THEORETICAL STUDIES OF ELECTRON IMPACT EXCITATION
OF POSITIVE IONS

W. Derek Robb
Theoretical Division, Group T-4
Los Alamos Scientific Laboratory
Los Alamos, NM 87545 USA

1. INTRODUCTION

Electron impact excitation of impurity ions is a dominant mechanism for producing the radiation emitted by CTR-type plasmas.\(^1\) In addition, the relative intensities of impurity lines excited by electron impact provide a sensitive diagnostic of temperature and density in the plasma. For the densities and temperatures found in magnetically confined plasmas we can assume, as a good approximation, that the ions behave as if they were isolated, and thus neglect any plasma effects on either their structure or their interactions with electrons.

In power loss studies on a model Fe-seeded Tokamak plasma Merts et al.\(^1\) have shown that the radiative power loss from the Fe-ions is apportioned 76.5% to electron collisional excitation, 18% to dielectronic and radiative recombination and 5.5% to bremsstrahlung at an electron temperature of 2 keV. Power loss studies generally involve the summation and averaging over large numbers of individual lines of the ion and so the accuracy to which individual line rate coefficients is required is not critical, provided the summed rate is good to say 20%. Diagnostic calculations on the other hand, often depend critically on the relative accuracy of line rate coefficients and here a knowledge of each of them to better than 20% is desired.

The remainder of the paper is set out as follows, in Sec. 2 we define some basic aspects of collisional excitation processes, Sec. 3 describes the principal theoretical techniques for calculating excitation collision strengths, and in Sec. 4 we examine the sensitivity of the collision strength to target state wavefunctions. Section 5 deals with resonant contributions to excitation
while Sec. 6 examines analytic expressions that may be used to fit numerical collision strength data.

2. BASIC THEORETICAL CONSIDERATIONS

The rate coefficient for excitation $R_{ij}$ of an initial atomic state $i$ to a final state $j$, under the assumption of a Maxwellian electron energy distribution is

$$R_{ij} = \frac{8.01 \cdot 10^{-8}}{w_i T} \frac{\Delta E_{ij}^3}{3/2} \int_1^\infty \Omega_{ij}(X) e^{-\frac{\Delta E_{ij} X}{T}} dX \text{ cm}^3 \text{ s}^{-1}$$

(1)

where $\Delta E_{ij}$ is the threshold energy (in eV) for the transition, $w_i$ is the statistical weight of the initial state and $T$ is the electron temperature (in eV).

Two fundamental entities within the integral in Eq. (1) are the collision strength for the transition $\Omega_{ij}$ which is related to the collisional excitation cross section $Q_{ij}$ by

$$\Omega_{ij}(X) = w_i E Q_{ij}(E)$$

(2)

where $Q_{ij}$ has units of $na^2$, and the scaled electron energy $X$ is,

$$X = \frac{E}{\Delta E_{ij}}$$

(3)

where $E$ is the kinetic energy of the incident electron.

In the remainder of the paper we shall be concerned with ways of calculating the collision strength $\Omega_{ij}$ as a function of energy, and so it is instructive to examine overall trends in its behaviour relative to the conditions encountered in CTR plasmas.

First of all we shall assume that we are dealing with ions whose nucleii are not extremely heavy, say with $Z \ll 50$, and whose electronic structure makes them iso-electronic with first and second row elements. In this case we may assume that the electronic states are accurately described by LS term values within the Russell-Saunders coupling scheme, with the splitting into individual SLJ levels being a perturbation. Within this scheme there are three major categories of transitions to be considered, they are: