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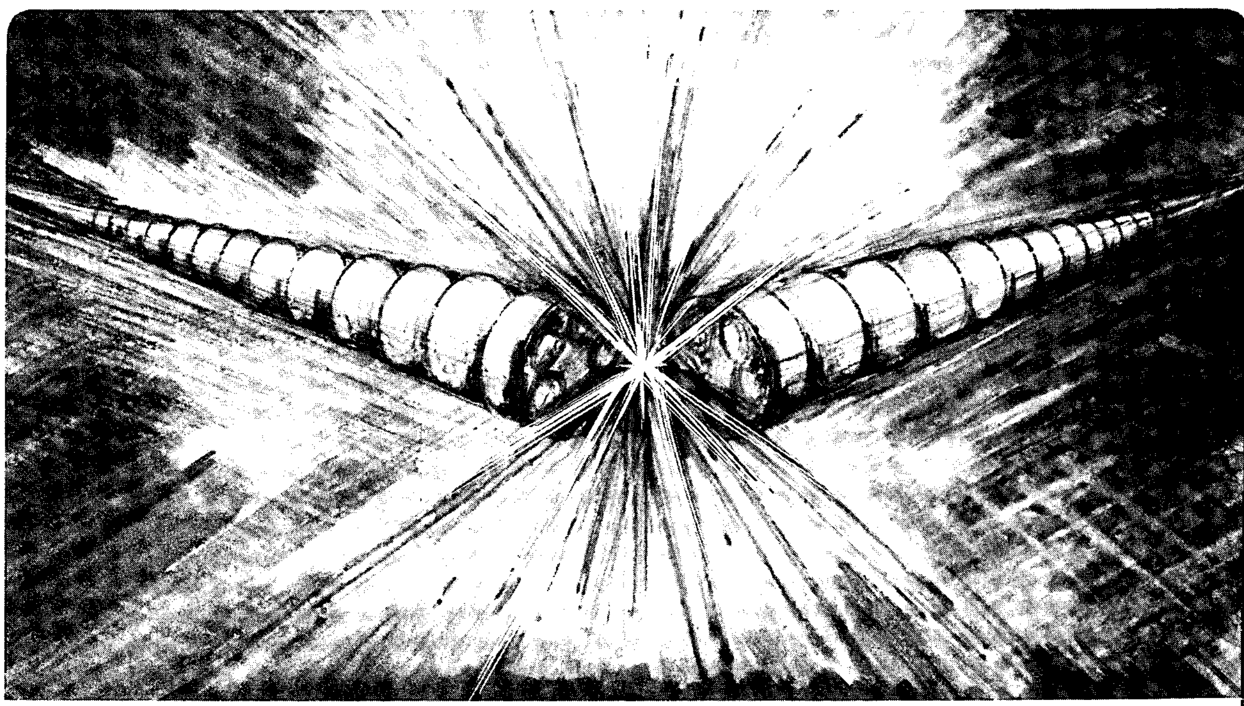

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MULTIPLE ELECTRON CAPTURE IN FAST ION-ATOM COLLISIONS*

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MULTIPLE ELECTRON CAPTURE IN FAST ION-ATOM COLLISIONS*

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Abstract

Many electrons can be captured by an energetic, highly charged ion in collision with a target atom, demonstrated for 47-MeV Ca^{17+} ions in Ar.

Introduction: Multiple-Electron Processes

Charge transfer, ionization, and excitation are fundamental processes in fast ion-atom collisions. Each of these processes can occur alone in a collision, or more than one process can take place in the same collision. When more than one electron is involved, electron correlation, due to an electron–electron interaction, can be important, as in resonant transfer and excitation (RTE) or in Auger-electron emission. When electron correlation is not important, the process can be described by an independent electron model, as is generally the case, for high-energy ion-atom collisions, in continuum-electron emission and recoil-ion production. A variety of these processes has been studied in experiments at the Lawrence Berkeley Laboratory, results of which have previously been reported [1].

Introduction: Multiple-Electron Capture

Many electrons can be lost by a projectile in a high-energy collision. The number of electrons lost to the continuum is limited only by the number of electrons originally belonging to the projectile. In principle, the number of electrons captured by a projectile in an energetic ion-atom collision is limited only by the number of vacant spaces available on the projectile (the projectile charge state) or by the number of electrons belonging initially to the target (the target atomic number). In fact, capturing electrons is, generally, more difficult than losing them, and capture of more than two electrons is rarely observed. Electron-capture cross sections generally decrease with increasing energy, and are thus small at high energies, while electron capture at lower energies often goes to excited states, resulting in multiple Auger decay, and few electrons remain attached to the projectile when viewed long after the collision.

