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State-selective single-electron capture in Ne^{4+}–He collisions

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Abstract

A cold-target recoil-ion momentum spectroscopy technique (COLTRIMS), capable of measuring simultaneously the energy-gain and the scattering angle of the projectile products, has been used for the study of state-selective single-electron capture from He by 8 keV Ne^{4+} ions. The dominant reaction channel is due to single-electron capture into the 3s ^4P state of the Ne^{3+} from the ground state incident Ne^{4+} ions. Also, there is clear evidence of capture into the 3s ^2P state. State-selective differential cross-sections for capture into the 3s ^4P and ^2P states have also been measured and compared with the semi-classical multichannel Landau–Zener calculations.

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1. Introduction

The understanding of single-electron capture by multiply charged ions from atomic and molecular targets has developed considerably during the last two decades. Aside from fundamental aspects, this interest arises from the importance of this process in areas such as energy-loss mechanisms of high temperature and astrophysical plasmas.

Few groups have studied state-selective single-electron capture by Ne^{4+} ions from He. Schmeissner et al. [1] measured energy gain spectra of the projectile ions following single-electron capture by 288–2094 eV Ne^{4+} ions from He by means of energy-gain spectroscopy technique. Tunnell et al. [2] measured the total differential cross-sections for single-electron capture by Ne^{4+} ions from He in the collision-energy range from 172 to 692 eV, but without energy analysis. Said et al. [3] observed the translational energy change in electron capture collisions between 100 eV Ne^{4+} and He at scattering angles between 0° and 6°, using a differential energy-gain spectrometer. Tan and Lin [4] applied a quantal two-channel calculations to study charge-transfer differential cross-sections in Ne^{4+} ions on He collisions at laboratory impact energies from 220 to 500 eV.

Measurements of the doubly differential cross-sections, in energy-gain and scattering angle of the projectile products, for single-electron capture in collisions between 8 keV Ne^{4+} ions from He are

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reported here. The data were obtained using a cold-target recoil-ion momentum spectroscopy (COLTRIMS), which has been described previously by Hasan et al. [5].

2. Results and discussion

Fig. 1 shows a density plot of the doubly differential cross-sections, in the energy-gain and projectile scattering angle, for single-electron capture by 8 keV Ne^{4+} ions from He. The observed spectrum is dominated by contributions from capture into the 3s ^4P state of Ne^{3+} ions, with smaller contributions from capture into the 3s ^2P state. Comparison with the results of Schmeissner et al. [1], Tunnell et al. [2] and Said et al. [3] for this collision system at collision energies of 2094, 2253 and 100 eV respectively shows good agreement with the present measurements for capture into the 3s state of Ne^{3+}. But because of their lower energy resolution, their spectra show only a single peak and were unable to distinguish between the exit channels involved.

Fig. 2 shows the energy-gain spectra at different scattering angles, obtained by projecting slices of the doubly differential cross-sections spectrum onto the horizontal axis (Q-value). At forward scattering angles ($\theta = 0$–0.54 mrad), two peaks are clearly resolved. The stronger peak correlates with capture from the ground state incident Ne^{4+} ($2p^2$ ^3P) ions into the excited state 3s ^4P of Ne^{3+}. The other peak arises from capture into the 3s ^2P state of Ne^{3+}. As the projectile scattering angle increases,

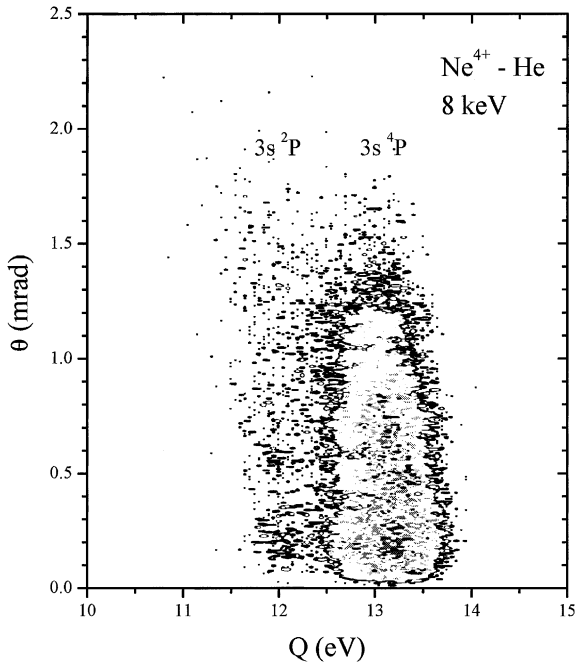

Fig. 1. A density plot of the energy-gain Q plotted against the scattering angle of the projectile for single-electron capture by 8 keV Ne^{4+} ions from He.

