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The Forbidden Oxygen Lines in Comets

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Summary. High spatial resolution observations of comet Bradfield (1979X) with the IUE spectrograph had allowed us to tentatively identify a feature at $\simeq 2972$ Å as the $^1S - {^3P}$ forbidden transition of oxygen atoms. It is shown here that the most likely source of this emission is the photodissociation of water molecules, mainly by solar Lyman-alpha photons, but that a significant contribution of CO_2 cannot be excluded.

Key words: comets – oxygen – forbidden lines

I. Introduction

The forbidden oxygen lines, suspected to be present in many cometary spectra (Swings, 1962), have been formally identified (actually only the red doublet at 6300–6364 Å [$^1D - {^3P}$]) in a high resolution spectrum of comet Mrkos (1957V) by Swings and Greenstein (1958). Besides the weakness of the green and red lines, the identification is made difficult by the presence of parasitic emissions. The 5577.35 Å green line [$^1S - {^1D}$] is lost among a few weak lines of the *P*-branch of the (1–2) band of C_2 while the 6300.23 Å red line is almost confounded with the *Q*-branch of the $(0,8,0 \rightarrow 0,0,0)$ NH_2 band. Only the 6363.87 Å line is free of contamination since the nearest NH_2 line lies at 6360.43 Å. Both green and red lines are also present in the night sky spectrum which is necessarily recorded together with the cometary emissions. Only high resolution spectra allow us to separate spectrally these different emissions and to proceed to identifications on the basis of Doppler shifts on the cometary lines. This procedure has been used successfully by Swings and Greenstein (1958) in comet Mrkos on the 6364 Å line and by Huppler et al. (1975) in comet Kohoutek (1973 XII) on the 6300 Å line. When the cometary lines are not spectrally resolved, a careful examination of their spatial extensions allows us to identify them. This method suggests the presence of the red doublet much farther away from the nucleus than the NH_2 emissions. However, this argument works poorly for the green line since the C_2 molecules are found as far as 10^5 km from the nucleus. Another use of spatial information follows from a consideration of the gradients of the intensity profiles: for both green and red lines, they are almost always reported to be very low (Swings, 1962) which suggests strongly, but not definitively, an airglow contamination. Finally, the presence of extension of the emissions in the direction of the tail should be a decisive element favoring a positive identification of the three forbidden lines of O I. However, we shall see later that the presence of the green line can still be questioned, unless the 2972 Å trans-auroral line [$^1S - {^3P}$] is detected (Herbig, 1976). This has been tentatively done in comet Bradfield (1979X) with data from the IUE spectrographs (Feldman et al., 1980). Combined with far UV observations of the oxygen triplet at 1304 Å (Feldman et al., 1974; Opal and Carruthers, 1977; Feldman and Brune, 1976; Weaver et al., 1981a), this new observation now allows us to fully reconsider the problem of the origin of atomic oxygen and of its emissions in cometary atmospheres.

II. On the Presence of the Green Line in the Cometary Spectra

A very large set of observations of the forbidden lines of O I is presented by Swings (1962). These observations divide into three families according to the intensity ratio of the green line to the red line (strong, equal, and low) and extensions (of mainly the red lines) into the tail. Two facts are very surprising. First the intensity gradient is always very low which, if we reject the idea of a night sky contamination itself affected by a vignetting effect, demands an explanation in terms of density distribution and/or excitation mechanism. Second, very strong variations in the same comet are recorded from one day to the next. Though a complete renewal of the oxygen atoms is quite possible in one day since this period of time is of the order of magnitude of the lifetime of possible O I parent molecules, a strong change in the activity of the nucleus would have been noticed in the other cometary emissions, which is not reported. A study by Huebner (1965) of the relation between the relative intensity of the forbidden oxygen lines versus the total production of gas enlightens this discussion: the higher the production rate of material by the comet, the higher the red line intensity. One should remember that in the absence of collisions, 95% of O(^1S) atoms return to the ground ^3P state via the ^1D state. Consequently, the red line should be as intense (at least) as the green line. If we recall, in addition, that despite a 1–10 ratio in the production of O(^1S) to O(^1D) atoms in the terrestrial atmosphere, the intensity ratio of the green to the red airglow lines is between 1 and 10, and depends mainly on the quenching rate of O(^1D) atoms, we may conclude with Arpigny (1965), that when the red line is the strongest (and so is the production rate of gas), the red line is of cometary origin (the exposure time is always short, and an eventual contamination by airglow lines is limited). However, when the

