MEASUREMENT OF THE FLUORESCENCE YIELD IN AIR WITH THE AIRLIGHT EXPERIMENT

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Abstract For the detection of ultra-high energy cosmic rays, many experiments rely on the fluorescence technique to measure the longitudinal development of extensive air showers in the atmosphere. The number of emitted fluorescence photons is related to the energy deposited by the shower in the air and therefore can be used to estimate the energy of the primary particle. The aim of the AirLight Experiment is to measure this relation for electrons in the energy range between \( \sim 500 \) keV and 2 MeV for different pressures, temperatures and air compositions with an accuracy of about 10%.

Introduction

Due to the very steep energy spectrum of cosmic rays, very-high energy cosmic rays can only be detected by the indirect method of observing extensive air showers (EAS). Apart from their detection by large detector arrays on the ground, very-high energy EAS can also be detected by the measurement of their fluorescence light emissions. This technique utilizes the atmosphere as a scintillator with the advantage of being able to directly access fundamental shower parameters, as the longitudinal development of the total electromagnetic energy deposit along the shower axis, without relying on theoretical interaction models. Furthermore, it is possible to investigate the whole longitudinal development of an EAS instead of measuring ”just” the lateral particle distributions at a certain shower stage as it is done by large detector fields. Challenging is the need of a very good understanding of the entire fluorescence detector, including the atmosphere! The relation between the number of observed fluorescence photons in the detector \( N_\gamma \) and the deposited energy \( E_{\text{dep}} \) of an EAS per unit of traversed matter \( X \) is assumed to be:
\[
\frac{dN_\gamma}{dX} = \frac{dE_{\text{dep}}}{dX} \int y(\lambda, T, p) \cdot \varepsilon_{\text{atm}}(\lambda) \cdot \varepsilon_{\text{FD}}(\lambda) \, d\lambda \quad (1)
\]

where \(\varepsilon_{\text{atm}}\) and \(\varepsilon_{\text{FD}}\) are the integral efficiencies of the atmosphere and the fluorescence detector which have to be monitored very carefully. The quantity \(y(\lambda, T, p)\) is the fluorescence yield, which depends on the wavelength \(\lambda\) of the emitted fluorescence light as well as on the temperature \(T\) and the pressure \(p\) of the air at the position of emission. Eq. (1) is only applicable if \(y(\lambda, T, p)\) does not depend on the energy of the ionizing particles which implies the number of emitted fluorescence photons at the shower axis \(N^0_\gamma\) per wavelength and unit of traversed matter to be [2; 3]:

\[
\frac{d^2N^0_\gamma}{dX d\lambda} = y(\lambda, T, p) \cdot \frac{dE_{\text{dep}}}{dX} \quad (2)
\]

**Fluorescence Emission in Air**

Almost all the fluorescence emissions in air in the wavelength range between 300 nm and 400 nm originate from transitions of excited \(N_2\) and \(N_2^+\) molecules [1]. In an EAS most of the excitations are caused by electrons and positrons with energies below 1 GeV [2]. Once the nitrogen states are excited they will return to the ground state after their mean lifetime. Since the nitrogen molecules may suffer collisions with other molecules in the air, some of the excited states will lose their energy radiationless and therefore less fluorescence photons will be emitted. This effect is called collisional quenching. According to kinetic gas theory the mean time between molecular collisions \(\tau_c\) is decreasing with increasing pressure and temperature and it depends also on the type of the colliding molecules (i.e. oxygen, water vapor). The relaxation rate \(\frac{dN}{dt}\) and the effective lifetime \(\tau\) of an exited state are therefore:

\[
\frac{dN}{dt} = -N(t) \left( \frac{1}{\tau_0} + \frac{1}{\tau_c} \right), \quad \tau = \frac{\tau_0 \tau_c}{\tau_0 + \tau_c} \quad (3)
\]

with the number of excited states \(N(t)\), their intrinsic lifetime \(\tau_0\) and the effective lifetime \(\tau\). The fluorescence yield \(y(\lambda, T, p)\) therefore, is expected to depend also on temperature, pressure and the gas composition. Since an EAS usually develops from its first interaction point at high altitudes down towards sea level, the fluorescence yield has to be known for pressures between 10 hPa and 1000 hPa and temperatures in the range from -60°C to 20°C. The effect of water vapor in the atmosphere needs to be investigated, too.