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RAJARATA UNIVERSITY OF SRI LANKA
FACULTY OF APPLIED SCIENCES

B.Sc. (General) Degree in Applied Sciences
Third Year - Semester I Examination – October/ November 2014

PHY 3211 – MEDICAL PHYSICS I

Answer any four (4) questions **Time: 2 hours**

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{ms}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Plank constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
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	$g = 9.81\ \mathrm{m\,s}^{-1}$
electron volt	$1\ \mathrm{eV} = 1.60 \times 10^{-19}\ \mathrm{J}$

1. (a) State the function of the following parts of an X-ray tube:

   (i) The filament [2]

   (ii) The glass tube which encloses the anode and filament [2]

   (iii) Rotating anode [2]

   (b) An X-ray tube works by accelerating electrons through a potential of 65 kV towards a target.

   (i) What is the ***kinetic energy*** of an electron arriving at the target? [2]

   (ii) Assuming that the usual kinetic energy formula is valid, calculate the theoretical ***speed*** reached by an electron. [2]

(iii) What happens to the kinetic energy of the electrons when they strike the X-ray tube target? [2]

(iv) A typical X-ray tube has an efficiency of less than 1%. List two features of an X-ray tube target that enable it to cope with this low efficiency. [2]

(v) The electron beam in a certain X-ray tube is accelerated through a potential difference of 50 kV and carries a current of 0.005 A. The tube has an efficiency of 1%. Calculate,

I. The electrical ***power supplied*** to the X-ray tube. [2]
II. The X-ray ***energy emitted*** per second. [2]
III. The ***heat generated*** per second at the anode. [2]

2. (a) The equation $I = P/4\pi r^2$ where, P is the power and r is the radius, can be used in calculating the intensity of x-rays from a source.

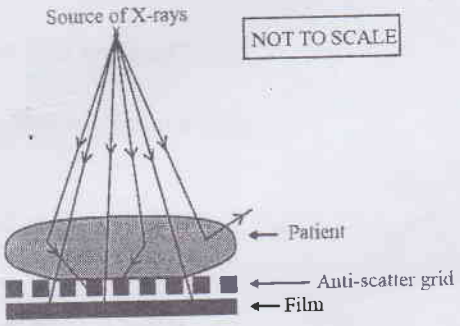
(i) Use this equation to show that the base units of intensity are kg s^{-3} [2]

(ii) An X-ray beam has an intensity of 5.7 W mm^{-2} at a distance of 0.4 m from an X-ray tube. How far from the X-ray tube should a radiographer stand in order to reduce the intensity to 0.80 W mm^{-2}? [3]

(b) On an X-ray photograph, bones show up as bright areas and air spaces such as the lungs produce very dark regions. Explain why. [3]

(c) State two ways in which the radiographer is protected from over-exposure to X-rays [4]

(d) The diagram shows keV X-rays being used for diagnosis.



(i) Use the diagram to explain how an anti-scatter (collimator) grid improves the sharpness of an X-ray image. [3]

(ii) State the material from the anti-scatter grid is made [1]

(e) Briefly explain the following.