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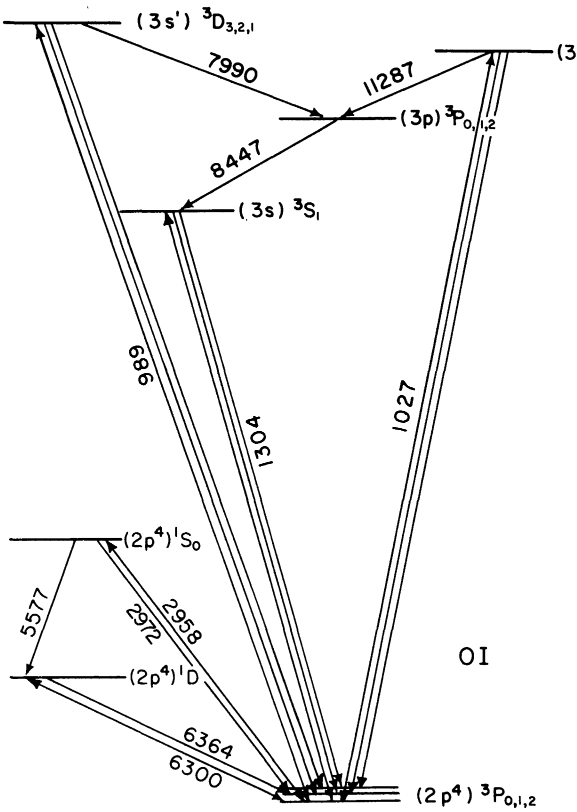

Fig. 1. Transitions involved (allowed and forbidden) in the spectrum of the oxygen atoms in a cometary atmosphere

green line is overwhelming (in faint comets like Encke), this emission is mainly due to the airglow, the red airglow emission being quenched and consequently weaker than the green. If the green line were of cometary origin and observed a few 10^3 km from the nucleus, where no collisions occur, the red line should be as intense as the green line whatever is the mechanism responsible for its formation. Though we have no explanation for the observation of the green line without the presence of the red one in the direction of the tail, we think that the above argument concerning the minimum value of the ratio of the green to red lines can be used to suspect an instrumental effect which is impossible to analyse here. On the other hand, when the red line is strong, there is no reason to demand the green one to be present since oxygen atoms can be created directly in the ^1D state. Note that in bright comets, the green line is never as intense as the red one and that extensions in the tail always concern the red doublet. The only test of the presence of a cometary green line then is the detection of the ^1S oxygen atoms by their emission at 2972.3 Å which must necessarily be carried out from above the Earth's atmosphere, thus avoiding the problem of airglow contamination. Figure 2 of Feldman et al. (1980) shows, from measurements made on 10 January 1980, a feature near 2972 Å which has been tentatively identified with the $[^1S-{}^3P]$ oxygen line (the spectral resolution is ≈20 Å). The measured intensity on 10 January 1980, when the comet was 0.71 a.u. from the Sun and 0.615 a.u. from the Earth, is 30±15 Rayleighs. Observations made on 16 January showed the same feature, very close to the limit of instrumental sensitivity and a reliable intensity cannot be derived. A re-analysis by Feldman (1981) of the Comet Seargent (1978XV) spectra enhances a small feature around 2970 Å which did not appear in the spectrum presented by Jackson et al. (1978). Since the 2972 Å feature also appears, superimposed on a very strong dust continuum, in the spectrum of Comet West (1976VI) (Feldman and Brune, 1976), it is likely that it is a common, though weak, feature in most comets. In the following, we discuss the question of the excitation mechanism of the 2972 Å line of O I and re-examine the hypothesis of the origin of the forbidden oxygen lines in cometary spectra from a quantitative point of view.

III. The Excitation Mechanisms

Following earlier published suggestions concerning the origin of the forbidden oxygen lines, we successively consider:
- the fluorescence of solar light.
- the production of excited oxygen atoms by direct dissociation of various molecules.
- the electron recombination of cometary ions.

