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LETTER TO THE EDITOR

Large-angle superelastic electron scattering from Na(3P)

J J McClelland, M H Kelley and R J Celotta

Radiation Physics Division, National Bureau of Standards, Gaithersburg, MD 20899, USA

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Abstract. Measurements of superelastic scattering of 2 eV electrons from oriented Na(3P) atoms have been carried out over the angular range 10 to 120°. Results are presented in terms of $L_\perp$, the angular momentum transferred perpendicular to the scattering plane. Comparison is made with previous experiments at small angles, and with close-coupling calculations. Good agreement is seen with the earlier experimental work, but significant disagreement is seen with theory at angles beyond 40°.

The study of $S \rightarrow P$ transitions in electron–atom scattering has seen a great deal of work in recent years. Because a P state has three degenerate magnetic sublevels, this type of transition has been the subject of quite a few investigations into the best way to characterise a scattering event that creates a final atomic state which is some sort of coherent, partially coherent or incoherent superposition of substates. Various schemes have emerged for describing the excited state and its coherence properties, especially with regard to the fluorescence radiation resulting from the decay to the ground state. Among the parameters introduced, λ and χ (Eminyan *et al* 1974), which represent a ratio and a phase difference of different M_L excitation amplitudes, have seen wide usage. Stokes parameters describing the emitted light have also been used (Blum and Kleinpoppen 1975). We find that the most physical description to emerge so far makes use of three parameters to describe the P state after collision (Andersen *et al* 1986): $L_\perp$, the angular momentum transferred to the atom perpendicular to the scattering plane, $P_{\rm lin}$, the normalised difference between the length and width of the charge cloud and γ, the alignment angle of the charge cloud. These three parameters can be derived in a straightforward manner from the scattering amplitudes for the different M_L excitations, and provide a very clear picture of the excitation process.

The quantity $L_\perp$, which can also be identified with the net orientation transferred to the atom, has generated a fair amount of interest in itself. Classical arguments (see e.g., Kohmoto and Fano 1980) are often invoked in describing its behaviour and, indeed, at small scattering angles they seem to give correct results. Large-angle behaviour, however, cannot in general be explained classically and the interpretation becomes less clear. Unfortunately, there has been a general lack of measurement at large angles because of the rapid fall-off of inelastic cross sections with increasing scattering angle.

$S \rightarrow P$ transitions are often studied in electron–photon coincidence experiments, in which the degree of polarisation or angular distribution of the photon emitted after electron impact excitation is correlated with the scattering angle of the scattered electron. In some special cases, they can also be studied by performing a time-inverse experiment, in which a P-state atom is prepared with a particular charge cloud configuration via laser optical pumping, and the electrons which de-excite this atom in a superelastic collision are detected as a function of scattering angle.

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Na has proven to be a very convenient target for superelastic scattering studies because its 3^2P excited state, at 2.1 eV above the 3^2S ground state, is readily accessible with tunable dye lasers. The first such investigations were done by Hermann *et al* (1977, 1980), whose results showed excellent agreement with a four-state close-coupling calculation of Moores and Norcross (1972).

In this letter we present measurements of $L_\perp$ over a large angular range for an incident energy of 2 eV (corresponding to an inelastic energy of 4.1 eV). The results were obtained in an apparatus developed for spin-dependent studies (McClelland *et al* 1985, 1986). The resolution of $L_\perp$ into singlet and triplet contributions will be the subject of a forthcoming publication.

Electrons are produced in a GaAs photoemission source (Pierce *et al* 1980) and transported to the scattering volume through a set of low-energy electron optics. The spin polarisation of the electrons was averaged over in order to simulate an unpolarised electron beam. The electron energy was calibrated by observing the onset of electron impact ionisation at 5.14 eV. Sodium atoms, produced in an effusive oven, are optically pumped (Hertel and Stoll 1977) in the collision region by a single-frequency, ring-dye laser locked to the $3^2\mathrm{S}_{1/2}(F=2)\rightarrow 3^2\mathrm{P}_{3/2}(F=3)$ transition. The laser, incident perpendicular to the scattering plane, was circularly polarised either in a left-handed (LHC) or right-handed (RHC) sense. The scattered electrons were detected by a channel electron multiplier equipped with a retarding field analyser which rejects all elastically and inelastically scattered electrons, as well as a significant amount of background electrons from various sources. The detector is mounted on a turntable which can access scattering angles from −135 to +70°.

