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On the possibility of nitrous oxide (N_2O) as a cometary parent molecule in Comet 1P/Halley

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Abstract. Nitrous oxide as a possible parent molecule in Comet 1P/Halley is discussed in light of in situ measurements and theoretical considerations. Hitherto undiscussed in cometary context, N_2O could be a trace parent molecule with $Q(N_2O)/Q(H_2O) \sim 2 \times 10^{-4}$ in Comet 1P/Halley. Having a photo lifetime $>10^5$ s at 1 au heliocentric distance during solar minimum conditions and with a gas outflow speed of 0.85 km s^{-1} in the coma of Comet 1P/Halley, N_2O could reach into the tail of comet where it dissociates into N_2 and O. In this scenario, N_2O acts as a camouflage for N_2 and may help solve the puzzle of the presence of N_2^+ ions only in the tail of Comet 1P/Halley.

Keywords : Comet 1P/Halley, cometary molecules: nitrous oxide, molecular nitrogen ion

1. Introduction

Molecular nitrogen has never been observed in any of the astronomical objects as it has no observable transitions accessible to current instrumentation (Bockelle-Morvan, 1997). Molecular nitrogen has not been detected in comets as all of its resonance lines have wavelengths shorter than Lyman-α (A'Hearn and Festou, 1990). The presence of N_2 in comets, therefore, is inferred from observations of N_2^+ ions.

Comets are deficient in elemental as well as in molecular nitrogen. The deficiency of nitrogen in Comet 1P/Halley has been discussed in detail by Wyckoff *et al.* (1991), who deduced that nearly all of the elemental nitrogen is in the dust component of the

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comet. Four nitrogen bearing cometary parent molecules viz., NH_3, HCN, CH_3CN and HC_3N have been firmly identified (Bockelle-Morvan, 1997). If N_2 is a parent molecule and could not be observed for reasons mentioned above, it should have been detected spectroscopically in the coma itself where solar radiation would have ionized it into N_2^+ ion. Thus N_2 does not seem to be a cometary parent molecule.

The purpose of the present work is to explore the source of N_2^+ ions in Comet 1P/Halley where these ions are observed only in comet's tail (Wyckoff *et al.* 1991). The problem seemingly has evaded attention so far.

We have identified a compound of nitrogen viz., N_2O, hitherto undiscussed in cometary context, which dissociates into N_2 and O on time scales of $>10^5$ s (Huebner *et al.* 1992) and if present in cometary nucleus, may be the source of N_2^+ ions in the tail of Comet 1P/Halley.

2. Origin of nitrous oxide (N_2O) in cometary context

The production of N_2O in the Solar nebula is to be considered in the framework of ion-molecule and radical-radical reactions, which are relatively fast and need no activation energy. The production of NH_3 in the Solar nebula (Aikawa *et al.* 1997) and also its destruction (Kim and Huntress, 1975) through cosmic ray generated H_3^+ and He^+ reactive ions, lead to the production of nitrogen hydrides which in turn may produce N_2O molecules via radical-radical reactions involving O and OH (Warnatz *et al.* 1996). The possibility of occurrence of such reactions cannot be ruled out in the Solar nebula. N_2O molecules thus produced may get incorporated, like other volatiles, in the cometary nucleus.

3. N_2O as a cometary molecule

The following criteria support the possible parent nature of N_2O molecule in cometary context:

1. Solid state N_2O is less volatile than solid state N_2, as the temperatures corresponding to vapour pressure of 1 mm of Hg of N_2 and N_2O, both being in the solid state, are respectively -226.1 C and -143.4 C (Weast, 1979-80 (a)). As such nitrogen in N_2O (solid state) in the cometary nucleus would be retained therein for a longer time than in its molecular form (solid state).
2. CO_2 is the main contributor to the ion mass peak at AMU 44 during in situ ion gas measurements at Comet 1P/Halley (Krankowsky *et al.* 1986). However, if present, N_2O could also contribute to this ion mass peak, as the I.P. of N_2O is 12.894 eV (Weast, 1979-80 (b)) which is close to I.P. 12.8 eV of H_2O (Langhoff, 1984). The solar radiation which ionizes H_2O is expected to ionize N_2O as well.

