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/MP36 Medical Imaging and Measurement

Summer 2006

Time allowed: THREE Hours

Candidates must answer ALL parts from SECTION A,
and 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}	$\mathrm{N\ m^{-2}}$

SECTION A – Answer ALL questions from this section

B 1.1) Describe the process of filtered back projection in Computed Tomography (CT), and explain how the reconstruction filter affects the resulting images.

[5 marks]

B 1.2) a) Explain, with the aid of a diagram, the term *aliasing* with reference to digital imaging systems.

P b) State the relationship between pixel size and the Nyquist limit on resolution. Calculate the Nyquist frequency for a system with a pixel size of 200 µm.

[6 marks]

B 1.3) Sketch graphs of the optical density against relative exposure for a slow X-ray film and a fast X-ray film. Using your sketch, explain the meaning of the term 'latitude'.

[5 marks]

B 1.4) a) Draw a simple diagram (with labels) showing a typical compression device used on a mammography X-ray unit.

b) What are the advantageous of using compression?

[6marks]

B/P 1.5) In Doppler ultrasound, the Doppler frequency f_d resulting from blood moving at velocity V is given by

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

where θ is the angle between the beam and flow direction, c the speed of sound in tissue and f_t the transmitted ultrasound frequency.

In pulsed Doppler the maximum velocity measureable is limited by the need for pulses to be received before the next pulse is transmitted. Show that the relationship between maximum unambiguous velocity V_{max} measured by pulsed Doppler ultrasound and depth d of the vessel under investigation is given by:

$$V_{\max} d \cos\theta = \frac{c^2}{8 f_t}$$

[7 marks]

B 1.6) What are the main differences between gradient echo and spin echo sequences in Magnetic Resonance Imaging?

[5 marks]

B 1.7) Describe the effects of increasing the potential of an X-ray tube on: the wavelength of the X-ray spectrum, the penetration of the beam, the dose given to the patient, and the contrast of the image.

[6 marks]

SECTION B – Answer TWO questions from this section

B2) For a single slice Computed Tomography (CT) scanner describe how changing the following acquisition parameters and settings will affect patient radiation dose, image noise, spatial resolution, z-axis resolution, contrast and image artefacts:

(i) X-ray tube potential
(ii) X-ray tube current
(iii) Rotation time
(iv) X-ray beam collimation
(v) X-ray tube focal spot
(vi) Helical pitch.

[30 marks]

P3) a) Find the energy difference between the low and high energy states for a proton in a 1.5 T magnetic field, given that the resonance frequency for a proton in a 1 T magnetic field is approximately 43 MHz.

[6 marks]

P b) In a 1.5 T field the separation of the main spectral peaks due to water and fat is approximately 3 ppm (3 parts per million). Estimate the frequency shift (in Hz) between water and fat at 1.5 T.

[5 marks]

P c) Derive an expression for the fraction of nuclei in the upper and lower energy states in a constant magnetic field of *B* Tesla and a temperature of *T* Kelvin.

[12 marks]

P d) What is the net magnetisation in parts per million (given by the fraction of nuclei in the lower state minus the fraction of nuclei in the upper state) at 1.5 T and 298 K?

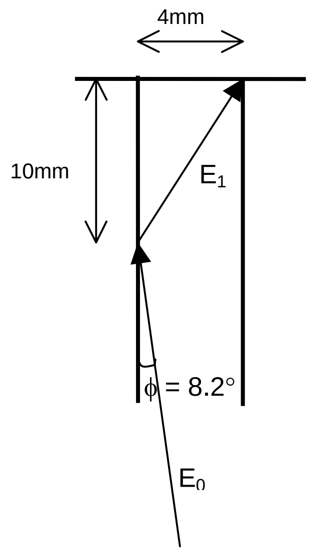
[7 marks]

B4) a) With the aid of a block diagram, describe the principal components of a gamma camera system. Describe the contribution of each of the components to the final image.

[16 marks]

B b) State two properties of sodium iodide which make it a good crystal for use in a gamma camera and give two disadvantages.

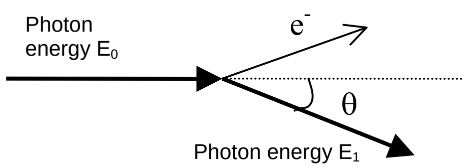
[6 marks]



P c) The diagram above shows one hole through a low energy collimator. A gamma ray of energy E_0 = 140 keV strikes the septum at an angle of 8.2°. If this photon is Compton scattered so that it just reaches the crystal (as shown in the diagram), using the Compton scattering equation below, calculate the energy E_1 of the scattered photon. Will this photon be accepted and form part of the image if the energy window is set at 140 keV±10%? Comment briefly on how events such as this will affect the image quality.

[8 marks]

The Compton scattering equation is given by



$$E_1 = \frac{E_0}{1 + E_0\left(\frac{1-\cos\theta}{m_e c^2}\right)}$$

where $m_e c^2$ = electron rest mass = 511 keV and θ is the scattering angle of the photon.