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RAJARATA UNIVERSITY OF SRI LANKA
FACULTY OF APPLIED SCIENCES

B.Sc. (General) Degree in Applied Sciences
Third Year Semester II Examination – February /March 2019

# PHY 3311 – MEDICAL PHYSICS

**Time: 03 hours**

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- **Answer All Questions**
- A non-programmable calculator is permitted.

**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 | $1\mathrm{\AA} = 1 \times 10^{-10}\ \mathrm{m}$ |
| Roentgen | $1R = 2.58 \times 10^{-4}\ C\mathrm{kg^{-1}}$ (X-ray or $\gamma$-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 | $1\ \mathrm{Bq} = 1\ \mathrm{decays\ s^{-1}}$ |

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Continued...

1. A patient with a suspected broken arm is going to have an X-ray image taken.

   (a) Explain the risk to the patient of exposure to X-rays. (3 marks)

   (b) Discuss three ways by which the design and use of the X-ray equipment minimises this risk. (6 marks)

   The blood vessel called the aorta passes through the abdomen. A second patient with a suspected fault in the wall of the aorta can be given an ultrasound scan or an X-ray of the abdomen.

   (c) Suggest with reasons, which is the better procedure for investigating this suspected fault. (2 marks)

   (d) When ultrasound travels across a boundary from blood to the wall of the aorta there is a decrease in acoustic impedance across the boundary. This results in 0.0625% of the incident ultrasound being reflected at the boundary.

   Calculate the acoustic impedance of the aorta wall tissue,

   where acoustic impedance of blood = $1.64 \times 10^6$ kg m$^{-2}$ s$^{-1}$ (4 marks)

2. (a) State what is meant by the *acoustic impedance Z* of a medium. (1 mark)

   (b) Two media have acoustic impedances, $Z_1$ and $Z_2$.
   The intensity reflection coefficient $\alpha$ for the boundary between the two media is given by,

$$\alpha = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}.$$

   Describe the effect on the transmission of ultrasound through a boundary, assuming that is a large difference between the acoustic impedances of the two media.

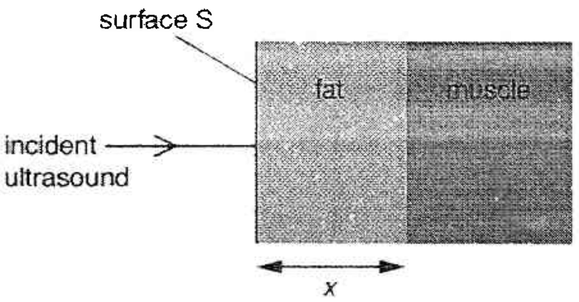
   (3 marks)

   (c) Data for the acoustic impedance $Z$ and the absorption coefficient $\mu$ for fat and for muscle are shown in the following table.

| | $Z$/kgm$^{-2}$s$^{-1}$ | $\mu$/m$^{-1}$ |
|---|---|---|
| fat | $1.3 \times 10^6$ | 48 |
| muscle | $1.7 \times 10^6$ | 23 |

**Continued...**

The thickness $x$ of the layer of fat on an animal as shown below is to be investigated using ultrasound;



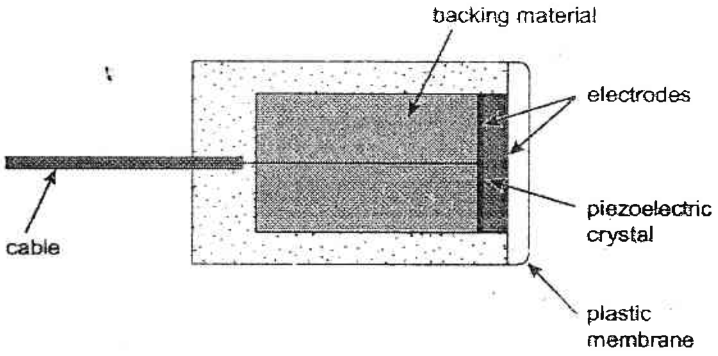

The intensity of the parallel ultrasound beam entering the surface S of the layer of fat is $I$. The beam is reflected from the boundary between fat and muscle. The intensity of the reflected ultrasound detected at the surface S of the fat is $0.012\ I$.