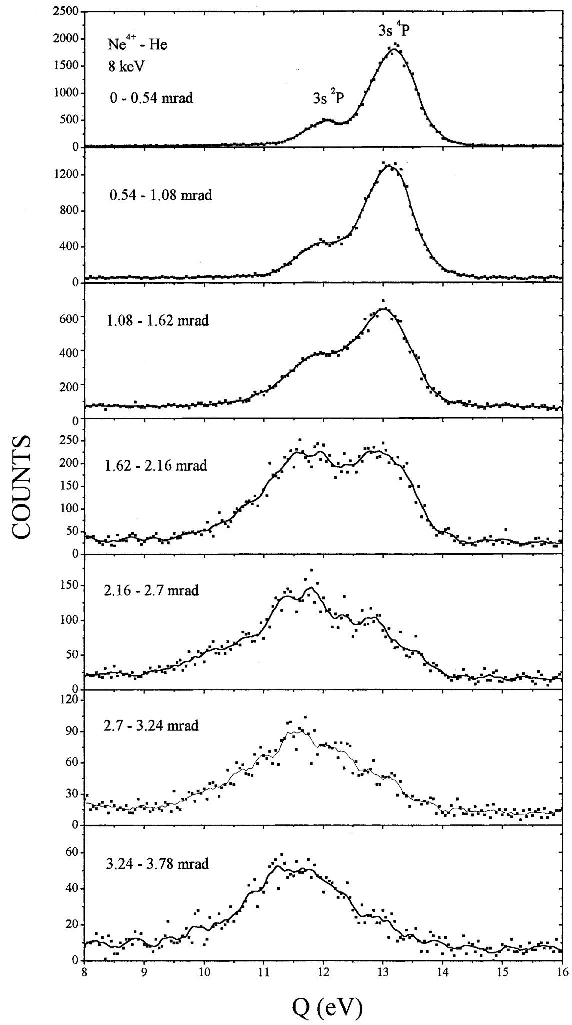

Fig. 2. Energy-gain spectra for single-electron capture by 8 keV Ne^{4+} ions from He at different scattering angles.

the importance of single-electron capture into the 3s ^{2}P state of Ne^{3+} increases, whereas the relative importance of electron capture into the 3s ^{4}P state strongly decreases. This observation is in good agreement with the low-energy measurements of Said et al. [3]. The shifts in the position of the peaks toward smaller Q-value at large scattering angles can be ascribed to the kinematic effects, indicating that the translational energy given to the recoil He^+ ions increases with increasing scattering projectile angles.

Our experimental state-selective differential cross-sections for capture into the 3s ^{2}P and 3s ^{4}P states are shown in Fig. 3. The data obtained from

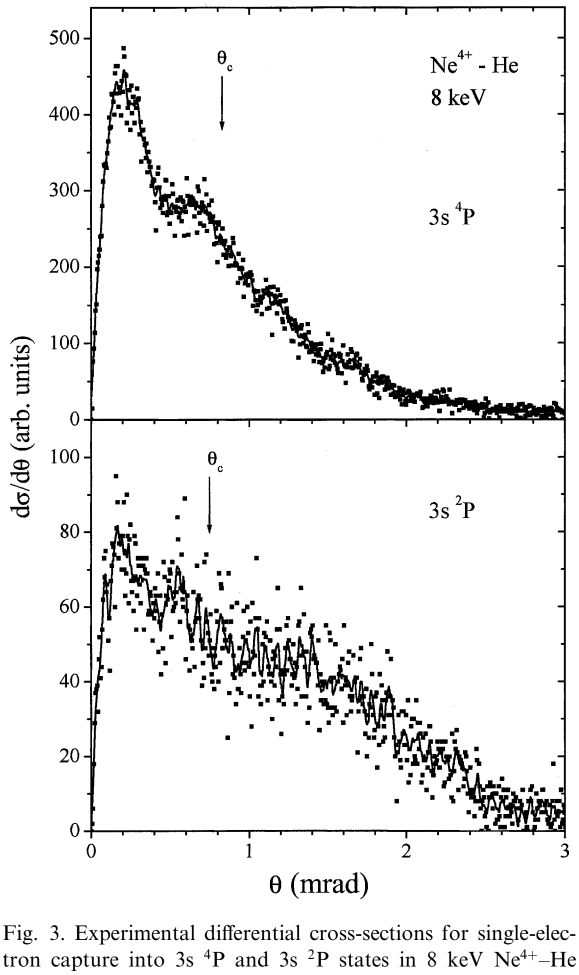

Fig. 3. Experimental differential cross-sections for single-electron capture into 3s ^{4}P and 3s ^{2}P states in 8 keV Ne^{4+}–He collisions. Smooth lines are drawn to guide the eye.

