King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CPMP25 Radiation Physics

January 2005

Time allowed: THREE Hours

Candidates should answer all SIX parts of SECTION A,
and no more than TWO questions from SECTION B.
No credit will be given for answering further questions.

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

Permittivity of free space	ε_0	=	8.854×10^{-12}	F m^{-1}
Permeability of free space	μ_0	=	$4 \pi \times 10^{-7}$	H m^{-1}
Speed of light in free space	c	=	2.998×10^{8}	m s^{-1}
Gravitational constant	G	=	6.673×10^{-11}	N m^2 kg^{-2}
Elementary charge	e	=	1.602×10^{-19}	C
Electron rest mass	m_e	=	9.109×10^{-31}	kg
Unified atomic mass unit	m_u	=	1.661×10^{-27}	kg
Proton rest mass	m_p	=	1.673×10^{-27}	kg
Neutron rest mass	m_n	=	1.675×10^{-27}	kg
Planck constant	h	=	6.626×10^{-34}	J s
Boltzmann constant	k_B	=	1.381×10^{-23}	J K^{-1}
Stefan-Boltzmann constant	σ	=	5.670×10^{-8}	W m^{-2} K^{-4}
Gas constant	R	=	8.314	J mol^{-1} K^{-1}
Avogadro constant	N_A	=	6.022×10^{23}	mol^{-1}
Molar volume of ideal gas at STP		=	2.241×10^{-2}	m^3
One standard atmosphere	P_0	=	1.013×10^{5}	N m^{-2}

SECTION A – Answer all SIX parts of this section

1.1) Raman scattering in a certain material produces a photon at an energy 0.165 eV lower than the energy of the exciting light. Calculate the wavelength of this photon when the wavelength of the exciting radiation is 435.8 nm.

[7 marks]

1.2) The vibrational frequency ν for a diatomic molecule can be written as $\nu = \frac{1}{2\pi}\sqrt{\frac{k}{\mu}}$.

Explain the meanings of the terms k and μ.

For carbon monoxide, ^{12}CO, the vibrational frequency in wavenumbers is 2143 cm^{-1}. Calculate the corresponding frequency for ^{13}CO. The atomic mass number of oxygen is 16.

[7 marks]

1.3) A laser produces either (i) a near-infrared output or (ii) a green output by using a frequency-doubling crystal with an efficiency of 35%. The diameter of the beam is the same at both wavelengths. A lens was used to focus, in turn, the infrared beam and the green beam to diffraction-limited spots. Calculate which of these spots has the higher power density.

[7 marks]

1.4) The mass attenuation coefficient of concrete for gamma rays of a certain energy is 0.0089 m^2 kg^{-1}.

(i) Calculate the thickness of concrete needed to reduce the number of gamma rays in a well-collimated beam to 1 % of the incident number.

(ii) Calculate the half-value layer for gamma rays of this energy.

The density of concrete is 2.35×10^3 kg m^{-3}.

[7 marks]

1.5) Show that, when a non-relativistic particle, with mass m_1 and kinetic energy Q_1, collides with a stationary particle having mass m_2, it transfers to that particle an energy

$$Q_2 = 4\frac{m_1 m_2}{(m_1 + m_2)^2} Q_1 .$$

Hence show that, for a low-energy α-particle colliding with an electron, the energy transferred is approximately given by

$$Q_e \approx \frac{4 Q_\alpha m_e}{m_\alpha} .$$

[7 marks]

1.6) Explain the terms *exposure*, *absorbed dose* and *dose equivalent* used in radiation dosimetry, giving the units in each case.

[7 marks]

SECTION B – Answer TWO questions

2) (a) Describe the phenomenon of *stimulated emission*. Explain what is meant by a *population inversion*, and explain why this is required for the operation of a laser.

[8 marks]

(b) Outline briefly, giving a diagram, the construction of a ruby laser. Sketch an energy level diagram showing the important transitions.

[10 marks]

(c) Explain why the ruby laser can only be operated in the pulsed mode.

[3 marks]

(d) A ruby laser, with a wavelength of 693.4 nm, provides pulses of energy 5 J, lasting for 3 ms at a repetition frequency of 4 Hz.
Calculate:
(i) the number of photons in one pulse,
(ii) the power during a pulse, and
(iii) the average power.

[7 marks]

(e) Describe one medical application for the ruby laser.

[2 marks]

3) (a) Describe and explain three processes by which gamma rays lose energy when passing through an absorbing medium. In each case, indicate the energy range of the gamma rays for which the process is important.

[15 marks]

(b) A source emitting gamma rays with energy 2.61 MeV was placed in contact with a scintillation counter connected to a spectrum analyser. A *back-scatter peak* was observed in the energy spectrum at 0.233 MeV.

(i) Explain the processes by which the back-scatter peak is produced.

[3 marks]

(ii) Determine the energies of four other prominent features in the spectrum.

[12 marks]

4) (a) Show that, for microwaves in a rectangular waveguide

$$\left(\frac{1}{\lambda_g}\right)^2 = \left(\frac{1}{\lambda_a}\right)^2 - \left(\frac{1}{2a}\right)^2$$

where λ_g is the wavelength in the guide, λ_a is the wavelength in free space and a is the larger internal dimension of the waveguide.

[15 marks]

(b) Describe how λ_g can be measured.

[8 marks]

(c) A waveguide has $a = 23$ mm.

(i) Calculate the wavelength in the guide for microwaves of frequency 10 GHz.

(ii) Calculate the lowest frequency that can be propagated in the guide.

[7 marks]