IV. ATOMIC RESONANCE AND SCATTERING

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RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

Our interests center on the structure and interactions of atoms and simple molecules, and on their interactions with radiation at both optical and radio frequencies. Experimental methods involve colliding beam scattering, atomic and molecular beam resonance spectroscopy, high-precision maser spectroscopy on stored atoms, and optical fluorescence with tunable lasers.

1. Studies of Superradiance and Coherence

U. S. Air Force — Office of Scientific Research (Contract F44620-72-C-0057)

D. Kleppner

The objectives of this work are to study superradiance and subradiance in small systems, and to investigate the dynamics of free-to-bound and bound-to-free radiative processes in diatomic systems.

We have undertaken a study of superradiance in small systems. In order for superradiance to occur in a two-particle system, the radiators must remain within a wavelength during their radiative lifetime. We have met this problem by making use of the first-order dipole energy in a coherently excited two-atom system to form a quasi-stationary two-atom superradiant complex. The lifetime of the complex is approximately one-half the lifetime of a single radiator. The complexes are also capable of existing in subradiant states, in which the two dipoles oscillate out of phase and dipole radiation is forbidden.

In addition to revealing the effects of coherence in small systems, the excited complexes yield a detailed picture of free-to-bound and bound-to-free transitions in simple molecules. Such processes can play an important role in gas discharges and stellar atmospheres, but heretofore they have never been observable at low densities where the complexes evolve in essential isolation.

2. Van der Waals Molecules

National Science Foundation (Grant GP-39061X)

D. Kleppner, D. E. Pritchard

The objective of this work is to study magnetic interactions in weakly bound paramagnetic systems. The binding energy of a van der Waals molecule is so small, typically a few percent of that of a chemical bond, that the atoms are relatively unperturbed. The molecular interactions can thus be approached from an atomic point of view, and the systems offer a unique testing ground for atomic and molecular theory.

We have undertaken a series of experiments on paramagnetic van der Waals molecules, with our initial interest centered on alkali-rare gas molecules. The molecules are created by expanding a mixture of alkali vapor and rare gas into a vacuum through a small orifice, and their properties are observed by molecular-beam techniques. We have succeeded in creating a beam of potassium-argon, and recently we observed the spin rotation interaction. The alkali hyperfine frequency is expected to be decreased because of the polarization effects associated with van der Waals binding. Work on this is in progress.

3. Alkali Atom Interactions

Joint Services Electronics Program (Contract DAAB07-71-C-0300)

D. E. Pritchard

In this work our objectives are as follows.

1. To study mechanisms of atomic collisions involving alkali atoms in specific states (e.g., spin-polarized or optically excited).

2. To interpret these results in terms of models that have application to wider classes of collisions (such as nuclear collisions or atomic collisions in different energy domains and environments).

3. To improve the technology for producing high-intensity beams of state-selected atoms.

The approach that we have adopted is to observe the effects of an isolated collision between a state-selected alkali atom and a target molecule (or atom). High-intensity jet sources are typically used for both primary atoms and target molecules; the state of the primary atoms is determined with a magnet or a laser. Use of a velocity selector and a small detector permits the determination of atomic scattering cross sections with good angular and energy resolution. (Another state selector is optionally used prior to the detector to analyze the state of the alkali atoms after the collision.)

In 1973, our main efforts were directed toward building and testing a new high-intensity source of polarized alkali atoms, installation of a new velocity selector (permitting study of the energy lost by the atoms as a result of collisions), final development and testing of a dissociating source for iodine atoms, and writing and debugging computer programs to analyze data taken with these new improvements. In addition, we designed and built (but have yet to test) a system for using a tunable dye laser to produce a beam of excited-state atoms for use in these experiments.

Measurements were made on collisions between Na and I_2 and Na and I. In the former case we hope to analyze the results in terms of the "optical model" which has been successfully applied to nuclear collisions. In the latter, we are trying to isolate the effects of "curve crossing" collisions, a type of collision that might be responsible for anomalously large cross sections for inelastic processes such as energy and excitation transfer.

In 1974, we plan to concentrate heavily on studies involving sodium atoms in an excited state. A beam containing a large fraction of excited-state atoms will be produced by directing our continuous-wave tunable dye laser at the atomic beam in the collision region. By changing the frequency and polarization of the laser, we shall be able to select the desired excited state and also control its polarization.

This technique should be capable of producing an excited-state atomic beam whose intensity is comparable to the ground-state atomic beams that have revolutionized the field of atomic scattering in the last decade. Techniques have been developed to interpret the scattering of ground-state atoms. We shall now be in an excellent position to apply these techniques to the understanding of the interactions of excited-state atoms. Our initial application of the excited-state beam will be to the determination of excited-state interatomic potentials for alkali-rare gas systems. One application of these potentials results from the fact that they determine the operating characteristics of excimer lasers. This type of laser (in a system with a repulsive ground state) offers the prospect of tunability and high power, attributes that indicate wide potential application.