Primary Scintillation in Nitrogen and Dry Air

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Outline

- Activities in LIP-Coimbra
- Spectral analysis of the primary scintillation in N_2:
  - experimental set-up.
  - results
- Excitation and de-excitation mechanisms in N_2 and in air.
- Variation of the band intensities with T
- Summary
- Future work

Light Measurements in Coimbra

Detectors R&D for HEP, medical applications and others

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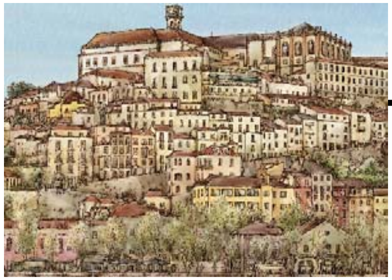
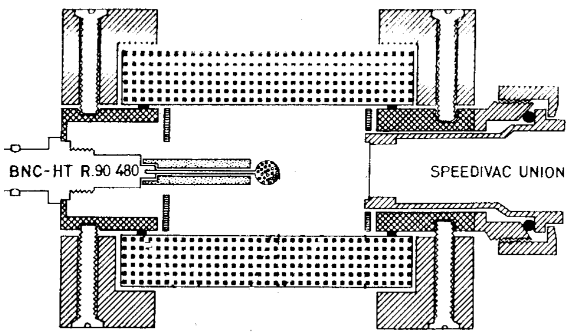
Study of fundamental processes in gases

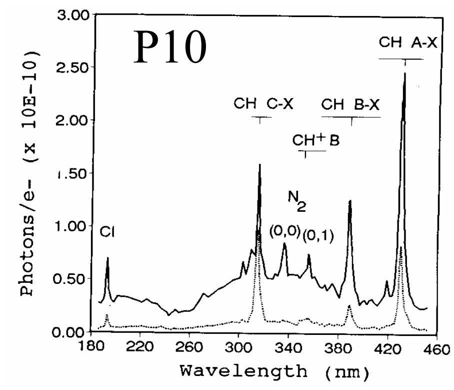


Detectors R&D

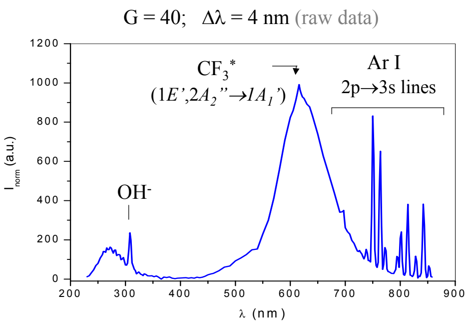
- Development of GSPCs and PIPs - rare gases and rare gas mixtures.

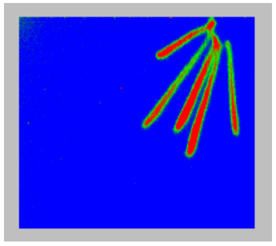


- Spectral and time resolved studies in Ar-based mixtures in PP and SQS detectors.

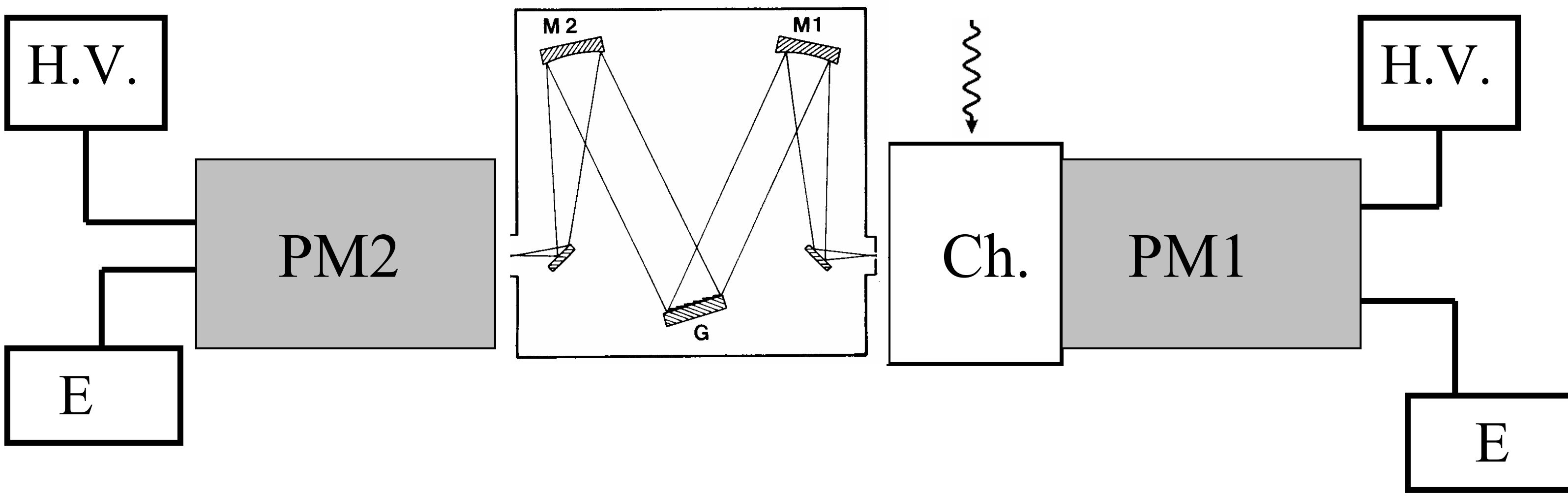


- Study of the light emitted in GEM detectors : quality control, neutron detection, X ray imaging