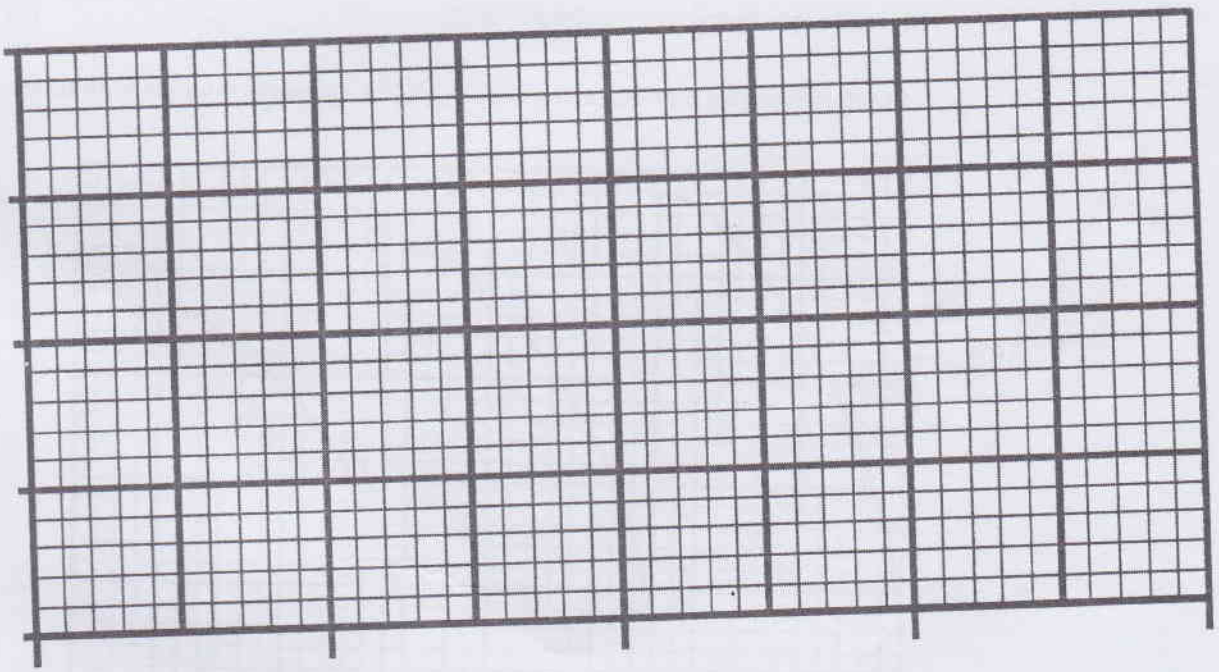
(i) Photoelectric effect [2]

(ii) Compton scattering [2]

3. (a) Compare and contrast alpha and beta radiation. [4]

(b) (i) Iodine-123 has a half-life of 13.3 hours. A sample of Iodine-123 has an initial activity of 800 Bq. How long will it take for the activity to fall to 1000 Bq? [2]

(ii) On the axes below sketch a graph to show how the activity of the sample varies with time over a period of 80 hours. [4]



(iii) An identical sample is administered to a patient. Discuss whether the measured activity from the patient produces the same graph you sketched or a different graph? [1]

(c) Read the short passage bellow and answer the questions.

$^{99m}_{43}Tc$ is a γ emitting radionuclide of half-life 6 hours used in tracer studies. It produces 43 protons when the radionuclide $^{99}_{42}Mo$ decays by β emission. This decay has a half-life of 67 hours. Because of its short half-life $^{99m}_{43}Tc$ must be produced in portable generators. These contain the parent isotope $^{99}_{42}Mo$. When required the $^{99m}_{43}Tc$ is obtained by flushing salt solution through the generator, a process known as elution. The molybdenum is not removed by this process and after approximately a day new daughter isotope will be produced for another elution to take place. The generator needs replacing approximately weekly since the $^{99}_{42}Mo$ activity falls to an inadequate level after this time.
[*Adapted from Medical Physics Imaging by J Pope*]

