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 1998

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

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Planck constant, $h = 6.63 \times 10^{-34}$ J s 1 eV = 1.60×10^{-19} J
Speed of light, $c = 3.00 \times 10^{8}$ m s^{-1} 1 R = 2.58×10^{-4} C kg^{-1}
Rest mass of the electron, $m_e = 9.11 \times 10^{-31}$ kg

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

1.1) Sodium has a proton number of 11. Write down the electronic structure of sodium, explaining the convention you use. Explain briefly how the electronic structure of an atom is determined on the basis of quantum mechanics.

[7 marks]

1.2) Define the *linear attenuation coefficient* (μ) as used to quantify the attenuation of photons passing through a material. Hence derive the relationship $N = N_0\exp(-\mu x)$, defining each symbol in the equation.

[7 marks]

1.3) Outline mechanisms that can lead to biological damage when ionising radiation is incident upon tissue. (Descriptions of individual processes are NOT required.)

[7 marks]

1.4) The kinetic energy transferred in a one-dimensional collision between two particles of masses M and m is $4MmQ/(M+m)^2$, where Q is the kinetic energy of the incident particle. Discuss the the differences in appearance between the tracks of α- and β-particles in a cloud chamber. Explain the observed differences in terms of the above equation and the range of energies of the emitted particles.

[7 marks]

1.5) Describe briefly the construction and operation of a solid-state device for the detection of ionising radiation. Suggest how the detail of the designs of detectors for α-, β- and γ-particles may differ.

[7 marks]

1.6) Explain the meaning of (a) *exposure* and (b) *absorbed dose* as used in radiation physics. Given that the average energy needed to produce ion pairs in air is 34 J C^{-1}, determine the absorbed dose in air for an exposure of 1R.

[7 marks]

1.7) In a biological system the total dielectric loss may be expressed as

$$\varepsilon_T'' = \varepsilon'' + \frac{\sigma_S}{\varepsilon_0 \omega}.$$

Briefly explain the significance of this equation. Show, by sketching a graph of ε_T'' against log(frequency), how the above equation reflects the behaviour of conductive water at frequencies much less than the relaxation frequency of water.

[7 marks]

1.8) What is meant by dipole moment? Explain briefly why many macromolecules have a dipole moment. How might such molecules behave in an a.c. field?

[7 marks]

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

2) The interaction of x-rays with biological tissue takes place through the photoelectric process, the Compton effect and pair production. Compare and contrast these processes in terms of the appropriate photon-electron interactions.

[15 marks]

The following equation can be derived for the Compton effect:

$$\lambda - \lambda' = \frac{h}{m_e c}(1 - \cos\theta) .$$

Explain the significance of each term in this equation.

[5 marks]

In a Compton collision process, show that
(a) the energy of the photon scattered in the forward direction is equal to that of the incident photon;
(b) if the energy ($h\nu$) of the incident photon is much greater than the electron rest-mass energy, the photon scattered through 90° has an energy of approximately 0.511 MeV. What will be the energy of the recoil electron, approximately?

[10 marks]

3) Describe the construction and operation of the following instruments used in the detection and measurement of ionising radiation:

(a) a Geiger counter;

[10 marks]

(b) a scintillation detector.

[10 marks]

In assessing the biological effects of ionising radiation, the term *dose equivalent* is used. Discuss the meaning of this term. Include units and the significance of *quality factor* and *linear energy transfer* in your discussion.

[10 marks]

4) What is meant by a *survival curve* in relation to the effects of ionising radiation on biological systems? Describe the two main types of survival curve obtained by experiment and give an account of physical models of radiation effects which can be used to generate the curves.

[10 marks]

Discuss the use of the Poisson distribution, $P_n = \frac{a^n e^{-a}}{n!}$, in assessing the success of radiation therapy, defining the terms in this equation. When tumour samples containing 10^9 cells are subjected to a dose D of ionising radiation, on average a single cell is left surviving. Determine the probability that the dose D will completely eliminate a tumour containing 10^9 cells.

[10 marks]

What is the main problem encountered in the treatment of a patient with a deep-seated tumour? How may *dose response curves* be used in planning the treatment of such a patient? Comment on procedures which may be used to enhance the treatment.

[10 marks]

5) Briefly explain why the relative permittivity of a biological system is usually expressed as a complex number of the form $\varepsilon = \varepsilon' - j\varepsilon''$.

[3 marks]

Write down, and briefly explain, the Debye equation which is often used to describe dielectric dispersion.

[6 marks]

Describe briefly the physical mechanisms by which microwaves could cause damage to living systems.

[7 marks]

Sketch a graph to show the dispersion curve expected for a protein molecule in aqueous solution at room temperature. You should indicate the various dispersion regions and give some indication of the frequencies at which they may be observed.

[7 marks]

Explain why the knowledge of a dispersion curve for a sample of tissue might be useful in helping to formulate a safety standard for exposure to microwave radiation.

[7 marks]