King's College London
UNIVERSITY OF LONDON

This paper is part of an examination of the University counting towards the award of a degree. Examinations of the University are governed by the Senate Regulations.

B.Sc. EXAMINATION

CP/1490 THE STRUCTURE OF MATTER

JANUARY 2000

Time allowed: THREE HOURS

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

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

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

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Constants

Electron charge (e):	1.602×10^{-19} C
Electron mass (m_e):	9.109×10^{-31} kg
The Planck constant (h):	6.626×10^{-34} J s
Speed of light in a vacuum (c):	2.998×10^{8} m s^{-1}
Atomic mass unit (u):	1.662×10^{-27} kg or 931.5 MeV/c^2
The Boltzmann constant (k):	1.381×10^{-23} J K^{-1}
Natural log of 2 (ln(2)):	0.693
Half life of the radio isotope ^{14}C:	5730 years
Mass of a Hydrogen atom (m_H):	1.00783 u
Electrostatic constant ($\frac{1}{4\pi\varepsilon_0}$):	8.99x10^{9} N m^{2} C^{-2}

SECTION A - Answer any SIX questions from this section

1.1) In the Bohr model of the hydrogen atom, the electron orbits have quantised angular momentum equal to nh, where n is an integer and h is Planck's constant divided by 2π. Show that the radius (r_n) of the nth orbit in a hydrogen atom is given by

$$r_n = \frac{4\pi \varepsilon_0 \hbar^2 n^2}{me^2}$$

[7 marks]

1.2) The kinetic energy E per atom of an ideal gas atom can be calculated from $E = \frac{3}{2}kT$, where T is the temperature in degrees Kelvin and k is the Bolzmann constant. An energy of 16 eV is required to ionise argon atoms. Briefly explain why a small percentage of argon atoms can be ionised by collisions at room temperature.

[7 marks]

1.3) Explain the function of the moderator in a fission based nuclear reactor. Calculate the kinetic energy transferred when a neutron which is travelling at $1\text{x}10^{8}$ mS^{-1} gives up most of its energy in collisions in a nuclear reactor. You may approximate the mass of neutron as being one atomic mass unit. [7 marks]

1.4) What is meant by the term “Q value” when applied to nuclear reactions? What is the significance of its sign?

[7 marks]

1.5) In the Thomson model of the atom, electrons were thought to be embedded in a cloud of positive charge. Briefly discuss one piece of experimental evidence which cannot be reconciled with this model.

[7 marks]

1.6) A fragment of wood from a site believed to be from an early Roman settlement is analysed by accelerator mass spectroscopy. The analysis shows the ratio of the number of ^{14}C atoms to the number of ^{12}C atoms to be $7.82\text{x}10^{-13}$. Determine the age of the wood fragment.

[7 marks]

1.7) Sketch a graph of the relationship between atomic number and atomic mass number for stable nuclei. Briefly explain the form of the graph.

[7 marks]

1.8) The atoms in a CO_2 molecule are arranged in a straight line with the carbon atom in the middle. Describe the origin and number of absorption peaks which occur in the infrared spectrum of this molecule.

[7 marks]

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SECTION B - Answer any TWO questions

2) A small lump of uranium 238 (^{238}U) emits α particles with an energy of 4.27 MeV. This α particle source is introduced into the entrance of a cloud chamber. The cloud chamber has a magnetic field of 2 Tesla applied to it with the field direction normal to the direction of motion of the α particles. The α particles have a mass of 6.65×10^{-27} kg.

Sketch the path of the α particles in the cloud chamber.

[4 marks]

Calculate the radius of the α particle trajectories in the cloud chamber.

[8 marks]

In one hour the ^{238}U source emits 10^6 α particles. Calculate the mass of ^{234}Th created in this time.

[9 marks]

Calculate the mass of the lump of uranium. Justify any approximations made.

[9 marks]

Mass of ^{238}U atom = 238.05078 u
Mass of ^{4}He atom = 4 .00260 u
The half life of ^{238}U is 4.47×10^9 years

3) Describe with the aid of a diagram how a scanning electron microscope can be used to determine the elemental composition of specimens.

[11 marks]

A sample is placed in the scanning electron microscope for analysis. It is known to contain copper. The x-ray energy spectrum shows copper Kα, Kβ, and Lα emission peaks at 8040, 8904, and 930eV. Draw an energy level diagram and indicate the transitions that give rise to these peaks.

