Convoy Electrons in Coincidence with Outgoing Charge States

of Ni (920 MeV)

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Abstract: We have studied the target thickness (px) dependence of the convoy electron yield Ye(qf) for the incident projectiles Ni^{q1}
(15.6 MeV/u) with q1-28 and 27 in coincidence with outgoing projectiles with charge qf-28 and 27. Simultaneously the charge state evolution F(qf, px) dependence on the incident charge q1 has been measured. For this collision system the charge state distribution equilibrates for target thicknesses > 650 µg/cm². In the framework of a model for convoy electron production the px dependence of the yield Ye(q1,qf) can be explained if one introduces an electron transport length λe which is much larger than the attenuation length λe of free electrons.

In the last years experimental evidence has accumulated that much of the convoy electron (CE) production takes place in the bulk of the solid [1]. If the convoy electrons are formed by charge exchange processes of the projectile ion inside the solid it is interesting to inquire how these electrons keep their correlation to the projectile core in spite of the elastic and inelastic electron scattering processes inside the solid. The mean free path for free electrons extends from several Angstrom for low energy electrons to 100 Å for electrons of 10 keV [2]. This is always less than the mean free path λcc for a charge exchange cycle of heavy ions at such projectile energies.

In a recent measurement of the CE yield Ye for Ni^{2+} and Ni^{3+} ions (E_p=920 MeV)
on carbon and aluminum foils the slowly increasing yield $Y_c$ has been interpreted as reflecting an enhanced transport length for convoy electrons. A value of $\lambda_c$ was obtained which is about an order of magnitude greater than the mean free path for isotachic free electrons [3]. For the interpretation of this result the charge exchange processes inside the solid had not been fully considered. Does the $Y_c(\rho x)$ increase alternatively track the evolution of charge and excitation states which produce mainly convoy electrons or is this dependence related to a truly enhanced transport length [4]?

To elucidate this question we have measured the $\rho x$ dependence of the CE yield $Y_e(q_f)$ for Ni$^{1+}$ at 920 MeV with incident charge states $q_i=27$ and 28 in coincidence with projectiles of the outgoing charge states $q_f=27$ and 28. Also the evolution of the charge states $F(\rho x)$ was recorded (Fig. 1). The experimental set-up is the same as that described in ref. [5]. The yield $Y_e(q_f)$ has been determined by integrating the electron velocity distribution over an interval of $\pm v_B$ centered at the peak maximum after point by point subtraction of a linear background arising from target ionization electrons. The number of CE was normalized to the total number of projectiles $N=IN(q_f)$ associated with all final charge states [5].

The evolution of the yield $Y_e(q_{i-27}, q_f=28)$ and $Y_e(q_i=27, q_f=27)$ proceeds much more steeply than the evolution of the corresponding charge states $F(q_{i-27}, q_f=28)$ and $F(q_i=27, q_f=27)$ respectively (see Fig. 1 and 2). But the yields of $Y_e(q_i=27, q_f=28)$ and $Y_e(q_i=28, q_f=27)$ increase at a similar pace as the corresponding outgoing charge states $F(q_f=28)$ and $F(q_f=27)$. With the procedure of Allison for charge exchange analysis [6] we find from the data of Fig. 1 for a charge changing cycle (28 --> 27 --> 28) a value of $\lambda_{cc}\approx650\ \mu g/cm^2$.

Allowing only for single step processes and one-electron exchange from ground states in an extended Allison [6] procedure introduced by Kemmler et al. [5] for the CE production in solids the data of Fig. 2 (i.e. 28 --> 28 and 27 --> 27) yield about equal contributions of electron loss (ELC) and electron capture to continuum (ECC) processes with an convoy electron transport length $\lambda_c=(24\pm5)\mu g/cm^2 > \lambda_e=2\mu g/cm^2$ (Powell).

However, there is strong evidence from other (lower $Z_p$ and $v_p$) collision systems that 1. the primary production mechanism for CE is projectile electron loss to low lying continuum states and 2. moderately excited states contribute significantly to the ELC process [7]. The above fit results for the ECC contribution (28 --> 28 or 27 --> 27) may be interpreted in terms of a two step process: Electron capture to the ground state or to low lying excited states followed by high cross section ELC events (e.g. 28 --> 27 --> 28, or 27 --> 26-->27), a view which is supported also by the charge state analysis data from Sofield et al. [8]. Within this approach the resulting transport lengths $\lambda_{cc} > \lambda_c > \lambda_e$ support the concept of electron trapping in excited states introduced by Burgdörfer [4].
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References

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