LECTURE 6: INTERACTION OF PHOTONS WITH MATTER

Problem Solutions

6.1 The Clinac 2100 is calibrated to deliver a photon dose rate of 1 cGy/MU at 100 cm from the source. What is the dose rate at 150 cm from the source?

Use the inverse square law:

\[ \frac{I_2}{I_1} = \left( \frac{d_1}{d_2} \right)^2 \]

\[ I_2 = 1 \text{ cGy/mu} \times \left( \frac{100 \text{ cm}}{150 \text{ cm}} \right)^2 \]
\[ = 0.444 \text{ cGy/mu} \]

6.2 The mass attenuation coefficient of copper is 0.0589 cm²/g for 1.0 MeV photons. The number of 1.0 MeV photons in a narrow beam is reduced to what fraction by a slab of copper 1 cm thick? The density of copper is 8.9 g/cm³.

\[ \frac{N}{N_0} = e^{-\mu x} \]

In this case:

\[ x = 1 \text{ cm} \]
\[ \mu = 0.0589 \text{ cm}^2 / \text{g} \times 8.9 \text{ g} / \text{cm}^3 \]
\[ = 0.524 \text{ cm}^{-1} \]

Then,

\[ \frac{N}{N_0} = e^{-0.524} \]
\[ = 0.59 \]
6.3 A $^{60}$Co unit gives an exposure rate of 80 R/min at 1 m when the source is “on.” Protection regulations require that when the source is “off”, the radiation level at 1 m be less than 2 mR/hr. Determine the thickness of lead shielding required if the HVL in lead is 1.25 cm.

\[
\frac{N}{N_0} = e^{-\mu x}
\]

Therefore,

\[
\log \frac{N}{N_0} = -\mu x
\]

and

\[
x = \frac{1}{\mu} \log \frac{N_0}{N}
\]

\[
\frac{1}{\mu} = \frac{HVL}{0.693} = \frac{1.25 \text{ cm}}{0.693} = 1.804 \text{ cm}
\]

\[
\frac{N_0}{N} = \frac{80 \text{ R/min}}{2 \text{ mR/hr}} \times \frac{1000 \text{ mR/R}}{60 \text{ min/hr}} = 2,400 \times 10^6
\]

So,

\[
x = 1.804 \text{ cm} \times \log (2.400 \times 10^6) = 26.5 \text{ cm}
\]
6.4  K- and L-shell binding energies for cesium are 28 keV and 5 keV respectively. What are the kinetic energies of photoelectrons released from the K and L shells as 40 keV photons interact in cesium?

\[ E_k = h\nu - E_B \]

For K shell electrons,

\[ E_k = 40\text{ keV} - 28\text{ keV} = 12\text{ keV} \]

For L shell electrons,

\[ E_k = 40\text{ keV} - 5\text{ keV} = 35\text{ keV} \]

6.5  A 1.25 MeV photon is scattered an angle of 60° during Compton interaction. What are the energies of the scattered photon and the Compton electron?

Wavelength of incident photon:

\[ \lambda = \frac{12.4}{1250\text{ keV}} = 0.00992\text{ Å} \]

Change in wavelength:

\[ \Delta\lambda = 0.0243(1 - \cos 60°) = 0.0243 \times \frac{1}{2} = 0.01215\text{ Å} \]

Wavelength of scattered photon:

\[ \lambda' = 0.00992 + 0.01215\text{ Å} = 0.0221\text{ Å} \]

Energy of scattered photon:

\[ h\nu' = \frac{12.4}{0.0221} = 562\text{ keV} \]
Energy of Compton electron:

\[ E_k = 1250 \text{ keV} - 562 \text{ keV} = 688 \text{ keV} \]

6.6 Prove that, regardless of the energy of the incident photon, photons scattered at an angle greater than 60° during a Compton interaction cannot undergo pair production.

In order for pair production to occur, the scattered photon must have an energy greater than 1.02 MeV. We shall demonstrate that allowing the energy of the scattered photon to be greater than 1.02 MeV leads to a contradiction.

If \( h\nu' > 1.02 \text{ MeV} \), then \( \lambda = \frac{12.4}{h\nu'} < \frac{12.4}{1020} = 0.122 \text{ Å} \).

Then \( \lambda + \Delta\lambda < 0.0122 \text{ Å} \).

For 60° scatter, \( \Delta\lambda = 0.0243(1 - \cos 60°) = 0.122 \text{ Å} \).

Thus, we must have \( \lambda + 0.0122 < 0.0122 \), or \( \lambda < 0 \). This is impossible, so \( h\nu' \) can never be greater than 1.02 MeV.