electrons orbiting the nucleus in "stationary states". How did this concept contravene the the ideas of classical physics.

[6 marks]

b) In the Bhör model of the hydrogen atom, the electrons orbits have quantised energies. By considering the force acting on an electron in an orbit together with the concept that its angular momentum is always an integral number of $h/2\pi$, show that the radius of the nth orbit (r_n) in a hydrogen atom is given by

[7 marks]

$$r_n = \frac{4\pi\epsilon_o\hbar^2 n^2}{me^2}$$

c) By considering the kinetic and potential energies that an electron has in the hydrogen atom, show that the energy of the nth state is

$$\epsilon_n = \frac{-e^4 m}{2\left(4\pi\epsilon_o\right)^2 \hbar^2 n^2}$$

[7 marks]

d) Briefly discuss how the expression for ϵ_n can be confirmed experimentally.

[3 marks]

e) The visible light spectrum can be considered as elecromagnetic radiaiton spanning the energy range 1.8eV to 3.0eV. Given this, determine the orbital in a hydrogen atom with the smallest value of n to which electrons can make a transition to and emit visible radiation.

[7 marks]

5)

a) Naturally occurring $^{210}_{83}$Bi undergoes a β^- decay to Polonium (Po) which then decays via an alpha p article emission to lead(Pb). Write down this decay scheme.

[6 marks]

b) Two radioactive isotopes are prepared and labelled A and B. When the labels are stuck to the samples, they had equal mass. After a period of 6 years, the samples are analysed. 3.54 grams of isotope A and 5.95 grams of isotope B remain. The half life of isotope A is 4 years.

(i) Calculate the half life of isotope B

[11 marks]

(ii) Calculate the mass of the samples when the labels were fixed.

[3 marks]

c) In the "standard model" of elementary particles, neutrons and protons are each made from three quarks. Use this model to indicate how beta decay takes place.

[6 marks]

Why is the Boson involved in β^- decay called a *virtual* particle?

[2 marks]

Why is it much more likely for a neutron to decay into a proton than for a proton to decay into a neutron.

[2 marks]