King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/MP25 Radiation Physics

January 2000

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, $h = 6.63 \times 10^{-34}$ J s   1 eV = 1.60×10^{-19} J
Boltzmann constant, $k = 1.38 \times 10^{-23}$ J K^{-1} 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   Mass of α-particle $=6.62 \times 10^{-27}$ kg

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

1.1) The electronic structure of the atoms of a particular element is described as follows: $1s^2 2s^2 2p^6 3s^2 3p^3$. Explain the convention used, and determine the atomic number of the element concerned.

[7 marks]

1.2) The primary event in the absorption of ionising radiation by tissue is interaction with an electron. Describe, with the aid of a diagram, the possible succeeding events which may lead to biological damage to the tissue.

[7 marks]

1.3) Draw a vibration/rotation energy-level diagram for a diatomic molecule. (Assume the molecule behaves as a harmonic oscillator and a rigid rotor.) State the selection rules which govern possible energy transitions. Use this information to show on your diagram four of the transitions which lead to the absorption of radiation of different wavelengths.

[7 marks]

1.4) 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 a brief account of physical models of radiation effects which can be used to generate the curves.

[7 marks]

1.5) The resonant cavity of a laser at a temperature of 290 K is filled with atoms having an energy difference of 6×10^{-19} J between the ground and excited states. Calculate the fraction of atoms in the excited state and explain why pumping would be required for the laser to operate. Briefly describe ways in which the pumping can be achieved.

[7 marks]

1.6) Specify, giving reasons, the imaging procedure that is most appropriate for each of the following diagnostic investigations: (a) identifying a brain lesion; (b) locating a bladder tumour for radiotherapy treatment planning; (c) detecting bone metastases.

[7 marks]

1.7) Sketch the Debye dispersion curve for water at room temperature over the frequency range 1 GHz to 100 GHz. Mark the dispersion parameters ε_s, ε_∞, Δ and f_R on your graph, where the symbols have their usual meaning. Define each of the parameters.

[7 marks]

1.8) Briefly explain how dielectric dispersion curves can provide useful information about possible hazards from exposure to non-ionising radiation.

[7 marks]

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

2) Compare and contrast the physical aspects of the three processes by which energy is absorbed when ionising electromagnetic radiation passes through a material.

[15 marks]

Explain the meaning of *scattering cross section* applied to the absorption of radiation by matter. By considering the scattering cross sections for each of the three processes described above, draw a diagram to illustrate the relative importance of the processes for different materials (described by atomic number) at different energies of the incident radiation.

[8 marks]

Determine the threshold **wavelength** of a photon for pair production. A 4 MeV photon is involved in a pair-production process. If the positron emerges with a kinetic energy of 1.2 MeV, what is the kinetic energy of the electron?

[7 marks]

3) When two particles, masses m_1, m_2 and initial velocities v_1, 0, collide head-on, the velocity of mass m_2 after the collision is $\frac{2m_1}{m_1 + m_2} v_1$. Use this information to show that the maximum energy lost by an α-particle of energy Q_α in collision with a stationary electron is $4\frac{m_e}{m_\alpha} Q_\alpha$, while the maximum energy lost by a non-relativistic β-particle of energy Q_β in collision with a stationary electron is Q_β. (Assume all collisions are elastic.)

[12 marks]

Describe the tracks left in a cloud chamber by α-particles and β-particles, and use the results of the first paragraph to give a qualitative explanation of their appearance.