Experimental set-up for spectral studies



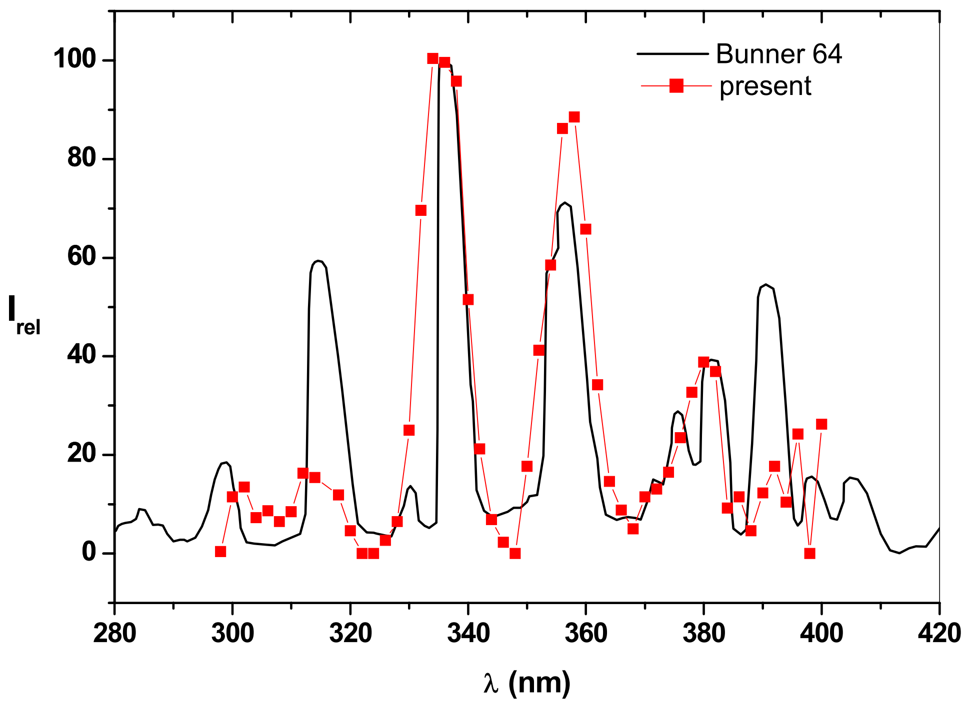
Monochromator: Applied Photophysics mod 7300, with a 1200 g/mm grating blazed at 300 nm; Dispersion = 4,7 nm/mm; focal length = 175 mm;

PM1 - EMI 9750QR ;

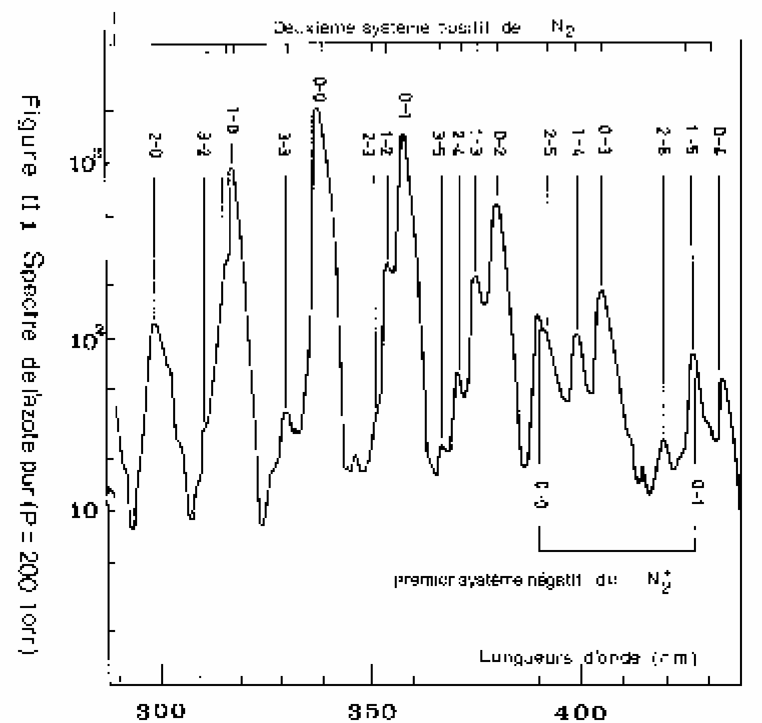
PM2 - XP2020Q operating in single photon counting mode.

Results : primary scintillation of N_2

2nd pos. system $N_2^*(C^3\Pi_u, v') \xrightarrow{A_{v'}} N_2^*(B^3\Pi_g, v'') + h\nu$



