1. The photon absorption properties of materials are given in several different interrelated ways. Three that we have discussed are cross section $\sigma$, optical depth $\tau$, and mass absorption length $\lambda$. (I was a little sloppy with my terminology in class, and did not include the word “mass” when I talked about $\lambda$.) Another, the mass absorption coefficient is the reciprocal of the mass absorption length.

   (a) Find the relationship between cross section and mass absorption length.

   (b) The mass absorption length and mass absorption coefficient incorporate a factor of the density $\rho$, and have units of g/cm$^2$ and (g/cm$^2$)$^{-1}$, respectively. The “absorption length,” without the “mass” in the name, truly has units of length, e.g. cm. Similarly, the absorption coefficient $\mu$ is inverse of the absorption length and has units of cm$^{-1}$. Find the relationship between $\mu$ and $\lambda$.

2. The density profile of the atmosphere can be approximated by an exponential with “scale height,” $i.e.$ the length scale in the exponent, about 7.6 km, $\rho = 1.205 \times e^{-a/(7600 \text{ m})} \text{ kg m}^{-3}$, where $a$ is the altitude. Estimate the average altitude of first interaction for photons of 100 eV, 10 keV, 1 MeV, 100 MeV, and 10 GeV. You may use data for carbon as an approximation for the chemical composition of the atmosphere. Explain why this is a reasonable approximation. (You are not expected to calculate cross sections or interaction lengths from the formulae for the various processes; you can use tabulated or graphed data.)

3. You are building an X-ray detector to launch on a satellite, and you want to shield it on five sides so that only one side is exposed to incoming X-rays.

   (a) You want to minimize the weight of the shield, for a given effectiveness of the shielding. Explain whether you want a material with a large or small value for absorption length (expressed in terms of g/cm$^2$). Justify your choice with an argument showing how the mass of the shield depends on the absorption length (inversely proportional? proportional to the square? etc.)

   (b) What might be a good choice then for the material to shield against 100 keV X-rays? Why?

   (c) Assuming you use a solid material for the shield, what energy X-ray or gamma-ray <20 MeV is most difficult to shield? Give two reasons for this. One of the reasons you will probably come up with easily; the other is harder. Think about what interactions are taking place.

4. The lead tiles forming the coded mask of the Swift Burst Alert Telescope (BAT) are 1 mm thick. Determine the energy at which an X-ray or $\gamma$-ray has a 50% probability of passing through the tile (at normal incidence) without interacting. You can think of this as the energy at which the mask becomes transparent and the coded mask technique (for this particular mask) stops working.
5. Consider the list of candidate objects for the course project, on the web at:
   http://scipp.ucsc.edu/~daw/astr117/sources.html
Choose your first, second, and third choice for the topic you would like to do. You can select an
object which is not on the list as your first choice, and if it is a suitable choice, you can then do
your project on that object. Your second and third choices must come from the suggested list.

(a) First choice for course project topic
(b) Second choice for course project topic
(c) Third choice for course project topic

We will draw numbers in class on Monday, April 16 to establish the order for who gets first
pick from the list. If you want to select an object not on the list, I urge you to check with me
about it beforehand. However, if you don’t have a chance to do that, you can submit it with this
homework and we can discuss it afterwards.