# Ion and Photon Interactions with Laser Cooled Targets

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**1) Capture cross sections, differential in scattering angle,** *B. D. DePaola, C. W. Fehrenbach, X. Flechard(CNRS, Caen, France), R. Bredy, H. Camp, and H. Nguyen.* The use of a laser cooled and trapped target in charge transfer studies has many advantages over conventional techniques such as COLTRIMS (COLd Target Recoil Momentum Spectroscopy). In new methodology, MOTRIMS (Magneto-Optical Trap Recoil Ion Momentum Spectroscopy) the target can be made colder than in the coldest COLTRIMS by several orders of magnitude. Thus, momentum spread in the target can be completely neglected; limitations in momentum resolution are now set by detector spatial resolution, limitations in flight time resolution, projectile beam energy spread, and deviations in recoil ion trajectories caused by stray magnetic fields. Thus, even for massive targets such as $^{87}$Rb, the resolution in momentum is factors of 3 to 10 better than the best COLTRIMS results in the kinematically favorable low mass He targets.

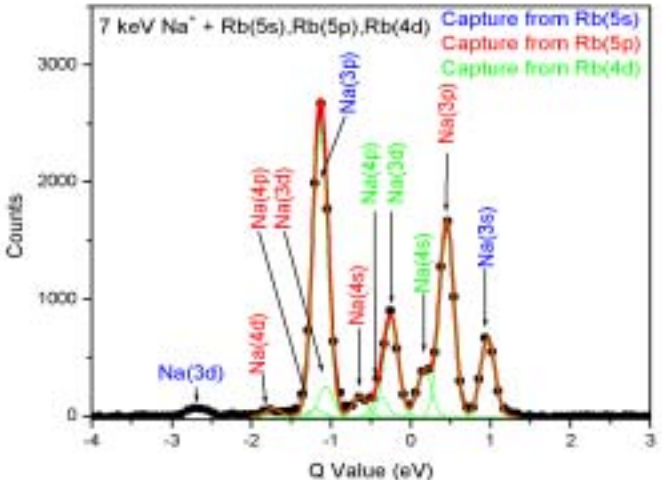


**Figure 1 Q-value spectrum for $Cs^+$ + Rb**

Perhaps more important than this modest improvement in resolution is that MOTRIMS allows the use of targets which can be laser-excited. (Generally speaking, pre-cooling and expanding in a supersonic jet results in molecule or cluster formation in atomic species having optically active electrons. Thus, COLTRIMS is not suitable for use with atomic species which can be readily laser-excited.) We have exploited both advantages of the MOTRIMS techniques to study charge transfer cross sections which are differential in initial state of the target, final state of the projectile, and projectile scattering angle. The target in all cases was $^{87}$Rb, trapped and cooled to roughly 130 K. In most experiments the Rb was in a mixture of the ground and first excited states (5s and 5p) due to the effects of the trapping lasers. However, in some cases, an additional laser at 1.5 μm was used to excite the transition from 5p to 4d. Projectiles studied thus far include $Cs^+$ and $Na^+$ at collision energies between 2 and 7 keV. Figure 1 shows a typical Q-value spectrum for 7 keV $Na^+$ incident on Rb in a mixture of 5s, 5p, and 4d states. Because the ion source currently in place on the MOTRIMS apparatus is of the thermionic type (chosen so as to have a very small spread in projectile velocity) the initial experiments

are limited to singly charged alkali and alkali earth projectiles. In the coming year, the alkali and alkali earth cross section measurements will be completed.

