Exercises in FYS-KJM4710

1. A 20 keV photon interacts at a given point in a carbon absorber. What is the probability (relative or %) that it undergoes a) Incoherent scatter (Compton) b) Coherent Scatter (Rayleigh) c) photoelectric effect, and d) pair production? Use Appendix D.2 in Attix. Repeat the calculations for 20 MeV photons.

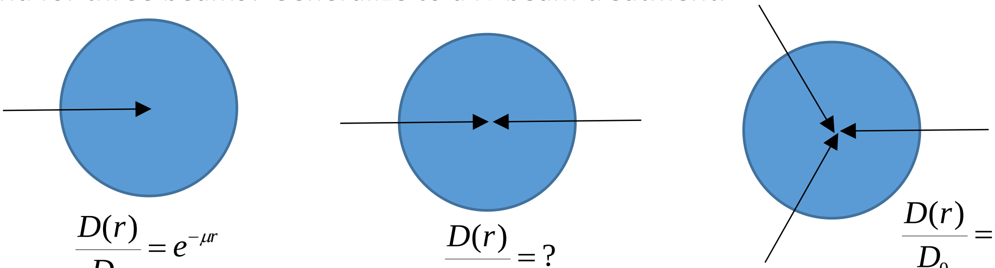
2. Use the definition of mass energy transfer coefficient and mass attenuation coefficient to derive a simple expression for the mean energy $\bar{T}$ transferred to secondary electrons. Plot the mean electron energy as a function of photon energy in water and lead. Use Appendix D.3 in Attix. Discuss differences, if any.

3. Follow-up to question 2. Using $\bar{T}$ as a representative electron energy, make a plot of the secondary electron range in water as a function of primary photon energy (See appendix E in Attix). Finally, plot the photon attenuation over the electron range in water as a function of photon energy. Discuss implications with respect to charged particle equilibrium.

4. Assume that photons undergo Compton (Incoherent) scattering only. Plot a mean trajectory for a 100 keV and a 10 MeV photon in carbon (assume density ρ=2.2 g/cm^3). Use the expression for mean free path. Use Appendix D.2 in Attix. Estimate mean energy lost to the electron (see ex. 2), mean energy and resulting scattering angle of the photon in each interaction. Calculate mean free path of scattered photon and so forth. Terminate the trajectory after 3 interactions.

5. Consider heavy charged particles traversing an absorber. Scattering and secondary particles can be neglected. Assume a) 125 MeV protons and b) 500 MeV alpha particles. What is their velocity relative to the speed of light – β? Calculate their stopping power in water using the expression found in the textbook (assume I= 75 eV). Neglect shell and density corrections. Furthermore, look at PSTAR and ASTAR data (https://www.nist.gov/pml/stopping-power-range-tables-electrons-protons-and-helium-ions). Compare your calculated stopping powers with values in the tables. Find the range of the two particles with given energy. Assume now that the particles traverse 1 cm into water. What is their energy at this depth (use the "residual range approach" - calculate both for protons and alpha particles)? Calculate the dose at a *point* corresponding to this depth, relative to that at the entrance (i.e. at initial kinetic energy). Then repeat at 2 cm depth; find energy and relative dose. Continue until the residual range is zero. Plot the dose vs the depth in water – do you get a 'familiar' curve?

6. Assume that we are treating a cylindrically shaped patient with photons, and that scattered photons and electrons can be neglected. The patient material is water, and the cylinder radius is *r*. The patient is irradiated from an arbitrary angle with one photon beam. Show that the central dose in the patient, relative to the entrance dose $D(r)/D_0$, is $e^{-\mu r}$. Assume that two *opposed* photon beams are used – what is now the dose ratio (see below)? And for three beams? Generalize to a N-beam treatment.



$$\frac{D(r)}{D_0} = e^{-\mu r} \qquad \frac{D(r)}{D_0} = ? \qquad \frac{D(r)}{D_0} = ?$$

Use r=12 cm. Use attenuation coefficients in Attix. Plot the dose ratio as a function of energy and number of beams. Use 200 keV, 1 MeV and 10 MeV, and vary the number of beams from 1 to 10. We first simulate a treatment with 200 keV photons and 9 beams. What is the dose ratio? Roughly how many 1 MeV photon beams would have been sufficient to create the same dose ratio? And how many 10 MeV beams? Discuss the usefulness of increasing the photon energy and employing multiple beams in radiotherapy.

7. Same problem as above, but now employing heavy charged particles. Use PSTAR and ASTAR data. Calculations should be performed for both protons and helium ions (alpha particles). Scattering and secondary particles can be neglected. What is the approximate kinetic energy required to reach into the center of the patient (r=12 cm)? Assume that you select ions with a range of roughly 12.5 cm – what is their kinetic energies at 0 and 12 cm depth? Calculate the resulting dose ratio $D(r)/D_0$ (with r=12 cm; no analytical answer is expected here). Compare these ratios with those for photons. Compare the ratio for protons and helium ions. Which ion species would you prefer for radiotherapy?