Observation of capture of up to four or five electrons has been reported in the literature. The observations fall generally into several categories:

- slow collisions, in which potential energy plays more of a role than kinetic energy;
- intermediate-energy, nearly symmetric collisions;
- fast collisions with a nearly bare highly charged projectile.

An example of multiple-electron capture in slow collisions is found in the work of Salzborn and Müller and their collaborators [2], who found that cross sections for electron capture by low-energy highly charged rare-gas ions in rare-gas targets are large and nearly independent of energy; cross sections were measured for capture of up to four electrons in a single collision. An example is shown in Fig. 1, for xenon ions in krypton, with the projectile energies of the order of 1 keV/u. Examples of the second category, intermediate-energy, nearly symmetric collisions, are found in the work of Macdonald and his collaborators [3] for 0.3–3 MeV/u fluorine ions in nitrogen and argon targets, as shown in Fig. 2, and for oxygen ions in various gases. An example of multiple-electron capture in a fast collision is found in the work of Anholt and his collaborators [4] for 82 MeV/u Xe^{54+} ions in various solid targets (capture of up to three electrons observed) and for 105 MeV/u U^{90+} ions in various solid targets (capture of up to 5 electrons observed), shown in Fig. 3. However, in general, the cross section for capturing even two electrons in a single collision is small [5].

Total Electron Capture: 47-MeV Ca^{17+} in Ar

A collision system of particular interest is Ca^{17+} in an argon target. The calcium-ion projectile is lithium-like, with a filled K shell and 7 vacancies in the L shell; higher shells are entirely empty. The target argon atom is neutral, and thus has filled K, L, and M shells. For a projectile velocity corresponding to an energy of 47 MeV, or 1.2 MeV/u, the projectile has nearly the same velocity as that of electrons in the target L shell. It is thus plausible that a large number of electrons be transferred from the target to the projectile, especially from the target L shell to the projectile L shell, although transfer of electrons from or to other shells cannot be excluded. We have reported measurements of the total electron-capture cross section for this system [6], with the observation of capture of up to 8 electrons in a single collision, shown in Fig. 4. It would appear that, in some collisions, an appreciable number of electrons is transferred, and, if they come from the L shell of the target, some appreciable autoionization must occur to stabilize the target after the collision. It is also likely that many of these electrons are transferred to low-lying levels of the projectile, otherwise many would be lost by autoionization of the projectile following the collision. In summary, multiple electron capture is observed because the projectile has a nearly empty shell for electrons to be captured into, and the target has many electrons available, for a projectile having a velocity similar to that of electrons in one shell of the target. The same system has been studied as a function of projectile charge state; similar results have been obtained, which will be reported elsewhere [7].

Electron Capture in Close Collisions: 47-MeV Ca^{17+} in Argon

We have studied close collisions for this system [6] by measuring electron capture in coincidence with emission of a projectile or target K x ray; emission of a K x ray indicates a collision with an impact parameter less than the radius of the K shell. A collision within the K-shell radius ensures that the projectile and target L shells have maximum interpenetration. Again, the projectile has a nearly empty L shell and the projectile velocity approximately matches that of electrons in the target L shell. Results for close collisions of 47-MeV Ca^{17+} ions in an argon target are shown in Fig. 4. Results for coincidence with an argon K x ray have been shifted by one charge state to account for the difference in the production mechanism of the K vacancy [6], and cross sections for Ar and Ca K x-ray coincidence have been summed. It is seen that the cross section for capturing several electrons exceeds that for capturing only one electron in a single close collision; a fit to a binomial distribution indicates an electron-capture probability of the order of 0.5, under appropriate assumptions. The relative electron-capture probabilities are observed to agree with a binomial distribution [6], which is consistent with uncorrelated electron capture.

These results for close collisions are possibly related to previous observations of multiple-electron capture or loss in a single close collision, where close collisions have been selected by scattering of the projectile through a large angle [8]. This connection is being studied at present [7].