the doubly differential cross-sections by projecting the contribution of each exit channel onto the vertical axis (projectile scattering angle). The distributions for capture into the 3s ^{4}P and 3s ^{2}P states are strongly forward peaked and display an oscillatory structure, although the structure for 3s ^{2}P channel is less pronounced when compared to the 3s ^{4}P state. The half-Coulomb scattering model has been used to estimate the critical angle θ_c, which corresponds to capture at an impact parameter equal to the crossing radius, by assuming that capture occurs at a localized curve crossing between the potential energy curves for the entrance and exit channels. For small angles, $\theta_c = Q/2E$, where E is the impact energy. The calculations of differential cross-sections usually show a minimum at θ_c. This angle separates the events that scattered at smaller angles due to capture on the way out and events scattered at larger angles due to capture on the way into the collision. Arrows in Fig. 3 indicate the angle θ_c for each reaction channel. The forward peaks clearly represent contributions from capture into the final channel on the way out of the collision, while the structures occurring at larger angles entirely represent contributions from capture that takes place on the way into the collision [6].

The measured differential cross-sections are interpreted using a multistate collision model (MCLZ) based on classical trajectories for the nuclear motion and multichannel Landau–Zener transition probabilities, which have been described in detail by Andersson et al. [7]. The experimental cross-sections and the theoretical calculations folded with the experimental angular resolution as a function of the reduced scattering angle τ, the product of impact energy E and the scattering angle θ, are shown in Fig. 4. The value of the largest calculated cross-section has been normalized to the height of the peak observed in the spectrum. The calculation constructed assuming that the 3s ^{4}P and 3s ^{2}P channels contribute to single-electron capture with the ^{4}P or ^{2}P channel to be the exit channel and 2s 2p^4 ^{2}P channel as the promoter. For the 3s ^{4}P channel, the calculations predict the locations of the main and secondary peaks to be at about 4 and 7.5 eV rad, respectively, in disagreement with the measured data. The main

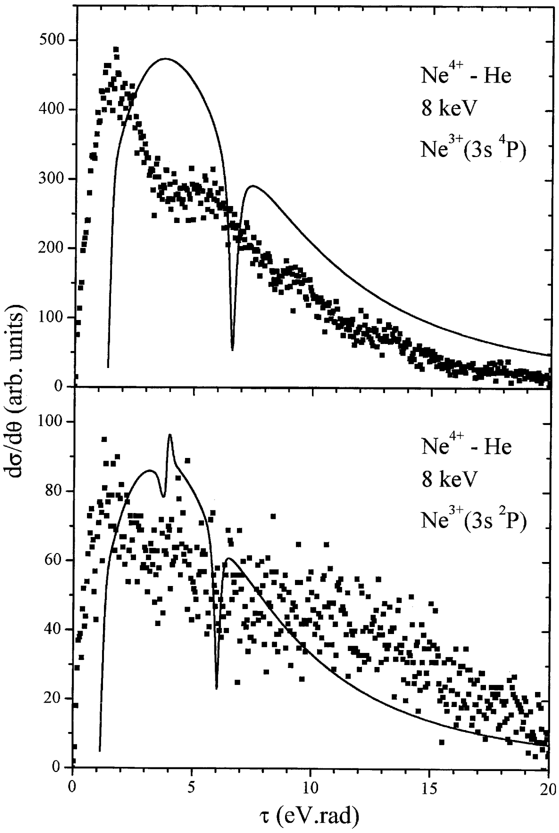

Fig. 4. Experimental and calculated differential cross-sections for single-electron capture into 3s ^{4}P and 3s ^{2}P states in 8 keV Ne^{4+}–He collisions: (•) the present results; full curves, theoretical calculations folded with experimental resolutions.

peaks are rainbow effects caused by 2s 2p^4 promotion of the entrance channel. Classically, this effect occurs when the scattering from a very large number of impact parameters results in the same scattering angle.

Comparison with results of Tunnell et al. [2] shows good agreement with our measurement. Their measurements at 484 eV show a strong forward peak and an oscillatory structure with two secondary peaks at about 10.3 and 17.6 mrad. These oscillations were well reproduced and described as the envelope of the unobserved fast oscillations due to the combined effect of rainbow scattering and of Stuckelberg oscillations by Tan et al. [4] using a quantal two-channel calculation.

3. Conclusion

In conclusion, we have studied doubly differential cross-sections for single-electron capture in collisions of 8 keV Ne^{4+} ions with He by means of COLTRIMS. The energy-gain spectrum indicated that the dominant reaction channel was correlated with capture into 3s ^{4}P state with significant contributions from capture into the higher excited state 3s ^{2}P, which make this collision a three-state system rather than only a two-channel one. This is probably the reason why the MCLZ calculations did not describe the structure observed in the differential cross-sections. The behavior of the dominant peak in the angle-dependent Q-spectra that shifts to smaller Q-values is not exactly as expected. This could be another feature of the rainbow effect. The main peak observed in the angular distributions can be ascribed to the rainbow effect and the secondary peaks observed at larger scattering angles are due to the Stuckelberg oscillations.

Acknowledgements

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