Fluorescence

The detection of the ultraviolet resonance triplet of oxygen at 1304 Å in the spectra of comets Kohoutek, West, Bradfield and others (Opal and Carruther, 1977; Feldman and Brune, 1976; Feldman et al., 1980; Weaver et al., 1981b) demonstrates the presence of oxygen atoms in the coma, the predominant source being the photodissociation of H_2O. For comets with heliocentric velocity, $\dot{r}$, less than ≈30 km s^{-1}, the emission is produced by resonance scattering of the solar oxygen lines (Weaver et al., 1981a). The actual emission rate, however, is critically dependent on both the solar lineshape and flux, both of which vary during the solar cycle (Mount et al., 1980). For comets Kohoutek and West, both observed when $\dot{r}$ was in the range of 44–55 km s^{-1}, the solar line appears Doppler shifted completely away from the cometary absorption wavelength, and the excitation is produced mainly by solar *Lβ* induced fluorescence (Feldman et al., 1976). This mechanism can account for the magnitude of the O I λ 1304 flux observed by Feldman and Brune (1976) in Comet West.

To assess the contribution of fluorescence to the forbidden oxygen lines, we then simply need to compare the fluorescence efficiencies, or "*g*-factors", for the forbidden lines to that for the ultraviolet resonance triplet. Figure 1 shows an O I energy level diagram on which the wavelengths of the relevant transitions have been indicated. The lifetime of the $^3P_0$ and $^3P_1$ states are respectively 6 10^4 s and 1.1 10^4 s so that all oxygen atoms will be in the $^3P_2$ state if the excitation rate for this state is smaller than about 10^{-5} s^{-1}, an assumption which will be verified a-posteriori. The lifetimes of all considered excited states are short enough so that we can neglect reabsorptions. The absorption rate for the transition λ_{is} is given by:

$$g(\lambda_{is}) = 8.86\ 10^{-21}\ \lambda_{is}^2 f_{is} F(\lambda_{is})\ \text{photons s}^{-1}\ \text{atom}^{-1} \qquad (1)$$

where f_{is} is the oscillator strength (Wiese et al., 1966; Pradhan and Saraph, 1977) and $F(\lambda_{is})$ is the solar flux at 1 a.u. in photons s^{-1} cm^{-2} $Å^{-1}$. Solar flux values have been taken from Arvesen et al. (1969), Broadfoot (1972), Heroux and Hinteregger (1978), and Mount et al. (1980). Table 1 gives the emission rates at 1 a.u. corresponding to the multiplets shown in Fig. 1. The branching ratios for radiative de-excitation are $A_{si}/\sum_i A_{si}$, where the coefficients A_{si} are the transition probabilities of the considered emissions (Wiese et al., 1966; Lawrence, 1970). It should be noted that the emission rate factor of the 2972 Å line is 5% of that of the

Table 1. Atomic oxygen emission rate factors at 1 a.u.

Multiplet (Å)	g (photons s^{-1} atom^{-1})
989	$1.6\ 10^{-8}$
1027	0.4–$1.5\ 10^{-6}$ [b]
1304	1.1–$3.9\ 10^{-7}$ [a, b] $+0.6$–$1.5\ 10^{-5}$ [b]
2972	$3.1\ 10^{-15}$
5577	$6.2\ 10^{-14}$
6300	$4.2\ 10^{-10}$
6364	$1.3\ 10^{-10}$

[a] H I Lβ induced fluorescence (Feldman et al., 1976)

[b] Variable with solar ultraviolet flux and heliocentric velocity of the comet

Table 2. Branching ratios from the metastable states of oxygen

	2972	5577	6300	6364
O(^1D)	—	—	0.76	0.24
O(^1S)	0.05	0.95	0.72	0.23

5577 Å line and that the ratio of the red to the green lines is 6800, a value slightly different from the value derived by Remy-Battiau (1962) because we have used more recent solar fluxes and transition probabilities. This ratio would become much closer to unity if it were assumed that the $^3P_1$ state were populated by collisions since then direct pumping at 2972 Å of the ^1S state would be much more efficient than the one at 2958 Å (the resolution of the oxygen triplet at 1304 Å is certainly one of the best means to estimate the importance of collisions in cometary atmospheres). However, there is no possibility, assuming a pure fluorescence mechanism, to obtain a green line more intense than the red line. This argument has been used by Remy-Battiau to reject fluorescence as the excitation mechanism.

