Temperature Dependence of $N_2(C\ ^3\Pi_u\ v' = 0, 1)$ Quenching by $N_2(X)$ and $O_2(X)$

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Over the past ten years there was a considerable increase of interest in the nitrogen UV scintillation due to its importance in astroparticle physics for the detection of ultra high energy cosmic rays [1]. Fluorescence detectors are used to measure the altitude profiles of UV light produced in the atmosphere by the charged particles of extensive air showers (EAS). The results provide a calorimetric measurement of the energy of the primary cosmic ray particle [2]. The dependence of the molecular nitrogen $C\ ^3\Pi_u \rightarrow B\ ^3\Pi_g$ (second positive system or 2P) emission intensity from air pressure, temperature and humidity has to be established in order to characterize the Earth's atmosphere performance as a scintillation detector. The intensity of the 2P emission from the atmosphere is used to determine the energy of an incomming cosmic ray particle. The accuracy of this measurement depends on the precision of photon yield data for all possible atmospheric conditions.

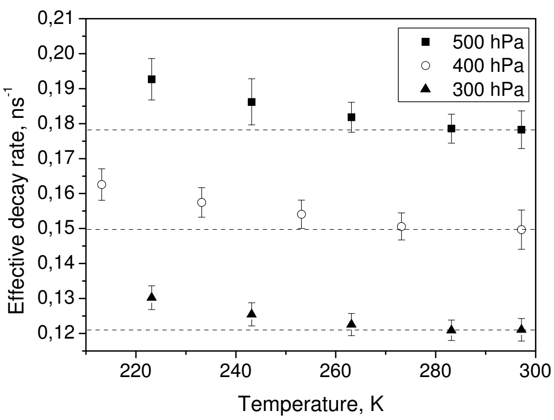

Fig. 1: Effective decay rate of the $N_2\ C\ ^3\Pi_u\ (v' = 0)$ emission as a function of gas temperature.

Here we describe our experimental results with respect to the temperature dependence of the collisional quenching of the state $C\ ^3\Pi_u$ by $N_2(X)$ and $O_2(X)$, and present calculations of the temperature dependence of the 2P emission intensity based on these data. The quenching data have been obtained from an analysis of the effective depopulation rates of the $C\ ^3\Pi_u$ state at different gas densities, oxygen admixtures and gas temperatures. The effective depopulation rates have been obtained from exponential fits of the recorded time evolution of the 2P emission following short electron beam pulse excitation (see description of the technique in Ref. [3]). Gas cooling has been performed in the range of 300 - 210 K using a helium expansion cooling system, keeping the target gas at constant density. Fig. 1 shows an example of the temperature dependence of the effective depopulation rate of the $N_2\ C\ ^3\Pi_u\ (v' = 0)$ state by ground state nitrogen for several nitrogen densities.

The following temperature dependencies of the quenching rate constants by N_2 and O_2 have been found (T in K and all $k(T)$ in cm^3s^{-1}).

- For $v' = 0$:

$$k_{0,N_2}(T) = 1.24 \times 10^{-11} \times \left(\frac{T}{300}\right)^{-0.33}$$

k_{0,N_2} increases by $(13 \pm 3)\%$ when cooling from 300 to 210 K;

$$k_{0,O_2}(T) = 2.61 \times 10^{-10} + 1.15 \times 10^{-13} \times T$$

k_{0,O_2} decreases by $(4 \pm 2)\%$ when cooling from 300 to 210 K;

- For $v' = 1$:

$$k_{1,N_2}(T) = 2.25 \times 10^{-11} + 1.41 \times 10^{-14} \times T$$

k_{1,N_2} decreases by (5.0±2.5)% when cooling from 300 to 210 K;

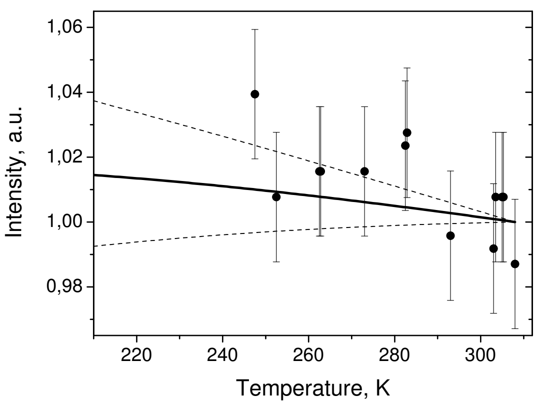

Fig. 2: $N_2\ C\ ^3\Pi_u\ (v' = 0)$ emission intensity as a function of dry air temperature at constant gas density (1 bar at room temperature). The thick solid line shows the intensity trend calculated using the temperature dependencies of the quenching rate constants. The dashed lines demonstrate the uncertainty in this intensity trend resulting from the uncertainties in the quenching rate constants. The experimental data from Ref. [5] are shown as round dots. All data are normalized to unity at 308 K.

Using these quenching data, the temperature dependence of the emission intensity from $C\ ^3\Pi_u\ (v' = 0)$ in air has been calculated disregarding vibrational relaxation [4]. The results have been compared with the, to the best of ower knowledge, only experimental intensity dataset which is available in the literature [5]. As shown in Fig. 2, the experimental data show a weak temperature dependence, which corresponds to a $(4 \pm 1.5)\%$ increase for gas cooling from 300 to 210 K. Our calculations also show a very weak temperature dependence: $(2 \pm 2)\%$ increase with cooling in that temperature range. Assuming a very strong temperature dependence of the vibrational relaxation between $v' = 1$ and 0 results in a reduction of the amplitude of the temperature variation by not more than 1.5%. Intensity data for pure nitrogen have also been analysed and compared with available experimental data. The agreement between direct intensity measurements and calculations based on the quenching rate constants given here is an important consistency test for the parametrization of the scintillation of the atmosphere.

References

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