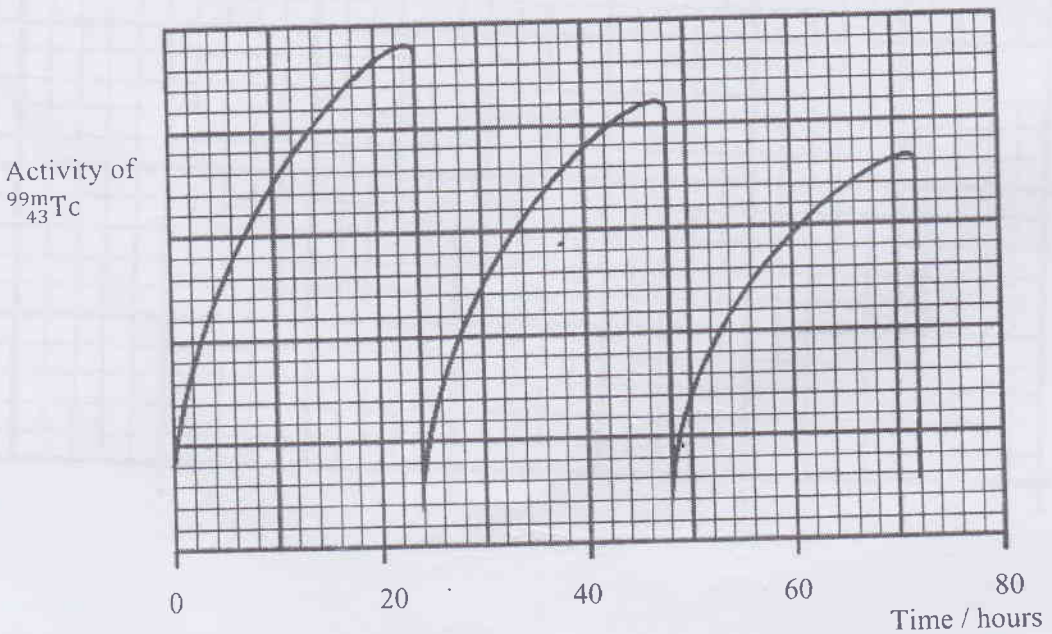
(i) Explain what is meant by ***elution*** [1]

(ii) Write a nuclear equation for the decay of molybdenum [2]

(iii) Why should $^{99m}_{43}Tc$ be produced in portable generators? [1]

(iv) Show that after 1 week the activity of the $^{99}_{42}Mo$ in a portable generator has fallen to less than $\frac{1}{4}$ of its original value. [2]

(v) The sketch shows how the activity of $^{99m}_{43}Tc$ in a generator varies with time.



Indicate on the graph, the time at which the second elution takes place. [1]

(vi) Explain why ***successive*** Tc activity peaks are smaller. [1]

(vii) Why is it advisable to leave a period of approximately 1 day between elutions? [1]

4. (a) What does the term CT stand for of a CT scan [1]

(b) Explain how a CT scan is produced [4]

(c) Technetium-99m is an artificial isotope which is frequently used to obtain a scan of the human body.

(i) Using the graph, determine the half-life of technetium-99m. [1]

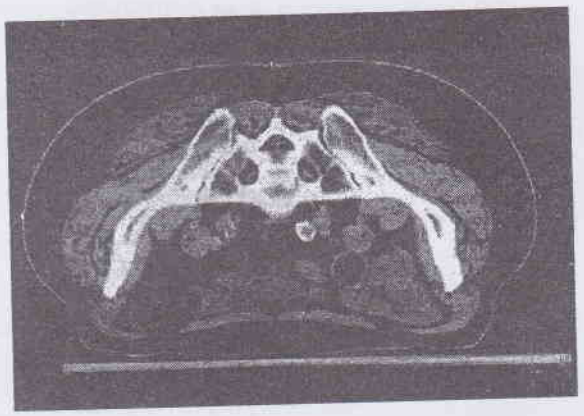
(ii) A patient is given an injection containing 6.0×10^{-18} kg of technetium-99m. The scan is taken four hours after the injection.

How much technetium-99m remains undecayed when the scan is taken? Give your answer in kilograms. [2]

(iii) Propose reasons why scans are best taken between two and five hours after injection of this radioisotope. [2]

(d) The diagrams shown are an X-ray of a human hand and a CT scan of the human pelvis (hipbone) as seen in cross-section from above.

