Measurement of the absolute fluorescence yield in Nitrogen between 0.5 and 2.3 MeV

G. Lefeuvre[a], P. Gorodetzky[a] and P. Salin[a]

(a) APC, 11 place Marcelin Berthelot, 75231 Paris cedex 05, France *

Presenter: G. Lefeuvre (lefeuvre@cdf.in2p3.fr), fra-lefeuvre-G-abs1-he15-poster

Detecting UHECR showers using fluorescence to determine energy requires a precise knowledge of the fluorescence yield. If the fluorescence mechanism itself is well understood, as well as the number of excited lines in N_2 and their precise wavelengths, the yield is known to only about 25% (even worse for each line). So, different collaborations (Auger, EUSO, HiRes...) decided to create a consortium of about ten experiments, called AirLight, where the fluorescence yield is measured accurately for different electron energies and with different setups. In APC (Paris, France), the EUSO group uses a ^{90}Sr source (0.5 - 2.3 MeV electron energy, different energies being selected) to produce the fluorescence and a grating spectrophotometer to count the number of photons produced per cm of gas traversed by the electron. Pressure, temperature and gas composition can be varied. The aim is to obtain an accuracy better than 10 %. A great attention is paid to the determination of the different efficiencies of the setup. In particular, the weak point of most experiments: the PMT efficiencies (quantum and collection) will be measured by comparison to a NIST photodiode. This delicate point will be detailed.

1. Introduction

In an extensive air shower, a fraction of the total energy is spent in the electromagnetic part, which gives rise to atmospheric fluorescence. This fluorescence produces photons mainly between 300 and 430 nm.

The phenomenon of de-excitation of N_2 and N_2^+ in the near UV is well known : there are 13 lines, the most intense being 337, 316 and 357 nm for N_2, and 391 nm for N_2^+ (see the spectrum in fig1).
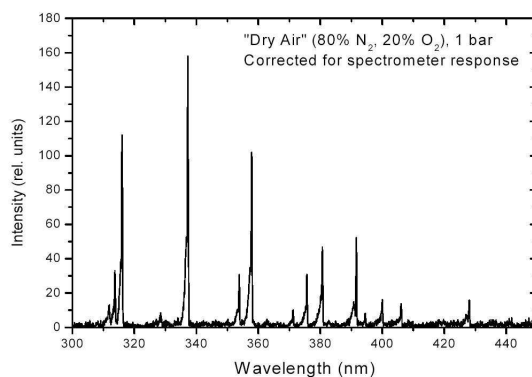

Figure 1. Fluorescence spectrum, see Ulrich in [2]

The fluorescence yield Y_γ, defined as the number of photons emitted by a charged particle per meter of travel, has not yet been quantified accurately enough : the overall precision is around 25 %, reaching 14 % only when

the electron energy is integrated in the range 0.5 - 2.3 MeV [1]. Still several questions remain unsatisfactorily answered, such as :

- what is the efficiency of each line ?

- does the production of fluorescence really follow the electron $\frac{dE}{dx}$ in the gas ?

- what are the pressure, temperature and gas composition dependences ?

In order to improve the precision on Y_γ by at least a factor 2, about ten experiments are running in many countries (AirLight consortium) [2, 3], either at low energy with a radioactive source, or at high energy in accelerators.

In Paris, the aim is to measure the fluorescence yield with a precision around 10 % in different conditions of pressure, temperature, gas composition (O_2/N_2 ratio), and relative humidity. The use of a ^{90}Sr source limits this work to relatively low energy (0.5 - 2.3 MeV), still much higher than the electron gun experiment ($E \sim 10$ keV) and around minimum ionisation energy.

The experiment is based on photon counting and spectral analysis. A schematic view of the bench test is showed in fig 2.

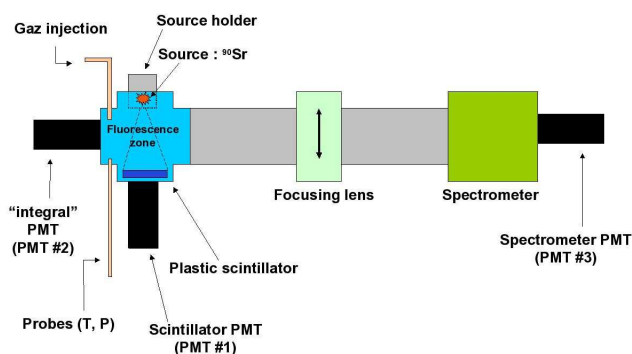## 2.   Description of the fluorescence bench test

Figure 2. Schema of the fluorescence bench

The ^{90}Sr source provides electrons between 0 and 2.28 MeV with an activity of 370 MBq. The electrons are collimated by a lead collimator and strike a conical scintillator ($\phi = 20$ mm) read by the photomultiplier (PMT 1), after they have traversed a volume of gas in which they excite Nitrogen molecules. The useful volume is a portion of a cone of heigth 40 mm and mean radius 13 mm. The solid angle of the useful volume is $6.4 \ 10^{-3}$ sr.

On each side of the cone, the emitted light goes to the photodetectors through quartz windows. The electrons inside this cone are counted and their energy measured by the PMT 1 placed below the scintillator. The other two PMT detect the photons : one with a BG3 filter, which select the photons between 300 and 400 nm (PMT 2), the other behind a monochromator (PMT 3). Both of them work in single photoelectron mode.

