H_2O^+ IONS IN COMETS: COMET KOHOUTEK (1973f) AND COMET BRADFIELD (1974b)

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1. INTRODUCTION

Herzberg and Douglas (1973) first predicted that the H_2O^+ ion might be observable in comet tail spectra. Subsequently Lew and Heiber (1973) discovered the laboratory spectrum of H_2O^+. In October and November 1973, Herbig (1973), Benvenuti and Wurm (1974), and Wehinger and Wyckoff (1974) reported unidentified features in the tail spectrum of comet Kohoutek. On the basis of these observations, Herzberg and Lew (1974) made a tentative identification by pointing out coincidences with several strong low-lying lines in the H_2O^+ spectrum. Further observations were obtained in November 1973 and January 1974 at the Wise Observatory and by Herbig at the Lick Observatory. Six vibronic bands (5-0 through 10-0), including a total of approximately 50 rotational lines were identified with laboratory H_2O^+ spectrum (Wehinger et al. 1974). The predicted spin splitting of those lines with 2 to 4 Å separation was observed in the coude spectra of Herbig. In February 1974 comet Bradfield (1974b) was discovered and spectra were subsequently obtained at the Wise Observatory in March and April. Comet Bradfield displayed the same H_2O^+ bands as seen in comet Kohoutek (Wehinger and Wyckoff 1974).

2. OBSERVATIONS

The image-tube Cassegrain slit spectra (150 Å mm^{-1}, 5000 to 9000 Å and 75 Å mm^{-1}, 3500 to 5200 Å), obtained of comets Kohoutek and Bradfield, listed in Table 1, were calibrated and reduced to relative intensities using Oke's (1964) spectrophotometric standard stars, observed at the same zenith angle as each comet. The spectral energy distributions were put on an absolute scale, with a zero point in wavelength at 5556 Å, adopted from Ney's (1974) photometric observations, assuming essentially all of the light from the cometary coma entered the diaphragm of his photometer (20 arc sec square). Digital microphotometer scans of our spectra (unwidened and giving a spatial resolution of ~2000 km), were made at a distance r_n of 2×10^4 km from the nucleus in the tail with a projected slit width approximately equal to the seeing disk (~2 arc sec or ~1000 km at the distance of the comet). From several scans (at various r_n) through the tail spectra, perpendicular to the direction of dispersion, we determine monochromatic changes in the surface brightness for various neutral and ionized molecules. The intensities of C_2 and CN decreased approximately four times faster than the intensity change for the H_2O^+ features as a function of r_n (out to $r_n \sim 5 \times 10^4$ km). We estimate the uncertainty in the absolute luminosities to be a factor of 2 or 3 while the relative band intensities are accurate to ~±30 percent. The orbital parameters were taken from Yeomans (1973), Candy (1974) and Jacobs (1974). The integrated visual magnitudes of the comae were from Deutschmann (1974) and Ney (1974).

Table 1

Observational Data

Comet	UT Date	r (AU)	Δ (AU)	m_v	$\mathcal{L}(H_2O^+)$ (phot s^{-1})	g (phot s^{-1} cm^{-2})
Kohoutek	1973 Nov 30.1	0.9	1.4	5.6	20 x 10^{28}	0.68
(1973f)	1974 Jan 10.7	0.5	0.8	4.2	8	2.2
	1974 Jan 18.7	0.7	0.8	5.1	6	·1.1
Bradfield	1974 Mar 28.7	0.6	0.7	5.8	1	1.5

The luminosity radiated in the H_2O^+ $\tilde{A}^2A_1 \to \tilde{X}^2B_1$ system was determined from measurements of the absolute energy distributions derived by Wyckoff and Wehinger (1975).

3. DISCUSSION

We have shown that the excitation mechanism for the observed H_2O^+ bands is by fluorescent scattering of the incident solar radiation (Wyckoff and Wehinger 1975). Consequently the g-factor for the H_2O^+ $\tilde{A}^2A_1 \to \tilde{X}^2B_1$ bands ($v_2' = 5$ through 15) was calculated from

$$g = \sum_{v''} \left[\frac{\pi e^2}{mc^2} \right] \lambda_{ov'}^2 \cdot f_{ov'} \cdot \pi F_\odot \cdot \frac{A_{v'v''}}{\sum_{v''} A_{v'v''}} \qquad (1)$$

where g is expressed in phot sec^{-1} ion^{-1}, $\frac{\pi e^2}{mc^2} = 8.83 \times 10^{-21}$ cm^2 A, $\lambda_{ov'} =$ wavelength of the Q-branch of a given H_2O^+ band, $f_{ov'}$ is the absorption band oscillator strength computed from lifetimes for the upper vibronic levels deter-

mined by Erman and Brzozowski (1973); $\pi F_\odot$ is the integrated solar flux over the solar disk including effects of the Fraunhofer spectrum (Labs and Neckel 1968), $A_{v'v''}/\Sigma A_{v'v''}$ is the probability that the ion de-excites to the $v''_2 = 0$ level and was assumed to be 0.5 for all bands. We note that no H_2O^+ bands with $v'_2 > 10$ were detected in our spectra of comet Kohoutek. The relevant g-factors for the observational data are listed in Table 1. The g-factors for fluorescent scattering at 1 AU for H_2O^+ was 0.6 phot sec^{-1} ion^{-1}.

The production rates for H_2O^+ ions in both comets were estimated using Feldman et al. (1974),

$$Q_{H_2O^+} = \frac{\mathcal{L}}{g\tau} \tag{2}$$

where $\tau \sim 25$ hr is the lifetime for the H_2O^+ ions (assumed equal to the H_2O lifetime, Jackson 1972). The H_2O^+ production rates are listed in Table 2 for comets Kohoutek and Bradfield.

If we assume H_2O^+ is produced entirely by photoionization and that decomposition of H_2O is essentially complete at $r_n \sim 10^4$ km, then the H_2O production rate $Q_0 \sim 25\ Q_+$ (Wyckoff and Wehinger 1975). Thus from the production rates given in Table 2 we infer $Q_0 \sim 10^{25}$ s^{-1}, which is orders of magnitude less than the production rate determined for comet Kohoutek by Feldman et al. (1974). We conclude that either the H_2O^+ or the H_2O lifetime is much smaller than the photo-decomposition lifetime.

4. EFFECTS OF SOLAR ACTIVITY

Solar activity data were compiled from data kindly supplied by Thomas (1974) for the nights when observations of comet Kohoutek were obtained. The relative sunspot numbers and the solar flux at $\lambda = 10.7$ cm were used as indicators of solar activity. On one night's observation (1974 January 10.7) a flare of importance "one" was observed simultaneously in the United States while the comet was observed in Israel. However, owing to the low sensitivity of our spectral intensities to small intensity changes in the source, we did not detect any changes due to the flare. It is expected that the photoionization rate of H_2O in a comet would increase if the ultraviolet solar radiation in the Lyman continuum were enhanced by flare activity. Observations of another bright comet at the time of maximum solar activity to determine changes in band intensities of comet tail ions would be of interest.

Table 2

Observed Production Rates for H_2O^+

in Comets Kohoutek and Bradfield

Comet	r(AU)	Q_+(ion s^{-1})
Kohoutek	0.9	3.7×10^{24}
	0.5	1.5×10^{24}
	0.7	1.1×10^{24}
Bradfield	0.6	1.9×10^{23}

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