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Studies of Spin-Polarized Electron Scattering from Rubidium

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Abstract. A_2 spin asymmetry measurements have been made for electron excitation of the 5S – 5P transition in atomic rubidium for incident electron energies of 20 eV and 30 eV. The data are compared with calculations from a semi-relativistic R-matrix Breit-Pauli model. Good qualitative agreement is obtained clearly demonstrating the existence of significant relativistic effects in the electron-atom interaction.

INTRODUCTION

The study of collisions between electrons and atoms by measurement of Stokes parameters has enabled detailed information of scattering amplitudes to be obtained [1]. The availability of this experimental data was the catalyst for the development of more sophisticated theoretical models. The convergent close coupling (CCC) model of Bray and Stelbovics [2] has been applied with considerable success to calculating collision parameters for a range of atoms including the lighter alkalis Li, Na and K [3-5].

Measurement of the collision parameters for inelastic scattering of unpolarized electrons from the heavier Rb[6] and Cs[7] also showed good agreement with the non-relativistic CCC theory. This agreement was surprising as these targets were considered heavy enough to warrant a relativistic treatment.

In a recent paper[8], Andersen and Bartschat showed that these collision parameters were insensitive to relativistic effects, demonstrating why the CCC theory had worked so well. In this work they also identified several generalised Stokes parameters which are sensitive to relativistic effects. They further showed that two asymmetry parameters, that can be measured for collisions between spin-polarized electrons and atoms, will indicate the presence of relativistic effects.

The pioneering work of Baum's group has seen the measurement of these two asymmetry parameters in elastic collisions between spin-polarized electrons and Cs atoms [9], while the NIST group did not observe relativistic effects in asymmetry measurements for Na [10]. Baum's group extended the Cs measurements to include

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inelastic asymmetries from the 6S-6P transition[11], with the preliminary results indicating the presence of relativistic effects.

In this paper, we report on the measurement of the A_2 asymmetry parameter for excitation of the 5S-5P transition in Rb using spin-polarized electrons. The data are compared to preliminary predictions from a Breit-Pauli R-matrix calculation.

THEORY

In the semi-relativistic R-matrix calculation performed for this work, the lowest twelve states of Rb, $(5s)^2S_{1/2}$, $(5p)^2P^0_{1/2,3/2}$, $(4d)^2D_{3/2,5/2}$, $(6s)^2S_{1/2}$, $(6p)^2P^0_{1/2,3/2}$, $(5d)^2D_{3/2,5/2}$ and $(4f)^2F^0_{3/2,5/2}$ were included in a Breit-Pauli close-coupling plus correlation expansion. We expect that these results are close to convergence with respect to coupling effects within the discrete spectrum of Rb, but coupling to the continuum states will still need to be checked by including a large number of pseudo-states in a convergent R-matrix with Pseudo-States (RMPS) calculation, similar to that described by Bartschat and Fang [12] for electron-Cs collisions.

In the calculations, the target description was based upon a model potential for the inner 36 core electrons. It was constructed from the Hartree potential generated from the Rb^+ orbitals of Clementi and Roetti [13], supplemented by polarization and exchange potentials as described by Albright et al [14]. Excellent agreement with experiment was achieved for the ionization potentials of all valence orbitals, the electron affinity of Rb^-, and the dipole polarizability of Rb. Finally, the relativistic effects were included by explicitly adding the one-electron spin-orbit term to both the N-electron target and the $(N+1)$-electron collision Hamiltonian before diagonalization. In addition, optimizing the core potential effectively accounts for the spin-conserving mass correction and Darwin terms.

EXPERIMENT

The set of spin asymmetry parameters can be obtained from an experiment in which a beam of spin-polarized atoms crosses a beam of spin-polarized electrons [9]. The beams are polarized perpendicular to the scattering plane. Four differential cross sections are measured relative to each other by observing the count rates $N^{\uparrow\uparrow}$, $N^{\downarrow\downarrow}$, $N^{\uparrow\downarrow}$, and $N^{\downarrow\uparrow}$ where the first superscript denotes the target atom spin and the second the electron spin. The asymmetry parameters are formed by the appropriate combinations of the differential cross sections, normalized to unity spin polarizations P_a (atom), P_e (electron) and P_aP_e.

