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

CPMP10 Introductory Medical Physics

August 2006

Time allowed: THREE Hours

Candidates should answer ALL 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}	$\mathrm{F\,m^{-1}}$
Permeability of free space	μ_0	=	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
Speed of light in free space	c	=	2.998×10^{8}	$\mathrm{m\,s^{-1}}$
Gravitational constant	G	=	6.673×10^{-11}	$\mathrm{N\,m^2\,kg^{-2}}$
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}	$\mathrm{J\,K^{-1}}$
Stefan-Boltzmann constant	σ	=	5.670×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
Gas constant	R	=	8.314	$\mathrm{J\,mol^{-1}\,K^{-1}}$
Avogadro constant	N_A	=	6.022×10^{23}	$\mathrm{mol^{-1}}$
Molar volume of ideal gas at STP		=	2.241×10^{-2}	$\mathrm{m^3}$
One standard atmosphere	P_0	=	1.013×10^{5}	$\mathrm{N\,m^{-2}}$
Mass of the Earth	M_E	=	5.97×10^{24}	kg
Radius of the Earth	R_E	=	6.380×10^{6}	m
Mass of the Sun	M_S	=	1.99×10^{30}	kg
Radius of Earth–Sun orbit		=	1.50×10^{8}	km

SECTION A – Answer ALL parts of this section

1.1) What equipment is used to measure the electrical activity of the heart? Draw a typical signal produced by this equipment and indicate which part of the signal is associated with the ventricular stimulation.

[5 marks]

1.2) The exposure rate, measured at 1 m distance from a source of ionising radiation is 80 mR/min. What is the exposure suffered by a person who spends 10 minutes in the radiation beam, while standing at a distance of 2 m from the tube?

[6 marks]

1.3) Describe, with the aid of diagrams, how a Gamma camera works.

[7 marks]

1.4) With the aid of diagrams, explain briefly the function of an ionisation chamber. State, and explain, whether the following statement is true or false: "A photon with 70 keV energy produces approximately 2000 ion pairs in an ionisation chamber".

[7 marks]

1.5) Make a brief comparison between the following two methods of medical imaging: Gamma Camera imaging and MRI scanner imaging. Comment on the patient risk, image quality and main applications of these two methods.

[7 marks]

1.6) Briefly describe the photo-thermal, photo-mechanical, photo-chemical and photo-ablative effects of laser light when it interacts with tissue.

[8 marks]

SECTION B – Answer TWO questions

2)

a) Draw a labelled diagram showing the design of a modern diagnostic x-ray tube (either with a stationary or a rotating anode).

[10 marks]

b) What material is normally used for the construction of the cathode? Why is this material chosen?

[4 marks]

c) What material is normally used for the construction of the anode? Why is this material chosen?

[8 marks]

d) Sketch a typical spectrum of the x-rays emitted by a diagnostic imaging device, when the accelerating voltage is (i) 50 kV, and (ii) 100 kV. Briefly discuss how the dose to the patient, and the contrast of the x-ray image, depend on the accelerating voltage.

[8 marks]

3)

a) Ultrasound images are formed by pulse-echo techniques. Explain the interactions by which echoes are generated by tissue to give clinical images. What are the practical limitations to ultrasound images and why do these occur?

[14 marks]

b) What factors affect the axial resolution (resolution along the beam) and the lateral resolution (resolution across the image) of the ultrasound image?

[6 marks]

c) Show that the Doppler frequency produced by moving blood can be approximated by the formula:

$$f_d = \frac{2v f_t \cos\theta}{c},$$

where f_d is the Doppler frequency, f_t is the transmitted ultrasound frequency, v is the speed of the scatterer, c is the speed of sound, and θ is the angle between the ultrasound beam and the direction of flow.

[10 marks]

4)

a) Ionising radiation is thought to interact with cellular material through one of two mechanisms. Name the two mechanisms and explain how they may cause damage to cells.

[10 marks]

b) At a macroscopic level, damage may result in deterministic effects or stochastic effects. Using graphs to illustrate your answer, explain what is meant by deterministic and stochastic effects.

[8 marks]

c) The basic principles of protection against ionising radiation are summarised as justification, optimisation and limitation. Explain how these principles have been derived from a knowledge of the effects you have described in your earlier answers.

[12 marks]