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Elastic Scattering of Electrons from Multiply Charged Ions

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Abstract

A crossed-beams energy-loss spectrometer has been used to investigate angular distributions for electron scattering from N^{q+} ions, $q = 1$–3, at a collision energy of 10 eV. Results are compared with the predictions of a partial waves calculation based on a semi-empirical potential, and with the classical Rutherford formula.

1. Introduction

The elastic scattering of an electron from a partially dressed ion, coupling both long-range Coulombic and short-range interactions has until recently, received only scant attention. First experimental evidence of structure in the angular distribution arose from fast ion-atom and ion-molecule ionisation studies, where the binary encounter (BE) peak has been interpreted as the elastic scattering of a quasifree target electron in the field of the projectile ion [1]. Anomalies in the BE peak, such as multipeaks and energy shifts, have been attributed to being the result of minima in the corresponding electron-ion elastic differential cross sections (DCS) [2]. However these studies are restricted to high effective electron-ion collision energies, and are complicated by the role of the host atom, via momentum distribution of the quasifree electron [3] and in postcollision interactions [4].

Direct electron-ion scattering measurements have only appeared very recently. DCS for Ba^{2+} at 41.4 eV and Xe^{6+}, Xe^{8+} at 50 eV have shown structure in good agreement with a many-body Hartree-Fock calculation [5]. Measurements from our own laboratory on Na^+ and Cs^+ at 10 eV [6, 7] have been shown to agree well with partial waves calculations based on semi-empirical potentials, but for Cs^+ show poor agreement with the more sophisticated many-body theory.

In the present work we further pursue the scattering problem at low collision energies where the scattering process is expected to be complex due to enhancement of electron-electron correlations as the velocity of the free electron reduces below the velocity of the electrons dressing the ionic core. We have extended our work to multiply charged ions, directly measuring angular distributions for the elastic scattering of electrons from N^{q+}, where q is in the ionisation stages 1–3.

2. Experimental method

The CBEL electron spectrometer, shown schematically in Fig. 1, has been described in a previous publication [6], and hence only a brief description is given here. Electrons from an electrostatically focused gun intersected a target ion beam at 90°. A combination of lenses on the front end of the gun ensured an almost parallel electron beam of spot size 1–2 mm at the interaction region. Electrons scattered during the interaction were analysed by a 180° hemispherical analyser which was free to rotate in a plane perpendicular to the plane containing the electron and ion beams. A microchannel plate position sensitive detector utilising an integrated chip with 128 discrete anode/pre-amp/discriminator/counter units was used in the dispersion plane of the analyser. The target ion beams of N^+, N^{2+} and N^{3+} were produced from the Belfast 5 GHz electron cyclotron resonance ion source.

3. Results and discussion

Figure 2 shows the measured angular distributions for the elastic scattering of electrons from N^{q+} ions, $q = 1$–3, over the angular range 30°–55°, at a centre of mass collision

