Exercise sheet 9

1. Greisen-Zatsepin-Kuzmin cutoff.
a.) Calculate the threshold energy (the "Greisen-Zatsepin-Kuzmin cutoff") of protons for the reaction $p + \gamma \to p + \pi^0$ on CMB photons with temperature 2.7 K. Estimate the mean-free path of a proton above the threshold using $\sigma = 0.1$ mbarn.
b.) Why the energy-loss length $\frac{1}{E}\frac{dE}{cdt}$ is the more useful quantity than the mean-free path?
c.) What reaction could be important at smaller energies as energy-loss mechanism for protons? Estimate the corresponding cross-section.

2. Proton-photon interaction in sources.
The same reaction can happen in CR sources as AGNe. What is the theshold energy using photons from the accretion disk (UV) or X-rays? How would neutrinos from proton interactions on CMB-, UV photons or X-rays fit to observations?

3. Interaction length of electrons on CMB.
Estimate the interaction length of an electron scattering on CMB photons with temperature 2.7 K. in the Thomson limit.