Index Number: .....

50

RAJARATA UNIVERSITY OF SRI LANKA
FACULTY OF APPLIED SCIENCES

B.Sc. (General) Degree in Applied Sciences
Third Year Semester II Examination – July 2020

PHY 3211 – MEDICAL PHYSICS

Time: Two (02) hours

- **Answer four (04) questions only**
- A non-programmable calculator is permitted.
- The answers should be written in the question paper itself.

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{ms}^{-1}$
electron charge	$e = 1.60 \times 10^{-19}\ C$
the Plank constant	$h = 6.63 \times 10^{-34}\ \mathrm{Js}$
mass of electron	$\mathrm{m}_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
mass of proton	$\mathrm{m}_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
acceleration of free fall on the Earth's surface	$\mathrm{g} = 9.81\ \mathrm{ms}^{-1}$
electron volt	$1\ \mathrm{eV} = 1.60 \times 10^{-19}\ \mathrm{J}$
Rydberg constant	$R_H = 1.097 \times 10^{7}\mathrm{m}^{-1}$
Atomic mass unit	$1\ \mathrm{U} = 931.6\ \mathrm{MeV}$
Angstrom	$1\text{Å} = 1 \times 10^{-10}\ \mathrm{m}$
Roentgen	$1R = 2.58 \times 10^{-4}\ C\mathrm{kg}^{-1}$ (X-ray or γ-rays in dry air at STP)
Rad	$1\ \mathrm{rad} = 0.01\ \mathrm{J\ kg}^{-1}$
Curie	$1\ \mathrm{Ci} = 3.7 \times 10^{10}\ \mathrm{decays\ s}^{-1}$
Becquerel	$1\ \mathrm{Bq} = 1\ \mathrm{decays\ s}^{-1}$

Continued...

Index Number: .....

1. The following figure shows how the binding energy per nucleon varies with nucleon number.

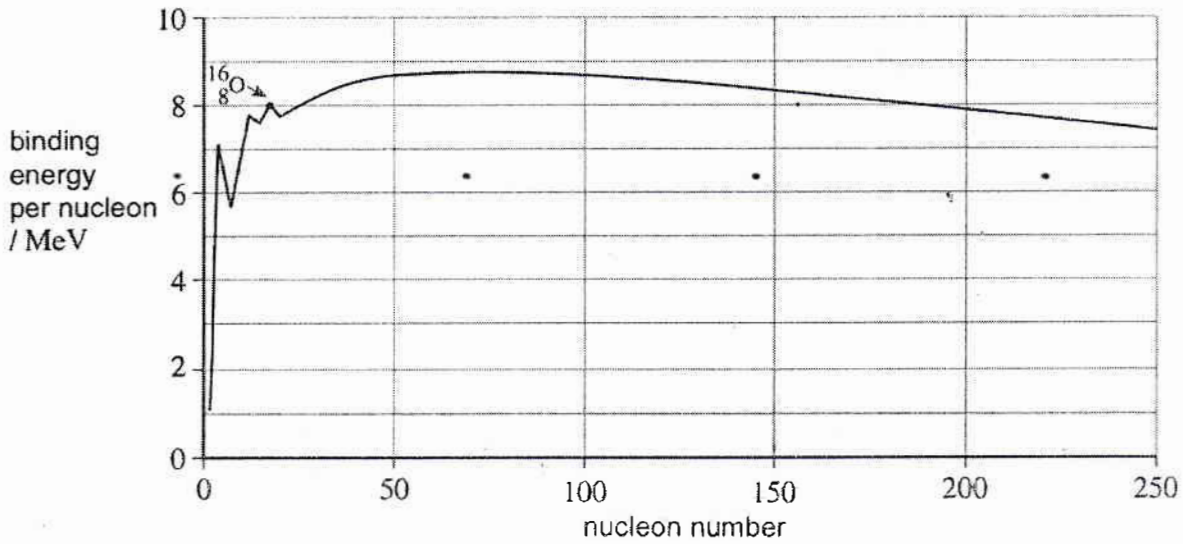

Figure 1

a) i. Fission and fusion are two nuclear processes in which energy can be released. Explain why nuclei that undergo fission are restricted to a different part of the graph than those that undergo fusion. (3 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

ii. Explain, with reference to **Figure 1**, why the energy released per nucleon from fusion is greater than that from fission. (2 marks)

.....
.....
.....
.....
.....