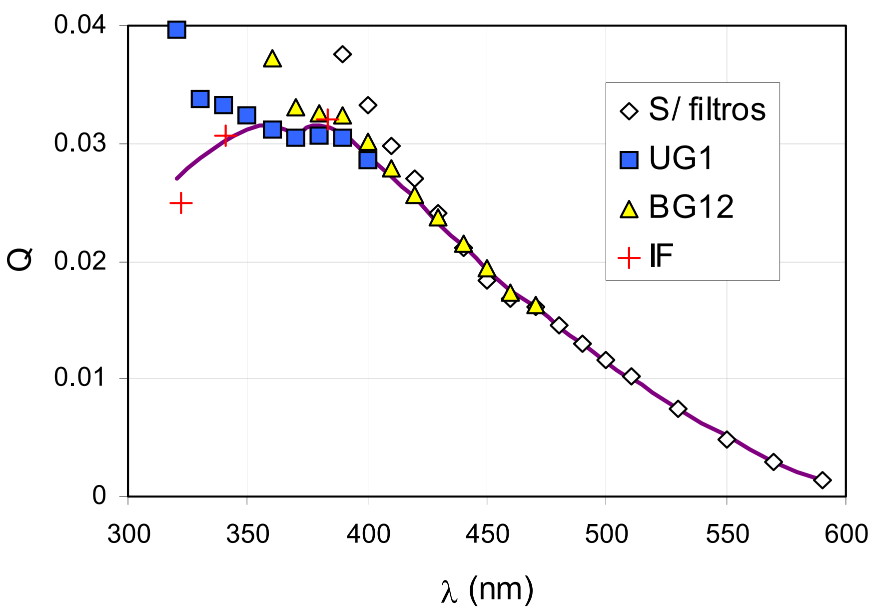
$P = 10^5$ Pa; $T = 296$ K; $\Delta\lambda = 9$ nm



H. Brunet, PhD thesis, UPS, Toulouse, 1973; α (2.8 MeV)

Calibration of the optical system

Calibration will be performed with a calibrated tungsten lamp. A calibrated deuterium lamp is also available.



Calibration curve for a detection system composed by the same monochromator and an identical PM.

Energy loss by charged particles

- Energy is lost in ionizations and excitations of gas molecules by the primary particle and secondary electrons.
- Air fluorescence in the wavelength region between 300 and 400 nm is due to the radiative de-excitation of the $C^3\Pi_u$ electronic state - 2nd positive system of N_2 :

$$N_2^*(C^3\Pi_u, v') \xrightarrow{A_{v'}} N_2^*(B^3\Pi_g, v'') + h\nu$$

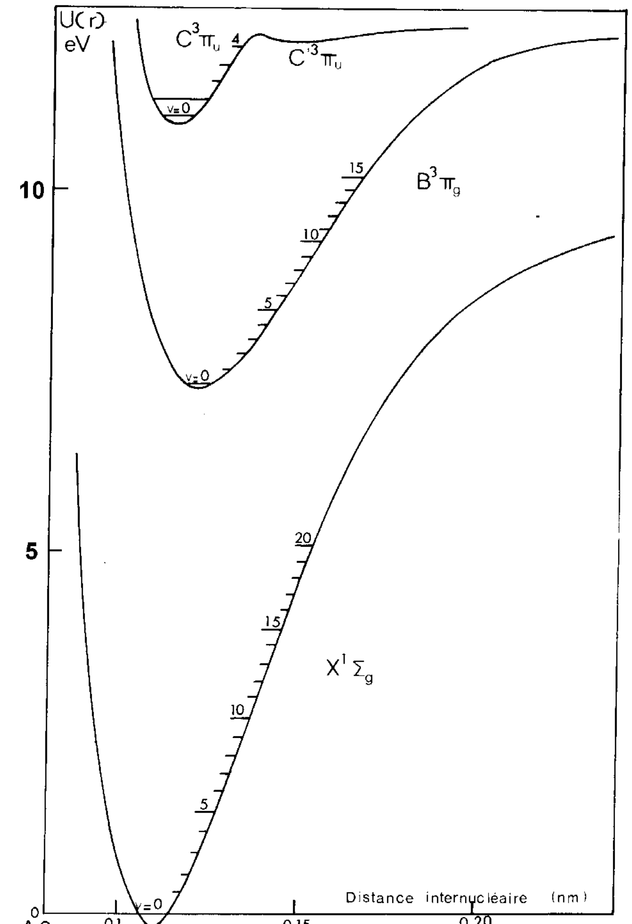
Excitation processes

- The $C^3\Pi_u$ electronic state is a forbidden state; it cannot be directly excited by fast charged particles.

