UNIVERSITY OF SOUTHAMPTON PHYS2007W1

SEMESTER 2 EXAMINATION 2014-2015

MEDICAL PHYSICS

Duration: 120 MINS (2 hours)

This paper contains 10 questions.

Answer **all** questions in **Section A** and **only two** questions in **Section B**.

Section A carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 mins on it.

Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 mins on it.

An outline marking scheme is shown in brackets to the right of each question.

A Sheet of Physical Constants is provided with this examination paper.

Only university approved calculators may be used.

A foreign language word to word® translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

Section A

A1. With the aid of a suitable diagram, define the terms *mean range*, *extrapolated range*, and *straggling* for heavy charged particles. [4]

A2. Briefly explain the differences between *absorbed dose*, *equivalent dose*, and *effective dose*. Your answer should indicate the appropriate units for each case. [3]

A3. Briefly explain how $^{99}\mathrm{Tc}^{m}$ meets three key requirements of radioisotopes for use in nuclear medicine. [3]

A4. Explain the meaning of *image contrast* and how it is quantified. [4]

A5. What purpose does a grid serve in radiography? Draw an example of a focused grid which illustrates your answer. [4]

A6. Describe how protons interact with a magnetic field to create two spin states. [2]

Section B

B1. (a) With the aid of a block diagram, describe how MV photons are generated and delivered by a medical linear accelerator (LINAC). [11]

(b) With the aid of a diagram, describe the depth dose curve for an MV photon beam. Include in your answer a discussion of the dominant interactions between photons and tissue. What are the main clinical advantages of using an MV photon beam instead of a kV X-ray beam for treatment? [5]

(c) A patient is planned to receive a total dose of 40 Gy in 20 fractions with MV photons. If the clinician decided that they wanted to deliver the dose in n=10 fractions instead, calculate the dose per fraction d that must be delivered in order to have the same biological effect on the tumour, given that

$$EQD_2 = \frac{nd(d + \alpha/\beta)}{(2 + \alpha/\beta)}$$

and $\alpha/\beta = 10$ for the tumour. [2]

What might be the disadvantages of this change? [2]

TURN OVER

B2. Positron Emission Tomography (PET) is increasingly utilised in diagnostic imaging, particularly for oncology applications.

(a) PET offers functional information with unrivalled sensitivity. Briefly discuss two other aspects of PET imaging that make it particularly attractive as a functional (molecular) imaging modality. [4]

(b) Sketch a line diagram of the principal components of a PET detector system. [5]

(c) Explain why 2-D PET scanning was used historically, but is not required for modern detector systems. How was 2-D PET scanning achieved? What advantage do modern 3-D systems have compared to earlier 2-D systems? [5]

(d) For more than a decade, PET imaging systems have been combined with other imaging modalities, producing dual-modality systems. What are two of the key advantages to obtaining X-ray computed tomography (CT) data concurrently with PET images? [3]

(e) Time of Flight (ToF) PET has the potential to deliver improved image contrast, potentially improving lesion detection. For a timing window of $\Delta t = 0.5$ ns, what is the theoretical event localisation distance Δx? Which component limits ToF performance in current systems? [3]

B3. (a) The equation that describes signal intensity in an inversion recovery pulse sequence is

$$M_z = M_0[1 - 2\exp(-TI/T_1)].$$

Sketch the signal intensity as a function of TI and, making use of your sketch, explain the terms in this equation. What is the significance of the point at which $M_z = 0$? [3]

In a fluid attenuated inversion recovery (FLAIR) pulse sequence, calculate the inversion time used to null signal from cerebrospinal fluid (CSF), assuming $T_{1CSF} = 3600$ ms. [3]

Briefly explain why fat has a shorter T_1 time than CSF. [3]

(b) Provide a description of k-space (as applied to MRI) and describe how phase and frequency encoding gradients are used to fill k-space (include diagrams). [8]

(c) Calculate the acquisition time (in minutes and seconds) of a spin echo pulse sequence if the repetition time $TR = 500$ ms, the echo time $TE = 40$ ms, the flip angle $= 90°$, a 256 x 256 matrix image is acquired and the number of signal averages (NSA) = 2. [3]

TURN OVER

B4. (a) With the aid of a diagram, describe the function of the components of a simple continuous wave Doppler ultrasound transducer. Explain how the sizes of the critical components are optimised. [4]

(b) Show that for a sound wave of frequency f, incident normally on a reflector moving in the same direction at a velocity v, the change in frequency of the reflected wave, Δf, is given by:

$$\frac{\Delta f}{f} = -\frac{2v}{v_s}$$

(assume that v is much less than the speed of sound $v_s = 1540$ m/s in tissue) [8]

(c) If a continuous wave ultrasound system has a transducer that operates at a frequency of 6 MHz, what Doppler shift frequency would be observed from blood cells that are moving away from the transducer at a velocity of 2 m/s? (assume the blood cells move along the ultrasound axis) [2]

(d) If the transducer described above is replaced with a pulsed Doppler transducer operating at the same frequency, *by deriving an appropriate expression*, calculate the maximum velocity of blood that can be accurately measured if the distance to the target blood cells of interest is 5 cm. [6]

END OF PAPER

