

NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHYSICS DEPARTMENT

SPH 4160 MEDICAL PHYSICS I

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BSc HONOURS PART I : Nov/Dec 2001

DURATION : 3 HOURS

ANSWER ALL PARTS OF QUESTION 1 IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS

Rydberg Constant	$R = 1.10 \times 10^7 \text{ m}^{-1}$
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J.s}$
Boltzmann constant,	$k = 1.38 \times 10^{-23} \text{ J/K}$
Avogadro's Number,	$N = 6.02 \times 10^{23} \text{ mol}^{-1}$
Electron rest mass,	$m_e = 9.11 \times 10^{-31} \text{ kg}$
Speed of light,	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
1 electron volt	$e = 1.60 \times 10^{-19} \text{ J}$
Mass of electron,	$m_e = 5.48 \times 10^{-4} \text{ u}$
Mass of proton,	$m_p = 1.007 825 \text{ u}$
Mass of neutron,	$m_n = 1.008 665 \text{ u}$
1 atomic mass unit,	$1 \text{ u} = 931.49 \text{ MeV}/c^2$
Electronic Charge,	$e = 1.60 \times 10^{-19} \text{ C}$
Stefan – Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$
Wein's constant,	$k = 2.90 \times 10^{-3} \text{ m} \cdot \text{K}$
Wien's displacement law constant	$= 2.898 \times 10^{-3} \text{ m} \cdot \text{K}$
Mean radius of the sun,	$R_0 = 6.96 \times 10^8 \text{ m}$
Mass of the sun,	$m_{\text{sun}} = 1.99 \times 10^{30} \text{ kg}$
1 Ci	$= 3.70 \times 10^{10} \text{ Bq}$
1 Tesla	$= 10^4 \text{ G (Gauss)}$
Gyromagnetic ratio,	$\gamma = 42.58 \text{ MHz/T}$

SECTION A

1. (a) A sample contains water at two locations, $x = 0 \text{ cm}$ and $x = 2.0 \text{ cm}$. A one-dimensional magnetic field gradient of 1 G/cm is applied along the x -axis during the acquisition of an FID. The frequency encoding gradient is 1 G/cm . What frequencies (relative to the isocenter frequency) are contained in the Fourier transformed spectrum? [5]
- (b) Computed tomography is based on the interpretation of Hounsfield Numbers. What are they? [4]

- (c) What is the term used given for :
- (i) the difference in dB between the thresholds of hearing and the uncomfortable loudness level [1]
 - (ii) the test to determine the relationship between stimuli and the sensations they produce? [1]
- (d) Discuss one method by which directional flow can be detected in Doppler ultrasound [5]
- (e) Using illustrative diagrams, describe the general mechanisms of production of the refraction artefact in ultrasound imaging. [5]
- (f) Name four desirable properties for radioisotopes used for nuclear medicine imaging. [2]
- (g) Define the following terms
- (i) tenth value layer, [2]
 - (ii) dose equivalent, and [2]
 - (iii) mass attenuation coefficient. [2]
- (h) A sample has a T_1 of 1.0 seconds. If the net magnetization is set equal to zero, how long will it take for the net magnetization to recover to 98% of its equilibrium value? [5]
- (i) What do you understand by the term 'fast film'? [2]
- (j) With the help of a diagram, show the effect of x-ray focal spot on the quality of the x-ray image. [4]

SECTION B

2. (a) Explain the difference between T1 and T2 processes in Magnetic Resonance Imaging (MRI). [12]
- (b) Write short notes on the safety of MRI [8]
3. Digital sound recording has seen the traditional *wav* format replaced for most applications by *mp3* and *WMA* audio formats. Give a technical overview of the *mp3* and *WMA* audio format highlighting the compression algorithm used and advantages over traditional *wav* and *cd* formats. [20]
4. (a) The radionuclide ^{99}Mo has a half life of 66.7 hrs and decays to $^{99\text{m}}\text{Tc}$. Show that for a sample which initially contains N_0 atoms of ^{99}Mo and no atoms of $^{99\text{m}}\text{Tc}$, the number of $^{99\text{m}}\text{Tc}$ atoms (N_T) present at a later time t is given by $N_T = \frac{N_0 \lambda_m}{\lambda_m - \lambda_T} (e^{-\lambda_m t} - e^{-\lambda_T t})$ where λ_m and λ_T are the decay constants of ^{99}Mo and $^{99\text{m}}\text{Tc}$ respectively. [7]
- (b) A ^{99}Mo - $^{99\text{m}}\text{Tc}$ system has an initial ^{99}Mo activity of 7.4 GBq at 8.00 am on a Wednesday. $^{99\text{m}}\text{Tc}$ is extracted from the system at 8.00 am the following day. Determine the activity of the extracted $^{99\text{m}}\text{Tc}$ if the extraction efficiency were 80%. [7]
- (c) At what time should the next extraction take place in order to obtain the maximum activity of the $^{99\text{m}}\text{Tc}$? [6]
5. (a) Outline the physics of X-ray photon production in the X-ray tube anode/target and explain how and why the energy characteristics of such X-ray output must be modified for use in the imaging of patients. [5]
- (b) Outline the two interactions of X-ray photons in the tissues of a patient being imaged. Explain how these interactions influence the quality of image production and patient dose as overall X-ray energy is progressively increased. [10]
- (c) Draw and label a double coated film suitable for x-ray imaging. [5]

6. (a) Describe how the attenuation coefficient varies with frequency for different tissues, and discuss the consequences of these variations (or lack of them) for ultrasonic imaging. [5]
- (b) How do the parameters describing image quality in list A depend on the scanner characteristics in list B?

List A	List B
Lateral resolution	Transmission pulse bandwidth
Maximum useful penetration	Transducer aperture
	Depth of selected field of view
	Transmission focal length
	Width of selected field of view
	Transmission pulse centre frequency

[5]

- (c) Draw a functional block diagram for a continuous wave Doppler machine. [4]
- (d) A 4 MHz pulsed Doppler system is used to examine blood flow in part of an artery at a range of 10 cm. In the examined part of the artery, the direction of blood flow is towards the probe, at an angle of 45° to the direction of the ultrasound, and the peak speed achieved by the blood in each cardiac cycle is 1.80 m/s. (Assume that the speed of sound is 1540 m/s, and that $\cos 45 = 0.707$.)

Calculate the

- (i) peak Doppler frequency shift. [2]
- ii) highest pulse repetition frequency that could be used, if range ambiguity is to be avoided. [2]
- iii) highest blood speed that could be measured without aliasing. [2]

END OF PAPER