E_{lim} ($C^3\Pi_u$) = 11.03 eV

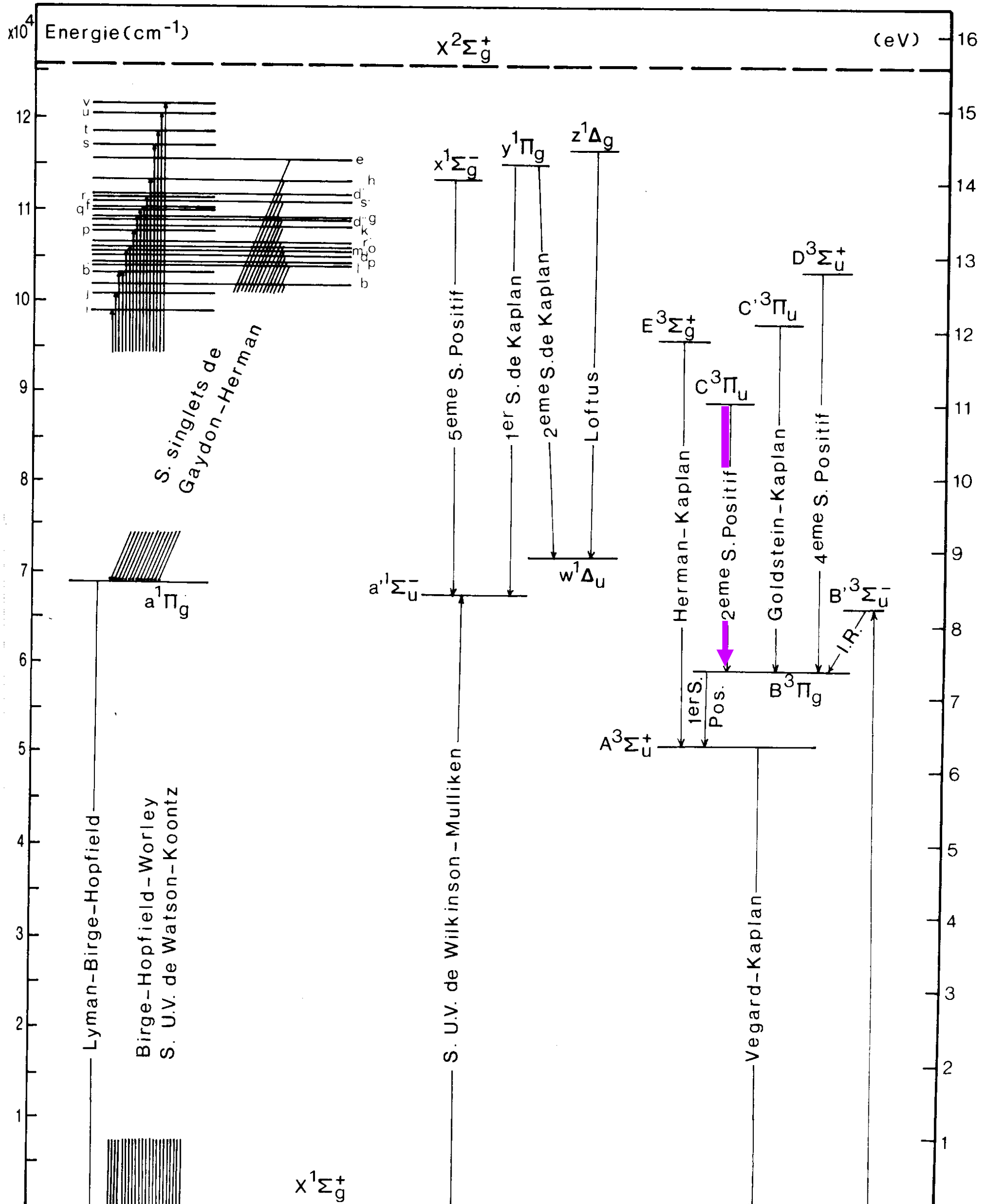
P.I. = 15.6 eV

W ~ 36 eV



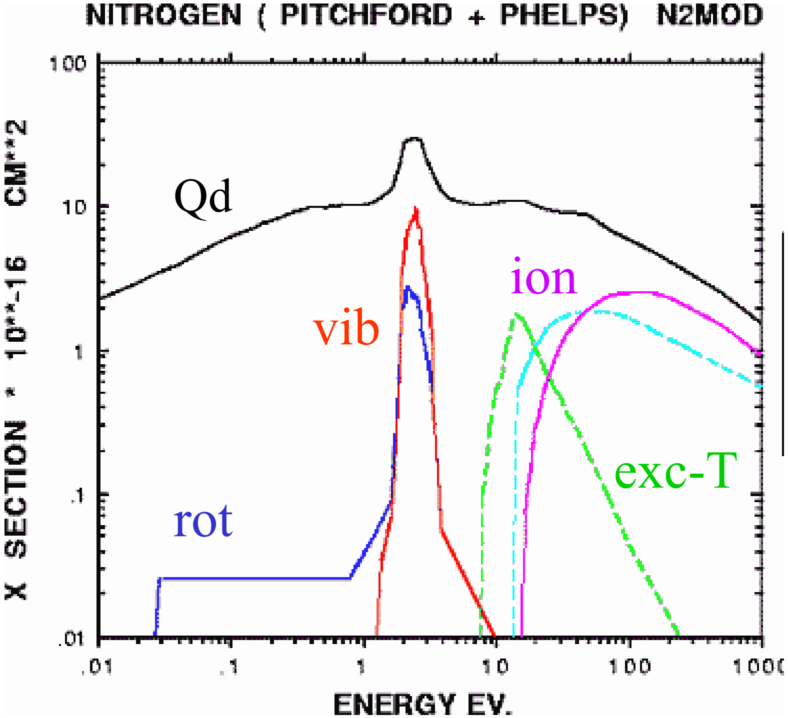
IGURE A 2.5 Courbe de potentiel de la molécule d'azote (Gi 2).

