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CONVOY ELECTRONS IN COINCIDENCE WITH OUTGOING PROJECTILE CHARGE STATES OF Ni (15.6 MeV/u)

J. KEMMLER, O. HEIL, C. BIEDERMANN, P. KOSCHAR, H. ROTHARD, K. KRONEBERGER, K.O. GROENEVELD and I.A. SELLIN⁽¹⁾

Institut für Kernphysik der Joh. Wolfg. Goethe-Universität, August-Euler-Strasse 6, D-6000 Frankfurt-am-Main 90, F.R.G.

RESUME: Nous avons étudié le nombre des électrons convoyés $Y_e(q_f)$ en fonction de l'épaisseur (ρx) des cibles de carbone pour des projectiles incidents Ni^{q_i+} (15.6 MeV/u) avec $q_i=27$ et 28 en coincidence avec les projectiles émergeant de la charge $q_f=28$ et 27. Simultanément nous avons mesuré la distribution d'états de charge $F(q_f, \rho x)$ en fonction de la charge incident q_i . Le domaine d'équilibre de charge est obtenu pour une épaisseur de cible plus grande que $650 \mu\text{g}/\text{cm}^2$. Dans le cadre du model des électrons convoyés la ρx dependance de $Y_e(q_i, q_f)$ peut être expliquer si on tiend compte les deux processus ECC et ELC. Il faut introduire une longueur de transport λ_c , qui est douze fois plus grande que la longueur de la atténuation λ_e des electrones libres.

ABSTRACT: We have studied the target thickness (ρx) dependence of the convoy electron yield $Y_e(q_f)$ for the incident projectiles Ni^{q_i+} (15.6 MeV/u) with $q_i=28$ and 27 on carbon foils in coincidence with the outgoing projectiles with charge $q_f=28$ and 27. Simultaneously the charge state evolution $F(q_f, \rho x)$ dependent on the incident charge q_i has been measured. For this collision system the charge state distribution saturates for target thicknesses larger than $650 \mu\text{g}/\text{cm}^2$. In the framework of the model for convoy electron production and transport the ρx dependence of the yield $Y_e(q_i, q_f)$ can be explained by assuming ECC and ELC processes. A transport length λ_c must be introduced, which is twelve times larger than the attenuation length λ_e obtained with isotachic free electrons.

In the last years great experimental evidence had been achieved that convoy electron production takes place in the bulk of the solid. Therefore the last-layer model for convoy electron production was discarded [1].

If the convoy electrons are formed by the charge exchange processes of the projectile ion inside the solid the question arises how these electrons keep still correlated to the projectile ion in spite of the elastic and inelastic scattering processes inside the solid. The attenuation length for free electrons λ_e extends from several Å for

⁽¹⁾Oak Ridge National Laboratory and University of Tennessee, Oak Ridge, TE 37831, U.S.A.

low energetic electrons to 100 Å for electrons of 10 keV [2]. This is in general less than the mean free path for charge exchange λ_{CC} of heavy projectile ions.

In a recent measurement of the convoy electron yield Y_C for Ni^{24+} and Ni^{26+} ions ($E_p=15.2$ MeV/u) on carbon and aluminum foils the slow increase of the yield Y_C has been interpreted as an enhanced transport length for convoy electrons. A value for λ_C was obtained which is 20 times larger than λ_e for isotachic free electrons [3].

For the interpretation of this result the charge exchange processes inside the solid had not been considered. Therefore it was not clear, if the ρx dependent increase of Y_C only describes the evolution of a charge state which produces mainly convoy electrons or is related to a real enhanced transport length.

To clear this situation we have measured the ρx dependence of the convoy electron yield $Y_e(q_f)$ for Ni^{q_i+} ($E_p=15.6$ MeV/u) with the incident charge states $q_i=27$ and 28 in coincidence with projec-

tiles of the outgoing charge state $q_f=27$ and 28. Also the evolution of the charge state distribution $F(q_f)$ (fig. 1) was recorded. The experimental arrangement is the same than described in ref. [4].

The yield $Y_e(q_f)$ has been determined by integrating the electron velocity distribution over an interval of $\pm 4 v_B$ centred at the peak

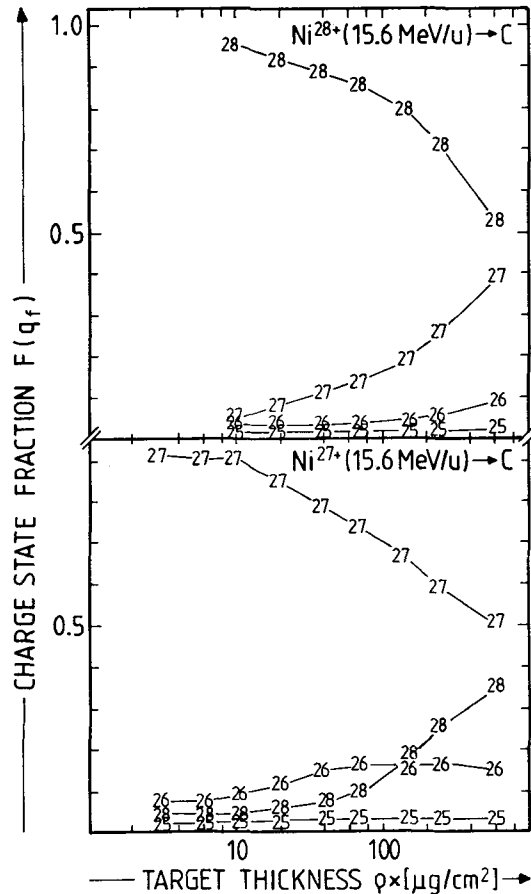


Fig. 1: Charge state distribution $F(q_f)$ for the incident projectile ions Ni^{28+} (top) and Ni^{27+} (bottom) $E_p=15.6$ MeV/u on carbon foils. The numbers denote the outgoing charge states q_f . The lines are drawn to guide the eye.

