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Strong Directional Out-of-Plane Scattering in Multiple Ionizing Highly Charged Ion-Atom Collisions

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Abstract

The azimuthal (ϕ_P) and polar angle (θ_P) scattering of projectiles in coincidence with recoil ions has been studied for 0.53 MeV/u F^{8+} + Ne. For high degree of ionization of the target we find the resultant transverse momentum of all electrons emitted into the continuum to increase with the number of ejected electrons and to have a direction mostly not co-planar with the scattering plane.

I. Introduction

The mechanism by which many electrons are simultaneously emitted in comparatively slow collisions of highly charged ions with atoms has been of considerable interest, since experiments[1,2] characterizing the impact parameter dependence of the electron emission patterns in F^{8+} + Ne revealed strong angular dependences of the emission probabilities. Observation of very high longitudinal electron momenta [3] and strong polarization of target electron states [4] showed the strong influence of electron nuclear interaction.

We report here on inclusive measurements of multi-electron emission probabilities measured via a coincidence between recoil ions and scattered projectiles in well defined charge states q_f detected at scattering angle (θ_P, ϕ_P). The data show that the ejected electron momentum summed over all outgoing electrons increases with increasing degree of ionization and is mostly non co-planar to the scattering plane resulting in strong non co-planar nuclear scattering effects.

Experiment

A highly collimated beam of 0.53 MeV/u F^{8+} of the J.R. Macdonald Laboratories EN Tandem intersected with a Ne gas jet. The projectiles were charge state selected after the collision and then after 700 cm flight path detected with a 2-dimensional position sensitive parallel plate avalanche detector (PPAD) equipped with a wedge and strip anode. Recoil ions in different charge states q_R extracted electrostatically from the collision zone were detected in coincidence with scattered projectiles in cartesian coordinates (x, y), the recoil ion flight time identifying charge states q_R (see Fig 1). Due to the small extraction field the detection efficiency of the recoil spectrometer is maximal for recoil ions going parallel to the +x axis, i.e. with a vanishing y-component of the transverse momentum. A maximum in the coincident projectile azimuthal distribution thus will correspond to recoils with $(P_R^T)_Y = 0$. In off-line analysis for each polar angle θ_P recoil TOF spectra as function of the azimuthal angle ϕ_P were constructed from recoil projectile coincidence events recorded on-line with cartesian coordinates (x, y).

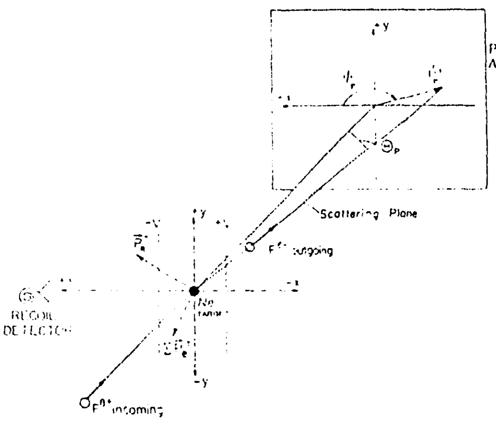

Fig 1. Experimental Set-up.

III. Results

Fig. 2 shows, for a fixed polar scattering angle θ_P=0.28 mrad, the azimuthal (ϕ_P) dependence of the recoil projectile coincident probability for selected recoil ion charge states $3 < q_R < 7$. We observe for a low recoil charge, q_R=3, i.e. 1 electron in the continuum and two electrons captured into the projectile a single peak for ϕ_P= 180°. For higher recoil charge states, that is a higher multiplicity of electrons emitted into the continuum, we note that the single peak splits into two peaks moving away from 180°. For q_R=7+, that is for the emission of 5 electrons, the recoil projectile coincident rate peaks for ϕ_P=137° and ϕ_P=223°, which is clearly non-coplanar with the recoil ions. The analysis of the transverse momentum balance of scattered projectile and recoil ion allows to deduce the role which the momentum of electrons emitted into the continuum plays in the collision. Fig. 3 illustrates the transverse momentum balance. Recoil ions can only be detected if the transverse recoil momentum P_r^T lies within the acceptance cone of the TOF spectrometer. Then, for a fixed polar scattering angle $\theta_P \pm \Delta\theta_P$ (i.e. projectiles falling into the horizontally shaded ring) recoil ions can only be detected in coincidence with projectiles at azimuthal angles $\phi_P \neq 180°$, if $P_{Proj}^T + P_{Rec}^T + P_e^T = 0$, where P_e^T is the electron momentum vector summed over the transverse momenta of all emitted electrons.

The observation of maxima in the ϕ_P distribution of recoil projectile coincident events for fixed polar angles then imposes restrictions on the possible form of the momentum density distribution of electrons. If for a given degree $n_e = q_R - 2$ of ionization the probability distribution $n(|p_e(q_R)|)$ follow a monotonic decrease with

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a maximum at $|p_e|=0$ the recoil projectile coincidence yield as function of would always peak at $\phi_P=180°$. Only, with increasing mean value $<|p_e|>$ the observed peak width in the recoil projectile coincidence distribution as function of ϕ_P would increase too.

