King’s College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CPMP10 Introductory Medical Physics

Summer 2004

Time allowed: THREE Hours

Candidates should answer no more than 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	e_0	=	8.854×10^{-12}	F m^{-1}
Permeability of free space	m_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
		=	4.136×10^{-15}	eV s
Boltzmann constant	k_B	=	1.381×10^{-23}	J K^{-1}
Stefan-Boltzmann constant	s	=	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 SIX parts of this section

1.1) Briefly describe the methods used for controlling external radiation hazards to both patients and occupationally exposed radiation workers.

[7 marks]

1.2) A 100-minute measurement of sample plus background counts yields 10^6 counts, and a 5-minute count of background alone yields 900 counts. Calculate the net signal count rate and its standard deviation.

[7 marks]

1.3) Describe the Compton scattering mechanism by which diagnostic X-ray photons interact with soft tissues. Indicate qualitatively how the interaction depends on photon energy and tissue properties.

[7 marks]

1.4) An air-filled ionization chamber produces a voltage pulse of 0.8 mV when a particle with kinetic energy 1.7 MeV loses all its energy within the chamber. The particle loses 34 eV for each ion pair produced in the chamber. What is the capacitance of the chamber?

[7 marks]

1.5) Explain the following terms, used in magnetic resonance imaging: *gyromagnetic ratio*; *Larmor frequency*; *longitudinal relaxation time* (T_1).

[7 marks]

1.6) How many atoms of C-11, with a decay constant $\lambda = 2\ \mathrm{hr}^{-1}$, are required to produce an activity of 10^6 Bq ?

[7 marks]

1.7) The intensity of a narrow mono-energetic X-ray beam is reduced to 10^6 photons per second by a slab of material 2 cm thick and with a linear attenuation coefficient of 0.07 mm^{-1}. How many photons per second are incident on the slab?

[7 marks]

1.8) Explain what is meant by *digitisation* of an analogue signal. What considerations govern the sampling rate and the precision of the samples?

[7 marks]

SECTION B - Answer TWO questions

2)a) Explain the following terms: *the ALARA principle*; *the ten day rule*; *Roentgen*; *absorbed dose*; *dose equivalent*. State the units employed for measuring the last three listed.

[12 marks]

b) Make a labelled sketch of a portable scintillation device for radiation monitoring. Mention two advantages of using NaI as the scintillator.

[10 marks]

c) Indicate the ways in which radiation workers may become contaminated, and mention what methods are used to remove the contamination.

[8 marks]

3)a) Make a labelled sketch showing the the major components of a modern diagnostic X-ray tube. Indicate the features that help to minimise the radiation dose to the patient and to the operator.

[14 marks]

b) Draw a schematic, but typical, spectrum of the X-rays emitted by a diagnostic imaging device. Briefly discuss the physical processes giving rise to the emitted radiation, and indicate how the spectrum changes when the tube voltage is increased.

[8 marks]

c) The half-value layer of copper is 1.5 mm for mono-energetic X-rays of energy 200keV. Calculate the wavelength and frequency of the photons, and the linear and mass attenuation coefficients of copper, which has a mass density of 8.9 gm cm^{-3}.

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[8 marks]

4)a) Make a labelled sketch of a single element ultrasound transducer for producing short pulses.

[6 marks]

b) A 10 MHz ultrasound beam is used for the detection of blood flowing in a vessel making an angle of 60^{O} with the beam. The echoes back-scattered back to the ultrasound source exhibit a Doppler shift of 0.5 kHz. Calculate the speed of the flowing blood. What can be said about the direction of blood-flow?
Assume that the speed of sound is 1500 m s^{-1} in soft tissues.

[8 marks]

c) Explain what is meant by the following terms, used in medical ultrasound: *wave intensity*; *characteristic acoustic impedance*; *amplitude reflection coefficient*; *absorption*; *wave attenuation*.

[10 marks]

d) Describe the factors which establish the range of the diagnostic frequency range.

[6 marks]

5)a) Make a schematic sketch and briefly explain the operation of a generator for producing Tc-99m in a hospital environment

[10 marks]

b) List the two major imaging techniques included in emission computed tomography, and state what type of radionuclides are used to produce the images.

[4 marks]

c) A radio-active pharmaceutical of activity 1.6×10^{5} Bq and a half-life 6 hours is injected into a patient's blood-stream at 11.00am. The next day, at 2.00pm, a blood sample is taken, and is found to have an activity of 14Bq per 10ml. Estimate the patient's blood volume. State the approximations made in order to arrive at your result.

[8 marks]

d) List the advantages and disadvantages of magnetic resonance imaging (MRI) relative to X-ray imaging.

[8 marks]