M. Fraga, Air Light 03

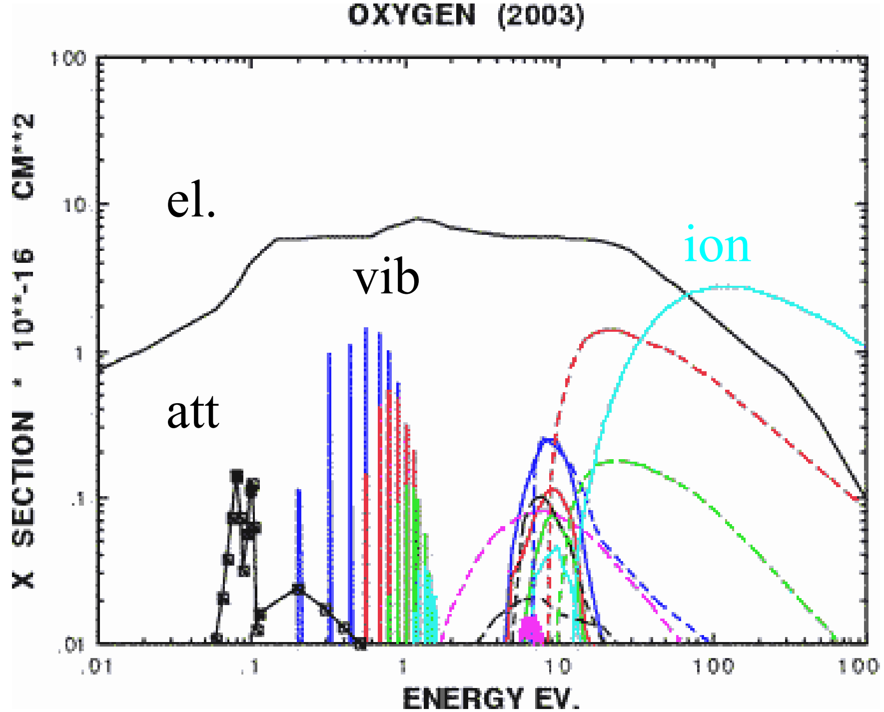


H. Brunet, PhD thesis, UPS,Toulouse,1973

Electron impact cross sections for N_2 and O_2



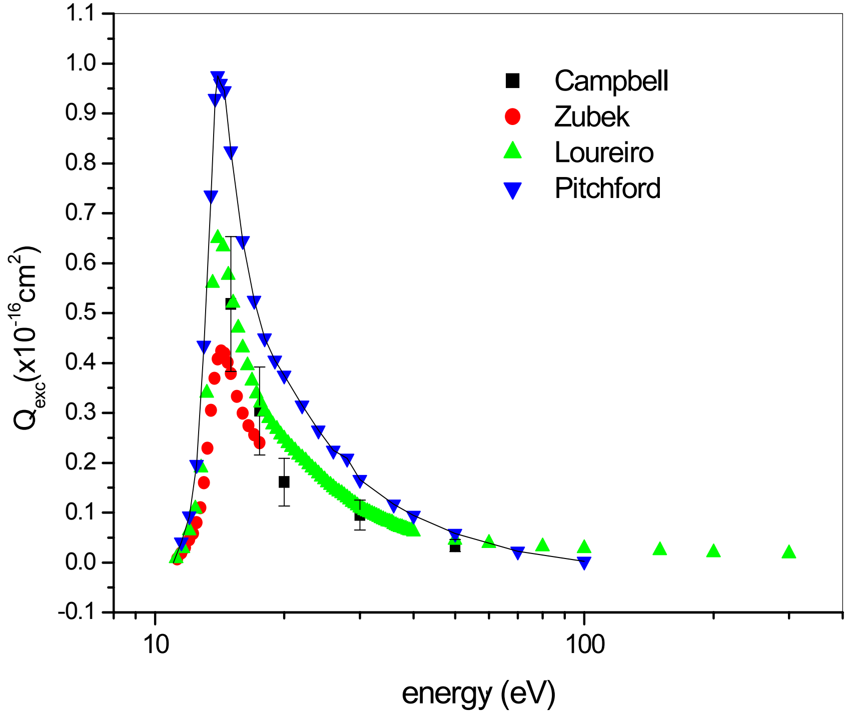
Pitchford and Phelps, MagBoltz



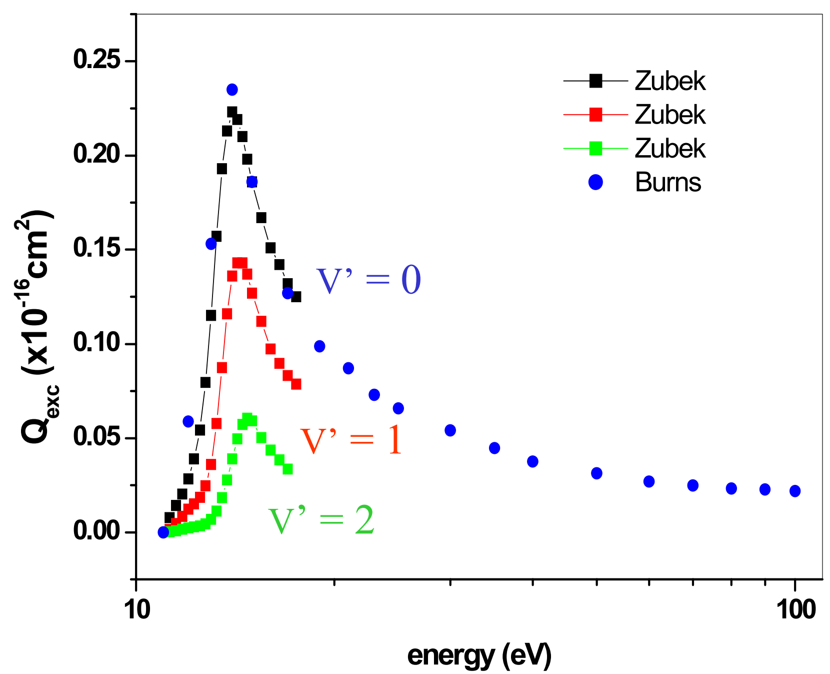
Dashed curves - excitations

Magboltz -CERN

Excitation of the $C^3\Pi_u$ (v'=0,1,2) state



Excitation cross section of N_2 $C^3\Pi_u$ electronic state by electron impact.