From Table 1, it is clear that fluorescent excitation of O (^1S) is always negligible. For O (^1D), the ratio of the λ6300 g-factor to that for λ1304, for the conditions of observation of comet Bradfield, is $\approx 5\ 10^{-5}$, so that based on the 330 R of λ1304 emission (10 January 1980, $r = 0.71$ a.u.) from a projected area of $\approx 4500 \times 6700$ km^2, the expected λ6300 emission rate would be ≈ 0.02 R. From the analysis of the spatial distribution of the λ1304 emission (Weaver et al., 1981a), it is found that the oxygen distribution is fairly uniform near the nucleus, since it is a daughter (and grand-daughter) product, so that the λ6300 brightness due to fluorescence will not appear enhanced with higher spatial resolution. Even in the case of an extremely active comet, such as Comet West (1976VI), in which the derived water product rate at 0.385 a.u. was found to be greater than 10^{30} s^{-1}, the λ6300 emission rate would still only be a fraction of a Rayleigh, considerably less than the typical 100 R of the night sky. Thus, fluorescent scattering can be completely neglected in any further discussion of the forbidden oxygen lines.

Collisional Deactivation

Before proceeding to a discussion of the other possible excitation mechanisms, the possibility that excited oxygen atoms could be collisionally quenched should also be examined. Owing to their high densities in the inner coma, only dominant neutral species need be considered. The efficiency of the quenching process can be assessed by comparing the quenching frequency $k_Q\,[M]$, k_Q being the quenching coefficient of the molecule M with O*, with the lifetime of the oxygen atoms, 0.6 s for O(^1S) and 148 s for O(^1D). The coefficients k_Q for the quenching of O (^1S) and O (^1D) by H_2O are respectively $3\ 10^{-10}$ cm^3 s^{-1} (Zipf, 1969) and $2\ 10^{-10}$ cm^3 s^{-1} (Streit et al., 1976). The quenching coefficients for O(^1S) by CO_2 and CO are respectively $\leqq 3\ 10^{-14}$ cm^3 s^{-1} and 10^{-13} cm^3 s^{-1}. The corresponding numbers for O(^1D) are respectively $\leqq 2.3\ 10^{-10}$ cm^3 s^{-1} and $\leqq 10^{-11}$ cm^3 s^{-1} (Zipf, 1969). It is easily checked that even with production rates of H_2O, CO_2 or CO as high as 10^{30} s^{-1}, the quenching mechanism will not be an efficient deactivation process beyond the first few hundreds of kilometers above the nucleus surface. Consequently, most of the excited oxygen atoms will freely radiate. In the discussion below, the effects of quenching will be evaluated quantitatively.

Dissociation of Parent Molecules

The oxygen bearing molecules may dissociate under the action of the solar flux and lead to the production of excited oxygen atoms. Neglecting quenching, the detection of any of the $\lambda\lambda$2972, 5577, 6300, and 6364 Å lines then constitutes a direct measurement of the column densities of the oxygen parent molecules since we can also neglect the displacement of the atoms before they radiate. The relation between the column density of the parents (N), the dissociative lifetime of the parents (τ_p), the yield of the dissociation for the production of excited atoms (α), and the branching ratio (β) corresponding to the intensity $I(R)$ of the observed line is:

$$I = 10^{-6}\,\tau_p^{-1}\alpha\beta N \qquad (2)$$

Table 2 provides the values of β for the various forbidden lines according to the nature of the excited oxygen atom which produces them.

Among the potential candidates for the production of excited atoms by a single dissociation are H_2O, CO_2, and CO. The first dissociation of molecules such as H_2CO, HCOOH, and CH_3OH does not lead to oxygen atoms. The atoms appear in subsequent photodissociations via destruction of OH, CO or HCO. However, OH undergoes a predissociation (Brzozowski et al., 1978) and produces O (^3P) atoms. Jackson (1980) has shown that this process can account for the observed lifetime of OH in comets. Then, very little, if any, of excited atoms result from the dissociation of OH. CO can either be a primary molecule existing in the nucleus or a dissociation product of CO_2. In the following, we shall only consider the case of H_2O, CO_2, and CO which we assume exist in the nucleus. The results show a-posteriori that if O (^1S) atoms were produced via a multiple photodissociation, the production rate of the initial parent molecule would have to be much higher than 10^{30} s^{-1}, a value which is inconsistent with the production rates derived from the study of the other features measured in Comet Bradfield.