$$NA_{nn} = \left[\left(N^{\uparrow\downarrow} + N^{\downarrow\uparrow}\right) - \left(N^{\uparrow\uparrow} + N^{\downarrow\downarrow}\right)\right] / \left(P_a.P_e\right) \quad (1)$$

$$NA_1 = \left[\left(N^{\uparrow\downarrow} + N^{\uparrow\uparrow}\right) - \left(N^{\downarrow\downarrow} + N^{\downarrow\uparrow}\right)\right] / P_a \quad (2)$$

$$NA_2 = \left[\left(N^{\uparrow\uparrow} + N^{\downarrow\uparrow}\right) - \left(N^{\uparrow\downarrow} + N^{\downarrow\downarrow}\right)\right] / P_e = NS_A \quad (3)$$

$$N = N^{\uparrow\downarrow} + N^{\downarrow\uparrow} + N^{\uparrow\uparrow} + N^{\downarrow\downarrow} \quad (4)$$

A_{nn}, the "exchange" asymmetry, can have non-zero values even if relativistic effects are absent [15]. A_1 requires the presence of both relativistic and exchange effects while A_2 will be non-zero if relativistic effects alone are significant. For inelastic scattering, A_2 is equivalent to S_A, the standard left–right asymmetry function for inelastic scattering of spin-polarized electrons from a beam of unpolarized atoms.

A schematic of the apparatus used in the experiment is shown in Fig. 1. The detailed description of the apparatus has been presented previously [16]. Circularly polarized radiation at 810 nm incident on a GaAs crystal produces a beam of polarized electrons (P_e=35%). These electrons are transported to the interaction region where they intersect a beam of Rb atoms that is produced by a standard, two-stage, crucible oven. In the absence of the atomic beam, the polarization of the electron beam is measured by a Mott polarimeter. A hemispherical electron energy analyser followed by a channel electron multiplier detect those electrons inelastically scattered by exciting the Rb 5S-5P transition. The energy resolution of the detection system was approximately 390 meV at the incident energies used.

Before performing an asymmetry run, a measurement of the energy loss spectrum was performed and the experiment tuned for measurement of electrons scattered from the combined $5^2P_{1/2,3/2}$ state, which is located 1.58 eV below the elastic peak.

Typically a measurement proceeds as follows. The electron polarization is switched once every 10 seconds by changing the handedness of a calibrated liquid-crystal retarder. Pulses from the channel electron multiplier that have been amplified and converted to NIM standard pulses are collected into one of two counters, depending on the electron spin. This procedure is repeated for a number of 'spin reversals', usually 10 at each scattering angle. The analyser is then moved to the next scattering angle and

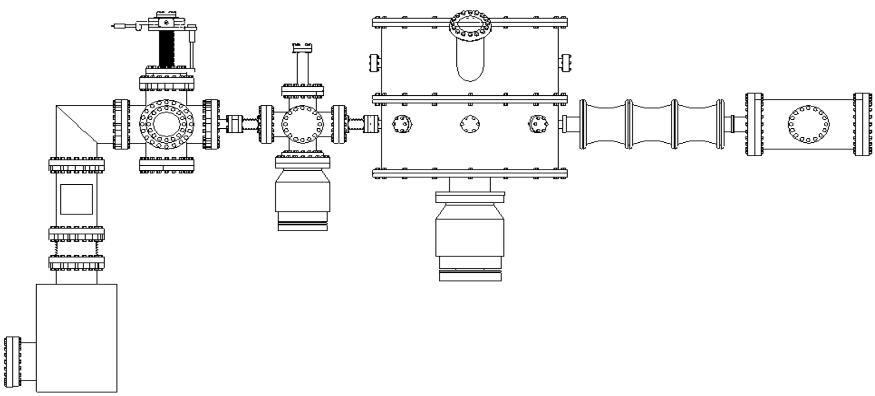

Figure 1. Schematic diagram of apparatus

the process repeated. Once the analyser has completed one angular scan (30° to 130°) the analyser is returned to forward scattering angles and a new scan is started. At the end of measurement for each scattering angle the data is written to file. Once a number of scans is completed, usually 60, the program finishes. This procedure takes about 48 hours to complete.

