King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/1490 Structure of Matter

January 1998

Time allowed: THREE Hours

Candidates should 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:

Electronic mass $m_e = 9.109 \times 10^{-31}$ **kg**
Electronic charge $e = 1.602 \times 10^{-19}$ **C**
1 atomic mass unit u $= 1.661 \times 10^{-27}$ **kg**
Neutron mass $= 1.00866$**u**
Speed of light in a vacuum $c = 2.998 \times 10^{8}$ **ms**$^{-1}$
Boltzman's constant $= 1.381 \times 10^{-23}$**JK**$^{-1}$
Gravitational constant $= 6.672 \times 10^{-11}$ **Nm**^{2}**kg**$^{-2}$

SECTION A – Answer SIX parts of this section

1.1) 3 mg of a radioactive isotope is prepared. After ten years 1 mg of the original isotope remain. Show that the half life ($t_{1/2}$) of the isotope may be expressed as

$$t_{1/2} = 10\,\frac{ln(2)}{ln(3)}\ \text{years}$$

[7 marks]

1.2) Explain the function of the moderator in a fission based nuclear reactor.

[7 marks]

1.3) Describe the Thomson model of the atom, and state one piece of experimental evidence which is hard to reconcile with this model.

[7 marks]

1.4) Explain, with reference to the form of a typical inter-atomic potential, why most materials expand when they are heated.

[7 marks]

1.5) Sketch a graph of atomic mass number versus atomic number for the stable nuclei and briefly explain the reasons behind its form.

[7 marks]

1.6) When a metal wire is placed under load, the graph of stress versus strain is shown in figure 1.6. Describe the physical processes which give rise to the features labelled A and B on the graph.

[7 marks]

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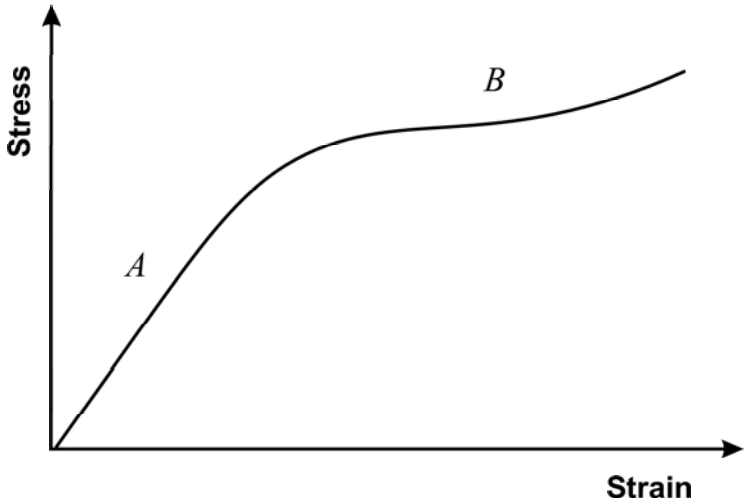

Figure 1.6

1.7) Helium gas will become liquid at atmospheric pressure when its temperature is lowered to 4.2 degrees Kelvin. State what type of bond the helium atoms form in the liquid state and estimate the minimum binding energy of one of these bonds if each atom has 12 nearest neighbours.

[7 marks]

1.8) Draw a Feynman diagram of the β^- decay scheme according to the 'standard model' of particle physics.

[7 marks]

SECTION B – Answer TWO questions

2)

a) Draw a labelled diagram of Thomson's apparatus for measuring the charge to mass ratio of the electron.

[7 marks]

b) Explain how the charge to mass ratio of the electron is derived from experimental measurements using this apparatus.

[10 marks]

c) Using the Thomson apparatus, an electron beam is deflected by an electric field of 2500 Vm^{-1} which is maintained by parallel plates. A magnetic field of 2.5×10^{-4} T is required to bring the electron beam to an undeflected position. Through what potential difference have the electrons been accelerated in the electron gun?

[13 marks]

3) A neutron star can be considered as a "soup" of neutrons in which the strong force contributes about 10MeV of binding energy per neutron. The average distance between neutrons is 2.5×10^{-15}m. If the neutron star is 10,000 m in diameter, calculate the total binding energy in the neutron star due to the strong force.

[12 marks]

How much mass has been converted to generate this energy?

[6 marks]

Now consider a single neutron at the surface of this star. Assuming that the gravitational force acts as if the whole mass of the star is concentrated at its centre, what gravitational potential energy does this neutron have?

Compare the gravitational binding energy with the binding energy due to the strong force for this surface neutron.

[12 marks]

4) Sketch the graph of x-ray intensity versus energy for a copper target x-ray source which is bombarded by electrons of energy 20 keV. Explain briefly the processes which give rise to the features on your sketch.

[11 marks]

X-Rays of wavelength λ are incident on a crystal making an angle θ with the crystal surface. If the x-rays are reflected from planes in the crystal which have a spacing d, show that there will be intense reflections when

$$n\lambda = 2d\sin\theta$$

where n is an integer.

[6 marks]

A sample of undetermined composition is placed in an electron beam as shown in the figure below. The x-rays emitted from the sample are incident on a crystal which can be rotated so that its surface makes an angle θ with the x-rays. Strong reflections are found at angles: 13.41 and 23.72 degrees. The crystal planes that provide the reflections have a spacing of 3.5×10^{-10}m.

From the table below, identify the elements in the specimen which are responsible for generating the x-rays which give the strong reflections.

Element	X-ray emission wavelength
Ca	2.82×10^{-10}m
Fe	1.62×10^{-10}m
Cr	1.92×10^{-10}m
Ti	2.30×10^{-10}m

[13 marks]

5) At low temperature, the oscillations of an atom in a solid about its equilibrium position are small and the motion of the atoms about the equilibrium approximate to simple harmonic motion. Using this 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 equilibrium position, V is the potential experienced by the atom and m is its mass.

[12 marks]

If the potential V of the atom is described by the Lennard Jones 6-12 potential,

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

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, ϵ is the binding energy of a single atom and the other symbols have their usual meanings.

[11 marks]

In modelling the potential for van derWaals bonded materials, only nearest neighbours are taken into account. Why is this insufficient when modelling the potential for ionically bonded materials?

[7 marks]