At atmospheric pressure, the counting rate is of order of 1 MHz in PMT 1, some kHz in PMT 2 and a few Hz in the PMT 3.
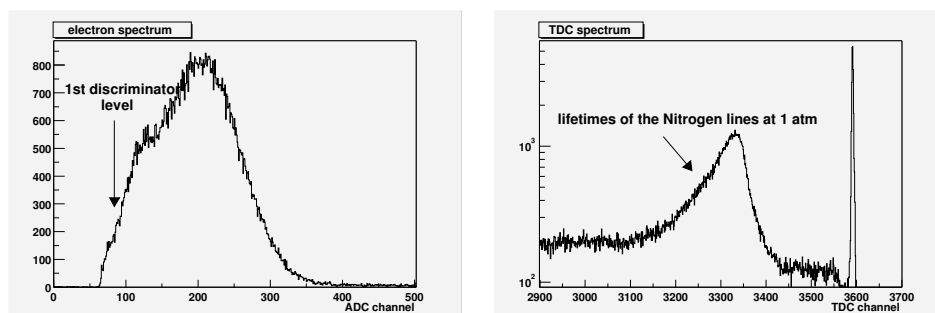
Figure 3. On the left, the electron spectrum. The slope between the channels 50 and 100 is due to the threshold of 0.5 MeV applied to the signal. On the right, a TDC spectrum in log scale, showing the integrated lifetimes of the Nitrogen levels between 300 and 400 nm. One can see the randoms on the left of the spectrum.

The PMT 2 and 3 are Photonis XP2020Q, with special single photoelectron voltage dividers for two of them.

The monochromator is a Jobin-Yvon H25, with a resolution of 6 nm per mm, and a spectral width of 1 nm. We make sure that we get all the photons emitted toward the monochromator by inserting a converging lens (f = 150 cm) between the window and the entrance slit of the monochromator. The lengths are such that the entrance slit is the optical image of the fluorescence volume and the numerical aperture is respected. The magnification, given the focal length of the lens, is 7, which means that the dimensions of the image are 5.7 mm by 1.8 mm : the image can be entirely included in the slit.

The pressure, temperature and gas flow are controlled inside and outside the volume. We use pure Nitrogen gas and dry Air. A mixer also allows to introduce impurities, mainly water vapor.

Data taking is based on coincidences between electron and each photon signal. The electron signal is about 100 ns wide to take into account the lifetimes of the Nitrogen levels. An energy binning is made by applying three different thresholds to the electron energy spectrum (0.5, 0.8 and 1.2 MeV). For each of these thresholds, ADC and TDC spectra are recorded. Moreover, electrons, photons and coincidences are counted at each step of the data acquisition, which allow to take into account the dead times of the electronics.

3. Calibrations

3.1 calibration of the experiment

The solid angles and the different absorptions (windows, grating of the monochromator...) have been precisely measured. The effective counting rates have been compared to those expected. A great attention is paid to gain variations. These variations can be compensated detecting the position of the peak of the ADC spectra and sending a feedback to the high voltage power supplies of the PMT.

3.2 calibration of the photomultipliers

The difficult point of this kind of experiment is the systematic error on the quantum and collection efficiencies of the PMT. The manufacturer rarely gives a better precision than 15 %. But if we aim at obtaining a total systematic error lower than 10 %, it is necessary to measure the PMT efficiency.

The overall PMT efficiency is proportional to the product of the photocathode efficiency ρ_{ph} by the collection efficiency ρ_c (defined as the ratio between the number of photoelectrons reaching the first dynode and the number leaving the cathode).

ρ_{ph} is not totally flat along the surface of the entrance window, due to the way the bialkali photocathode is deposited by flash in situ in the glass envelope. However, it does not depend on the applied high voltage. On the other hand, ρ_c is highly non-uniform for the first dynode is not axially symmetric. ρ_c also strongly varies with the high voltage. Because what is of interest is how many electrons are collected on the anode for one photon falling on the photocathode (which is proportional to $\rho_{ph} \cdot \rho_c$), we first make a relative mapping of the photocathode by sending light through a fiber mounted on an X-Y movement. The anode pulses are recorded for each X-Y position at the single photoelectron gain, which interests us (around 2200 V).

Then the absolute efficiency is measured at one position. For that, we use a NIST photodiode, accurate to 1 %. The gain of this diode is around 1, hence we have to reduce by some 10^4 the light which enters the PMT (whose gain is around 10^7). A factor 10^4 is enough since the important point is to have a *level* in the diode and single photoelectron *pulses* to count in the PMT. To reduce the background, the light is pulsed. We use either a pulsed LED or a halogen lamp whose light goes through a rotating blade linked to a locking amplifier. In that case, the light wavelength is selected by the monochromator.

The setup is the following (fig.4): exiting the monochromator, the light enters an integrating sphere with two other ports : one for the diode and another one, much smaller, leading to a second integrating sphere. Another port with a small hole (1 mm^2) on the second sphere is connected to the PMT. Then both the light in the diode and in the PMT are measured at the same time.
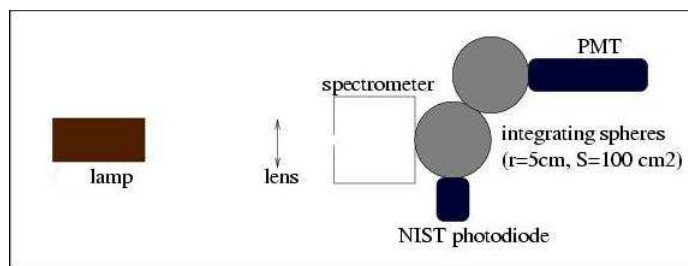

Figure 4. Calibration of the PMT

4.   Acknowledgements

References

[1] M.Nagano et al., Astr.Phys. 20 (2003) 293-309
[2] http://www.auger.de/events/air-light-03/index.en.html
[3] http://lappweb.in2p3.fr/IWFM05/
[4] Photomultiplier tubes, principles and applications, Photonis, 2002