Since the preponderance of mother molecules is found near the nucleus, quenching of the metastable atoms could be significant and is evaluated using the radial outflow model (Festou, 1981a) with the parameters given by Weaver et al. (1981a). The parameters relevant to our discussion are given in Table 3 for the molecules considered. The results for H_2O are shown in Fig. 2 (λ5577 Å) and Fig. 3 (λ6300 Å) for three cases: the Comet Bradfield observation of 10 January 1980, and two hypothetical cases of 10^{28} s^{-1} and

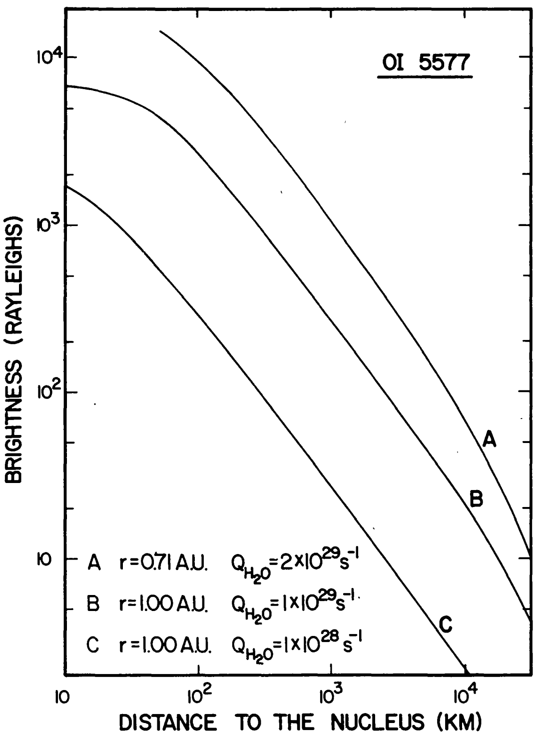

Fig. 2. Predicted brightnesses of the oxygen green line in three different cases. The oxygen ^1S atoms are assumed to be produced by the photodissociation of H_2O molecules. High spatial resolution observations are required to separate the cometary green line from the typically 100–200 R airglow emission

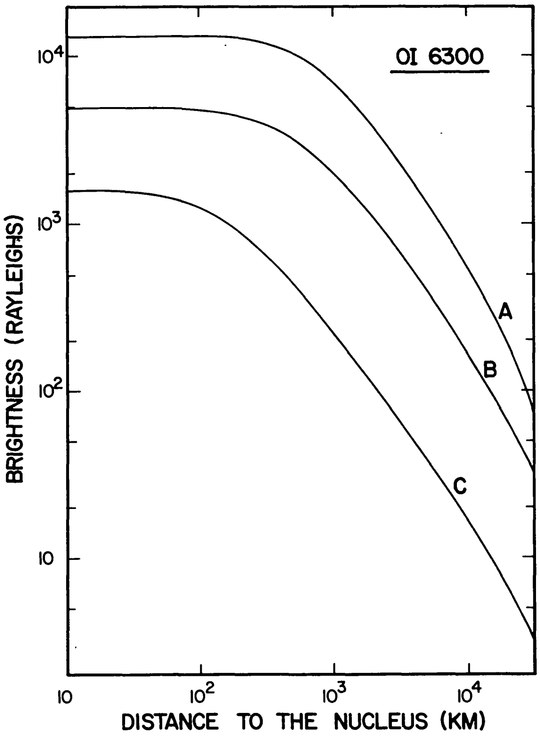

Fig. 3. Predicted brightnesses of the oxygen red lines (the intensity of the 6364 Å line is 24% of the intensity of the 6300 Å line) for the 3 cases defined in Fig. 2. The oxygen ^1D atoms are assumed to be produced by photodissociation of H_2O molecules. Note the flattening of the intensity profiles due to the quenching of the oxygen atoms by the water molecules. As for the green line, high spatial resolution observations are required

Table 3. Effective excitation rates from the dissociation of various parent molecules

Parent	Excitation rate (s^{-1} – at 1 a.u.)	
	For $O(^1D)$	For $O(^1S)$
H_2O	8–12 10^{-7}[a]	7–12 10^{-8}[a]
CO_2	5 10^{-7}[b]	4.4 10^{-7}[b]
CO	<4 10^{-8}[c]	<4 10^{-8}[c]

[a] Festou (1981b)

[b] Lawrence (1972a, b) for the $O(^1S)$ dissociation cross sections and solar fluxes from Huebner and Carpenter (1979)

[c] Huebner and Carpenter (1979)

10^{29} s^{-1} water production rates at a heliocentric distance of 1 a.u. The intensities for the 6364 Å line can be deduced from Fig. 3 by dividing the intensities for the 6300 Å line by a factor of 3.2. Even with quenching accounted for, these results demonstrate the sharply peaked spatial distribution, characteristic of the parent molecule column density at cometocentric distances much less than the parent scale length, and suggest that the highest possible spatial resolution be used in ground-based observations to reduce the effect of the night airglow contamination.