Excitation cross section of the vibrational levels v'=0, 1 and 2 of the $C^3\Pi_u$ state by electron impact.

Kinetic schemes:

$$N_2(X^1\Sigma_g) + e^- \xrightarrow{k_{ev'}} N_2^*(C^3\Pi_u, v') + e^-$$

$$N_2^*(C^3\Pi_u, v'') + N_2 \xrightarrow{k_{iv''}} N_2^*(C^3\Pi_u, v') + N_2 \quad \textit{with} \quad v'' > v'$$

$$N_2^*(C^3\Pi_u, v') \xrightarrow{A_{v'}} N_2^*(B^3\Pi_g, v'') + h\nu$$

$$N_2^*(C^3\Pi_u, v') + N_2 \xrightarrow{k_{2v'}} \text{products}$$

$$N_2^*(C^3\Pi_u, v') + N_2 \xrightarrow{k_{iv'}} N_2^*(C^3\Pi_u, v''') + N_2 \quad \textit{with} \quad v' > v'''$$

$$N_2^*(C^3\Pi_u, v') + X \xrightarrow{k_{Xv'}} \text{products}$$

Light yield

$$\frac{d[C,v']}{dt} = k_{ev'} n_e [N_2] - \left(A_{v'} + k_{2v'} P_{N_2} + k_{iv'} P_{N_2} + k_X P_X \right) [C,v']$$

- Steady state conditions:

$$[C,v'] = \frac{k_{ev'} n_e [N_2]}{A_{v'} + k_{2v'} P_{N_2} + k_{iv'} P_{N_2} + k_X P_X} = k_{ev'} n_e [N_2] \, \tau_{v'}$$

with

$$\tau_{v'} = \frac{1}{A_{v'} + k_{2v'} P_{N_2} + k_{iv'} P_{N_2} + k_X P_X}$$

and

$$Y_{v'v''} = A_{v'v''} k_{ev'} n_e [N_2] \, \tau_{v'}$$

Rate constants

$k_{xv'}$ ($torr^{-1} ns^{-1}$)

	N2*	O2	H2O	CO2	CH4
transition 0-v"	3,73E-04	0,009	0,0138	0,0116	0,0188
transition 1-v"	8,55E-04	0,01	0,0132	0,0109	0,0193

* For $X = N_2$, $k_{xv'} = k_{2v'} + k_{iv'}$

From H. Brunet, PhD thesis, 1973

Einstein coefficients for levels v' = 0 and v' = 1

$A_0 = 0.0342\ ns^{-1}$

$A_1 = 0.0343\ ns^{-1}$

Relation between rate constants and cross sections:

$$k' = \bar{v}_r Q = \left(\frac{8 k_B T}{\mu\pi}\right)^{\frac{1}{2}} Q\ (cm^3 s^{-1})$$

$$k'[N_2] = k' N_0 \frac{P}{T} = k(T)P$$

with $k \propto \frac{\sqrt{T}}{T}$ ⇨ $\tau_{v'} \propto \sqrt{T}$

Quenching by O_2 and H_2O

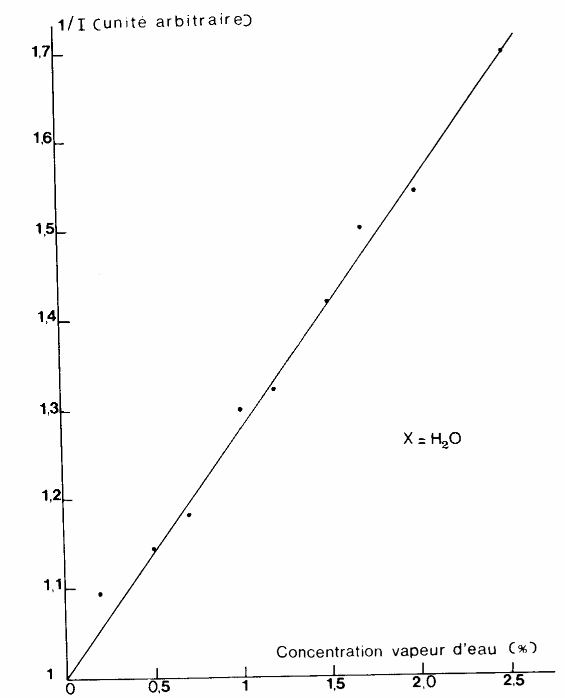


Figure IV 21 Bande 2P(0-0) Variation de 1/I normalisé à l'azote pur en fonction de C_x (P_T = 100 torr)

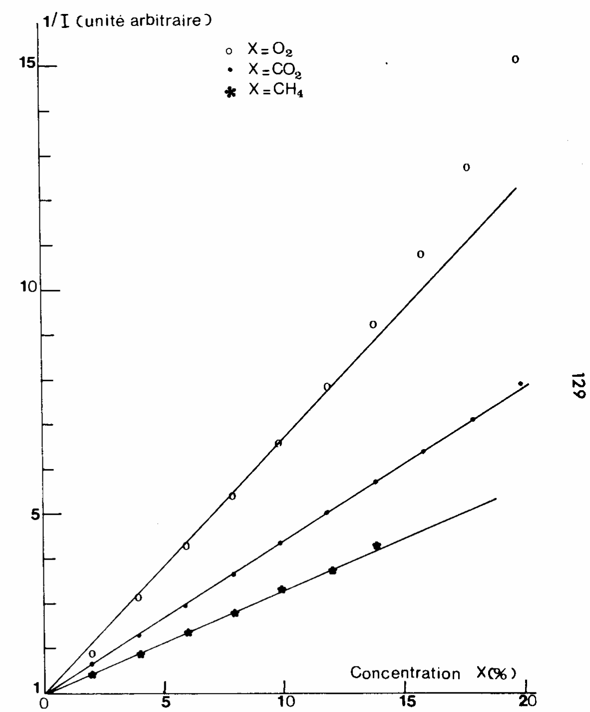


Figure IV 20 Bande 2P(0-0) . Variation de 1/I normalisé à l'azote pur en fonction de C_x (P_T = 100 torr) .

