NE 495 – Week 8 - Solutions

LECTURE 20 - PHOTON INTERACTIONS

Problem 1

Statement: What fraction (not percent) of 2.5 MeV photons interact within 1 foot of water?
Solution: We use the equation

$$\frac{I}{I_o} = exp\left(-\mu x\right) ,$$

where μ is the total macroscopic cross section for photon absorption, which we can get from appendix C.3 of the textbook. We use the table for water, and find that the cross section for 2.5 MeV is not in the table, but by linear interpolation and using $\rho = 1\mathrm{g/cm}^3$, we find that

$$\frac{\mu}{\rho} = \mu = 4.454 \times 10^{-2}\mathrm{cm}^{-1} .$$

After converting 1 foot into centimeters and plugging in values to our equation, the fraction is found to be,

$$\begin{aligned}\frac{I}{I_o} &= \exp\left(-\mu x\right) \\ &= \exp\big(-(4.454 \times 10^{-2}\mathrm{cm}^{-1})(12 \times 2.54\mathrm{cm})\big) \\ &= 0.2572\end{aligned}$$

However, this is the fraction that does not interact in 1 foot, thus the answer is found by subtracting this value from one or,

$$1 - \frac{I}{I_o} = 1 - 0.2572 = \boxed{0.743} \qquad (1)$$

Problem 2

Statement: What fraction (not percent) of 2.5 MeV photons are absorbed by 1 foot of water?
Solution: Here, we have to look at the types of photon reactions, which include Compton scattering, the PE effect, and pair production. The latter two dominate at low and high energies, respectively, and both lead to the complete loss (i.e., absorption) of the incident photon. Interpolation (assuming $\rho = 1$ g) leads to

$$\begin{aligned}\mu_{\text{absorb}} &= \mu_{ph} + \mu_{pp} \\ &= 0.5(1.063 \cdot 10^{-6} + 5.937 \cdot 10^{-7}) \\ &+ 0.5(3.904 \cdot 10^{-4} + 1.131 \cdot 10^{-3}) \\ &\approx 7.615 \cdot 10^{-4}/\mathrm{cm} .\end{aligned}$$

Using the same exponential argument, we have

$$\begin{aligned}1 - I/I_0 &= 1 - e^{-(7.615 \cdot 10^{-4}/\mathrm{cm})(12 \times 2.54\mathrm{cm})} \\ &= 1 - 0.977 \\ &= 0.023 .\end{aligned}$$

So many interact, but most of that is scattering.

LECTURE 21 - NEUTRON INTERACTIONS

Problem 1

Statement: he nuclide B-10 is a great neutron absorber and is often used in nuclear systems. Its absorption cross section is 3840 b for neutrons of energy equal to 0.0253 eV. Suppose that B-10 exhibits perfect $1/v$ absorption. Estimate its neutron absorption cross section σ_a for neutrons of 0.1 eV. Enter your answer in units of barns.
Solution: Here, $E = \frac{1}{2}mv^2$. If $\sigma_a \propto 1/v$, then $\sigma_a \propto 1/\sqrt{E}$. Hence, $\sigma_a(0.1) = \sigma_a(0.0253)\sqrt{0.0253}/\sqrt{0.1} \approx$ 1931.5 b.

Problem 2

Statement: Which of the following most completely describes why neutrons are hard to shield? Here, to "shield" means to stop neutrons from propagating to some location surrounding by a "shielding" material (like water, concrete, lead, etc.).

```
a. Neutrons are much more massive than electrons, are
   neutral, and, hence, interact only with atomic nuclei.
b. Neutrons have roughly the same mass as protons, and
   so collisions with nuclei lead to very small energy losses.
c. Neutrons have a half life of about 14 m, so many of them
   decay before they can be shielded.
d. Neutrons are actually the easiest of the subatomic
   particles to shield.
```

Solution: Option (a) is the only one that is fully true. Neutrons do have the same mass as protons (roughly), which actually leads to large energy losses with light nuclei. Such elastic scattering can be good for cheap shielding. However, it's because they are neutral and massive that they are so hard to shield.