X-ray of human hand
Procedure time: 5 min



CT scan of human pelvis (hipbone)
Procedure time: 40 min

(i) A patient is brought into a hospital out-patients ward complaining of a severe headache. He explains that he hit his head while playing football. The doctor thinks that the patient may be suffering from a fractured skull.

Out of these two methods, what is the best method a doctor could order to confirm the diagnosis of a fractured skull? Comment. [3]

(ii) What are the advantages of CT scans over X-ray scans. [4]

(iii) In a CT scan, the X-rays are filtered so that X-rays passing through the patient are monochromatic. Give reasons. [3]

5. (a) With reference to the process of ***nuclear fusion***, explain why energy is released when two small nuclei join together, and why is it difficult to make two nuclei come together. [2]

(b) A fusion reaction takes place when two deuterium nuclei join, as represented by

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n}$$

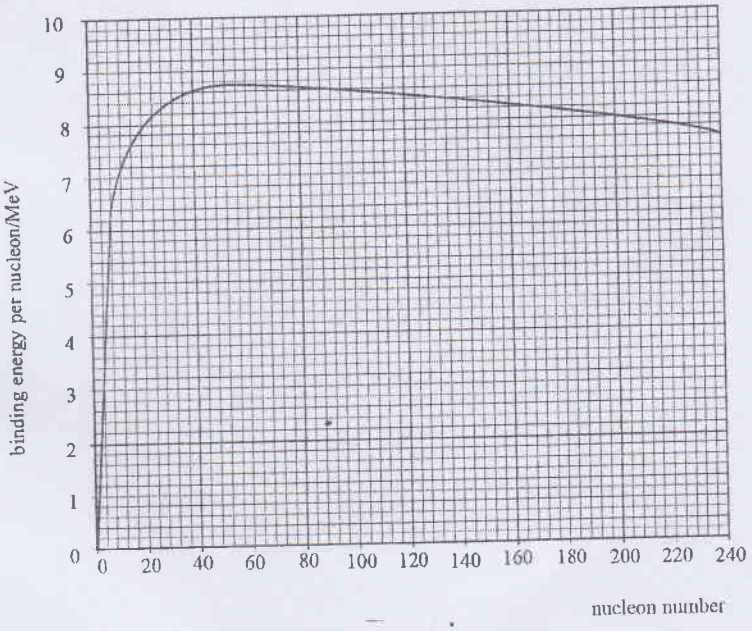
mass of deuterium nucleus = 2.01355 u
mass of helium-3 nucleus = 3.01493 u
mass of neutron = 1.00867 u
$(1\mathrm{u} = 1.66 \times 10^{-27}\ \mathrm{kg})$

Calculate

(i) The mass difference produced when two deuterium nuclei undergo fusion [2]

(ii) The energy released, in J, when this reaction takes place. [2]

(c) (i) The following figure shows the variation of binding energy per nucleon with nucleon number.



A uranium-235 nucleus undergoes fission and produces two fission products of approximately equal nucleon number. Using data from the figure, estimate the energy released from the fission of one uranium-235 nucleus. [4]

(iii) One other possible fission reaction is

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{236}_{92}\mathrm{U} \rightarrow ^{144}_{56}\mathrm{Ba} + ^{90}_{36}\mathrm{Kr} + 2\,^{1}_{0}\mathrm{n}$$

Calculate the energy released by this reaction. [4]

The masses of particles are given below in atomic mass units, u, where
$1\mathrm{u} = 1.66 \times 10^{-27}$ kg.
Mass of $^{1}_{0}\mathrm{n}$ = 1.009 u
Mass of $^{235}_{92}\mathrm{U}$ = 235.124 u
Mass of $^{144}_{56}\mathrm{Ba}$ = 143.923 u
Mass of $^{90}_{36}\mathrm{Kr}$ = 89.920 u
Speed of electromagnetic radiation (light) = 3.00×10^{8} ms^{-1}

(d) The radiation level can be expressed by two quantities. Briefly describe them. [6]