For comparison with the IUE observation of ≈30±15 R of O I 2972 Å at 0.71 a.u. averaged in the central 10″×15″ of the spectrograph large aperture, the brightness profile *A* shown in Fig. 2 was integrated over the same area. This gives a value of 32 R for the 2972 Å emission, which is quite good agreement considering the numerous model uncertainties and the variability of the solar ultraviolet flux (Oppenheimer and Downey, 1980). Clearly, the abundance of H_2O is sufficient to account for the observed (^1S) emission, and in fact, produce sufficient λ5577 and λ6300 emission to be easily detectable over the night sky emission at a spatial resolution of a few arc s. However, the uncertainties in both the model parameters and the data are such as to preclude a definitive identification of water source, as CO_2 is a more efficient producer of $O(^1S)$ than H_2O and hence a smaller production rate this molecule could also account for the magnitude of the observed emission. Also, CO is present in relatively high abundance as in comet West (Feldman and Brune, 1976) and may make a significant contribution to the $O\,^1S$ population. Furthermore, if CO_2 and CO are parent molecules, the spatial distribution of the emission will be the same as if the source were H_2O.

There are, however, additional observational constraints that can be used to estimate the relative importance of both CO and CO_2. For the former, the weakly appearing fourth-positive system can be used to obtain a CO production rate of 4 10^{27} s^{-1} from Comet Bradfield at $r=0.71$ (A'Hearn and Feldman, 1980). This is 0.02 of the H_2O production rate derived for the same day (using the same model parameters such as outflow velocity, etc.), and would require a (^1S) effective excitation rate of 5 10^{-6} s^{-1} at 1 a.u. to produce the observed 30 R emission, a value not consistent with the data given in Table 3.

For CO_2 we note that both laboratory data (Lawrence, 1972a, b) and the analysis of the Mars dayglow spectrum (Fox and Dalgarno, 1979; Conway, 1981) demonstrate that photodissociation of CO_2 leads to the simultaneous emission of $O(^1S)$ emissions and the forbidden Cameron band system ($a^3\Pi - X^1\Sigma$) of CO. Since the Mars airglow data above 140 km represents a good example of nearly a pure solar photodissociation source, we use the high altitude spectra of Conway to determine the expected ratio of the strongest Cameron bands to OI λ2972. This ratio is 2.2 for both the (0, 0) band at 2063 Å and the (0, 1) band at 2158 Å. Unfortunately, the IUE sensitivity is low near 2100 Å and an upper limit (1 σ) of 50 R was found for the CO^+ (0, 0) first negative band at 2191 Å (A'Hearn and Feldman, 1980). The expected brightness of the (0, 0) and (0, 1) Cameron bands would then be ≈ 66 R which is just at the noise limit of the available spectra. This limit could probably be reduced further by considering the entire band system, but it is clear that while CO_2 is probably not the sole source of the observed $O(^1S)$ emission, it could contribute a significant fraction. The appearance of the CO_2^+ bands at 2890 Å, strongly suggests the presence of CO_2 in the coma, but modelling of this emission is necessary to derive a CO_2 production rate. Further observations, either of gassier comets or with improved sensitivity in the spectral region near 2100 Å, that allow for detection of the Cameron bands should be able to resolve this question.

Dissociative Recombination of CO_2^+

Since CO_2^+ is clearly present in the coma, and since the dissociative recombination of CO_2^+ with electrons is a very efficient source of both the oxygen green line and the CO Cameron bands (Wauchop and Broida, 1971) with comparable yields as photodissociation (Lawrence, 1972a), we consider whether CO_2^+ recombination could be a significant source of $O(^1S)$. From IUE offset exposures, the CO_2^+ band at 2890 Å appears to decrease in intensity only very slowly at distances $\approx 10^4$ km from the nucleus in the tailward direction. Since electron recombination is probably the principal loss mechanism for CO_2^+ (Festou et al., 1981), we can deduce that the total recombination rate is considerably less than the resonance fluorescence rate (the g-factor), so by comparison with the CO_2^+ column emission rate (the surface brightness at 2890 Å) we can derive an upper limit to the $O(^1S)$ production rate via recombination. Using 0.25 (Zipf, private communication) for the efficiency of ^1S production, and the 5% branching ratio for λ2972, the observed 600 R of CO_2^+ emission gives an upper limit of 7 R for the λ2972 emission, so that this mechanism must be considered only a minor source of the forbidden lines. Again, the spatial distribution will not be symmetrical about the nucleus but will depend on the CO_2^+ ion distribution into the tail.