3. N_2O dissociates mainly into N_2 and O (Okabe, 1978). Ion mass peaks at AMU 28 and AMU 16 have also been observed during in situ measurements at Comet 1P/Halley (Huebner *et al.* 1991), though CO mainly contributes to the former, being the most abundant molecule next only to H_2O in comets.

4. The possibility of production of N_2O molecule in the framework of ion-molecule and radical-radical reactions in the Solar nebula.

4. Discussion

If N_2O produces N_2 in Comet 1P/Halley, then $Q(N_2O) \cong Q(N_2)$ and the derived ratio $Q\ (N_2)/Q(H_2O)\ \sim 2 \times 10^{-4}$ (Wyckoff *et al.* 1991) would then result in $Q\ (N_2O)\ \sim 2 \times 10^{26}\ s^{-1}$, taking $Q(H_2O) = 1.3 \times 10^{30}\ s^{-1}$ at 1 au heliocentric distance in Comet 1P/Halley(Krasnopolsky *et al.* 1991). Nitrous oxide (N_2O) would thus be a trace parent cometary molecule in Comet 1P/Halley.

The observations of N_2^+ ions in the high resolution spectra of recent comets 122P/1995 S1, C/1995 O1 (Hale-Bopp) and C/2002 C1 (Ikeya-Zhang) have resulted only in upper limits viz., $\leq 10^{-5} - 10^{-4}$ on abundance of N_2 relative to CO (Bockelle - Morvan *et al.* 2004) which roughly translate to $N_2/H_2O \leq 10^{-6} - 10^{-5}$ in these comets, assuming $CO/H_2O \sim 0.1$. Wyckoff *et al.* deduced the value of $Q(N_2)/Q(H_2O)\ \sim 2 \times 10^{-4}$ from observations of the tail spectrum of Comet 1P/Halley (Wyckoff and Theobald, 1989), which were of much lower resolution than those of the above three comets. From modeling, Wyckoff *et al.* estimated the contribution of N_2^+ ion to the weak emission feature in the spectral region 3885 A – 3950 A.

If upper limits of N_2/H_2O are to be believed in comets, and if N_2O is a parent of N_2 in comets, then $(N_2O)/H_2O \leq 10^{-6} - 10^{-5}$. As $H_2O/H_2 \sim 10^{-4}$ in comets, we get $N_2O/H_2 \leq 10^{-10} - 10^{-9}$, which is in fair agreement with the observed fractional abundance of 10^{-9} of N_2O relative to H_2 in hot molecular core Sgr B2(M) (Ziurys *et al.* 1994).

The N_2O molecule has a photo lifetime $>10^5$ s (Huebner *et al.* 1992). With a gas flow speed of 0.85 km s^{-1} observed in Comet 1P/Halley, it could reach beyond the cometary coma into the cometary tail before it dissociates into N_2 and O. Molecular nitrogen thus reaches in the cometary tail without revealing its identity elsewhere. N_2O molecule acts as a camouflage for N_2.

Thus, N_2^+ ions can be produced exclusively in the cometary tail from charge exchange reactions between solar wind α-particles and N_2 molecules and/or solar photoionization of N_2 molecules.

5. Conclusions

(1) Hitherto undiscussed in cometary context, nitrous oxide (N_2O) could be a trace parent molecule in Comet 1P/Halley with $Q(N_2O)/Q(H_2O) \sim 2 \times 10^{-4}$.

(2) N_2O can act as a camouflage for N_2 in Comet 1P/Halley, thus unfolding the puzzle of N_2^+ ions only in the tail of the comet.

(3) Molecular nitrogen (N_2) could thus be the daughter species of the trace parent molecule N_2O in Comet 1P/Halley.

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