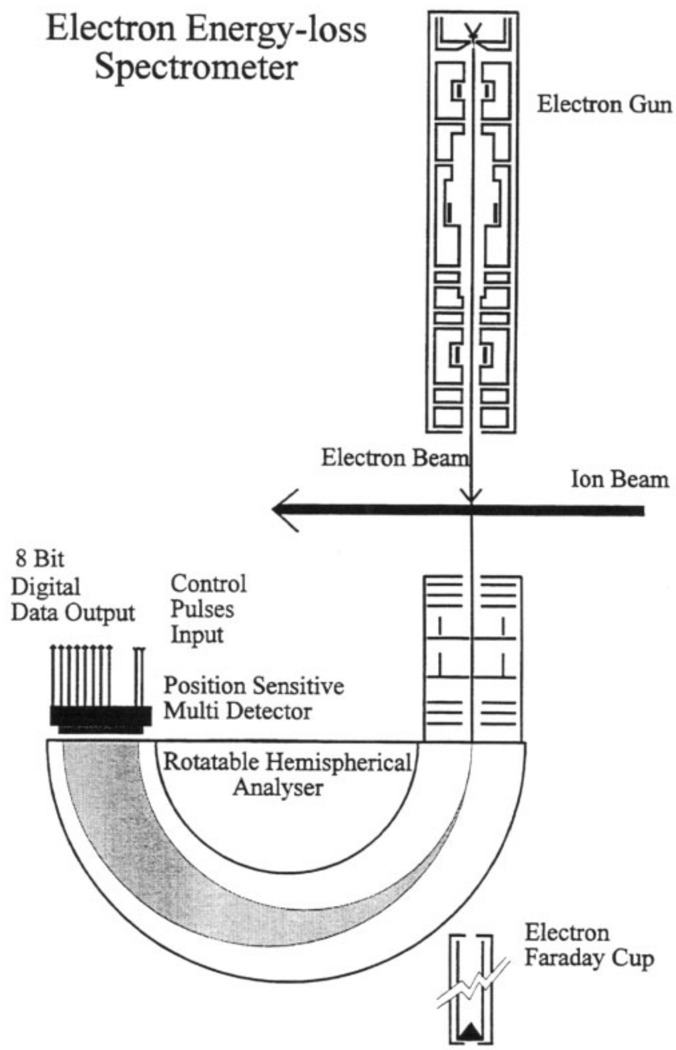

Fig. 1. Schematic diagram of the electron spectrometer.

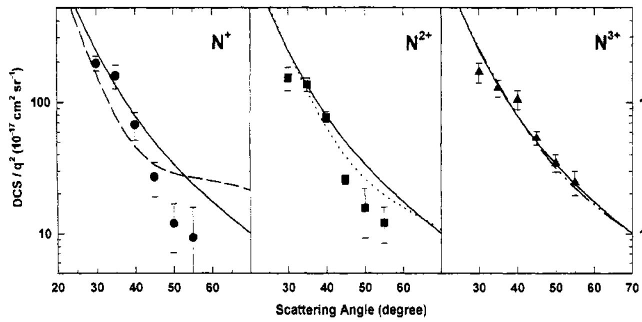

Fig. 2. Differential cross sections, reduced by q^2, for the elastic scattering of electrons from N^{q+} for $q = 1$–3 at 10 eV. The error bars denote the statistical reproducibility of the experimental data at the 90% confidence level. Present experimental data: N^+ (●), N^{2+} (■), N^{3+} (▲). Partial waves calculations, short range phase shifts due to Szydlik *et al.*: N^+ (– – –), N^{2+} (· · ·), N^{3+} (– · · · –). Rutherford formula (——).

energy of 10 eV. Also shown are theoretical curves calculated using short-range phase shifts computed by Szydlik *et al.* [8], using a semi-empirical potential. They obtained phase shifts for the $l = 0$, 1, 2, 3 and 4 partial waves using the independent particle model potential of Green *et al.* [9] *viz.*:

$$V(r) = -\frac{2}{r}\left(\frac{Z-q}{H(e^{r/d}-1)+1} + q\right) \tag{1}$$

where q is again the degree of ionization, and H and d are adjustable parameters selected for a particular ion by minimizing the total energy of the neutral atom. Coupling these short-range phaseshifts with the Coulomb phaseshifts, we have calculated angular differential cross sections for the elastic scattering of electrons from N^{q+} at 10 eV. The theoretical curves plotted in Fig. 2 have been reduced by q^2, and the experimental data has been arbitrarily normalised to the theory at 30° in each case. Also shown is the prediction of the classical Rutherford formula, i.e. purely Coulombic scattering.

In the angular range studied the partial waves theory predicts a rapid convergence towards pure Coulombic scattering for $q > 1$. This trend is also present in the measurements, but clearly far less dramatic. In the case of the singly charged ion N^+ the dcs appears to be showing a strong interference dip at the largest angles studied, a feature that we have also witnessed in a similar study of Cs^+ [7] and Na^+ [6] ions, also at 10 eV collision energy. In N^{2+}, structure due to interference between the Coulomb and short-range interactions is again evident, but less strongly than for the singly charged ion. In N^{3+}, the theory is in far better accord with the data, and the Coulombic interaction clearly dominates over this angular range.

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