THE OVI EMISSION FROM THE SUN

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Abstract. The ionization equilibrium of oxygen is calculated for various temperatures. A peculiarity in the dielectronic recombination leads to a considerable fraction of O VI in the corona. Thus, the O VI lines may be emitted from the corona rather than the transition region.

The resonance lines of O VI are of special interest because they are the only strong lines in the XUV spectrum from an ion with ionization potential between 113 eV (O V) and 207 eV (Ne VII). Thus they are a key to the transition from chromosphere to corona. Further, these lines (1038 and 1032 Å) are the strongest from any ion of more than 70 volts ionization potential. Because it is important to understand the manner and location of the production of the O VI lines, we have computed the ionization equilibrium of this ion and the emission rates for various circumstances.

When we consider the ionization equilibrium of O VI, an important peculiarity is immediately obvious. The configuration of O VI is lithium-like ($1s^2 2s$) and is easily ionized. The next stage of ionization, O VII, is He-like, and hard to ionize. Thus at coronal temperatures, almost all the oxygen will be in the form of O VII, a point noted by ZIRIN *et al.* (1963). This produces an important effect on the distribution of O VI. The ionization of O VI is a balance between collisional ionization and electronic and dielectronic recombination. For the last to occur, the ionized state (O VII) must be excited by an incoming electron to produce an auto-ionization state of the next lower ion. But the lowest excitation potential of O VII is 559 volts; thus dielectronic recombination is only important at high temperatures, when kT 559 eV. As a result, O VI is relatively highly ionized at lower temperatures, because only radiative recombination is important.

As a result, the fraction of O VI has a long high temperature tail. It is as great at 2000000° as it is at 175000°. Because of the great extent of the 2000000° region, the greatest contribution to the O VI emission comes from the corona.

We have carried out the usual coronal ionization calculation (ZIRIN, 1966) following Elwert's and Burgess's methods. The ionization equation is:

$$n_i q_i = n_{i+1} \left(\alpha^R(i) + \alpha^D(i) \right), \tag{1}$$

where n_i is the number density of the ith state of ionization; q_i the rate coefficient for

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TABLE I

Stage of ionization	$T = 2 \times 10^5$ K			$T = 1 \times 10^6$ K			$T = 1.5 \times 10^6$ K			$T = 2 \times 10^6$ K		
	V	VI	VII	V	VI	VII	V	VI	VII	V	VI	VII
$\alpha^D(i)$ $(\times 10^{-12})$ cm^3/sec	42.7	3.3×10^{-11}	5.8×10^{-13}	15.1	1.0	8.0×10^{-2}	10.1	2.4	0.5	7.3	3.4	1.0
$\alpha^R(i)$ $(\times 10^{-12})$ cm^3/sec	1.6	2.0	5.8	0.5	0.7	2.4	0.4	0.5	1.9	0.3	0.4	1.6
$\alpha^D + \alpha^R (\times 10^{-12})$	44.3	2.0	5.8	15.6	1.7	2.4	10.5	2.9	2.4	7.6	3.8	2.6
$\phi_i (\times 10^{-12})$ cm^3/sec	2.9	0.25	1.1×10^{-16}	1.3×10^3	3.4×10^2	2.0×10^{-2}	2.5×10^3	7.3×10^2	0.48	3.6×10^3	1.1×10^3	2.3
N_i/N_{i+1}	15.3	8.0	5.3×10^{16}	1.2×10^{-2}	5.1×10^{-3}	1.2×10^2	4.2×10^{-3}	4.1×10^{-3}	4.94	2.1×10^{-3}	3.5×10^{-3}	1.1

collisional ionization of the ith state; $\alpha^R(i)$ the total radiative recombination to all levels of the ith ion; and $\alpha^R(i)$ the total dielectronic recombination coefficient. For q_i and $\alpha^D(i)$ we have used the formula of HOUSE (1964). We calculated the dielectronic recombination by BURGESS's (1965) formula, using energies and oscillator strengths from WIESE *et al.* (1966). The calculated values of the various rate coefficients are given in Table I. The resulting fractional abundances of the different ionization stages of oxygen are shown in Figure 1.

