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Experimental determination of air fluorescence yield from low-energy electrons (LEEAF experiment)

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Data on air fluorescence yield in the 1KeV-1Mev energy region are very scarce, but necessary for several cosmic ray experiments presently in progress. For this purpose the LEEAF experiment (*Low Energy Electron Air Fluorescence*) has been developed at Madrid. This is intended for the measurement (below 1hPas) of absolute cross sections for excitation and/or ionization of N_2 molecular levels by electron impact, as well as the lifetime of the excited levels. While operation of the system has been presently checked only in the 10-30 keV region, future operation at larger energies is foreseen. Measurements of the fluorescence yield at high pressure (thick target) are also planned. The current status of the experimental system, absolute calibration procedures and preliminary results are presented.

1. Introduction

Air fluorescence yields upon passage of energetic particles are essential data for experiments using our atmosphere as a scintillator for cosmic ray detection, like the fluorescence detector of the Pierre Auger Observatory [1]. A non-negligible fraction of the fluorescence light is expected to be generated by low energy electrons (E<0.5Mev). While electron fluorescence has been measured by many authors at energies below 1keV [2] and is being studied [3] at energies between 1Mev and 1Gev, data is very scarce in the 1KeV-1MeV region. While these data can be extrapolated from low-energy measurements, experimental check is desirable, as they are critical for the precise calibration of this kind of cosmic ray experiments. Air fluorescence yield in this energy region is very large, and a strong 1/E dependence [4] is expected on the electron kinetic energy.

As known fluorescence emission $\varepsilon_{vv'}$ from a gas sample, in a given vv' spectroscopic line or band, depends on several factors

$$\varepsilon_{vv'}(P,T,E) = N\sigma_v \frac{A_r^{vv'}}{\sum_{v'} A_r^{vv'} + A_c^v\,(P/\sqrt{T})} \qquad (1)$$

where T is the absolute temperature, N is the number of molecules per unit volume, P is the pressure, σ_v is the cross section for excitation of the emitter levels, $A_r^{vv'}/\Sigma_{v'}A_r^{vv'}$ is the branching ratio for radiative emission in the vv' band, and $A_c^v(P/T^{1/2})$ is the quenching deexcitation probability. As known σ_v and A_c are specific of the gas composition, and introduction of the P^v quenching parameter and the $\sigma_{vv'}$ emission cross section allows rewriting the above in the Stern - Volmer form.

$$\varepsilon_{vv'}(P,T,E) == \frac{P}{RT}\sigma_v \frac{A_r^{vv'}}{A_r^v}\frac{1}{1+P/P^v(T)} = \sigma_{vv'}(E)\frac{P/RT}{1+P/P^v} \qquad (2)$$

Here, while pressure and temperature dependencies are reasonably well known, the $\sigma_{vv'}(E)$ energy dependence is presently poorly known. Figure 1 resumes the available information on the main Nitrogen emitting bands. As can be seen experimental data (symbols) are very scarce in the 1kev-1Mev energy range, specially for the neutral N_2 species. The LEEAF experiment is intended to provide some data in this energy region (primarily at around 30keV).

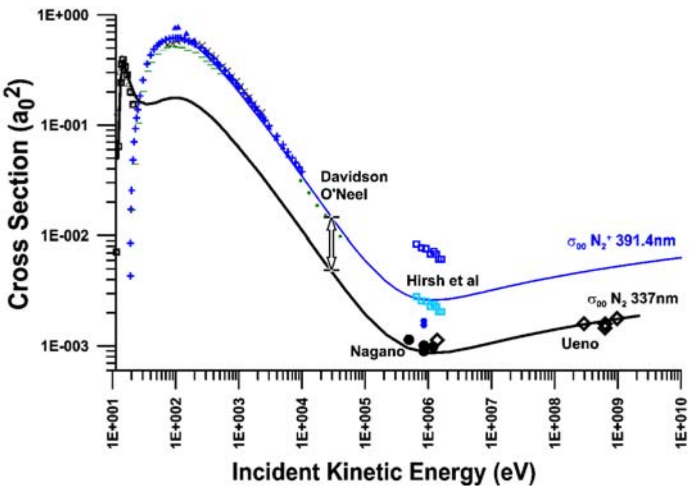

Figure 1. Available information on the main N_2 emitting bands [2,3,5]. The vertical arrow indicates our preliminary results for the observed ratio of N_2^+ to N_2 emission fluorescence at 30keV.

