

# A Measurement of the Fluorescence Efficiency of Air

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## Abstract

Air fluorescence in the region 310 nm to 400 nm is due to nitrogen fluorescence. [1] We measured the nitrogen fluorescence yield in air as a function of pressure between 1.4 MeV and 1 GeV by means of a strontium  $\hat{a}$  source and an electron beam. The pressure dependency of nitrogen fluorescence is well described by a formula derived from simple kinetic theory. Results indicate that nitrogen fluorescence yield in air is proportional to electron energy loss from 1.4 MeV to 1 GeV. The  $dE/dx$  relativistic rise in air is detected.

## 1 Introduction

Nitrogen fluorescence between 310 and 400 nm was identified as due to molecular 2P and the first excited 1N bands. Those experiments were carried out with low energy (below tens of keV) electrons at low pressure in order to study production cross sections. Due to a suggestion by Suga [2] that nitrogen fluorescence (NF) induced by particle cascades can be used to detect high energy cosmic rays, Bunner [3] measured the NF in air using 3.93 MeV singly ionized alpha particles. He and others found that NF in the presence of oxygen at any pressure is greatly reduced due to collision de-excitation between nitrogen and oxygen molecules. NF yield increases slowly with pressure and decreases with increasing temperature. Kinetic theory provides an adequate explanation for NF pressure and temperature dependency.

Since most of the particles in the cascade have energy near the critical energy, we decided to measure the fluorescence yield from 1.4 MeV to 1 GeV, a region useful for fluorescence detection of cosmic rays.

## 2 Experiment

Because of the low fluorescence yield, we chose a photon counting method to measure this quantity. Briefly, we injected a beam of known electrons into a tank of nitrogen and counted photons by means of a photomultiplier from which fluorescence yield was computed.

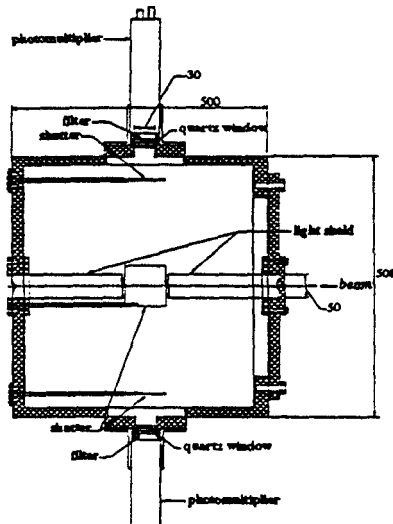


Figure 1: Schematic drawing of the tank

A cylindrical tank, 25 cm in radius and 50 cm in length, with five viewing quartz-covered ports, was made for this experiment (Fig.1). A movable shutters was placed in front of each port for making background measurements. Four Hamamatsu photon-counting photomultiplier (pmt, H1161PX) tubes were used. A 30 mm diameter collimator was placed in front of each pmt, so that only the well- calibrated portion of the pmt face was used for the detection of photons. Quantum efficiency, collection efficiency, and gain data were provided by the manufacturer. Quantum efficiency of one of the tubes was measured at Utah at 325 nm and 351 nm. Agreement between the two quantum efficiency measurements was achieved at five percent level. Results reported in this paper came from two pmt's; one of which was used for all four energy measurements.

Three narrow band filters with  $\delta\lambda/\lambda$  of 10 nm were used to measure the fluorescence yield of 337.1, 357.1, and 391.4 nm bands. A wide band filter used by the High Resolution Fly's Eye Detector (HiRes) was used to measure the total fluorescence yield between 310 and 400 nm. Electrons from a 1 millicurie strontium 90 source were used to make the 1.4 MeV measurement. In this measurement, the electrons were stopped in a scintillation counter after going through 9.5 mm of dry air. We are confident that the photons are from the fluorescence process since we detected the exponential nature of light emission at low pressure with TDC measurements. The pressure dependency of NF at 15°C is shown in Fig.2. Not shown are the statistical errors of all the points which are 1%.

An extracted electron beam from the 1.3 GeV electron synchrotron of Institute for Nuclear Study of the University of Tokyo was used as the source of high energy electrons. In this case, the number of electrons was measured by an ionization chamber, which was calibrated by a pair of counters in the beam at low beam intensity.