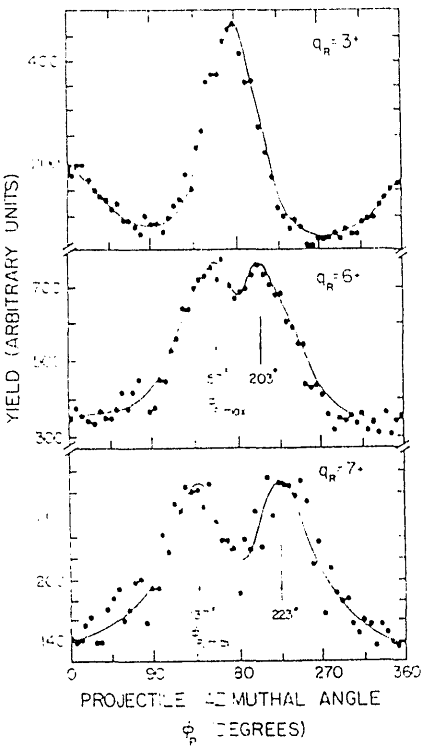

Fig 2. Recoil-projectile coincident distribution for different recoil charge states as function of ϕ_P for polar scattering angle θ_P = 0.28mrad of projectiles.

The observed maxima at $\phi_P \neq 180°$ can only be obtained if already the distribution $n_e(|p_e|)$ has a maximum at $|p_e| \neq 0$. The deviation of ϕ_P from 180° degree is therefore a direct measure of the mean electron momentum vector $|p_e|$.

An estimate for the magnitude of the transverse electron momenta can be derived as follows: at the azimuth ϕ_P, where the coincident scattered projectile distribution has a maximum, we have

$$(1) \quad P_{Proj,x}{}^{T} + P_{Rec,x}{}^{T} + P_{c,x}{}^{T} = 0$$

$$(2) \quad P_{Proj,y}{}^{T} + 0 + P_{c,y}{}^{T} = 0.$$

Eq. (1) will not be used at this time due to large uncertainties in the determination of $P_{Rec,x}{}^{T}$ (see also Fig 3). Eq. (2) reads for small scattering angles

$$(3) \quad P_{Proj}{}^{i} \cdot \theta_P \cdot \sin \phi_{P,max} + P_{c,y}{}^{T} = 0,$$

where $P_{Proj}{}^{i}$ is the incident projectile momentum. $P_{c,y}{}^{T}$ we then derive as lower bound for the electron transverse momentum $<|P_e{}^T|>$ [a.u.].

Table 1.

q_R	n_e	θ_P=0.28mrad $<\|P_e{}^T\|>$	θ_P=1.1mrad $<\|P_e{}^T\|>$
5	3	9	12
6	4	18	18
7	5	30	24
8	6	35	36

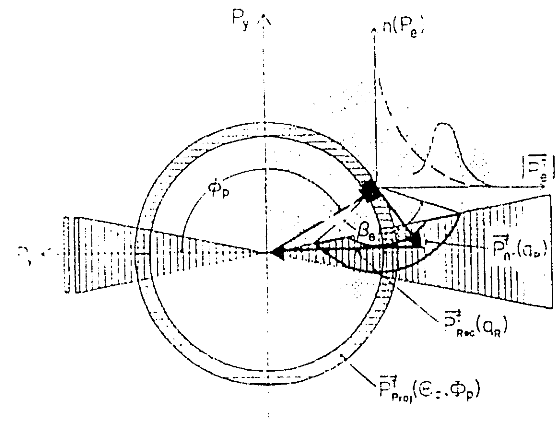

Fig 3. Transverse momentum balance for scattered projectile, recoil-ion and summed transverse electron momentum.

This leads to individual single electron energies between 122 and 463 eV in qualitative agreement with preliminary data from delta electron-recoil coincidence experiments [5].

IV. Summary

We have measured inclusive multielectron emission probabilities via recoil-scattered projectile coincidences with a defined scattering plane. We find that the total transverse electron momentum increases with the number of electrons emitted into the continuum. We also find that at very small scattering angles electrons are emitted non-isotropically with respect to the scattering plane giving rise to strong out of plane scattering of the projectile.

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References

1. A. Skutlartz, S. Hagmann, Phys. Rev. A 28, 3268 (1983).
2. H. Schmidt-Böcking, A. Skutlartz, S. Hagmann, Phys. Lett. 122A, 421 (1987).
3. R. Schuch, H. Schöne, S.Datz, Phys. Rev. Lett. 60, 925 (1987).
4. R. Doerner, J.Ullrich, H. Schmidt-Böcking, R. Olson, Phys. Rev. Lett. 63, 147 (1989).
5. B.Krässig, S.Hagmann, A.Gonzalez, and T.Quinteros (to be published).

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