2. Experimental set-up

The LEEAF experiment is based on the measurement of the fluorescence emitted by a controlled gas sample under passage of well known energy electron beam. As the schematics of figure 2 shows, all the involved techniques are of common use in an atomic/molecular spectroscopy laboratory as ours. The electron gun is the only somewhat original part, but it is also based on previous work of the group. The electron source is a pulsed laser produced plasma of the kind usual in LIBS (*Laser Breakdown Induced Spectroscopy*).

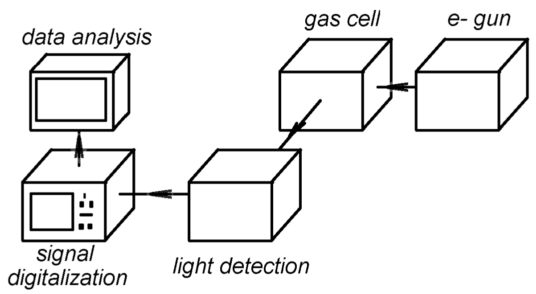

Figure 2. Schematic of the LEEAF experimental system.

Presently the system generates a pulsed (about 5ns) beam of 30KeV electrons. Pulsed operation considerably improves signal/noise ratio, and will also allow some lifetime measurements. As the only limitation for this kind of gun is H.V. isolation we expect there will be no difficulty in extending its operation up to 100KV in DC or perhaps higher in pulsed mode.

Taking into account that pressure dependency is already reasonably well known, first studies are being carried out below 1hPas, in order to simplify the connection between electron gun and gas chamber. At these low pressures, which are optimal for determination of the basic σ parameters, quenching effects are not significant (characteristic P^{v} values are of the order of 15hPas or higher).

The light detection system involved a calibrated Mini-Chrom/C monochromator, which attains a 20nm resolution with a 300μm slit, and an Oriel-77348 side window photomultiplier and registered by means of a Tektronix TDS-1012 digital storage scope (figure 4). Simultaneous registering of the electron signal from a Faraday cup allows correction of the fluorescence signal for any fluctuation in the electron beam intensity during data acquisition.

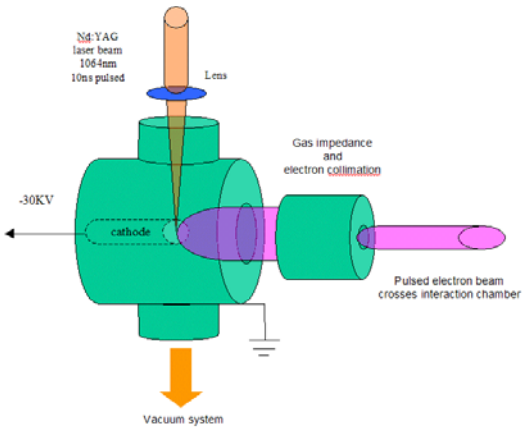

Figure 3. Schematics of the electron gun. Electrons are electrostatically extracted from a pulsed laser produced plasma. A vacuum impedance isolates the electron gun form the gas chamber.

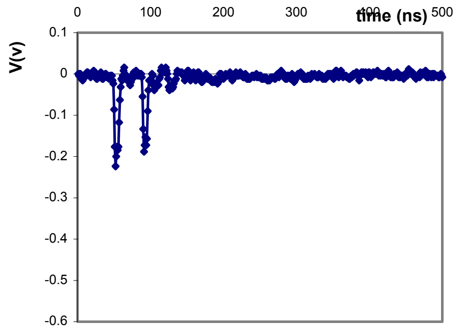

Figure 4. Typical signal from the photomultipler, digitized with a digital scope. A signal like this is captured for each electron-gun pulse. All the data analysis (threshold discrimination, photon counting, lifetime statistics or correction for e-gun fluctuations) can be carried out by software once the data is transfered from the scope to a PC computer.

3. Some preliminary results

Our preliminary results included lifetime measurements for 391.4nm and 337.1nm bands. The obtained values were consistent with the well known values at low pressure and low energy, i.e., about 60ns for the first one (N_2^+), and 40ns for the second one (N_2). While these values are not critical here, they serve as a check of the oveall system operation.