Continued...

b) i. Calculate the mass difference of the $^{16}_{8}O$ nucleus. (5 marks)

mass of $^{16}_{8}O$ nucleus = 15.991 u

ii. Using your answer to part **(b)(i)**, calculate the binding energy, in MeV, of an oxygen $^{16}_{8}O$ nucleus. (3 marks)

iii. Explain how the binding energy of an oxygen $^{16}_{8}O$ nucleus can be calculated with information obtained from **Figure 1**. (2 marks)

Index Number: .....

2. In order to take an X-ray photograph, the X-ray beam is passed through an aluminium filter to remove low energy X-ray photons before reaching the patient.

a) Suggest why it is necessary to remove these low-energy X-rays. (2 marks)

.....
.....
.....
.....
.....

b) The average linear attenuation coefficient for X-rays that penetrate the aluminium is 250 m^{-1}. The intensity of an X-ray beam after travelling through 2.5 cm of aluminium is 347 W m^{-2}.

Show that the intensity incident on the aluminium is about 2×10^5 W m^{-2}. (3 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

c) The X-ray beam at the filter has a circular cross-section of diameter 0.20 cm. Calculate the power of the X-ray beam emerging from the aluminium filter. Assume that the beam penetrates the aluminium filter as a parallel beam. (3 marks)

.....
.....
.....
.....
.....
.....

d) The total power of X-rays generated by an X-ray tube is 18W.
The efficiency of conversion of kinetic energy of the electrons into X-ray photon energy is 0.15%.

i. Calculate the power of the electron beam. (2 marks)

ii. Calculate the velocity of the electrons if the rate of arrival of electrons is $7.5 \times 10^{17}\ s^{-1}$. Relativistic effects may be ignored. (2 marks)

Continued...

Index Number: .....

iii. Calculate the potential difference across the X-ray tube required to give the electrons the velocity calculated in **(ii)**. (3 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

3. a) Outline the basic principles of a magnetic resonance (MR) scanner used to scan a patient's brain. (3 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

Continued...

b) State and explain two advantages of using an MR scanner to scan a patient's brain compared with a CT scanner. (4 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

c) An endoscope is used to view an area inside the body. The endoscope contains two bundles of optical fibres. Name each bundle and explain its use in the process. (4 marks)

Bundle 1:

.....
.....

Bundle 2:

.....
.....

d) A single optical fibre is placed in the air. The optical fibre has a core surrounded by cladding. The critical angle is 75° at the core-cladding boundary.

Complete **Figure 2** to show how the refractive index varies with radial distance from the centre of the core to the air surrounding the fibre.
Your answer should be supported by a suitable calculation. (4 marks)

refractive index of core = 1.6

.....
.....
.....

