Homework #1

1. Identify the rang of diagnostic x-ray in terms of wavelength (from ? nm to ? nm); frequency (from ? Hz to ? Hz); and energy (from ? keV to ? keV).

Solution:

20 keV to 150 keV
0.062 nm ~ 0.008 nm
4.8×10^{18} Hz ~ 3.6×10^{19} Hz

Useful equations:

$$E(KeV) = \frac{1.24}{\lambda}(nm)$$

$$\nu(Hz) = \frac{C}{\lambda}$$

$$C = 3.0 \times 10^{8} m/s$$

2. Mammography is an x-ray Imaging procedure for breast cancer diagnosis and screening. Assume that 20keV x-ray is used in mammography. Also assume that the breast of a patient is 6 cm in thickness (soft tissue), and the propagation speed of x-ray photons in soft tissue is about the same as in vacuum. How long will it take for x-ray photons to travel through the breast?

Solution:

$$C = 3.0 \times 10^{8} m/s$$

$$t = \frac{d}{C} = \frac{6 \times 10^{-2}}{3 \times 10^{8}} = 2 \times 10^{-10} (\text{second})$$

3. Describe the nature of radiographic image formation (Hint: what is the difference between radiography and photography?)

Solution:

Photography: Reflection
Radiography: Transmission

4. A material has a mass attenuation coefficient of 0.35 cm^2/g (for a given photon energy) and has a density of 1 g/cm^3. What is the thickness of the Half-Value Layer (HVL) of this material? (Note: the Half-Value Layer is the material thickness required to reduce an incident beam intensity by a factor of two).

Solution:

Step 1:

Linear attenuation coefficient (μ) = (Mass attenuation coefficient) × (Density)
= 0.35 (cm^2/g) × 1 (g/cm^3)
= 0.35 (1/cm)

Step 2:

$$N = N_0\, e^{-\mu x}$$

Let:

$$N / N_0 = 1/2$$

We have:

$$\ln(1/2) = -\mu\, x$$

Then:

$$-0.693 = -0.35\,(1/cm)\; x$$

$$x = 1.98\,(cm)$$

5. Design a technique to measure the Half Value Layer (HVL) (Hint: assume you have an X-ray exposure meter, and thin sheets of Aluminum).

Solution:

Step 1: Measure x-ray exposure with the meter, no Aluminum sheets are placed in between the X-ray tube and the meter. Assume the result of the measurement is ***A*** mR.

Step 2: Place a thin sheet of Aluminum in between the X-ray tube and the meter, measure the x-ray exposure again.

Step 3: Add another thin sheet of Aluminum in between the X-ray tube and the meter, measure the x-ray exposure again.

Step 4: Repeat the above procedure until the result of the measurement reaches approximately ***A/2*** mR. Measure the thickness of the Aluminum sheets.

Step 5. Perform interpolative calculations if necessary to determine the accurate *HVL*.

6. An X-ray machine that generates x-ray beam at 32 KVp. You are given a meter that measures X-ray exposure in terms of mR; a ruler; and a slab of Lucite. Please design a procedure to measure the linear attenuation coefficient of the Lucite slab under the beam quality.

Solution:

Step 1.

The basic formula is: $N = N_0 \ e^{-\mu x}$

Step 2.

Place X-ray exposure meter under the x-ray tube, expose x-ray under a specific x-ray tube current and exposure time (*mAs*), measure x-ray exposure in terms of *mR*. Note the measured *mR* value is proportional to N_0

Step 3.

Place the slab of Lucite between the x-ray exposure meter and x-ray tube, repeat x-ray exposure as above (same *KVp*, *mAs*), measure x-ray exposure again in terms of *mR*. Note the measured *mR* this time is proportional to *N*.

Step 4.

Measure the thickness of the Lucite, ***x***.

Step 5.

Apply measured *N*, N_0 , ***x*** to the formula given in step 1, the linear attenuation coefficient, μ, is determined.

7. An x-ray tube operating at 60kVp, 120mA, 0.1second, generates a x-ray beam, and the number of x-ray photons per unit area at a given location is determined as 120,000. What will be the number of x-ray photons per unit area at the same location when the x-ray tube is operated at 100kVp, 50mA, 0.1 seconds?

Solution:

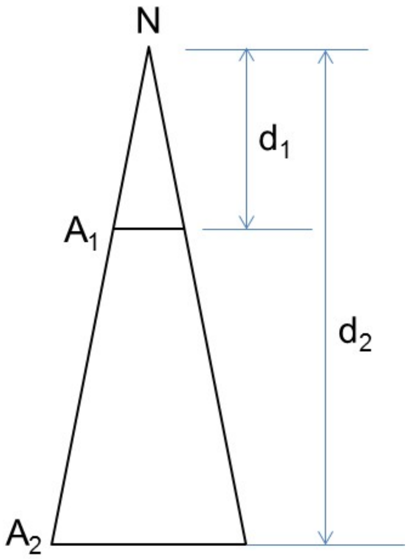
At 60 kVp: $N_1 \propto (60\text{kVp})^2 \times 12\text{mAs}$
At 100kVp: $N_2 \propto (100\text{kVp})^2 \times 5\text{mAs}$

$N_1 = 120{,}000$

$N_1 / N_2 = (60/100)^2 \times (12/5) = 0.864$

$N_2 = N_1 / 0.864 = 138{,}889$

8. Refer to the following schematic, the fluence of an x-ray exposure measured at position A_1 is 2.4×10^8 photons per m^2, what is the fluence at position A_2? (d_1=0.3m, d_2=1.0m)



Solution:

$$\Phi_1 = 2.4\times10^8\, photons/m^2$$
$$d_2 = 1.0m,\quad d_1 = 0.3m$$

Therefore:

$$\therefore \Phi_2 = \frac{d_1^2}{d_2^2}\times\Phi_1 = \frac{0.3^2}{1.0^2}\times 2.4\times10^8 = 2.16\times10^7\,(photons/m^2)$$