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/MP25 Radiation Physics

Summer 1997

Time allowed: THREE Hours

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

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

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

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

TURN OVER WHEN INSTRUCTED

Planck constant, $h = 6.64 \times 10^{-34}$ J s
Speed of light, $c = 3.00 \times 10^{8}$ m s^{-1}
Rest mass of the electron, $m_e = 9.11 \times 10^{-31}$ kg
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Boltzmann constant, $k = 1.38 \times 10^{-23}$ J K^{-1}
1 J = 6.24×10^{18} eV

Section A -Answer **SIX** parts of this section

1.1) Energy levels for the 1s, 2s and 3s electrons in copper, referred to the same arbitrary zero, are 9.5 keV, 1.2 keV and 0.1 keV respectively. Use this information to estimate the wavelengths of Cu K_α and Cu K_β x-rays.

[7 marks]

1.2) Give a qualitative description of the sequence of events that results in biological damage when x-rays or γ-rays interact with tissue.

[7 marks]

1.3) Describe the physical appearances of tracks generated in a cloud chamber by α-particles and β-particles with energies of a few MeV, emphasising the differences between them. Explain qualitatively, in terms of the physical interactions involved, why the tracks differ.

[7marks]

1.4) What is an Auger electron? Obtain an expression for the energy of an Auger electron in terms of atomic energy levels.

[7 marks]

1.5) What is meant by the *cross section* σ for a photon scattering process? Derive an expression in terms of σ for the reduction in intensity due to scattering when a beam of photons passes through a material.

[7 marks]

1.6) Draw a labelled diagram of the two main types of survival curve. Describe briefly physical mechanisms that lead to these curves.

[7 marks]

1.7) The following equation is found in dielectric dispersion:

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + i\omega\tau}.$$

Define each term. Describe the context in which the equation is of value.

[7 marks]

1.8) Give reasons why a safety standard for exposure to microwave radiation should take into account both power density and frequency.

[7 marks]

Section B - Answer **TWO** questions from this section

2. A narrow, monochromatic, parallel beam of photons of intensity I_0 is incident on a homogeneous slab of material of thickness x. Explain what is meant by the linear attenuation coefficient μ of the material. Obtain expressions in terms of μ for the intensity of photons which emerge from the slab and the half-value layer.

[10 marks]

A ^{60}Co unit gives an exposure rate of 90 R min^{-1} at a distance of 1 m when unshielded. To comply with safety regulations, the exposure rate at this distance when the source is shielded should be less than 2 mR h^{-1}. What thickness of lead is needed to achieve this, given that the linear attenuation coefficient for lead is 66 m^{-1}? Determine also the half-value layer.

[5 marks]

Compare and contrast the mechanisms involved in the attenuation of photons by the photoelectric effect, Compton scattering and pair production. By considering the passage of photons through water, explain how the attenuation processes vary with the energy of the incident photons and how they are combined to determine the overall attenuation.

[15 marks]

3. Neglecting relativistic effects, the energy lost by an α-particle in a single interaction with an electron is normally taken to be $\Delta E = \frac{k}{b^2}$, where k is a constant and b is the impact parameter. State the meaning of b, and show that the linear energy transfer is given by

$$\frac{dE}{dx} \propto Z \ln \frac{b_{max}}{b_{min}},$$

where Z is the atomic number of the atoms in the absorbing material.

[15 marks]

Discuss how values may be assigned to b_{max} and b_{min}.

[15 marks]

4. Describe the operation of a simple ionisation chamber and show that the saturation current gives a measure of the rate of energy absorption.

[10 marks]

How can the ionisation chamber be used to count charged particles? What is its disadvantage when used for this purpose? How is this disadvantage overcome in the proportional counter? Explain how the proportional counter can be used to differentiate between different types of ionising radiation.

[8 marks]

Describe how a Geiger counter works and discuss mechanisms used to improve its temporal resolution.

[8 marks]

Describe the action of one type of passive detector based on the ionisation of a gas.

[4 marks]

5. The complex permittivity ε of an aqueous solution of polar molecules is measured as a function of frequency. Sketch the forms of the real and imaginary parts of ε as functions of frequency, and indicate the frequency range if the solute molecule is a small protein. Use the Debye model to explain the observed dispersion curve.

[6 marks]

It has been suggested that, for a spherical molecule, the relaxation time τ can be related to molecular parameters by the equation

$$\tau = \frac{4\pi a^3 \eta}{kT}\,.$$

Define the symbols used and briefly explain the physical significance of this equation.

[4 marks]

Explain how dielectric dispersion curves may provide useful information concerning possible hazards of exposure to non-ionising radiation. Why may water be particularly significant when considering such hazards?

[10 marks]

The polar molecule myoglobin in aqueous solution has a radius of 2.1×10^{-9} m. Given that the viscosity of water is 10^{-3} Pa s, calculate the expected relaxation time of a dilute solution of myoglobin at 20°C.

[10 marks]