IV. ATOMIC RESONANCE AND SCATTERING*

Academic and Research Staff

Prof. D. Kleppner
Dr. M. T. Myint
Dr. I. Ozier
D. C. Burnham

Graduate Students

D. E. Pritchard
P. F. Winkler

RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

This group, which was formed in September 1966, is concerned with the properties of atoms and simple molecules as observed by resonance and scattering techniques.

The immediate goal of our resonance experiments is a new determination of the magnetic moment of the proton. In the experiment a hydrogen maser is used, which, for the first time, permits a determination of the proton g-factor in atomic hydrogen. Our scattering efforts are concerned with studying the interactions of atoms with ions, atoms, and electrons, as revealed by electron-spin exchange. This new scattering technique promises to enable a wide class of scattering studies that have not been possible previously.

D. Kleppner

1. Magnetic Moment of the Proton

Our goal is to measure the g-factor of the proton, in terms of the electron g-factor, to a precision substantially higher than has been attained heretofore. The experiment involves the use of a hydrogen maser that allows simultaneous observation of electron and proton transitions in atomic hydrogen. The importance of this experiment lies in the fact that the proton is examined in atomic hydrogen, as contrasted with the molecular environment in which all previous determinations have been made. We hope to achieve a precision of one part in 10^8. We shall also compare the moment of the proton in atomic hydrogen with that of the proton in H_2O and in H_2. This will yield experimental values of the diamagnetic shielding of the proton in water and in molecular hydrogen which should be precise to a few parts in 10^8. These values are of particular interest, since water is a standard reference for NMR and H_2 is the only molecule for which the shielding factor can be predicted with high precision.

Pivotal to all the studies described above is an atomic hydrogen maser, especially designed to work in a magnetic field of 3500 Gauss. The field is provided by a magnet possessing unusual stability and very high homogeneity. The combination of the maser and the magnet produces an electron resonance line that has an excellent signal-to-noise ratio and is considerably narrower than has been possible previously. Resonance lines in the present experiment are typically 150 Hz as contrasted with 20,000 Hz for the same resonance frequency in previous experiments. Previously, it was impossible to study the proton in atomic hydrogen because the coupling of the proton to the electron caused a prohibitive loss in sensitivity to the measurement of the proton moment. For

*This work is supported by the Joint Services Electronics Programs (U.S. Army, U.S. Navy, and U.S. Air Force) under Contract DA 36-039-AMC-03200(E), and in part by the Sloan Fund for Basic Research (M.I.T. Grant 95).

instance, in order to measure the g-factor ratio to one part in 10^8, it is necessary to obtain a fractional precision in the proton resonance line of nearly two parts in 10^{10}.

As well as the experiments outlined above, there are numerous other g-factor determinations that we are currently considering. Among these are a comparison of the g-factor for the electron in hydrogen with the electron in deuterium to a precision of 1 part in 10^8, and a determination of the temperature dependence of the chemical shift in H_2. We are also considering a determination of the proton moment in nuclear magnetons. By combining this result with the result above for the nuclear moment in Bohr magnetons, a new value of the proton-electron mass ratio can be obtained. This ratio is of particular interest, because of its influence on many of the other fundamental constants.

A preliminary determination of the proton moment has already been obtained.[1] A number of improvements to the maser have been made during the past quarter, including facilities for a stronger beam and a more reliable magnetic-field mapping probe. The next step will be the design of a data acquisition system, which will be undertaken as soon as the maser is again in operation.

D. Kleppner, T. Myint, P. F. Winkler

References

1. T. Myint, D. Kleppner, N. F. Ramsey, and H. G. Robinson, Phys. Rev. Letters 17, 405 (1966).

2. Spin-Exchange Scattering

Spin exchange, the process by which two atoms exchange electrons during a collision, offers a powerful tool for investigating interactions between atoms, ions, and electrons. In particular, it yields detailed information about the singlet and triplet potentials. For atom-atom or ion-atom scattering, extremely small differences in the long-range potentials may be measured by observing oscillations in the spin-exchange cross sections. In electron-atom scattering it is possible to infer all of the important partial wave phase shifts for both singlet and triplet scattering.

Our goal is to observe spin-exchange scattering by means of a crossed-beam scattering apparatus that will allow us to observe differential cross sections for both spin-exchange and non spin-exchange processes. The atom-atom results should be of interest to workers in optical pumping, who can look only at broad terminal averages of total cross sections. The ion-atom results should display a variety of interesting effects. At low energies the oscillations in the spin-exchange cross section can be readily resolved, while at higher ion energy rainbow scattering may be observed. Our observations of electron-atom differential spin-exchange scattering should be of interest to the many workers who have made calculations on this problem, as well as to workers in optical pumping, particularly since the individual phase shifts have not previously been measured. We are especially interested in ion-atom scattering, since we have developed a theory that can be directly compared with our experiments.[1]

A summary of the experiments that we are considering is presented in Table IV-1.

All of our experiments are centered about a scattering apparatus which is under construction and is now approaching completion. The apparatus normally utilizes an alkali beam. The beam passes through a magnetic state selector and into a scattering region where it collides with the target particle (usually provided by a second beam). A portion of the scattered beam passes through collimating slits, a velocity analyzer, and

Table IV-1. SUMMARY OF SPIN-EXCHANGE SCATTERING

Class	Scattered particle	Target particle	Examples	Comments
Ion-Atom	Alkali			Long-range collisions important, perturbation theory yields good results, excellent experimental momentum resolution.
		^2S ion	He^+	Simple system, theory developed by our group.
			Be^+, Mg^+	Theory under development
		^2P ion	Ne^+, Si^+	(Situation complicated by fine structure, qualitative aspects of theory have been developed.)
	^2P atom	^2S ion	$Tl\text{-}He^+$	
	^2P atom	Alkali Ion	$Tl\text{-}Na^+$ $Al\text{-}H^+$	Spin orbit interaction and excitations can be studied, no spin-exchange.
Electron-Alkali	Alkali	Electron	All Alkalis	Possibility of measuring singlet and triplet phase shifts. Differential and differential spin-exchange cross sections can both be measured. Theory developed in detail by various workers. Very low energy results can be compared with optical pumping results. Elastic cross sections can be observed up to 10X excitation energy, with sacrifice in angular resolution.
Atom-Atom				Only system for which theory has been developed in detail is H-H. Possibility of measuring differential cross sections using velocity selected beam. Wide variety of systems can be observed.
	Alkali	Alkali	Na-NA Na-K, etc.	
	Alkali	Hydrogen		
	Alkali	^2P atom	Na-Al Na-Ga etc.	
	^2P	Alkali, Ion		A number of ^2P atoms can be detected by a hot-wire detector, including Al, Ga, Tl. Changes in orbital angular momentum can occur and be detected.
	Alkali	Molecule	Na-02	
Hydrogen	Hydrogen	-	-	H-electron and H-H spin-exchange of great theoretical interest. However, these experiments will not be possible until a fast, efficient hydrogen detector is developed. We are not currently undertaking this work.

a magnetic spin-state analyzer. The two emerging beams, corresponding to the two electron states, pass into two identical detectors. The ratio of the signals from the detector can be directly related to the fraction of spin-exchange occurring in the scattering process. The sum of the detector readings yields the differential scattering cross section, a quantity also of a considerable interest.

D. C. Burnham, D. Kleppner, I. Ozier, D. E. Pritchard

References

1. D. E. Pritchard, D. C. Burnham, and D. Kleppner, Bull. Am. Phys. Soc. 11, 62 (1966).