The University Of Sheffield.

DEPARTMENT OF PHYSICS & ASTRONOMY

Spring Semester 2006-2007

ADVANCED TOPICS IN MEDICAL RADIATION PHYSICS **2 Hours**

The paper is divided into two sections: A and B.

The student should answer ALL questions in Section A. One sentence answers are sufficient for all questions in this section.

The student should answer TWO questions from Section B.

A formula sheet and table of physical constants is attached to this paper.

SECTION A (Answer <u>all</u> questions: 2 marks for each question)

A1 What is the name given to the 1-D light scattering theory that incorporates absorption and scatter of two opposing and independent fluxes?

A2 Laser irradiation of tissue can lead to local heating that generates explosive steam pockets capable of rupturing the tissue. What is the name given to this process?

A3 Write down the definition of the integral of $y(x)$ integrated between the limits a and b.

A4 What do the letters ALARP stand for in radiation protection?

A5 A radioactive source decays to 1/5 of its original activity in 2 days. What is its half life?

A6 Diagnostic imaging with MRI typically relies on the resonance of which biomolecular component?

A7 Sketch a graph illustrating the changing z-magnetisation of a tissue sample subjected to a magnetic resonance 180° pulse followed by Free Induction Decay.

A8 Spin-spin interactions are responsible for signal loss in MRI. By which time constant (T_1, T_2, T_2^*) are they characterised?

A9 Write the numerical value of charge associated with the positron.

A10 What is meant by reaction cross-section in radiation physics?

A11 What is the Henyey-Greenstein phase function?

A12 Which one of the following most closely approximates the depth of the sub-surface maximum dose for megavoltage X-rays incident on tissue?

(i) 0.1 mm
(ii) 1 mm
(iii) 10 mm
(iv) 100 mm

A13 What is the name given to the microwave generator in a therapy linear accelerator?

A14 What is meant by the ‘direct mechanism’ of radiation damage?

A15 Which one of the following describes the main reason why greater sensitivity (counts per second) is achieved with PET (dedicated) compared to SPECT:

(i) There is more scintillation crystal material in a PET scanner than a gamma camera.

(ii) Physical collimation is not required for PET imaging.

(iii) Two gamma rays are emitted per disintegration with PET radionuclides whereas there is only one with SPECT radionuclides.

(iv) The scintillation material used in PET scanners has a higher stopping power than NaI.

A16 Place the following activities in ascending order of acquired radiation dose

(i) CT scan;

(ii) living in Cornwall for 2 weeks;

(iii) chest X-ray;

(iv) nuclear medicine bone scan.

A17 A source of ^{99m}Tc is placed in front of a scintillation-based probe detector and an energy spectrum obtained. Calculate the full-width half maximum of the photopeak if the probe is known to have an energy resolution of 15.3%.

A18 The active face of a gamma camera is flooded with a uniform flux of radiation such that the measured count-rate is 25 K counts per second. An image is acquired for 10 minutes using a matrix size of 256×256. Approximately how many counts would you expect in each pixel?

A19 If the field of view of a gamma camera is 45 cm, what is the corresponding size of each pixel in an image acquired with a 256^2 matrix and a zoom of 2.5?

A20 Which two of the following statements about radionuclide therapy are true? A higher target dose is achieved with unsealed source radiotherapy compared to that obtained with a diagnostic nuclear medicine test because:

(i) Radionuclides are used which emit less penetrating radiation.

(ii) Radionuclides are used which emit more penetrating radiation.

(iii) Higher activities of radionuclide are used.

(iv) Pharmaceuticals with a higher specificity are used.

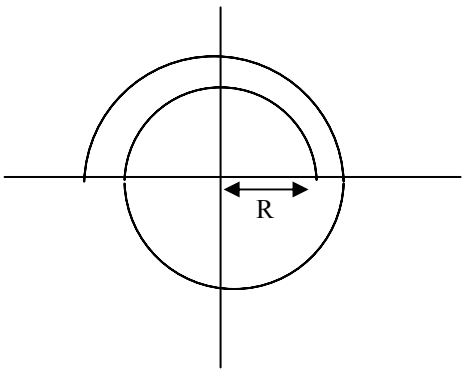
SECTION B (Answer two questions: 30 marks for each question)

B1 (a) The parametric description of a circle is given by

$$x = r\cos\theta$$
$$y = r\sin\theta$$

Sketch a graph illustrating how r varies with θ. [3]

(b) Consider a spiral whose radius is initially R, and steadily increases by 0.3 R over the angular range 3π (see diagram below). Sketch a graph illustrating how radius (r) varies with θ and write a formula describing this relationship. Use this to construct a parametric formula capable of describing the spiral. [8]



(c) Create an expression that describes the length of the spiral as a function of θ. [10]
(Hint: relate the elemental length of the spiral to its radius).

(d) A radioactive line source of activity 10 MBq/mm is bent into the spiral shown in the diagram (R = 1 cm). Calculate its activity. [3]

(e) The source is made of iridium wire (^{192}Ir), known to have a half-life of 74 days. What period of time must elapse in order for the activity of the spiral to drop to 1 MBq? [4]

(f) In which therapeutic area of medical physics are radioactive wire sources used to treat patients? [2]

B2 (a) Consider a collimated particle flux (N_0) incident upon a slab of absorbing material, characterised by the linear absorption coefficient μ. Assume that scatter within the material is negligible and derive the Beer's Law formula that relates the emergent flux to the thickness of the slab. [10]

(b) Scatter complicates description of light transport in tissue. Sketch the phase function for an isotropic point scatterer. [4]

(c) An isolated isotropic point scatterer will act as a point source. Use a physical argument to construct a relationship that links measured scattered intensity to distance from such an illuminated, isolated scatterer. [4]

(d) Scatter and absorption are attenuating processes that are also a feature of ionising radiation. What is the name given to the ionising radiation equivalent of the phase function? [2]

(f) Briefly describe the three principal photon attenuation processes for MeV photons incident upon tissue. [10]

B3 (a) With the aid of diagrams, describe how the tomographic images are produced from a dedicated PET scanner (ring system). [16]

(b) Briefly describe how a gamma camera can be modified so that it can be used to acquire PET images. What are the advantages/disadvantages of such a system compared to a dedicated PET scanner? [8]

(c) Time-of-flight reconstruction is a new, more sophisticated, method of reconstructing PET images where the location of each annihilation event is determined more accurately than just somewhere along a line joining the 2 triggered detectors (i.e. the event is isolated to part of the line). What temporal resolution would be required from the detectors in a dedicated PET scanner in order to enable time-of-flight reconstruction? (Assume that the radius of the scanner ring is 33cm.) [6]

END OF QUESTION PAPER