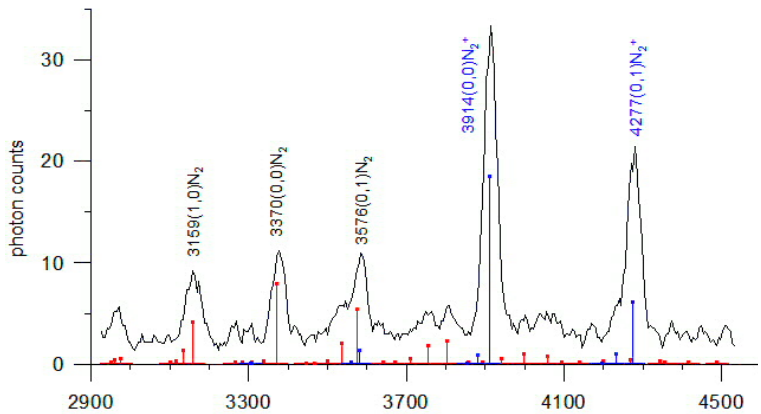

Figure 5. Sample spectra of N_2 and N_2^+ obtained in the 290-450nm region. Identification of some bands and theoretically expected intensity ratios are superimposed.

Figure 5 shows a typical spectra in the 290-450nm spectral region where most of the Nitrogen fluorescence is emmited. Taking into account the spectral eficiency calibration of the optical system, obtaining intensity ratios of some bands is straightforward. In this way the ratio of 0-0 bands from 1N and 2P Nitrogen systems resulted $\varepsilon_{337.1nm}/\varepsilon_{391.4nm} = 2.8\pm0.5$, which is close to the expected [4] theoretical ratio of ≈3 . No previous experimental data were previously known for these bands in this energy region. The above ratio is indicated by a vertical arrow in figure 1.

4. Future plans for LEEAF experiment

Future plans for this experiment basically include obtaining the spectra of Nitrogen bands with better statistics, at different electron energies. Operation of the system has already been verified in the 10keV-30keV energy region, but extension to larger energies will be studied. While presently only pure Nitrogen and room-air have been used, data adquisition is foreseen for gas compositions simulation those in the high atmosphere.

While presently the optical components of the system are calibrated only in a relative way, absolute calibration is underway. One possibility for an absolute calibration will be operating the system at lower energies (2keV or below) where accurate experimental values are available for nitrogen fluorescence. This would just require checking the stability of the electron gun at those energies, and somewhat improving present photon counting statistics.

A different possibility for an absolute calibration will be comparing electron fluorescence with the very well stablised Ryleigh dispersion. It can be estimated that a low energy (5μJ) pulsed nitrogen laser (337nm) crossing the gas chamber can be enough for that purpose. This procedure would account for all geometrical and spectral factors. Pressure uncertainties could also be corrected with this procedure if operating at the same gas conditions, but this would requiere a more intense (about 1mJ) laser beam.

5. Conclusions

Preliminary results for the LEEAF experiment (*Low Energy Electron Air Fluorescence*) promises valuable data in the 10keV-100keV energy region for the Nitrogen / air fluorescence induced by electrons. These are essential data for the accurate results demanded form cosmic ray experiments like Auger one. While some theoretical extrapolations are available in this energy region, an experimental check like present one was necessary. While present results include only relative intensities, two procedures are being considered for the absolute calibration of the system.

6. Acknowledgement

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References

[1] J. Abraham et al. (AUGER coll.), Nucl. Instrum. Meth. Phys. Res. A 523 (2004)5095; O.Catalano et al., Nuovo Cim. 24C (2001) 445-470; F.W. Stecker et al. Nucl. Phys. B (Proc. Suppl.) 136 (2004) 433438.
[2] M.N.Hirsh, E.Poss and P.N.Eisner, Phys.Rev. A 6 (1970) 1615-26
[3] M.Nagano, K.Kobayakawa, N.Sakay and K.Ando, Astroparticle Phys. 20(2003) 293-309; and 22(2004) 235-248; http://lappweb.in2p3.fr/IWFM05/
[4] F.Blanco and F.Arqueros. Submitted to Physics Letters.
[5] G.Davidson and R.O'Neil, Am. Science and Engineering Inc., Rep.no.AFCRL-67-0277, Cambridge, Mass., 1968