[7 marks]

The x-ray detector in the above system has an entrance window which is coated with a 0.2 μm thick layer of gold through which x-rays must pass before they are detected. The x-ray photon emission is recorded for a set period of time during which 8410 x-ray photons are detected due to the copper Kα radiation while 200 x-ray photons are recorded due to the copper Lα radiation. Calculate the ratio of the numbers of Kα and Lα x-rays emitted from the sample.

Gold has a linear x-ray absorption coefficient of 11.04 μm^{-1} for copper Lα radiation and 0.394 μm^{-1} for copper Kα radiation.

[12 marks]

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4) A metal wire is placed under increasing stress up to a level where a permanent deformation is induced in the wire. Sketch a graph of stress versus strain for the wire and label it appropriately. Give a brief description of the physical processes that give rise to its form.

[10 marks]

Guitarists frequently break the thinnest "E" string on electric guitars. Figure 1 shows a schematic diagram of the strings and frets on a guitar. The E string is undergoing a strain while being played. This string has an un-strained length of 0.8 m and is made from a metal with a Young's modulus of 4.0×10^{10} N/m^2. And breaking stress of 2×10^9 N/m^2. Calculate the displacement, *d*, of the string at the mid-string play position which will break the string. For the purposes of the calculation you may assume that the string is un-strained before it is displaced.

[10 marks]

In practice, tuning pre-strains the string by 3%. How does this alter your calculated value of breaking displacement?

[10 marks]

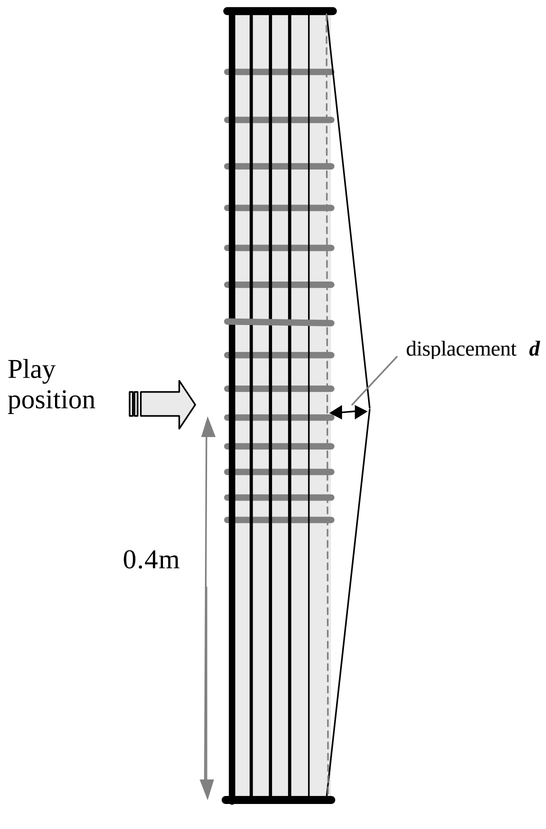

Figure 1

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5) Sketch a graph of the inter-atomic potential for two atoms in a metal lattice and use this to explain why the metal expands when heated.

[8 marks]

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 *n* is given by

$$n = \frac{1}{2p}\sqrt{\frac{\mathrm{d}^2V/\mathrm{d}r^2}{m}} \quad ,$$

where *r* is the displacement about the equilibrium position, *V* is the potential experienced by the atom and *m* is its mass.

[8 marks]

The potential of an ion in a metal-halide crystal can be written as

$$V(r) = \frac{1.75e^2}{4pe_0}\left(\frac{a^{11}}{12r^{12}} - \frac{1}{r}\right) \quad ,$$

where *a* is the distance between ions at equilibrium. Show that the frequency of oscillation is given by

$$n = \frac{1}{2p}\sqrt{\frac{\frac{1.75e^2}{4pe_0}\left(\frac{13a^{11}}{r^{14}} - \frac{2}{r^3}\right)}{m}} \quad .$$

[8 marks]

Positive ions in this crystal have a mass of $3.8\text{x}10^{-26}$ kg and have an equilibrium separation of $3.0\text{x}10^{-10}$m. Calculate the frequency of oscillation of these ions at low temperature.

[6 marks]

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