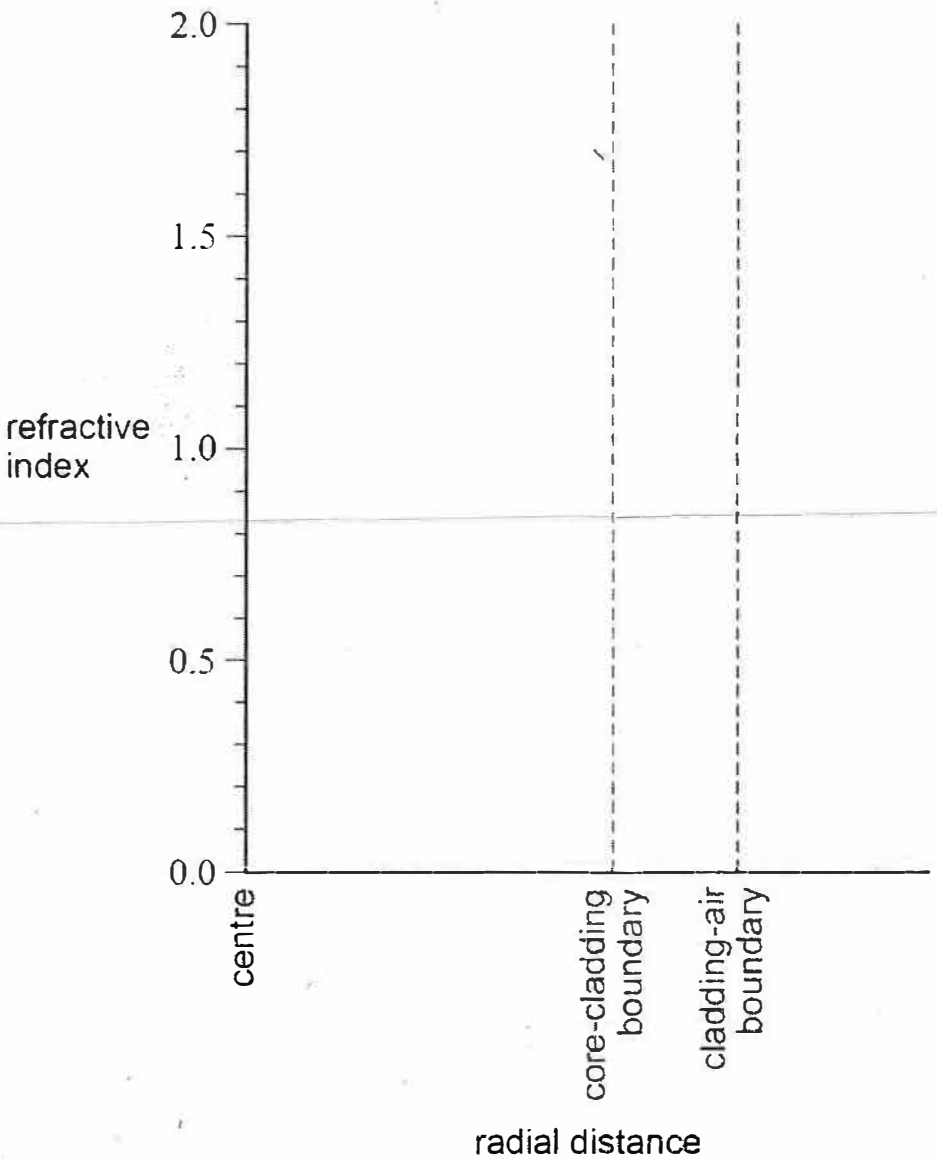

Figure 2

Continued...

4. a) Explain why the effective half-life of a radionuclide in a biological system is always less than the physical half-life. (2 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

b) The physical half-life of a radionuclide is 20 days. The nuclide was administered to a patient. Initially the corrected count rate at the patient's body was 2700 counts s^{-1}. Five days later, the corrected count rate at the same place on the patient was 1200 counts s^{-1}.

Calculate the biological half-life of the nuclide. (4 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

Continued...

c) The table below gives the properties of two radionuclides.

	Technetium 99 m	Iodine 131
emitted radiation	gamma	beta$^-$ and gamma
half-life / hours	6.0	190
energy of gamma ray / keV	140	610

By considering the information in the table, suggest which of these nuclides is more suitable to use as a tracer in medical diagnosis. (4 marks)

d) The age of an ancient boat may be determined by comparing the radioactive decay of $^{14}_{6}C$ from living wood with that of the wood taken from the ancient boat.
A sample of 3.00×10^{23} atoms of carbon is removed for investigation from a block of living wood. In living wood one in 10^{23} of the carbon atoms is of the radioactive isotope $^{14}_{6}C$, which has a *decay constant* of $3.84 \times 10^{-12} s^{-1}$.

