INTERACTIONS OF ULTRARELATIVISTIC 33-TEV Pb IONS WITH MATTER-ELECTRON CAPTURE AND IONIZATION AND RESTRICTED ENERGY LOSS

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At ultrarelativistic energies cross sections for ionization of projectile electrons – even K-shell electrons in the heaviest atoms - far exceed cross sections for total electron capture. At energies above ~10 GeV/nucleon, equilibrium charge-state fractions are dominated by the fully-stripped species, and only bare- and one-electron ions are usually considered. For example, we have previously measured[1] at the CERN SPS both the capture and ionization cross sections for 160 GeV/nucleon Pb ions in a variety of thin solid targets from Be to Au, and found that ionization of Pb^{81+} (1s) is approximately a thousand times more probable than capture of an additional electron. Our measured Pb ionization cross sections disagreed with calculations by Anholt and Becker,[2] being ~30-35% lower than theory, independent of target. The only other ionization measurements for heavy ions anywhere near this energy regime were carried out by Claytor et al.[3] for 10.8-GeV/nucleon Au ions at the Brookhaven AGS. They observed good agreement with Anholt and Becker. The apparent discrepancy was partly explained this year by Sorensen,[4] who re-calculated Pb and Au ionization at the appropriate energies. He has accounted for the observed reduction in ionization cross sections at the higher energies as arising from saturation by near complete screening for the large impact parameters that become important only at extreme relativistic energies. Anholt and Becker had included, but underestimated this effect in their tabulations. The table shows a comparison of our Pb^{81+} (1s) ionization cross sections for solid targets, Z_T, with calculations of Anholt and Becker, as well as those of Sorensen.

	Pb^{81+} (1s) Ionization Cross Sections (kb)		
Z_T	Experiment	Anholt and Becker	Sorensen
4	0.14	0.24	0.14
6	0.31	0.49	0.28
13	1.3	2.0	1.1
29	6.9	9.0	5.2
50	15	25	15
79	42	60	35

At 160 GeV/nucleon, electron transfer to a Pb ion in collisions with Au proceeds primarily (>95%) through capture of an electron arising from electron-positron pair production in close Coulomb collisions (electron capture from pair production). Interpretation of the measurements is somewhat complicated for solid targets by partial radiative relaxation of Pb^{81+} excited states formed either directly in the capture process or in collisional excitation of the Pb^{81+} (1s) ions. In heavy-solid targets, secondary ionization of excited-state Pb^{81+} competes

effectively with radiative stabilization because the cross sections are large, and the rapid radiative lifetimes are substantially Lorentz extended. In October 1998, we measured total cross sections for ionization and capture by 160-GeV/nucleon Pb ions in gas targets of Ar, Kr, and Xe. Along with previous solid-target data, these gas measurements, where delays between collisions are sufficient to yield nearly complete radiative relaxation, allow separation of ground-state from excited-state contributions. We also measured the yields and momentum, distributions of electrons captured by Pb ions, and subsequently stripped in solid targets. For thick targets, where effectively all captured electrons are stripped from the Pb ions, the electron yields directly give the total capture cross sections. The observed electron momentum distributions are very sharply peaked in the forward direction and centered on the projectile velocity. The cusp-shaped peaks are unexpectedly narrow, significantly less than the expected Compton profile of Pb(1s) electrons in the laboratory frame. At present, there is no theoretical explanation. We also measured rather precisely the restricted energy loss for 160-GeV/nucleon Pb ions under channeling conditions in a solid-state detector made of a single crystal of silicon, and in two gas ionization chambers. These data are all currently being analyzed. Comparisons with our previous measurements[5] of total energy loss will further test the previously confirmed theoretical predictions of Lindhard and Sorensen,[6] which attribute an observed reduction in total energy loss to a reduction in cross section (and number) of very high energy (small impact parameter) delta electrons. These high-energy delta electrons are automatically excluded from the restricted energy loss measuring devices.

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2. R. Anholt and U. Becker, *Phys. Rev. A* **36**, 4628 (1987).
3. N. Claytor et al., *Phys. Rev. A* **55**, R842 (1997).
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5. S. Datz et al., *Phys. Rev. Lett.* **77**, 2925 (1996).
6. J. Lindhard and A. Sorensen, *Phys. Rev. A* **53**, 2443 (1996).