PROTON-INDUCED FINE-STRUCTURE TRANSITIONS*

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Experimental studies of the intensity of the (2p1/2-1s1/2) and (2p3/2-1s1/2) lines of SXVI in the Alcator Takamak show large departures from the statistical ratio of 0.5 (Källne et al. 1982). Similar enhancements in the intensity ratio have been reported in solar observations (Grineva et al. 1973, Phillips et al. 1982) for the Mg XII lines and in laser produced plasmas (Boiko et al. 1977). Theoretical calculations of the intensity ratio have been carried out by Vinogradov et al. (1977), Beigman et al. (1979) and Ljepojevic et al. (1984). We suspect that proton-impact induced transitions play a crucial role which depends sensitively on the conditions of temperature and density in the Plasma. In this abstract we will present some preliminary results of proton-impact excitation cross section calculations, for the n=2 sub levels of hydrogenic ions.

FORMALISM

We can express the total wavefunction for the H^+-ion system by the expansion,

$$\psi_\Gamma(\vec{R},\vec{r}) = \sum_{\Gamma'} \frac{F_{\Gamma'\Gamma'}(|R|)}{|R|} \, |\Gamma'\rangle \quad ,$$

$$|\Gamma'\rangle \equiv |JM\ell\lambda jn\rangle \tag{1}$$

where $\vec{R},\vec{r}$ are the proton and electron coordinates respectively. The expansion kets $|\Gamma'\rangle$ are specified by, the total angular momentum JM, the proton angular momentum ℓ, the total and orbital electronic angular momenta j,λ, and the atomic radial quantum number n. We are interested in the transitions among the n=2 levels only. We can then restrict the expansion (1) to the $|JM\ell\lambda j\ n{=}2\rangle$ channels. The Schrödinger equation for the scattering amplitudes becomes,

$$\left(\frac{d^2}{dR^2} - \frac{\ell(\ell+1)}{R^2}\right)F_{\Gamma,\Gamma'} + \kappa_{nj}^2 F_{\Gamma,\Gamma'} = \sum_{\Gamma''} 2\mu\langle\Gamma'|v|\Gamma''\rangle \, F_{\Gamma,\Gamma''}$$

$$\kappa_{nj}^2 \equiv 2\mu(E-\varepsilon nj) \quad , \tag{2}$$

where μ is the reduced mass, E and εnj are the total and atomic energy eigenstates respectively. The potential matrix $\langle\Gamma'|v|\Gamma\rangle$ is given by

$$\langle\Gamma'|v|\Gamma\rangle = \langle J'M'\ell'\lambda'j'n' \mid \frac{Z}{|R|} - \frac{1}{|R-r|} \mid nj\lambda\ell MJ\rangle \quad ,$$

Z is the nuclear charge of the ion.

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Equation (2) decouples into two independent sets of four channel equations, each set having a definite parity. The total cross section for the inelastic $\lambda j \to \lambda' j'$ transitions can then be expressed as,

$$\sigma(\lambda\, j-\lambda' j') = \frac{\pi}{(2j+1)k^2_{n'j'}} \sum_{J\ell\ell'} (2J+1) \left| S^{j'\ell'\lambda'}_{j\ \ell\ \lambda}(J) \right|^2 \qquad (3)$$

where $S^{j'\ell'\lambda'}_{j\ \ell\ \lambda}(J)$ is the S-matrix of the scattering solutions to equation (2). We have calculated some cross sections for these transitions in Ar^{+17}. We have used the values $\Delta E(2p3/2-2p1/2) = 4.81eV$ for the fine structure separation, and $\Delta E(2s1/2-2p1/2) = 0.16eV$ (Wiese <u>et al</u>. 1966) for the Lamb shift. Some cross sections are presented in Table I.

DISCUSSION

Our results in Table I show the tendency of an enhancement in the (2s1/2-2p1/2) cross sections relative to the (2s1/2-2p3/2) cross sections in the range of energies presented. We can give a qualitative explanation for these results by resorting to a semi-classical argument. In the semi-classical picture, transitions in the ion are driven by the time dependent Coulomb field produced by the incoming proton on a given trajectory $\vec{R}(t)$. For a proton moving in a hyperbolic orbit $\vec{R}_H(t)$, the first order transition probability for the ion to go from state $|i\rangle$ to $|j\rangle$ is proportional to the integral

$$I(R_H) \equiv \left| \int_{-\infty}^{\infty} dt e^{i\Delta E t} \langle i | \frac{1}{|\vec{R}_H(t) - \vec{r}|} | j \rangle \right|^2$$

where ΔE is the frequency of the transition. At large impact parameter b, $I(R_H)$ is approximately equal to the straight-line integral $I(R_{SL})$, $(\vec{R}_{SL}(t) = \vec{v}t + \vec{b})$ multiplied by a screening factor $e^{-\pi|\zeta|}$ (K. Alder <u>et al</u>. 1956), where

$$|\zeta| = (Z-1)\mu \left| \left(\frac{1}{k_f} - \frac{1}{k_i}\right) \right| \approx \frac{(Z-1)}{v_f} \frac{|\Delta E|}{2E}$$

$$\text{i.e. } I(R_H) \approx e^{-\pi|\zeta|} I(R_{SL}) .$$

If the transitions are dominated by contributions coming from larger impact parameters then they are also very sensitive to the value of the ζ parameter. In our example the ζ parameter for 2s1/2-2p1/2 transition has a maximum value of .275 at 136eV, whereas for the 2s1/2-2p3/2 transition ζ has the range of values of 8.12 at 136eV to .14 at 2.04keV. The screening factor $e^{-\pi|\zeta|}$ is much smaller for the 2s1/2-2p3/2 transition than the corresponding factor for the 2s1/2-2p1/2 transitions the latter cross section is therefore larger than the former over the given energy range. Extension of our calculations over a wider energy range and for ions of different charges is now in progress.

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Table I. Proton-Impact excitation cross sections (cm^2) for the n=2 sublevels in Ar^{+17}

ENERGY	$\sigma(2s1/2 \rightarrow 2p1/2)$	$\sigma(2s1/2 \rightarrow 2p3/2)$	$\sigma(2p1/2 \rightarrow 2p3/2)$
136eV	1.3×10^{-15}	2.8×10^{-20}	$< 10^{-20}$
271eV	1.0×10^{-15}	1.8×10^{-19}	1.5×10^{-19}
544eV	6.4×10^{-16}	1.3×10^{-17}	1.2×10^{-17}
980eV	4.0×10^{-16}	5.2×10^{-17}	2.6×10^{-17}
1.52keV	2.6×10^{-16}	8.3×10^{-17}	2.8×10^{-17}
2.04keV	2.0×10^{-16}	9.8×10^{-17}	2.4×10^{-17}

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