ANOMALOUS MEAN FREE PATHS FOR SCATTERING OF CONVOY ELECTRONS GENERATED BY FAST,
HIGHLY IONIZED IONS IN THIN SOLID TARGETS*

CONF-8406206--1

DE85 001279

I. A. Sellin, S. D. Berry, and M. Breinig
Dept. of Physics, University of Tennessee, Knoxville, TN 37916
and
Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831

C. Bottcher
Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831

R. Latz, M. Burghardt, H. Folger, H.-J. Frischkorn, K.-O. Groeneveld,
D. Hofmann, and P. Koschar
Institut für Kernphysik der Universität Frankfurt/M
Federal Republic of Germany

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best
available copy to permit the broadest
possible availability.

Recent work by Betz et al.¹ and by Yamazaki and Oda² has emphasized the role of the potential step and sudden shielding change on high Rydberg state production and convoy electron production for fast, heavy particles exiting solid targets. An issue in question is whether the final states are formed at the surface on exit, or in the bulk over some characteristic distance before exit. All recent studies incorporate the latter suggestion, which is at first sight surprising, since it involves long term association of the electrons and the projectile over a long path length.

Several puzzling aspects of convoy electron production by fast projectiles traversing foil targets have been noticed. Chief among these are difficulty in reconciling the strong Z-dependence observed in our laboratory for the convoy electron yield with coincidence data from emergent C⁽⁴⁻⁶⁾⁺ and O⁽⁵⁻⁷⁾⁺ ions in various solid targets, which showed the observed yields to be nearly independent of emergent ion charge q_e . In channeling experiments³ the data indicated a precursor electron capture inside the solid, probably to an excited n-state, quickly followed by loss of such electrons to convoy states.

What was difficult to understand about these channeling coincidence experiments as well as similar experiments with amorphous solid targets was the mechanism which effectively broke the correlation between the convoy electron yield and q_e . Mean free paths for free electrons of rapid velocity were known to be ~20Å, whereas the mean free path for projectile charge change was ~200Å. Thus, an ion was unlikely to change charge in the 20Å layer from whence the observed convoy electron were thought to come (most others scatter out of the cone of observation).

In an attempt to sort out these problems, we have measured the yields of convoy electrons associated with 15.2 MeV/amu Ni²⁴⁺ and Ni²⁰⁺ ions transversing thin, poly-crystalline foils of C and Al. The thicknesses used were in the range 3-500 µg/cm². By observing how the yield saturates with increasing thickness, we obtained effective mean free paths (MFPs) for the scattering of convoy electrons out of the collector half angle (1.54°). Figure 1 shows a typical plot.

By acceptance of this article, the publisher or recipient acknowledges the U.S. Government's right to retain a non-exclusive, royalty-free license in and to any copyright covering the article.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Figure 1.

The MFPs thus derived are about 10 times those expected for free electrons of the same velocity! - e.g. at an equivalent electron energy of 8.3 keV we find a convoy electron MFP of 200 ± 20 nm in carbon, as opposed to the free electron value of 10 nm.

In seeking an explanation, we note that these electrons pass through $10^3 - 10^4$ scattering layers, so detected electrons are scattered in each layer through average angle $\theta = (\text{collector half angle}) + (\text{number of scatterings})^{1/2} = 0.05^\circ - 0.02^\circ$. θ is the difference between the angle θ_s through which the electrons are scattered away from the projectile and the angle θ_c through which they are being pulled back by the electric field F of the projectile. The "Coulomb focussing" angle is $\theta_c = Fa/mv^2 = .1^\circ$ per layer, where a is an interparticle distance, v is the projectile velocity, and m is the electron mass. Assuming Rutherford differential scattering (with $\sigma \propto \theta^{-4}$ for small scattering angles) we get an enhancement of the MFP by $(\theta + \theta_c / \theta)^2$. Taking the usual Bohr estimate $F \approx 1$ for captured electrons, we obtain a factor in the range 9-36.

This heuristic model can be more rigorously described in terms of combined diffusion and drift: the electrons diffuse due to collisions in the foil while drifting in the field of the projectile. If the electrons have an initially prescribed distribution in position and momentum $\Psi(\underline{r}, \underline{p}, t)$, these processes are described by a transport equation

$$\frac{\partial \Psi}{\partial t} = \frac{1}{m} \underline{p} \times \frac{\partial \Psi}{\partial \underline{r}} + \frac{1}{m} \underline{F}(\underline{r}) \times \frac{\partial \Psi}{\partial \underline{p}} + D \frac{\partial^2 \Psi}{\partial \underline{p}_1^2} \quad (1)$$

where D is a phenomenological diffusion coefficient (proportional to some combination of electron plus target cross sections) and $\underline{p}_1^2$ is the momentum transverse to the beam.

The solution of Eq. (1) is a fairly large-scale numerical problem, but preliminary analytical studies suggest a picture in which a substantial fraction of electrons drift from the center of the momentum distributions into bound states of the projectile. On exit from the foil, they can be shaken off into very forward angles.

The measurements were made at the GSI UNILAC. Research of CB was sponsored by the U.S. Department of Energy, Office of Basic Energy Sciences under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc; research for RL, MB, HF, HJF, KOG, DH, and RK was supported by BMFT-Bonn and DFG-Bonn; and research for SB, MB and IAS was supported by the U.S. National Science Foundation, Physics Division and Division of International Programs.

†Permanent address: Gesellschaft für Schwerionenforschung, GmbH, Darmstadt, FRG

*Work supported in part by NSF, Physics Division and Division of International Programs, in part by the U.S. Department of Energy, Office of Basic Energy Sciences under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

¹H.-D. Betz et al., Phys. Rev. Lett. 50,34 (1983).

²Y. Yamazaki and N. Oda, Phys. Rev. Lett. 52,29 (1984).

³M. Breinig et al., Phys. Rev. A25,3015 (1982).