5 Theory of Anisotropic Collisional Relaxation

5.1. Introduction

Polarization effects in ensembles of atomic particles (atoms or ions), excited by an external process and undergoing collisions with slow atomic perturbers having no nuclear spin and no hyperfine structure of the quantum states, will be examined in this chapter. Using a kinetic approach, the effect of collisions in this case can be qualitatively interpreted as the transformation of an ordering of the distribution of the relative velocity vectors into an ordering of momenta of the ensemble of excited atoms.\(^{10}\)

For an isotropic distribution of the relative velocity vectors (isotropic collisions), no collisional ordering of momenta can be created and the role of collisions is reduced only to depolarization, which is characterized by a one-exponent decay law. In this case an ensemble of excited particles is described by a set of \((2j + 1)\) relaxation constants, each of which determines the collisional relaxation of the polarization moment of particular rank.\(^{99,122,128}\)

The opposite situation takes place for collisions with anisotropic distribution of the relative velocity vectors (anisotropic collisions). In such a case collisions may create a new type of ordering of momenta of the excited atomic ensemble, and the type of this ordering reflects a symmetry of the collisional process. In the case of an axially symmetric excitation process, which takes place under beam excitation conditions, or sometimes, in an ordinary gas discharged plasma, transformation of aligned into oriented states, and vice versa,\(^{52–55}\) as well as the collisional creation of longitudinal alignment\(^{56,57}\) are possible. For lower symmetry of a collisional process, other types of ordering of momenta may be created. For example, if the interaction operator is invariant under reflections in the collision plane, an orientation could arise. The last situation could be implemented experimentally, for example, with the help of a magnetic field tilted at some angle to the axis of collisions.\(^{52–54}\)
The same type of symmetry is realized when the Stokes parameters of an optical emission are recorded only from particles scattered at a given angle or with the aid of a coincidence technique for the polarized photon and scattered particles. Such experiments are described in detail in review papers.\textsuperscript{(86, 108, 109)} Most such experiments have been carried out with electrons, for which significant deflection angles could be realized,\textsuperscript{(104-106)} but some experiments of this type with heavy low energy projectiles have been also implemented.\textsuperscript{(107, 110)}

In the present chapter we restrict ourselves only to axially symmetric collisional processes. For a description of slow collisions of heavy atomic particles with axial symmetry, when long-range interaction plays a principal role, one can employ multipole resolution, which simplifies calculations and enables one to obtain more general results. The general symmetry properties of the matrix of cross sections of the collisional relaxation of polarization moments and the internal symmetry properties of the quantum states of colliding particles (occasional degeneration) will be considered. The matrix elements of the rate constants of collisional relaxation will be introduced in the third section and the special role of the quadrupole moment of the relative velocity distribution function will be pointed out. Collisional relaxation of polarization moments in the case of fine or hyperfine structure will be analyzed in the fifth section. Sections 6.7 and 6.8 will be devoted to a substantial description of relaxation processes of fine structure doublet states and a spectropolarimetric method for determining the drift velocity of ions in a plasma.

\section*{5.2. Symmetry of the Collisional Relaxation Cross Section Matrix}

The evolution of polarization moments caused by population mixing during an axially symmetric process in the laboratory frame of reference may be expressed in the form

\[
\frac{\partial}{\partial t} \rho_q^k = n_0 \sum_{k'} (\nu \sigma_{q}^{kk'}) \rho_q^{k'} \tag{5.2.1}
\]

where \(n_0\) is the foreign gas density, \(\nu \sigma_{q}^{kk'}\) is the matrix of the rate constants of collisional relaxation, comprised from collisional relaxation cross sections for the extreme anisotropic case of counterpropagating beams (3.8.7), or \(\sigma_{q}^{kk'}\).

First, let us consider the symmetry properties of the matrix of rate constants of collisional relaxation. According to Eqs. (5.2.1) and (2.3.11) it is evident that

\[
\sigma_{q}^{kk'} = (-1)^{k+k'} \sigma_{-q}^{kk'} \tag{5.2.2}
\]