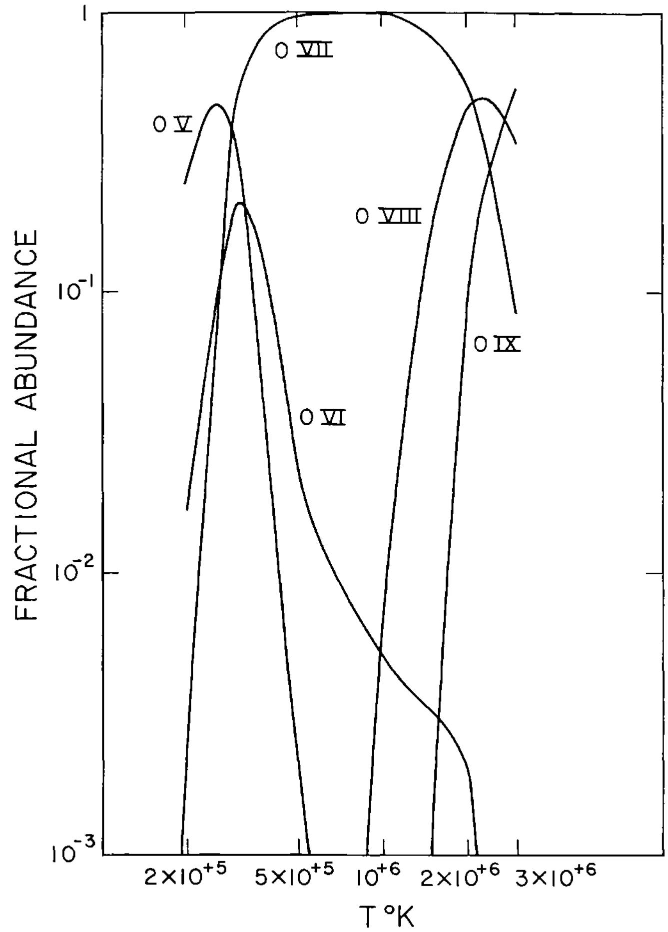

Fig. 1. Fractional abundances of the ionization stages of oxygen at different temperatures.

Similar calculations by ALLEN and DUPREE (1967) have just appeared for O, Ne, Si, and Fe. Our results are in good agreement with theirs for O, when slight differences in the adopted constants are allowed for. They find the same effect in all the Li-like ions.

We see from Figure 1 that O VI has indeed a most peculiar ionization curve. It never is the most abundant stage of ionization; at most it makes up 20% of the oxygen, and this only in a very narrow range. On the other hand, it shows an extended shoulder out to high temperatures as the dielectronic recombination becomes important. Even at 2000000°, the fraction of O VI is 0.002. The resonance lines of O VI may be excited by 12-volt electrons, so strong lines are produced. The resonance lines of O VII require 550 volts, so they are weak, even though the coronal oxygen is mostly O VII.

We may now calculate the contribution to the observed flux in the O VI resonance lines (0.065 erg/cm^2 sec – HINTEREGGER, 1964) by the corona and the transition region. We assume that all collisional excitations are followed by emission of the line (i.e., the optical depth is not great) but only $\frac{1}{2}$ are emitted outward. Using VAN REGEMORTER's (1962) value for the excitation cross section and Allen's value 6.3×10^{-4} for the oxygen/hydrogen ratio, and letting $N(H) = 0.83\ N_e$, we obtain the results in Table II for a 1-km thick layer with $N_e = 10^{10}$.

TABLE II

The intensity at the earth from a uniform layer 1 km thick ($N_e = 10^{10}$ cm^{-3})

T(K)	2×10^5	3×10^5	5×10^5	10^6	1.5×10^6	2×10^6	2.5×10^6	3×10^6
$I_{\mathrm{erg/cm^2/sec/km}}$	1.4×10^{-4}	1.7×10^{-3}	2.2×10^{-4}	7.2×10^{-5}	4.7×10^{-5}	2.8×10^{-5}	5.6×10^{-6}	2.1×10^{-6}

To calculate the flux from the corona we choose $T = 1.5 \times 10^6$, $N_e = 1.5 \times 10^9$, and $H = 5 \times 10^4$ km for the effective thickness of the corona. This gives a flux of 0.06 ergs/cm^2/sec at the earth. If we remember that a substantial fraction of the flux comes from active regions anyway, we see that the O VI resonance line flux can be completely accounted for by radiation from the corona and active regions. This would mean that the O VI emission would show a secant distribution, rather than a sharp limb peak, as would be produced by a thin transition region (and was observed by Tousey and Purcell (TOUSEY, 1967) for Ne VII). Preliminary observations with the Harvard spectrometer presented by NOYES *et al.* (1968) show a secant-like variation for O VI. Although the results are preliminary, it is clear that there is not a sharp spike and there is considerable coronal contribution.

The foregoing calculation does not exclude the possibility of some contribution from the transition region. However, if we can account for the O VI emission by radiation from the corona, whose existence and nature are well established, we do not need the hypothetical transition zone, the properties of which are but poorly known.

It may by noted in this regard that POTTASCH (1963) has placed great weight on the O VI point in establishing a curve of effective density vs. temperature in the solar atmosphere. Unaware of the dielectronic recombination effect, he placed the O VI emission at 200000°. If we remove the O VI point from his Figure 1 (or shift it to coronal temperatures) and also shift all the coronal lines to higher temperatures to allow for the dielectronic recombination, we see that there is no longer a continuous curve, as assumed by Pottasch, but two isolated groups, chromospheric and coronal, as pointed out by ZIRIN *et al.* (1963).

The effect discussed is characteristic of all Li-like ions; but only O VI is just at the transition temperature with a large coronal contribution. Ne VIII appears to be entirely coronal anyway. C IV is low enough to be predominantly chromospheric, but there may be some coronal emission. He II is another interesting case, since it is impossible to ionize He III.

Acknowledgments

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