Continued...

Index Number: .....

i. What is meant by the decay constant? (2 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

ii. Calculate the half-life of $^{14}_{6}C$ in years, giving your answer to an appropriate number of significant figures (1 year = 3.15×10^7 s) (3 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

Continued...

5. a) When using an X-ray source to produce an image of part of a patient a lead grid is sometimes placed between the patient and the photographic film, as shown in **Figure 3**. The channels in the grid diverge from the X-ray source.

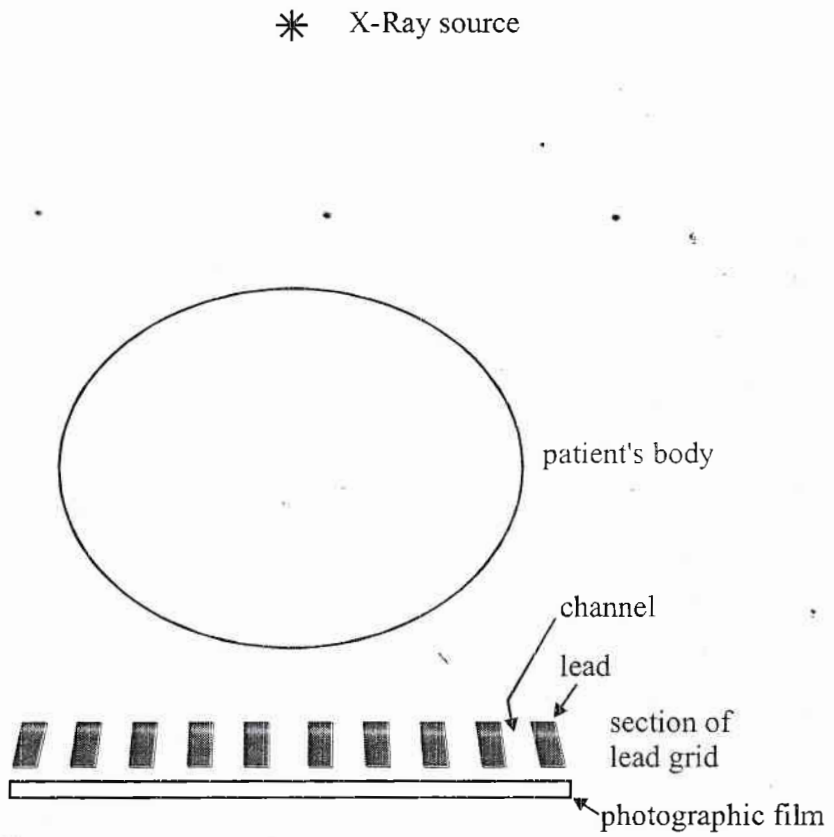

Figure 3

i. I. Why is the grid made of lead? (1 mark)

.....

.....

II. By drawing the paths of about 10 rays from the X-ray source in **Figure 3**, to illustrate your answer, explain how the use of the grid improves the clarity of the X-ray image. (4 marks)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

ii. Explain why is it important to use a point source of X-rays for imaging purposes.

(2 marks)

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

c) Define for a material,

i. The linear attenuation coefficient, μ (1 mark)

.....
.....
.....

ii. The half-value thickness. (1 mark)

.....
.....
.....

d) i. State two applications of laser radiation in medicine. (2 marks)

1. .....
.....
.....

2. .....
.....
.....

Continued...

ii. For one of the applications which you have given, describe how the laser radiation is applied and state any safety features needed. (4 marks)

Method of application

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

Safety features

.....
.....
.....
.....
.....
.....
.....

.....

.....
.....
.....
.....
.....
.....

--- END ---