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From H. Brunet, PhD thesis, U.P.S., Toulouse, France

Predictions

- Using the previous data and assuming that the addition of 20% of oxygen results in a 20% reduction of the total nº of excitations (not true!), the expected relation between the 0-0 band intensity in dry air and nitrogen would be 0.16.
- The value of Nagano* is ~ 0.125

* *M. Nagano et al., Astropart. Phys. 20 (2003) 293-309*

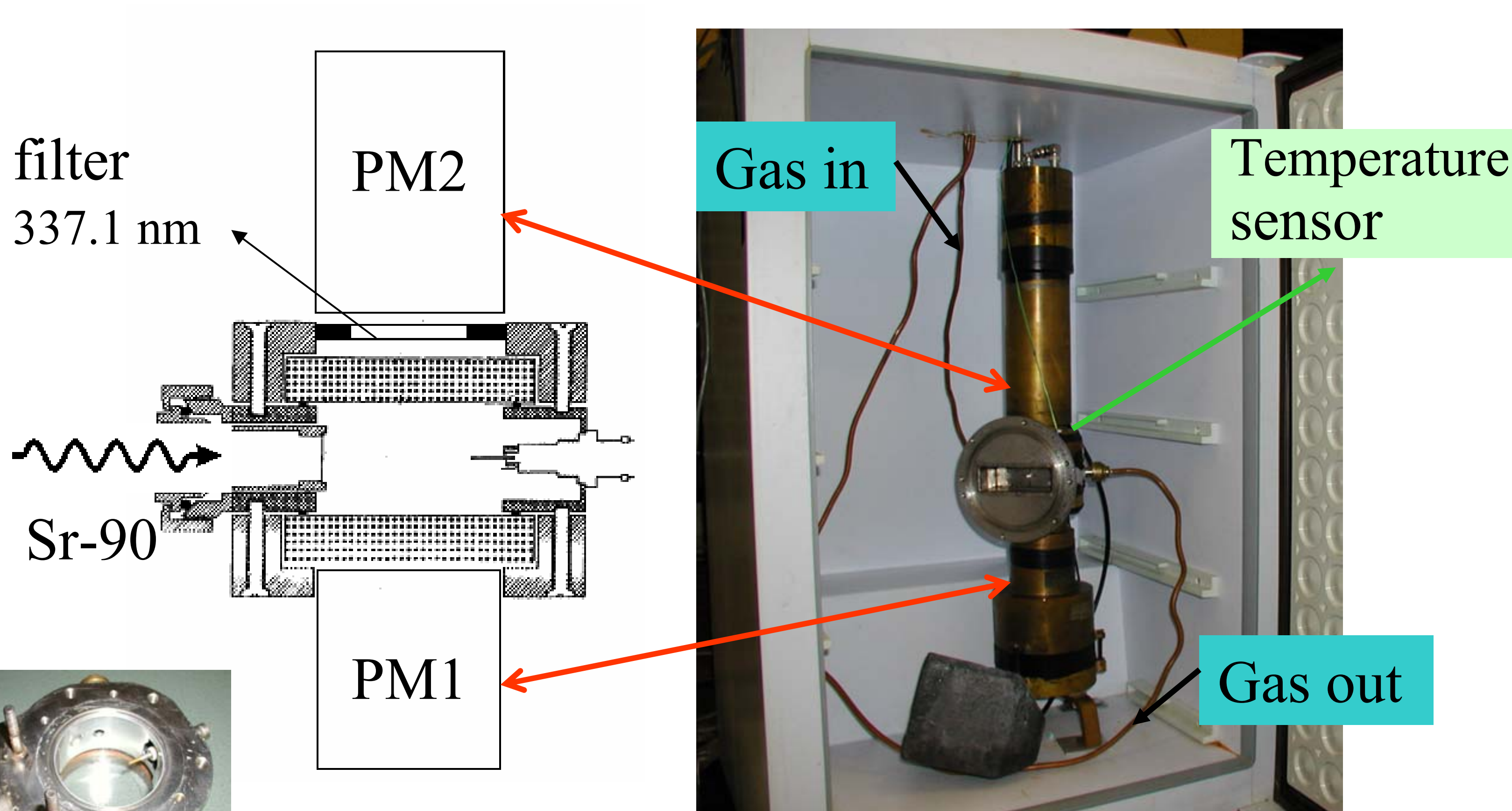
Quenching by water vapor:

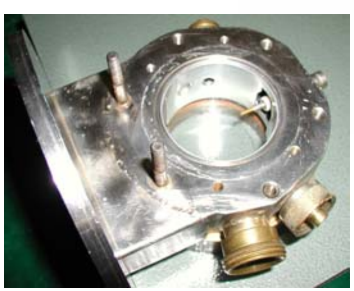
%H_2O	Y_{00}
0	1
0.5	0.97
1	0.94
2	0.88
3	0.83

0-0 band intensity decreases with increasing concentration of water vapor.