maximum and point by point subtraction of a linear background arising from ionisation electrons. The number of convoy electrons were normalized to the total number of projectiles $N = \sum N(q_f)$ associated with all final charge states.

The evolution of the yields $Y_e(q_i=28, q_f=28)$ and $Y_e(q_i=27, q_f=27)$ (fig. 2) proceeds much faster and into a different direction than the evolution of the related charge state fractions $q_f=28$ and 27. In contrast the yields $Y_e(q_i=27, q_f=28)$ and $Y_e(q_i=28, q_f=27)$ increase in the same way as the outgoing charge q_f . Assuming the model of charge exchange from Allison [5] the mean free path λ_{cc} for the loss of one electron ($Ni^{27+} \rightarrow Ni^{28+}$) and for the capture of one electron ($Ni^{28+} \rightarrow Ni^{27+}$) was found to be nearly equal, with $\lambda_{cc} \approx 650 \mu\text{g}/\text{cm}^2$. Introducing the charge exchange processes in a model for convoy electron production [4] we can determine the relative contribution of electron loss to continuum (ELC) and electron capture to continuum (ECC) and the transport length λ_c .

If the convoy electrons in the case of $Y_e(q_i=28, q_f=28)$ and $Y_e(q_i=27, q_f=27)$ are produced by pure ECC and $\lambda_c = \lambda_e$, after a very rapid increase the yield Y_e should follow the dependence of the incident charge state q_i . In the case of pure ELC the ρx dependence of the yield should follow the charge

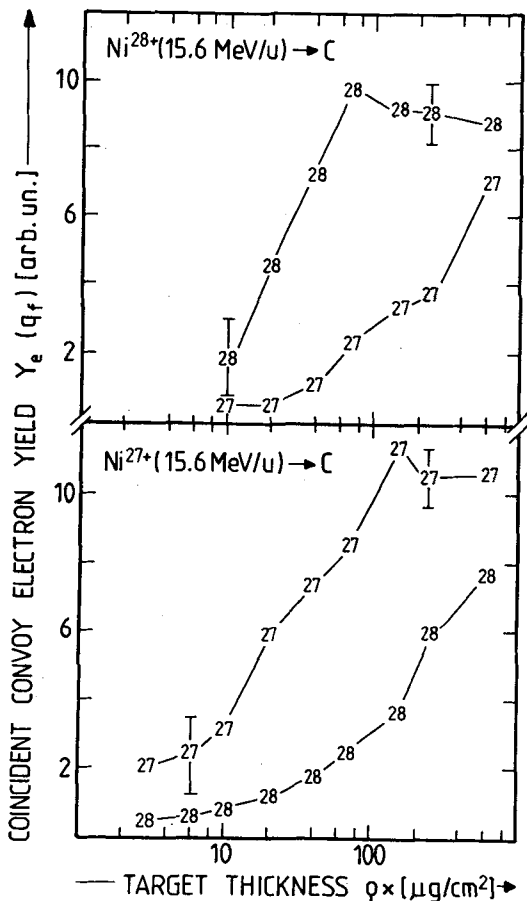


Fig. 2: Target thickness (ρx) dependence of the convoy electron yield $Y_e(q_f)$ for the incident projectile ions Ni^{28+} (top) and Ni^{27+} (bottom) $E_p=15.6$ MeV/u in coincidence with projectiles of the outgoing charge states $q_f=28$ and 27. The lines are drawn to guide the eye.

fraction $F(q_{f-1})$. Therefore in the scope of the used model the increase of $Y_e(q_i=28, q_f=28)$ cannot be explained only by assuming ELC events, because the responsible $F(q_{f-1})$ fraction increases to slow to explain the data. If a contribution of ECC and ELC is permitted the fitting procedure leads to a portion of 50% ECC and ELC. The increase of the yield point to an enhanced transport length with $\lambda_c=24\pm 5 \mu\text{g}/\text{cm}^2$. The comparable value for isotachic free electrons is $\lambda_e \approx 100 \text{ \AA}$ [2]. Interpreting the increase of $Y_e(q_i=28, q_f=28)$ as an indication for an enhanced transport length λ_c of the convoy electrons we find that

$$\lambda_{cc} > \lambda_c > \lambda_e$$

These results are obtained from a simple Ansatz, which does not include any type of excitation process of the projectile electrons. But the found enhanced transport length for convoy electrons supports the concept of refocusing of electrons which accompany highly charged ions in solids [6].

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