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References

[1] A. S. Schlachter, *Nuclear Instruments and Methods* B43, 265 (1989).
[2] E. Salzborn and A. Müller, Electronic and Atomic Collisions, edited by N. Oda and K. Takayanagi (North-Holland Publishing Co., Amsterdam 1980) p. 407.
[3] S. M. Ferguson, J.R. Macdonald, T. Chiao, L.D.Ellsworth, and S.A. Savoy, Phys. *Rev. A* 8, 2417 (1973); J.R. Macdonald, S.M. Ferguson, T. Chiao, L.D. Ellsworth, and S.A. Savoy, *Phys. Rev. A* 5, 1188 (1972).
[4] R. Anholt, W.E. Meyerhof, X.-Y. Xu, H. Gould, B. Feinberg, R.J. McDonald, H.E. Wegner, and P. Thieberger, *Phys. Rev. A* 36, 1586 (1987); W.E. Meyerhof, R. Anholt, J. Eichler, H. Gould, A. Munger, J. Alonso, P. Thieberger, and H.E. Wegner, *Phys. Rev. A* 32, 3291 (1985).
[5] J.A. Tanis, E.M. Bernstein, M.W. Clark, W.G. Graham, R.H. McFarland, T.J. Morgan, A. Müller, M.P. Stockli, K.H. Berkner, P. Gohil, A.S. Schlachter, J.W. Stearns, B.M. Johnson, K.W. Jones, M. Meron, and J. Nason, Proceedings of the Second U.S.–Mexico Symposium on Atomic and Molecular Physics: Two-Electron Phenomena, published in *Notas de Fisica* 10, 467 (1987).
[6] A.S. Schlachter, E.M. Bernstein, M.W. Clark, R.D. DuBois, W.G. Graham, R.H. McFarland, T.J. Morgan, D.W. Mueller, K.R. Stalder, J.W. Stearns, and J.A. Tanis, *J. Phys. B* 21, L291 (1988); A.S. Schlachter, J.W. Stearns, K.H. Berkner, E.M. Bernstein, M.W. Clark, R.D. DuBois, W.G. Graham, T.J. Morgan, D.W. Mueller, M.P. Stockli, J.A. Tanis and W.T. Woodland, *Nuclear Instruments and Methods* B40/41, 21 (1989); A.S. Schlachter, J.W. Stearns, K.H. Berkner, E.M. Bernstein, M.W. Clark, R.D. DuBois, W.G. Graham, T.J. Morgan, D.W. Mueller, M.P. Stockli, J.A. Tanis, and W.T. Woodland, in Proceedings of the 16th International Conference of Physics of Electronic and Atomic Collisions, edited by A. Dalagarno, R.S. Freuknd, P.M. Kock, M.S. Lubell, and T.B. Lucatorto (American Institute of Physics, New York, New York, 1989) pp. 366–371.
[7] A.S. Schlachter, J.W. Stearns, K.H. Berkner, E.M. Bernstein, M.W. Clark, R.D. DuBois, W.G. Graham, T.J. Morgan, D.W. Mueller, M.P. Stockli, J.A. Tanis, and W.T. Woodland, (article in preparation).
[8] B. Rosner and D. Gur, *Phys. Rev.* ,A15, 70 (1977); E.N. Fuls, P.R. Jones, F.P. Ziemba and E. Everhart, *Phys. Rev.*, 107, 704 (1957); E. Everhart and Q.C. Kessel, *Phys. Rev.* 146, 16 (1966); V.V. Afrosimov, Yu. S. Gordeev, M. Panov and N.V. Fedorenko, *Zh. Eksp. Teor. Fiz. Pisma Red.* 2, 291 (1965); Q.C. Kessel, *Phys. Rev.* A2, 1881 (1970).

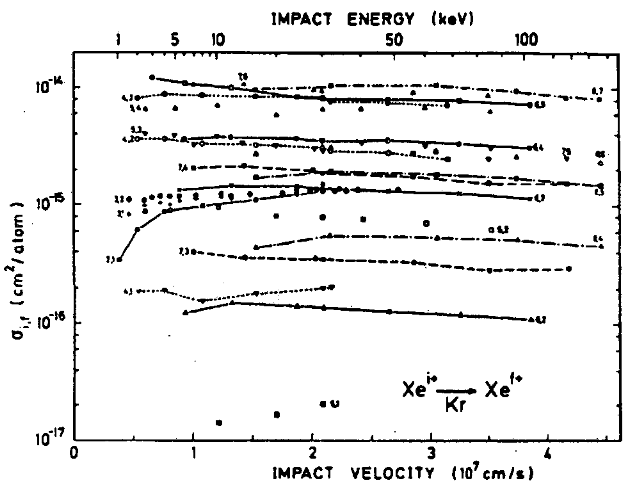

FIG. 1. Electron-capture cross sections $\sigma_{i,f}$ for Xe^{i+} ions incident on krypton, as a function of projectile velocity. From Ref. 2 by Salzborn and Müller.