IV. Discussion

The value of the ratio of the observed emissions at 2972 Å and 1304 Å in comet Bradfield (1979X) completely rules out the possibility that fluorescence would be the mechanism responsible for the 2972 Å emission on the basis that all oxygen atoms are in the $^3P_2$ state. Even if collisions in the inner coma were important, it would be difficult to increase significantly the population of the $^3P_1$ state. According to Weaver et al. (1981a), the oxygen atoms are daughter and grand daughter products: consequently, only a very small fraction of them can be thermalized inside the collision zone (Festou, 1981a).

The lifetime of the $^3P_1$ state of the oxygen atoms is about 10^4 s (Wiese et al., 1966), independent of the heliocentric distance. On the other hand, transitions leading to $^3P_1$ atoms (mainly via absorptions at 1302 Å and 1027 Å, see Fig. 1) give a total emission rate of about $5\ 10^{-6}\ s^{-1}$ at 1 a.u. Thus, if the heliocentric distance of the comet becomes of the order of 0.5 a.u. or less, approximately 10% (or more) of the oxygen atoms will absorb solar photons instead of radiating the 63 micron infrared line. Then, although the ^1S state can be populated via the direct absorption of 2972 Å solar photons, fluorescence will still not account for any significant fraction of the intensity of the oxygen forbidden lines.

Since electron recombination of the CO_2^+ ions has been shown to be inefficient in producing ^1S oxygen atoms, the only possibility which remains to produce them is the photodissociation of parent molecules such as CO_2 or H_2O. Because of the variability of the solar EUV flux (Oppenheimer and Downey, 1980), the accuracy of the numbers given in Table 3 is of the order of $\pm 50\%$. With these values, photodissociation of the H_2O molecules deduced from the OH observations, can account for the observed 2972 Å emission. However, it is possible that part of the emission could be due to photodissociation of CO_2 as this is a very efficient process for producing $O\,^1S$ atoms and would require only a small abundance of CO_2 in the coma.

The comparison of the IUE observations with previous ground based observations is very difficult because most of the latter are only qualitative. The only quantitative observations are those of Huppler et al. (1975) and Delsemme and Combi (1976, 1979). While the observations of Huppler et al., are free of airglow contamination, the NH_2 cometary lines may contribute to their recorded signal, and hence the indicated intensity of the 6300 Å line (about 200 R) can only be considered as an upper limit for the oxygen line. This value is consistent with what would be obtained by integrating our Fig. 3 over a 40,000 km diameter diaphragm (after scaling for the appropriate value of Q_{H_2O}). The case of Delsemme and Combi's observations of comet Bennett, obtained at low resolution, is much more doubtful. Not only have the NH_2 and airglow lines not been separated from the cometary oxygen line, but the examination of the telluric mercury lines shows that either a vignetting effect or an asymmetric contribution of the continuum or a combination of both phenomena does not allow us to fully interpret the data. In addition, if the 6300 Å line were due to the oxygen atoms and not to the NH_2 radicals, some signal should have been recorded at 6364 Å.

Recent observations, of only the red lines, in comets Bradfield (1979X) and Encke, amongst others, with a 4″ aperture, are consistent with the spatial distribution of Fig. 3 and provide further evidence for a photodissociation source of the forbidden oxygen lines in these comets without tails (Spinrad, private communication, 1981). Although both the present and Spinrad observations are consistent with H_2O as being the source of the oxygen atoms, it seems to us absolutely essential to carry out high resolution, both spatial and spectral, simultaneous observations of the green and red lines of atomic oxygen. Further observations of the intensity ratio of the green to the red line should allow us to distinguish between the potential parents and provide the production rate of CO_x molecules, since the production rate of H_2O can be derived from an observation of the OH (0–0) band.

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