Atmospheric pressure was assumed.

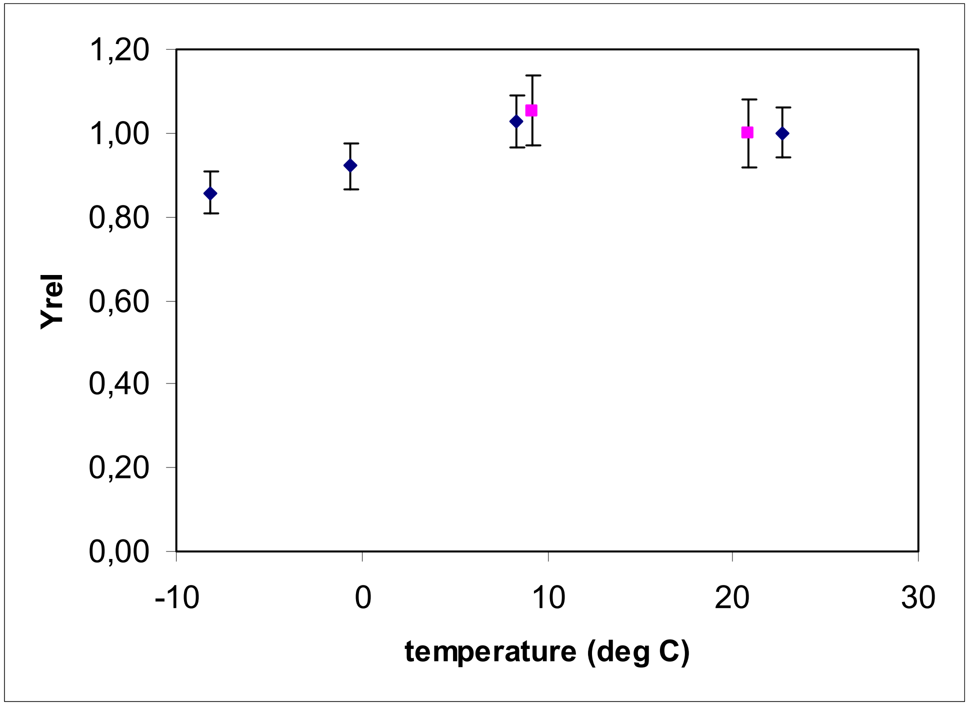
Light yield measurements as a function of T:





Chamber: $\phi = 5$ cm; h = 3cm

Preliminary results



Gas:

N_2 flowing through the detector at atmospheric pressure.

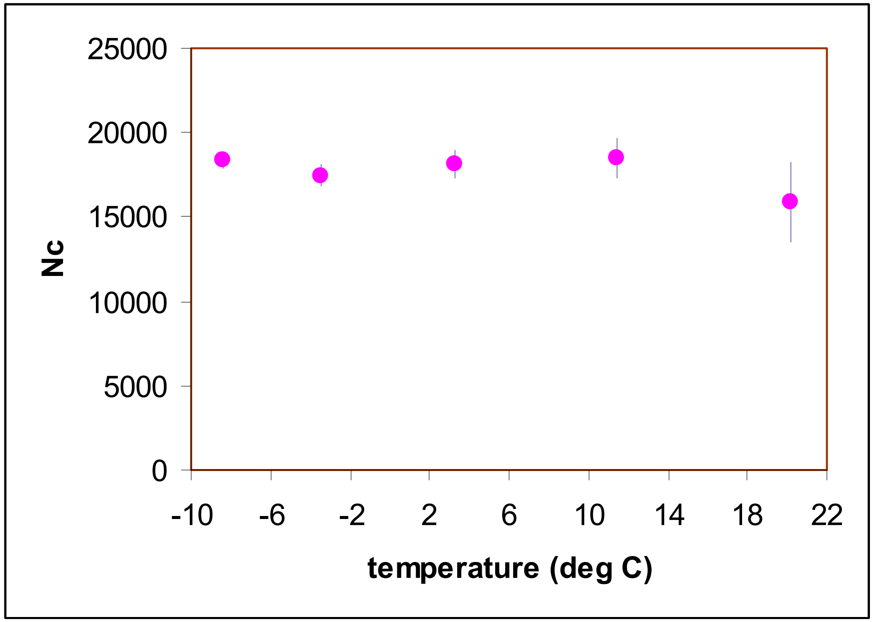
Excitation source:

α particles – Am-241

Filter:

centred at the band head of the 0-0 transition of the N_2 2nd positive system (337.1 nm).

Preliminary results



Gas:

N_2 flowing through the detector at atmospheric pressure.

Excitation source:

electrons (Sr-90)

Filter:

centred at the band head of the 0-0 transition of the N_2 2nd positive system (337.1 nm).

Summary

- Spectral analyses of the primary scintillation of nitrogen were performed;
- Preliminary measurements of the variation of light intensity with temperature were performed (P = const.)
- The role of low energy electrons in the air fluorescence study may be important.
- The influence of water vapor on total light yields may not be very important but should be considered.

Plans for the future

- Measurement of band intensities of the 2nd positive system as a function of pressure and temperature;
- Study of the role of water vapor on the light yields and on the emission spectra.
- Participation in the tests at CERN in the SPS beam facility - proposal submitted by the Annecy group (Ref:MacFly-MEMO-01 of 11/24/2003)