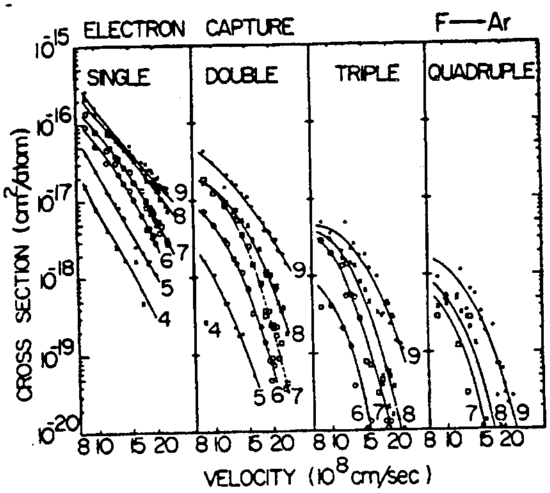

FIG. 2. Electron-capture cross sections for fluorine ions in argon. Curves are labeled with the charge state of the incident ion. From Ref. 3 by Ferguson et al.

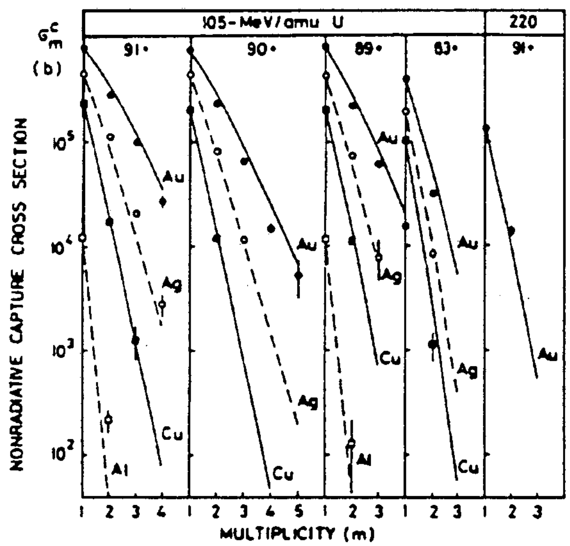

FIG. 3. Electron-capture cross sections for 105- and 220-MeV/U ions passing through Al, Cu, Ag, and Au target foils, as a function of the multiplicity (m) of the capture. From Ref. 4 by Anholt et al.

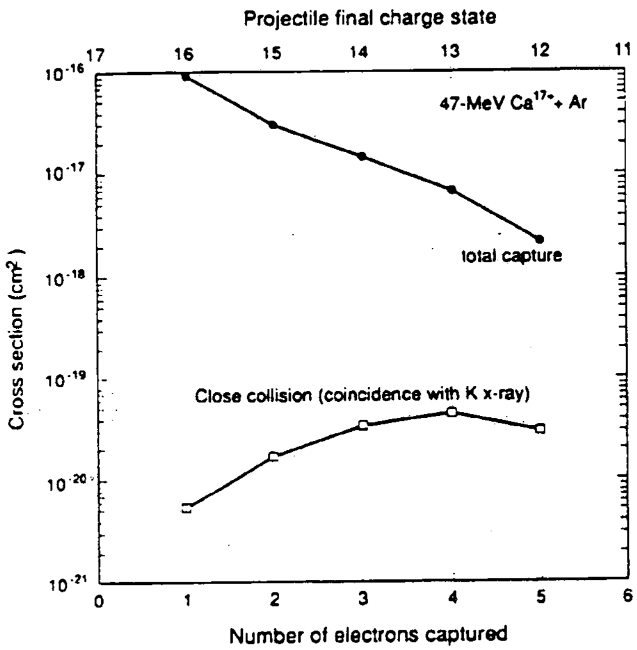

FIG. 4. Electron-capture cross sections for 47-MeV Ca^{17+} in Ar, as a function of the final charge state of the projectile and of the number of electrons captured. Lower curve shows electron capture for a close collision. Upper curve shows total electron capture. From Ref. 6.

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