Scattered electrons were counted for LHC and RHC optical pumping separately, generating two intensities, I^{LHC} and I^{RHC}. The laser polarisation was switched at intervals of 2 to 10 s, depending on the count rates, and after each cycle the laser was blocked and a background was measured. Count rates ranged from about 200 Hz at small scattering angles to about 0.5 Hz at 120°. Background rates varied from about a quarter of the total count rate at small angles, to a tenth at intermediate angles and half at the largest angles.

Due to the nature of the optical pumping, the two intensities I^{LHC} and I^{RHC} represent the scattering probability for a de-excitation of a pure $M_L=+1$ or $M_L=-1$ state, where the quantisation axis is taken perpendicular to the scattering plane. The time-reversal symmetry of the scattering process allows these de-excitation probabilities to be identified with the excitation probabilities in the inelastic process. Thus the scattering intensities represent relative measures of the two M_L-state populations that would be present after the corresponding excitation process. The difference of the two intensities divided by the sum then gives the net z component of the angular momentum, in units of $\hbar$, transferred to the atom. We write

$$L_\perp=\frac{I^{\mathrm{LHC}}-I^{\mathrm{RHC}}}{I^{\mathrm{LHC}}+I^{\mathrm{RHC}}}. \qquad (1)$$

Equation (1) was used to generate the results shown in figure 1, where $L_\perp$ is shown over the angular range from 10 to 120°. Measurements at positive and negative angles are included, averaged appropriately. Errors of one standard deviation, due to counting statistics, were generally less than the size of the plotting symbol, and are shown as error bars only when larger.

Also shown in figure 1 are the previous results of Hermann *et al* (1980) at 3 eV incident energy. Despite the difference in energy, the agreement with the present results

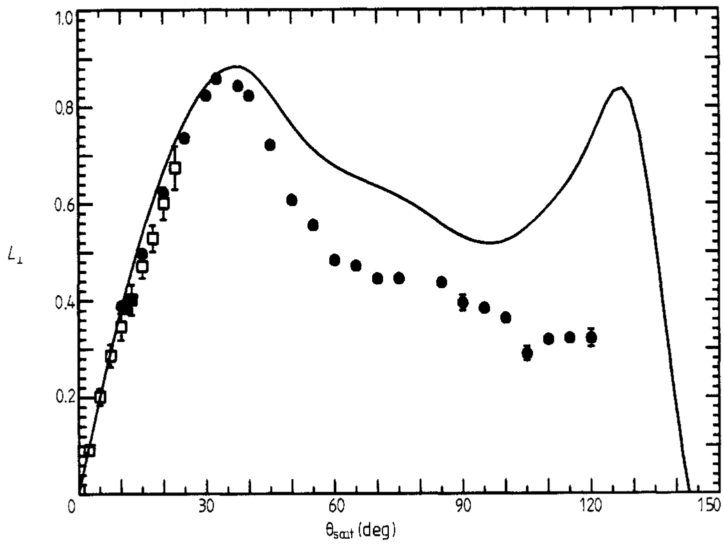

Figure 1. Angular momentum transfer $L_{\_}$ against scattering angle θ_{scat} for superelastic scattering of 2 eV electrons from Na(3P). Full circles, present results; open squares, results of Hermann *et al* (1980) at 3 eV; full curve, theory of Moores and Norcross (1972).

is quite good. Both experiments show a rapid increase in $L_\perp$ with scattering angle. This is consistent with the often-invoked classical picture, in which an electron scattering to the 'left' from an attractive potential initially has positive angular momentum and can thus easily give up positive angular momentum to the target by losing energy.

The full curve in figure 1 shows the calculations of Moores and Norcross (1972). As was the case with the earlier experiment, the comparison at small angles is quite favourable. Beyond 40°, however, there is significant disagreement between theory and the new experimental results. This is somewhat unexpected, especially since the incident energy is well below the ionisation limit. One might be tempted to blame the disagreement on some sort of partial wave effect, but at this low energy, the first few partial waves should be quite sufficient to account for all the scattering. So far, the explanation of this discrepancy is unknown.

By extending the previous measurements of $L_\perp$ to large angles, we have found a large difference between experiment and a generally well accepted calculation. Hopefully these new results will stimulate further work on this problem. More theoretical investigations, as well as new experimental data, are clearly required before it can be satisfactorily resolved. Studies with spin dependence will most likely be very helpful toward this end.

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