Problem 1 - The colour of the sky

Why is the sky blue and, at sunset, sometimes red?

Problem 2 - Half-value layer and effective atomic number Z_{eff}

The half-value layer is a practical measure to determine the characteristics of a material in terms of shielding against x-rays. The atomic number Z_{eff} on the other hand enables to calculate the attenuation of x-rays in compounds and mixtures.

a) Copper has a density of 8.9 g/cm^3 and a gram-atomic mass of 63.56 g/mol. The total atomic attenuation coefficient of copper is $8.8 \cdot 10^{-24}$ cm^2/atom for 500-keV photons. What thickness (in centimetres) of copper is required to attenuate 500-keV photons to half of the original number? (Atomic attenuation coefficient $\mu_a = \frac{\mu \cdot A}{\rho \cdot N_A}$).

b) What is Z_{eff} of water after adding 1 mM of $^{157}_{64}Gd$? Assume [H_2O] = 55 M and compare with Z_{eff} of pure water.

Problem 3 - Compton Scattering

Compton scattering is an important interaction of x-rays with matter, and essential in understanding radiobiology. Here, we investigate two experiments and derive the Compton shift mathematically.

a) A 2-MeV photon is scattered by a Compton interaction. What is the maximum energy transferred to the recoil electron?

b) Compute the energy of a photon scattered at 45 degrees during a Compton interaction, if the energy of the incident photon is 150 keV. What is the kinetic energy of the Compton electron? Is the energy of the scattered photon increased or decreased?

c) Prove the Compton shift: $\Delta\lambda = (h/m_e c)\cdot(1-\cos\theta)$ (cf. slide 3-8).

Problem 4 - Pair Production

Assuming that symmetry requirements are fulfilled and enough energy is available, matter is created during pair production.

a) A γ-ray of 2.75 MeV from ^{24}Na undergoes pair production in a lead shield. The negative and positive electrons possess equal kinetic energy. What is this kinetic energy?

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

Problem 5 - Radiation Protection

Applying x-rays for diagnosis or therapy requires a good understanding of the effects the radiation causes in biological tissue. This is also important for site planning (i.e. architectural considerations for radiation protection) and of course for protection of people working with radiating material.

a) A tumour with a mass of 10g receives a uniform dose of 10 cGy. How much energy is absorbed in the entire mass?

   Hint: $dose = \frac{absorbed\ energy}{mass}$; $[Gy] = \left[\frac{J}{kg}\right]$

b) Someone who recently started working at a PET centre asks you if it would be healthy to wear a lead apron (French *tablier*) as protection against the 511 keV annihilation radiation inherent to positron emitters. Given is that lead has a density of 11.35 g/cm^3 and a mass attenuation coefficient for 511 keV gamma radiation of 0.1542 cm^2/g.

   i. Calculate the linear attenuation coefficient (in cm^{-1})
   ii. An apron that would stop ¾ of the radiation would already provide passable protection. For which thickness is the transmission 25%? Assume perpendicular radiation entry.
   iii. What is the weight of a lead apron with a 75% attenuation if the skirt needs about 1.5 m^2 flexible lead containing material? The presence of other materials than lead can be neglected.
   iv. What is your advice for wearing lead aprons in a PET center?