[5 marks]

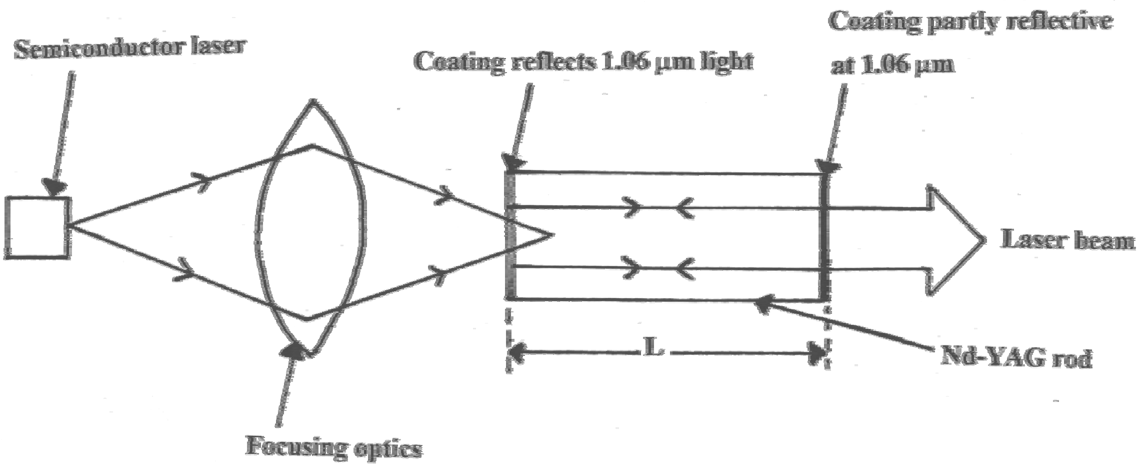
Estimate the number of collisions with electrons required to reduce the energy of a 5 MeV α-particle to 4 MeV.

[5 marks]

Explain what is meant by the *impact parameter* used in describing particle collisions. The momentum gained by an electron from an interaction with an α-particle moving with velocity v is proportional to $(bv)^{-1}$. Show that the energy transferred to the electron is proportional to $(b^2 E_\alpha)^{-1}$, where E_α is the energy of the α-particle.

[8 marks]

4) The schematic diagram below represents one type of continuous-wave-output Nd-YAG solid state LASER. Nd-YAG is an Yttrium Aluminium Garnet crystal doped with Neodymium.



L - Length of resonant cavity = 0.53 m

a) Explain how each labelled component contributes to the lasing process. Include a description of the electronic processes that underly the operation of this laser.

[13 marks]

b) How could the pumping arrangement be altered to produce pulsed output? If a pulse has an energy of 1.87 J, how many photons would be emitted?

[6 marks]

c) This type of laser can be used to treat bleeding stomach ulcers. Describe the radiation/tissue interaction utilised in this treatment.

[5 marks]

d) The LASER beam from this type of apparatus is attenuated on penetrating tissue. If the extinction length of the beam in the tissue is 0.4 cm, what is the corresponding absorption coefficient at the laser wavelength?

[6 marks]

5) Briefly describe, with the aid of a suitable diagram, a coaxial-line cell with which the complex permittivity of a liquid can be measured between 300 MHz and 4 GHz.

[8 marks]

Sketch the field pattern which would be observed in the cell at 2 GHz for (a) a very low-loss liquid and (b) an aqueous solution.

[6 marks]

The propagation constant γ is related to the complex permittivity ε (for the TEM mode) and the wavelength λ_a in air by the equation $\gamma = \frac{2\pi}{\lambda_a}[-\varepsilon]^{\frac{1}{2}}$. Show that the real and imaginary parts of the permittivity are given, respectively, by $\varepsilon' = \frac{\lambda_a^2}{4\pi^2}\left(\beta^2 - \alpha^2\right)$ and $\varepsilon'' = \frac{\alpha\beta\lambda_a^2}{2\pi^2}$, where α is the attenuation coefficient, β ($=2\pi/\lambda_m$) is the phase change constant and λ_m is the wavelength in the medium.

[8 marks]

Water is studied at room temperature at a frequency of 2 GHz in a coaxial-line cell. It is found that the wavelength in the water is 1.69 cm and that the attenuation coefficient is 0.2 neper per cm. Calculate the complex permittivity for water at 2 GHz.

[8 marks]