RESULTS

Inelastic differential cross section data (DCS) are obtained by adding the number of counts for each polarization direction. The results are shown in Fig. 2. Our DCS data are normalised to the absolute measurements of Vŭsković *et al* [17] at 100°. It is evident from these results that there are significant differences between the theoretical predictions and the measurements beyond 20°. In this region the theoretical model overestimates the size of the differential cross section by an order of magnitude.

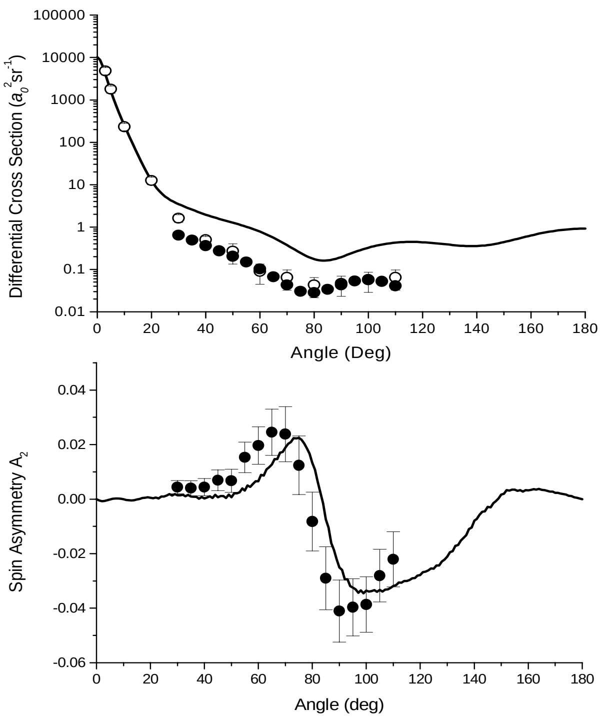

Figure 2.(Top) Differential cross section for Rb 5^2S-5^2P at 20 eV incident energy. Data are from this work (closed circles) and [17] (open circles). (Bottom) Asymmetry A_2 at 20 eV incident energy. The R-matrix calculation is shown as a solid line.

Agreement between our measurements and those of Vŭsković *et al* is within experimental uncertainty depending on the normalization. The other discrepancy between the calculations and the measurements is in the location of the cross section minimum, which is measured at 80°. The calculations predict this minimum to occur at approximately 85°. Otherwise the general shape of the cross section is predicted well by the theoretical model.

The measurement of the A_2 parameter for 5^2S-5^2P excitation at 20 eV is also given in Fig. 2. The overall agreement with theory is good. However the angular offset that was observed in the differential cross section produces a corresponding offset of approximately 5° in the A_2 parameter. The overall magnitude of the parameter is in excellent agreement if the offset is ignored. This may be considered surprising since the A_2 parameter is inversely proportional to the cross section, which the theory predicts so poorly in this region. However, the asymmetry depends on the difference between spin-up and spin-down cross sections so overall changes in the magnitude of these cross sections will not change the asymmetry. It is important to note that the magnitudes of the asymmetry measured in this case are considerably smaller than those of caesium [11], which were approximately three times larger.

Fig. 3 presents a measurement of the A_2 parameter and R-matrix calculations for 30 eV. Similar agreement is obtained at this energy, including a small angular offset.

An explanation for the lack of complete agreement between the R-matrix calculation and experiment may lie in the fact that the model is yet to contain pseudo states. However, the data confirms that the relativistic component of the electron-atom interaction is significant for Rb for these kinematics and must be included in any theoretical model for a complete description.

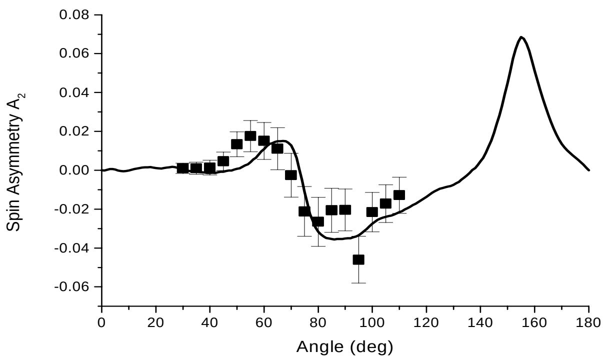

Figure 3. Asymmetry A_2 at 30 eV incident energy.

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