

# The behavior of N<sub>2</sub> and O<sub>2</sub> in pure, mixed or layered CO ices

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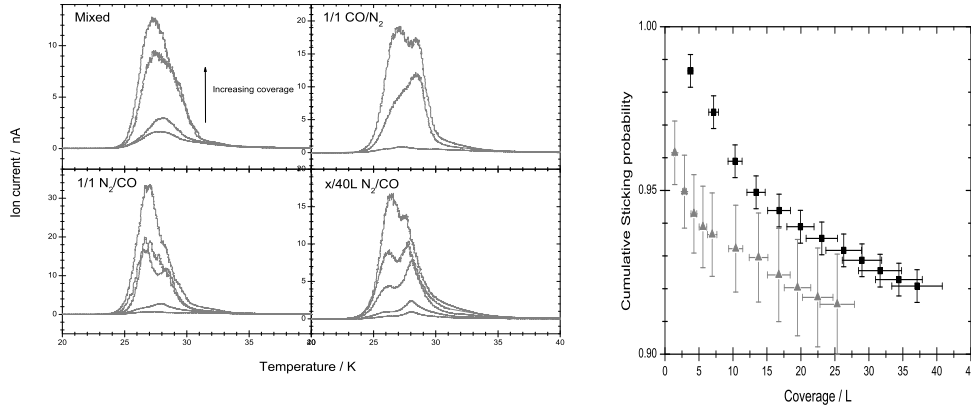
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## Abstract.

N<sub>2</sub> and O<sub>2</sub> are molecules that are predicted to be abundant in dense molecular clouds. Both molecules are difficult to detect as neither has a dipole moment. The chemical abundance of N<sub>2</sub> is mostly inferred from its daughter species N<sub>2</sub>H<sup>+</sup>, but was recently detected in the ISM for the first time, with an abundance of  $3.3 \times 10^{-7}$  (Knauth et al 2004). Searches for the submillimeter lines of O<sub>2</sub> have given upper limits for the abundance of  $\leq 2.6 \cdot 10^{-7}$  for star forming clouds and  $\leq 3 \cdot 10^{-6}$  for cold dark clouds (Goldsmith et al. 2000). Pontoppidan et al. (2003) deduced from the CO line profile that CO is present in both H<sub>2</sub>O poor and H<sub>2</sub>O rich ice layers, so it follows that N<sub>2</sub> is likely to be present in a H<sub>2</sub>O poor ice layer. In many cold and protostellar cores N<sub>2</sub>H<sup>+</sup> is found to anti-correlate with HCO<sup>+</sup> and CO (Bergin et al. 2001; Jørgensen et al. 2004). Models by, for example Bergin & Langer (1997), assume this is due to the balance between freeze-out and evaporation, where ratios for the binding energy for N<sub>2</sub> compared to CO of 0.50-0.70 are used. To model these processes, and reproduce the observed abundances of each species it is important to determine empirically the binding energies, sticking probabilities and desorption kinetics of model ice systems containing CO, N<sub>2</sub> and O<sub>2</sub>. It seems that these quantities depend on the degree to which N<sub>2</sub> and O<sub>2</sub> mix with CO.

Therefore, CO and N<sub>2</sub> ices were studied extensively in a Ultra High Vacuum (UHV) experiment ( $P \sim 1 \times 10^{-10}$  Torr) (Öberg et al. 2005; Bisschop et al submitted)). Ice samples were deposited at 14 K on a polycrystalline gold sample, mounted in the UHV chamber, covering morphologies from pure CO and N<sub>2</sub>, and 1:1 mixtures, to 1/1 layers of both CO over N<sub>2</sub> and N<sub>2</sub> over CO, and layers of 40 L of CO (1 L  $\approx$  1 monolayer) covered with 5 to 50 L of N<sub>2</sub>. The ices were studied using a combination of Reflection Absorption Infrared Spectroscopy (RAIRS) and Temperature Programmed Desorption (TPD), at a ramp-rate of 0.1 K min<sup>-1</sup>. The TPD data were modeled to accurately determine the binding energies and desorption kinetics of each system, using information from the RAIR spectra to develop the model. Sticking probabilities were calculated from a comparison between the molecular load at the mass spectrometer during dosing onto a hot and cold sample surface.

The experiments show that N<sub>2</sub> desorption from pure N<sub>2</sub> ice gives a slightly lower binding energy for N<sub>2</sub>-N<sub>2</sub> than CO-CO,  $790 \pm 25$  K and  $855 \pm 25$  K respectively, resulting in a ratio  $R_{BE} = 0.923 \pm 0.003$ . The TPD data for the mixtures and layers (see Figure 1) show that N<sub>2</sub> can also completely mix in with the CO ice. A fraction of the N<sub>2</sub> molecules that have mixed into the CO-ice, desorb with CO, giving them an effective binding energy of  $855 \pm 25$  K ( $R_{BE}=1$ ). In either case, this ratio is much closer to unity than that used in models by (for example) Bergin & Langer (1997).



**Figure 1.** Left: TPD spectra for N<sub>2</sub> in 1:1 mixed ice, 1/1 CO/N<sub>2</sub>, 1/1 N<sub>2</sub>/CO and x/40 L N<sub>2</sub>/CO where x= 5,10,20,30 and 50. Right: Cumulative sticking probabilities for CO (in black) and N<sub>2</sub> (in gray) for increasing coverages

Using  $R_{BE} = 0.923$  in their astrochemical models, Flower et al. (2005) suggested (on an *ad hoc* basis) that, in order to reproduce observations, at temperatures at or below 15 K the sticking probability of N<sub>2</sub> (to CO-ice) must be 0.1, compared to 1 for all other species. However, as Figure 1 shows, the experimentally determined equilibrium sticking probability of N<sub>2</sub> to CO (at 14 K) is only slightly lower than the sticking probability of CO to CO. Clearly, neither the binding energies nor the sticking probabilities of these systems are the key to matching observations and astrochemical models.

For O<sub>2</sub> a similar set of experiments is currently being undertaken to determine both the binding energy, kinetics and sticking probabilities. These data will also be presented.

**Keywords.** astrochemistry, line: identification, molecular data, molecular processes, methods: laboratory

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