King's College London

UNIVERSITY OF LONDON

This paper is part of an examination of the College counting towards the award of a degree. Examinations are governed by the College Regulations under the authority of the Academic Board.

B.Sc. EXAMINATION

CP/1490 Structure of Matter

Summer 1997

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:

1 atomic mass unit u $= 1.661 \times 10^{-27}$ **kg**
Atomic mass of hydrogen $= 1.00783$**u**
Neutron mass $= 1.00866$**u**
Electronic mass $m_e = 9.109 \times 10^{-31}$ **kg**
Electronic charge $e = 1.602 \times 10^{-19}$ **C**
Speed of light in a vacuum $c = 2.998 \times 10^{8}$ **ms**$^{-1}$
Planck's constant $= 6.626 \times 10^{-34}$**Js**
Coulomb constant $4\pi\epsilon_0 = 1.11 \times 10^{-10}$ **Fm**$^{-1}$
1 Bequerel (Bq) = 1 disintegration per second
1 Curie = 3.7$\times$**10**^{10} **disintegrations per second.**

SECTION A – Answer any SIX parts of this section

1.1) Sketch in two dimensions only a simple crystal lattice. Show at least two different inter-atomic planes. On your sketch, indicate which of the planes that you have chosen will have the smaller angle of incidence for a strong x-ray reflection.

[7 marks]

1.2) A beam of mono-energetic x-rays of are incident on a sheet of material which has an x-ray absorption coefficient μ. Derive an expression for the transmitted intensity (I) of the x-rays in terms of μ and the material thickness t.

[7 marks]

1.3) Draw a labelled diagram showing essential components of an atomic force microscope.

[7 marks]

1.4) Explain the function of the control rods in a nuclear fission reactor.

[7 marks]

1.5) Explain why beta particles emitted from radioactive isotopes have a continuous energy spectrum up to some maximum.

[7 marks]

1.6) Sketch a graph of the potential energy of an atom as a function of the separation distance of the atom to its nearest neighbour. Indicate the origin of strain energy on the graph.

[7 marks]

1.7)

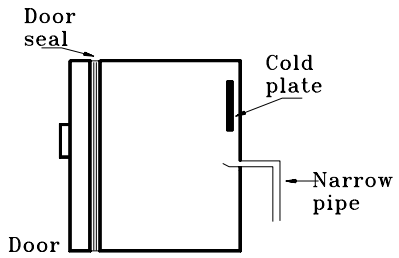

Figure 1.

Figure 1 shows a basic refrigerator. In normal use, it is found that for a few seconds after the door is shut, more force is required to open it than if it left for a minute and then opened. Explain why this might be so.

[7 marks]

1.8) Sketch the stress strain curve for a metal up to the fracture point. Indicate the region where Hooke's law is obeyed.

[7 marks]

SECTION B – Answer any TWO questions

2)

a) Sketch the relationship between atomic number and atomic mass. Explain why there is a deviation from linearity for the larger atomic numbers.

[10 marks]

b) Sketch a graph of binding energy per nucleon as a function of mass number. With reference to the curve, explain why the fusion of light nuclei yields more energy per unit mass than the fission of heavy nuclei.

[10 marks]

c) A $^{242}_{94}$Pu isotope undergoes alpha decay to produce $^{238}_{92}$U. Calculate the energy released in the decay, and show that the alpha particle carries most of the kinetic energy. The atomic masses of the isotopes of plutonium, uranium and helium are 242.05874 **u**, 238.05078 **u** and 4.00260 **u** respectively.

[10 marks]

3)

a) In the Bohr model of the hydrogen atom, the electrons orbit the nucleus with quantised angular momentum ($mvr = n\hbar$). The electrons therefore have quantised energies. Show that the energy of an electron in the nth orbital is

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

given that the radius (r_n) of the nth orbit is

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

[12 marks]

b) Hydrogen atoms in the ground state are stimulated by ultraviolet light of wavelength 103 nm. What are the energies of the emission lines which are produced by these excited hydrogen atoms?

[10 marks]

c) Hydrogen emission spectral lines can be obtained from a discharge lamp which consists of two electrodes in a tube containing hydrogen gas at low pressure, and an appropriate power supply. Why is low pressure necessary?

[8 marks]

SEE NEXT PAGE

4)

a) Describe how different flavours of quark may be combined to produce neutrons and protons.

[7 marks]

b) $^{60}_{27}$Co has an atomic mass of 59.93**u** and is made in a nuclear reactor. It is radioactive with a half life of 1925 days. Calculate the mass of $^{60}_{27}$Co which will give an initial activity of 10^4 Curies.

[12 marks]

c) Before the year 1900, the activity per mass of atmospheric carbon was 0.255 Bq per gram of carbon due to the presence of ^{14}C. The half life of ^{14} C is 5730 years. What fraction of the carbon atoms were ^{14}C.

[5 marks]

d) A bone specimen from an archaeological site contains 0.5g of carbon which gives an activity of 210 decays in one hour. Determine the age of the bone.

[6 marks]

5)

a) Why is the latent heat of vaporisation considerably greater than the latent heat of melting for inert elements?

[7 marks]

b) At low temperature, the oscillations of an atom in a solid about the inter-atomic mean separation are small. Hooke's law is obeyed and these oscillations approximate to simple harmonic motion. Using the above approximation, show that the frequency of oscillation ν is given by

$$\nu = \frac{1}{2\pi}\sqrt{\frac{d^2V/dr^2}{m}}$$

where r is the displacement about the mean separation, V is the potential experienced by the atom and m is its mass.

[12 marks]

c) If the potential V of the atom is described by the Lennard Jones 6-12 potential, show that the frequency of vibration (known as the Einstein frequency) is given by

$$\nu = \frac{1}{2\pi}\sqrt{\frac{72n\epsilon}{3a_0^2 m}}$$

where n is the number of nearest neighbours and ϵ is the binding energy of a single atom.

[11 marks]

SEE NEXT PAGE

6)

a) An argon gas atom with a diameter d has a mean velocity $\bar{v}$. It is one of N argon molecules in a container which has a volume V. Show that the expression for the mean free path of the gas atom between collisions is

$$\lambda = \frac{1}{\pi d^2 (N/V)}$$

[10 marks]

b) If the container is a cube with a volume of 1 cm^3, which contains 2.68×10^{19} argon atoms which each have a diameter of 1.7×10^{-10}m, calculate the mean free path of the argon atoms.

[6 marks]

b) Two electrodes are placed in the container and and are used to create an electric field of 200,000 Vm^{-1}. Occasionally one of the argon atoms between the electrodes loses an electron due to ionisation by a cosmic ray. The ion will be accelerated by the electric field. If the average amount of energy required to ionise an argon atom by collision is 25 eV, calculate the pressure at which the ions produced by the cosmic rays will result in an avalanche.

[15 marks]