CHAPTER 4

APPLICATIONS OF LASERS IN ATOMIC COLLISION PHYSICS

W. R. MacGillivray and M. C. Standage

1. INTRODUCTION

The introduction of lasers to the field of atomic collisions has provided a powerful new tool with which to investigate collision processes. Laser techniques have now been applied to the study of superelastic scattering and stepwise excitation processes, free-free transitions, photon recoil processes, Rydberg atom collisions, and spin-polarization effects. This chapter is restricted to consideration of two of these applications, namely, stepwise excitation and superelastic scattering studies of electron atom scattering.

Stepwise excitation techniques have been developed in which a combination of electron and laser beams are used to excite target atoms. Measurements of the intensity and polarization of fluorescence emitted from stepwise excited atoms have provided new techniques for studying the electron impact excitation of both optically allowed and forbidden atomic transitions. Such experiments may be categorized according to whether the laser excitation occurs in the first or second excitation steps. In the former case, information may be obtained about inelastic scattering processes from excited atomic states, while the latter case provides new methods of investigating inelastic scattering processes from the ground states. Coincidence techniques may also be applied to the investigation of such scattering processes using detection of stepwise excited photons in delayed coincidence with electrons inelastically scattered from target atoms. The narrow bandwidth of laser radiation enables the fine and hyperfine structure of many atomic transitions to be resolved in the laser excited step, thereby allowing the role of such structure in atomic collision processes to be studied.

W. R. MacGillivray and M. C. Standage • School of Science, Griffith University, Nathan, Queensland, Australia 4111.
The preceding discussion indicates very briefly the diversity of applications of lasers to atomic collision studies. In many respects, their use in such applications is still at an early stage of development, and it can be expected that as the advantages that laser techniques can bring to atomic collision studies become more fully realized, and as new laser technologies are developed, the significance and range of application of lasers in this field will steadily grow.

In this chapter, we attempt to highlight novel features of various laser techniques that either extend existing conventional techniques or provide new techniques capable of obtaining previously inaccessible information. A review of the theory associated with superelastic and stepwise excitation techniques is presented in Section 2. Case studies are discussed to illustrate with concrete examples theoretical aspects of the techniques. Section 3 contains a review of experimental work in stepwise excitation and superelastic scattering.

2. THEORY

The theory of both stepwise and superelastic experiments may be described by closely related treatments. Figures 1a and 1b show two stepwise excitation schemes I and II, while Figure 1c shows a superelastic scattering Scheme III.

In Scheme I, electron excitation from the ground state $|g\rangle$ to a first excited state $|e\rangle$ is followed by laser excitation to a higher excited state $|i\rangle$. The intensity and polarization of light emitted as the atom decays from state $|i\rangle$ to $|f\rangle$ provides information about the preceding stepwise excitation processes. Scheme II reverses the order of the excitation with laser excitation from $|g\rangle$ to $|e\rangle$ followed by electron excitation between the excited states $|e\rangle$ and $|i\rangle$. As for Scheme I, the fluorescence emission provides information.