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COHERENCE PARAMETERS AND EXCITATION CROSS SECTIONS FOR ELECTRON IMPACT EXCITATION OF THE 3^1P AND 3^1D STATES OF HELIUM

by

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GRADUATE COLLEGE
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This dissertation describes two experiments which measured:

1. the relative differential cross section for the excitation of the 3^1P $(m_\ell = 0)$ state in helium by electrons, and
2. the coherence parameters for electron impact excitation of the 3^1D state of helium using an angular correlation experiment.

Both of these experiments utilize the electron-photon coincidence technique which yields much more detailed information on the scattering process than is provided in more traditional electron atom scattering experiments.

In the 3^1P state of helium, the magnetic substates are degenerate with energy, and therefore, it is not possible to measure these magnetic sublevel differential cross sections with the traditional energy loss experiment. However, it was possible to measure the relative differential cross section

for the $m_\ell = 0$ substate of helium by detecting the $3^1P \rightarrow 2^1S$ decay photons (501.6 nm) in the scattering plane and perpendicular to the incident electron beam. These photons were detected in coincidence with the inelastically scattered electrons. The results are compared with previous experimental results and different theoretical model calculations.

The 3^1D excited state of helium is fully characterized by four coherence parameters. The behavior of these coherence parameters as a function of energy and scattering angle gives valuable information about the dynamics of the excitation process. An angular correlation experiment for the 3^1D state of helium was performed for the first time by measuring the angular distribution of the $3^1D \rightarrow 2^1P$ (667.8 nm) radiation emitted in the scattering plane in coincidence with the inelastically scattered electrons. With a measurement of intensity perpendicular to the scattering plane, this experiment yielded three of four coherence parameters, including one parameter that has never been measured before. These data are in good agreement with other published data obtained from polarization correlation experiments which measured linear and circular polarization of the $3^1D \rightarrow 2^1P$ decay radiation in coincidence with the scattered electrons. Results from the present experiment are compared with a number of recent theoretical models.

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To my late father

Victor

and my mother

Ethel

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Chapter 1

Introduction

The electron impact excitation of atoms has traditionally been studied by measurement of either

- the total (level) cross section, and, in some cases, the relative cross sections for particular magnetic sublevels as a function of incident electron energy,

- the differential electron scattering cross section as a function of scattering angle and incident electron energy.

These measurements have been made using two principal methods. One method involves measurement of the intensity of photons emitted from the decay of the excited states. The other method is electron spectroscopy in which measurements of the electron energy loss spectrum yield level cross

sections for those levels which can be resolved.

Both of these methods have provided valuable data and have contributed to the understanding of electron impact excitation of atoms. But the information that these experiments can provide is limited. To understand more about collision processes, more fundamental collision parameters have to be measured without averaging over other quantities such as different energy states of the atom, scattering angles, polarization of the emitted radiation etc. These measured fundamental parameters then become a stringent test for different scattering theories since the theoretical calculations of these fundamental parameters can be directly compared with the measured parameters. For example, measuring the individual magnetic sublevel cross sections of an excited state is more valuable than measuring the total cross section (sum of all magnetic sublevel cross sections) of the excited state.

1.1 Photoemission experiments

In photo emission experiments that detect the emitted photons rather than the scattered electrons, it is possible to make measurement on some excited states that cannot be resolved in the energy loss experiments. The photons

are emitted when the excited states decay to the lower energy levels. An interference filter or a monochromator can be used to select the photon to be detected. In these emission experiments, intensities of spectral lines excited by an electron beam are used to measure the total excitation cross section for the excited state, but it cannot be used to measure the differential cross section for the excited states.

However, the polarization and the isotropy of the radiation, found in photo emission experiments is dependent on the relative populations of the magnetic sublevels (Oppenheimer 1927, Percival and Seaton 1958). Polarization measurements of the emission lines in a few simple cases can give information about the relative population of magnetic sublevels but yield only cross sections integrated over all scattering angles. Unfortunately, there are several indirect ways an excited state can change its population resulting in intensity measurements which are difficult or impossible to interpret. Such complications include:

- Cascading from higher energy levels which were excited by electron impact and which then populate the lower level which is being investigated.