Calculate,

(i) the intensity reflection coefficient at the boundary between the fat and the muscle. (2 marks)

(ii) the thickness $x$ of the layer of fat (3 marks)

The following figure shows a cross-section through an ultrasound transducer;




(d) Explain how a transducer produces a pulse of ultrasound. (3 marks)

(e) A coupling gel is needed when performing an ultrasound scan. Explain how and why a coupling gel is used. (3 marks)

**Continued...**

3. (a) sound waves are incident on the ear canal of a normal human ear. Describe the physical processes involved in the transmission of the energy from air through to the inner ear.

   Give an outline of how the variations in air pressure in the ear canal are amplified to produce greater pressure variations in the ear. (4 marks)

   (b) Define *intensity* of sound. (2 marks)

   (c) A human ear has a threshold of hearing of 54 dB at a given frequency. Calculate the intensity of sound incident on the ear at this frequency, where

   $I_0 = 1.0 \times 10^{-12}$ Wm$^{-2}$. (3 marks)

An endoscope contains two bundles of optical fibres.

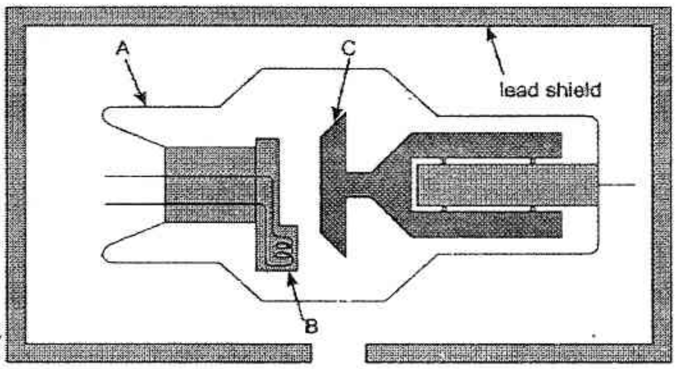
   (d) Name the **two bundles**. For each bundle state clearly the **arrangement of the fibres** and explain its **purpose in the operation of the endoscope.** (4 marks)

   (e) Each fibre has a core surrounded by cladding.
   Calculate the critical angle at the core – cladding interface of a fibre.

   Refractive index of core = 1.60
   Refractive index of cladding = 1.55.

   (2 marks)

4. The following figure shows a simplified modern X-ray tube with a rotating anode;




   (a) Explain the design and operation of the X-ray tube and the purposes of the components labelled on the diagram.

**Continued...**

In your answer you should include:

- Reference to the components labelled A, B, C and the lead shield
- An explanation of the physical processes by which X-rays are produced.

(6 marks)

(b) The X-ray tube produces photons of energy 50 keV. The half-value thickness of bone for photons of this energy is 15 mm

(i) Explain what is meant by half-value thickness. (1 mark)

(ii) Show that for 50 keV X-ray photons, the attenuation coefficient of bone $\mu$ is $0.046\ \text{mm}^{-1}$. (1 mark)

(iii) A beam of 50 keV X-ray photons is incident on a bone of thickness 12 mm. Calculate the percentage of the incident photons that leave the far side of the bone. (2 marks)

5. (a) During a magnetic resonance (MR) brain scan, the head of the patient is exposed to short pulses of radio frequency electromagnetic waves within a strong magnetic field. Outline the basic principles of an MR scanner used to perform this scan. (3 marks)

During MR imaging to obtain information about internal structures, a large constant magnetic field is used with a calibrated non-uniform magnetic field superimposed on it.

(b) State and explain the purpose of

(i) the large constant magnetic field. (2 marks)

(ii) the non-uniform magnetic field. (3 marks)

(c) The de-excitation energy $E$ of a proton in MR imaging is given by the expression

$$E = 2.82 \times 10^{-26} B,$$

where $B$ is the magnetic flux density.
The energy $E$ is emitted as a photon of electromagnetic radiation in the radio-frequency range.

Calculate the magnetic flux density when the radio frequency is 42 MHz.

(2 marks)

**End**

In your answer you should include:

- Reference to the components labelled A, B, C and the lead shield
- An explanation of the physical processes by which X-rays are produced.

(6 marks)

(b) The X-ray tube produces photons of energy 50 keV. The half-value thickness of bone for photons of this energy is 15 mm

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(iii) A beam of 50 keV X-ray photons is incident on a bone of thickness 12 mm. Calculate the percentage of the incident photons that leave the far side of the bone. (2 marks)

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The energy $E$ is emitted as a photon of electromagnetic radiation in the radio-frequency range.

Calculate the magnetic flux density when the radio frequency is 42 MHz.

(2 marks)

**End**