King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/MP36 Medical Imaging and Measurement

Summer 1997

Time allowed: THREE Hours

Candidates must answer SIX parts of SECTION A,
and TWO questions from SECTION B.

Separate answer books must be used for each Section of the paper.

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

SECTION A - **Answer SIX parts of this section**.

1.1) Derive an expression for the ultrasound amplitude reflection coefficient across a planar interface between two media of different acoustic impedance, for plane waves at normal incidence.

[7 marks]

1.2) Contrast "first-" and "fourth-" generation X-ray systems for medical computerised tomography. List those features of X-radiation, and its propagation in human tissues, that make it suitable for this type of imaging.

[7 marks]

1.3) Discuss how the design of an X-ray mammography unit is determined by the physics of the photon / tissue interaction.

[7 marks]

1.4) An imaging system has a point spread function expressible as $P(x, y) = A\exp(-|x| - |y|)$, where A is a constant. Calculate the modulation transfer function for this system.

[7 marks]

1.5) Discuss why Tc99m is a suitable radionuclide to use for SPECT scanning. Does it have any disadvantages for medical imaging?

[7 marks]

1.6) It is desired to obtain an ultrasound (pulse-echo) B-mode image to a depth of 15 cm in liver. What is the maximum pulse repetition frequency at which the system can be operated? If the nominal transducer frequency is 3 MHz, is it possible that two interfaces 0.25 mm apart can be resolved in the image?

[7 marks]

1.7) Calculate the projection (onto any direction in the plane of $\boldsymbol{r}$) of an annulus,

$$D(\boldsymbol{r}) = c \quad \text{for } a \le |\boldsymbol{r}| \le b$$
$$= 0 \quad \text{otherwise}$$

(with a, b, and c constants).

[7 marks]

1.8) The point spread function of an imaging system is isotropic, and is given by $h(r)$. Show that the Fourier transform of the image of a two-dimensional object, $O(\boldsymbol{r})$, is given by the product of the Fourier transform of the object and the optical transfer function of the system.

[7 marks]

SECTION B - answer TWO questions

2) Define what is meant by the terms *specific acoustic impedance*, and *characteristic acoustic impedance.*

[4 marks]

Derive the expression, $I = \dfrac{A^2}{2\rho c}$, for the intensity of the ultrasound pressure wave, $p(x,t) = A\sin(kx - \omega t)$, where ρ is the density of the medium and c is the velocity of the wave.

[7 marks]

What is the relationship between the particle displacement amplitude and the pressure amplitude for the wave described above?

[7 marks]

What is meant by the terms *acoustic absorption*, *scattering* and *attenuation*? Include a description of the physical processes involved for biological soft tissues.

[12 marks]

3) With the aid of a labelled diagram, discuss the basic principles of the operation of a typical modern PET scanner. State clearly how fundamental features of electron/positron annihilation are exploited in the design of such a scanner

[12 marks]

Explain how, in this type of scanner, the measured data may be corrected for photon attenuation in the body, using a transmission method. Calculate, explicitly, the form of the attenuation correction for a patient whose body cross-section may be assumed to be circular, with constant linear attenuation coefficient.

[12 marks]

Discuss the factors that influence the image resolution attainable by a PET scanner.

[6 marks]

4) A proton is placed in a constant magnetic field, $\boldsymbol{B}$, with its magnetic moment, μ, initially at an angle, φ, to the field. Show that μ precesses about the direction of $\boldsymbol{B}$ and obtain an expression for the magnitude of the Larmor frequency.

Hint: note the following vector identity, $(\boldsymbol{a} \times \boldsymbol{b}) \times \boldsymbol{c} = \boldsymbol{b}(\boldsymbol{c} \cdot \boldsymbol{a}) - \boldsymbol{a}(\boldsymbol{b} \cdot \boldsymbol{c})$.

[20 marks]

Describe how, in an appropriate magnetic resonance system, the free induction decay (FID) of the magnetisation of a tissue *slice* through a patient could be measured. How should the pulse sequence be changed if the longitudinal relaxation time of that slice is also to be measured ?

[10 marks]

5) Demonstrate that, when the Compton effect dominates, the linear attenuation coefficient of a diagnostic X-ray beam in soft tissue is approximately proportional to density. What is the maximum energy of the recoil electron in a Compton event occurring in such a beam, if the X-ray system is operated at *E* kVp?

[10 marks]

Explain, in a descriptive way, the principles underlying the filtered backprojection technique, as applied in computerised tomographic imaging.

[8 marks]

An X-ray system is known to have an isotropic point-spread function *('PSF')*. Derive the relationship between the point-spread and line-spread functions, making clear any assumptions made. Indicate how it would be possible in practice to obtain the *PSF* from the image of a straight rod. What constraints are there on the size and material of the rod?

[12 marks]