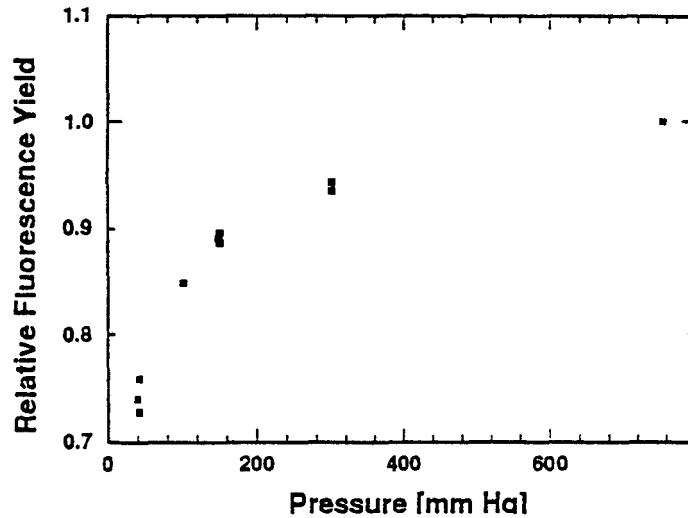


Figure 2: The pressure dependency of nitrogen fluorescence in dry air at 15° C

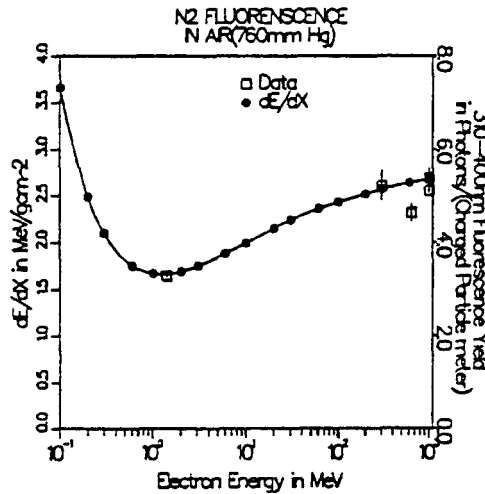


Figure 3: Energy dependence of nitrogen fluorescence in dry air at 760 torr. The  $dE/dx$  curve is shown as a solid line. The scale of the fluorescence yield is adjusted so that the 1.4 MeV point lies on the  $dE/dx$  curve.

Background (of the order of 10%) was obtained with shutters covering the pmt ports. We made measurements at three different energies: 300, 650, and 1000 MeV. The results together with the 1.4 MeV for the wide band filter are shown in Fig.3.

### 3 Results and Conclusions

Fig.2 shows the pressure dependency of NF. Our measurement extends from 760 torr to 40 torr, which is equivalent to sea level altitude to an altitude of 20 km. Guided by kinetic theory, we are able to use a 2-term 4 parameter fit to

obtain an adequate description of the NF yield as a function of pressure and temperature in air. Each term has the form  $A\rho / (1 + B\rho^{-1}T)$  where A and B are constants, and  $\rho$  and T are the density and temperature of the atmosphere respectively. Two terms are necessary because there are two major bands involved in the fluorescence process.

Our pressure dependence study together with the standard atmospheric model provides a model for NF in air at an altitude range useful for cascade studies. From ground level to tropopause, the fluorescence yield increases by about 10% due to the fact that in the denominator  $B\rho^{-1}T$  is larger than 1. In this case, the yield increases because the temperature decreases. After tropopause, the denominator starts to approach 1. The yield starts to decrease as a function of the density of the atmosphere since the temperature term in the denominator approaches and eventually becomes less than 1.

In Fig.3 the NF yield is plotted as a function of energy along side of a curve which shows the electron ionization energy loss in air. Scale on the left shows  $dE/dx$ , and scale on the right shows the fluorescence yield between 310 and 400 nm in photons per electron meter. The scale of the fluorescence yield is adjusted so that the 1.4MeV point coincides with the  $dE/dx$  curve. Results indicate that the fluorescence efficiency from 1 MeV to 1000 MeV follows that of the  $dE/dx$  curve which shows the relativistic rise. Details of the single line studies and other details will be published elsewhere. Errors shown include beam monitoring and statistical errors. PMT quantum efficiency and collection efficiency uncertainties, estimated to be around 7% dominate the systematic error which is not displayed.

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