- Availability of several channels for radiative decay of excited states

(branching ratio) reduces the emission of a selected photon which is being detected by the experiment.

- Imprisonment of resonance radiation (resonant trapping): Re-absorption of decay photons by atoms in the ground state effectively lengthens the life of the excited state. Thus, the longer effective lifetime of the upper state results in an increased probability for intervention of collisional processes, and for conversion through other radiative transitions which are not detected by the experiment.

- Collisional energy transfer: An excited atom can be de-excited in a collision with a ground state atom, with a transfer of excitation energy and possibly changes in the values of the angular momentum and spin associated with the excitation energy.

1.2 Energy loss experiments

In an energy loss experiment, an electron collides with an atom and excites the atom to a higher excited state. In this process, the electron loses its kinetic energy to the atom by an amount that is equal to the energy difference between the initial and final states of the atom. Thus, the excited state can be identified by the amount of energy that an electron loses dur-

ing the collision. With the development of high resolution monochromators and energy analyzers in the 1960 's, energy loss experiments have played an important role in measuring differential cross sections, and so understanding the collision processes. However, if there are excited states with nearly equal energies, an energy loss experiment may not be able to distinguish between the excited states because of the finite energy width of the incident electron beam combined with the limited energy resolution of the electron detection system. If a state has fine structure or hyperfine structure, there may also be substates that are different in energy by as little as .04 meV. In this case, the overall effective energy resolution of the system would need to be less than .04 meV in order to distinguish the substates. Unfortunately, practically it is almost impossible to get such a fine energy resolution with sufficient electron beam density to perform an experiment. Of course, when the substates are degenerate in energy , they cannot be distinguished by the the energy loss of the scattered electrons. Therefore, an energy loss experiment often measures the sum of the differential cross section of the unresolved states.

Thus to measure the differential cross section for the excitation of different magnetic sublevels or the relative phase of the corresponding ampli-

tudes, neither the photon emission method nor the energy loss method can be used.

1.3 Electron-Photon coincidence experiments

The first concise theory of "Atomic Photon-Particle Coincidence Measurements" was presented by Macek and Jaecks in 1971. They showed that it is possible to determine the differential cross sections for the magnetic substates by detecting the scattered particle in coincidence with the photon that is emitted when the excited state decays. The measurements of differential cross sections of magnetic sublevels is useful in determining the shape and the inherent angular momentum of the excited atom. The basic technique used in the present experiments is called the electron-photon coincidence technique. The essential point for the understanding of the electron-photon coincidence technique is that the observation is restricted to radiation emitted by only those atoms which were excited by those electrons which were then scattered with a precise energy in a given direction defined by the electron detector.

The electron-photon coincidence experiments can be divided into two categories; electron-photon angular correlation experiments and electron-

photon polarization correlation experiments. In an electron-photon angular correlation experiment, the angular distribution of the photon intensity emitted by the subsequent decay transition, in the scattering plane is measured in coincidence with the inelastically scattered electrons. In some cases, this can yield the complete set of collision parameters for a excited state. Eminyan et al (1973) performed their pioneering electron-photon angular correlation coincidence experiment in which they were able to determine for the first time a set of scattering parameters as a function of scattering angle for electron impact excitation of the 2^1P and 3^1P states of helium (Eminyan et al 1974, 1975). Since then, electron-photon angular correlation experiments have been performed for various collision systems at different energies and scattering angles. For electron-helium collisions, much of the work has been done for the 2^1P state at different energies and scattering angles. The most extensive studies have been carried out at an incident electron energy of 80 eV. By contrast, only a few angular correlation experiments have been performed for the 3^1P state. In particular, the 3^1D state has been studied only once (van Linden van den Heuvell et al 1981, 1983).

In a polarization correlation experiment, the linear and circular polariza-