In conclusion, we mention that several methods for measuring oscillator strengths, which are based on non-linear processes, have been demonstrated in the past years. [Note that for linear as well as for non-linear optical processes, the coupling of the electronmagnetic field with atoms or molecules takes place through electric-dipole (and higher-order) moments and thus can be expressed in terms of oscillator strengths.] Non-linear methods have, of course, not yet reached the maturity and experimental perfection of the classical dispersion, absorption and emission methods, yet they have been proven in concept.

In view of their potential it would be worthwhile exploring the suitability of non-linear processes for the measurements of oscillator strengths of astrophysical interest. A review of the relevant processes and applications is given by Huber and Sandeman (1986).

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MEASUREMENTS OF TRANSITION PROBABILITIES FOR INTERSYSTEMS LINES OF ATOMIC IONS USED IN DIAGNOSIS OF ASTROPHYSICAL PLASMAS.

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1. ASTROPHYSICAL MOTIVATION

In many low-charge ions of astrophysically abundant light elements, the spins of the ground and first-excited terms are different. Because of spin-orbit interactions, the states of these terms are mixtures of LS basis states, and as a consequence, transitions with $\Delta S = 1$, i.e., 'intersystem transitions', can occur. The transition probabilities (A-values) for such lines in low-Z ions are about 10^4 sec^{-1} to 10^2 sec^{-1}. These values are of the same order of magnitude as the collisional de-excitation rates in many low-density astronomical objects. Consequently, intersystem lines, which are not readily seen in the laboratory, are significant features in many astronomical spectra. IUE spectra that show such lines in novae, hot stars, cool stars, symbiotic stars, binary stars, variable stars, Herbig-Haro objects, H II regions, planetary nebulae, quasars, and galaxies are discussed in Kondo et al. (1982). Moreover, because of the commensurate radiative and collisional de-excitation rates for the upper levels, the ratios of intersystem-line intensities to allowed-line intensities are density sensitive in many objects.

Line ratio techniques for determining electron densities (and temperatures) in astrophysical plasmas have been reviewed most recently by Doschek (1985), who gives many references to other work. All such procedures are only as accurate as the atomic data used. The work reported here describes the first measurements of the necessary radiative transition probabilities.

2. EXPERIMENTAL METHOD

The apparatus, method, and procedure have been reviewed by Smith et al. (1984) and will be discussed only briefly here. Ions were created by electron bombardment on gases (Si^{++}, O^{++}, N^{+}, C^{++}) or in a laser-produced plasma (Al^{+}), and stored in a radio-frequency ion trap. In such a trap, electric fields are used to create a potential well that can hold ions in an approximately collision-free environment (see Wineland et al. 1983). A delay, of the order of tens of microseconds, followed the creation and storage of the ions. During this period, allowed transitions occured, thus eliminating cascade repopulation of the metastable levels during the measurement period that followed. The radiative lifetimes were measured by studying the time dependence of the intensity of the intersystem line. Then the ions were ejected from the trap. The create-store-delay-measure-eject cycle was repeated at a rate of 10 to 100 Hz. Smith et al. (1984) show the timing sequence in a schematic manner, discuss the collisional loss rates for the metastable ions, which are small relative to the measured A-values, and present details of the data analysis.

3. RESULTS

Our results and references to details of the measurements are presented in Table 1. For ions such as O^{++} and N^{+}, which have two intersystem decay transitions from the metastiable level, our lifetime measurement technique gives only the sum of the transition probabilities for the decays. Several of our measurements have uncertainties that are less than ±10 percent, and are, therefore, more accurate than any of the calculated values (which are given in the papers referenced in Table 1). Our results have shown that the more sophisticated theoretical techniques can produce accurate transition probabilities for the intersystem lines used in astrophysical plasma diagnosis, but in some cases, inaccurate values have been used in electron density determinations for some astrophysical plasmas.

TABLE 1

Measured Transition Probabilities for Intersystem Transitions

ION	TRANSITION	λ(nm)	A(10^3 sec^{-1})	NOTE
Si III	$3s^2\ {}^1S_0 - 3s3p\ {}^3P_1^0$	189.203	16.7 (±1.0)	a
O III	$2s^32p^3\ {}^4P_{2,3} - 2s3p^4\ {}^6S_3^5$	166.080 166.615	0.82(≠.05)	b
Al II	$3s^3\ {}^2So - 3s3p\ {}^4P_2^5$	266.916	3.33(≠.23)	c
N II	$2s^32p^3\ {}^4P_{2,3} - 2s2p^4\ {}^4S_3^5$	213.968 214.355	0.24(≠.03)	d
C III	$2s^3\ {}^2So - 2s2p\ {}^4P_2^5$	190.873	0.07(≠.02)	e

a Kwong et al. (1983a)
b Johnson et al. (1984)
c Johnson et al. (1986)
d Knight (1982)
e Kwong et al. (1983b)

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