Introduction to astroparticle physics

Part 2, Exercises 4

May 16, 2025

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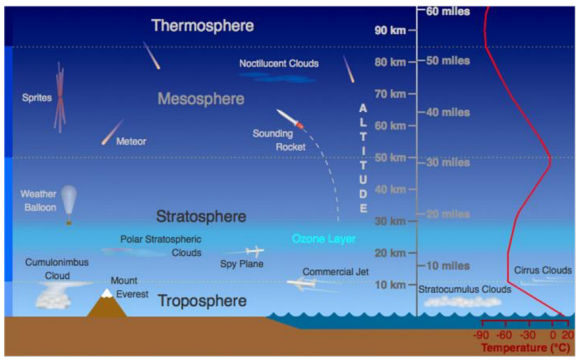
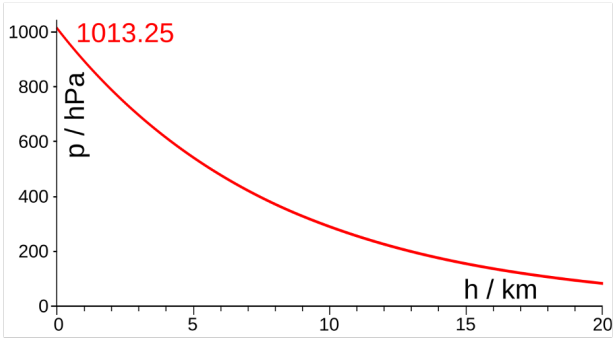
1 Atmospheric column density

The atmospheric pressure (p) varies with the altitude (h) according to the formula:

$$p(h) = p(h=0)e^{-\frac{h/\mathrm{km}}{8}}$$

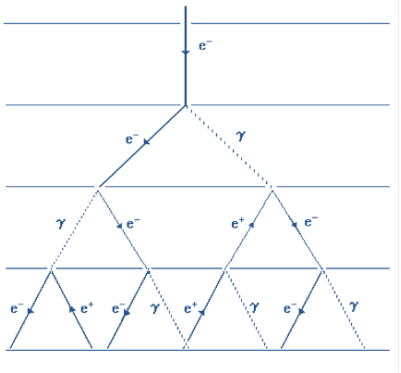
where $p(h=0) = 101325$ Pa is the atmospheric pressure at the sea level. Find the column density (in g/cm^2) at the altitude $h_1 = 20$ km and at the altitude $h_2 = 15$ km ?





2 Electromagnetic shower

An electron of energy $E_0 = 10^{12}$ eV initiates an electromagnetic (e.m.) shower.



1. After how many generations does the shower reach its maximum?
2. What is the number of particles ($N_{\max}$) present in the shower at its maximum?
3. What is the atmospheric depth ($X_{\max}$) where the maximum of the shower occurs? (We suppose that the depth at which the electron starts the e.m. shower is $X_{\mathrm{f}} = 0$).
4. The atmospheric depth depends exponentially on the altitude:

$$X(h) = X(h=0)e^{-\frac{h/\mathrm{km}}{8}}$$

where $X(h = 0) = 1033$ g/cm^2. At which height ($h_{\max}$) does the maximum of the shower occur?

5. Make the plot of the number of particles present in the shower as a function of the atmospheric depth for $0 \leq X \leq X_{\max}$.

6. Make the plot of the energy of the shower particles as a function of the atmospheric depth for $0 \leq X \leq X_{\max}$.

3 Cosmic muons

About the 80% of the charged secondary cosmic rays at the sea level are muons. The majority of these muons originate from the decay of charged pions.

1. Calculate the speed β of a muon with energy $E = 5$ GeV.

2. Find the time t the muon takes to reach the ground assuming it moves vertically down once created at the altitude $h = 20$ km.

3. Estimate the fraction r of 5 GeV muons created in the atmosphere at $h = 20$ km that survive and can be detected at the sea level.