In order to measure relative cross sections for capture from Rb(5p) and Rb(5s), one must know the fraction of atoms in the excited state. The extremely high Q-value resolution – and with it the capability of separating even closely spaced collision channels – allows us to determine the ratio of these cross sections without relying on model-dependent fluorescence measurements. This is accomplished by chopping trapping and re-pump lasers and measuring changes in the areas of the peaks in the Q-value spectra corresponding to various capture channels. Because the atoms are cold, the time it takes for them to drift out of the ion beam is very long compared to the excited state lifetime. Thus the same atoms are examined with lasers on and off. The excited state fractions obtained in this manner have uncertainties of less than 7%, while conventional methods, which rely on fluorescence from a MOT, are closer to 200%. The technique can be generalized to n-level systems, and will therefore be instrumental in our measurements of charge transfer cross sections from Rydberg targets.
In addition to initiating the measurements of these cross sections, quite a bit of effort has been spent on enabling the fast chopping of the MOT's quadrupole B-field. Based on numerical simulations of ion trajectories in an idealized quadrupole B-field, it is believed that at least a threefold improvement in scattering angle resolution will be achieved once this upgrade is implemented. During the coming year, we will try to implement the B-field chopping electronics and use the expected enhancement in scattering angle resolution to look for structure in $d\sigma/d\Omega$, as predicted by theory for certain selected collision systems.

**2) Use of charge exchange as a diagnostic of population dynamics,** *B. D. DePaola, C. W. Fehrenbach, R. Bredy, X. Flechard(CNRS, Caen, France), H. Camp, and H. Nguyen.* We have explored the capabilities of the MOTRIMS apparatus for measuring excited state fractions in the MOT. An important test case was to measure cross section ratios (as described in the preceding section) while deliberately varying excited state fraction by adjusting the detuning of the trapping laser. While the excited state fraction was measured to vary by a factor of 2 (from 15% to 30%) the cross section ratios remained constant – as they should for fixed collision energy. A second important test was the measurement of the *time dependence* of the excited state fraction in the MOT as the re-pump laser was chopped on and off as shown in Figure 2.

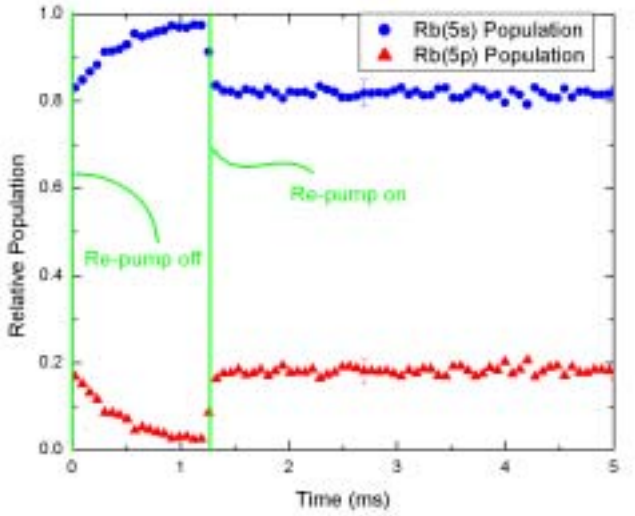


**Figure 2 Relative 5s and 5p populations in Rb MOT as a function of time. The trap laser is always on.**

The experiment confirmed what is already known: the excited state fraction falls to zero when the re-pump laser is blocked, since the trapping laser optically pumps the target atoms to the "dark", optically inaccessible lower hyperfine level. The success of these experiments opens the door to studies of population dynamics in the MOT caused by a variety of processes, including stimulated Raman adiabatic passage (STIRAP), dimer formation due to 3-body collisions, and photo-association. With the MOTRIMS apparatus, excited state dynamics can be studied with a temporal resolution of a few nanoseconds, over a time span of up to a few milliseconds. Unlike the use of an optical probe, the ion beam interacts so weakly with the target that the measurements may be viewed as non-perturbative.

**3) Ion spatial imaging to measure above threshold ionization rates,** *B. D. DePaola, Z. Chang, C. W. Fehrenbach, R. Bredy, X. Flechard(CNRS, Caen, France), H. Camp, and H. Nguyen.* A long-time problem in the measurement of ionization rates in interaction of intense laser pulses with atomic and molecular gasses and vapors, is in the accurate determination of the laser intensity which caused the ionization. The difficulty is that intensity variation in a focused laser beam can vary over more than an order of magnitude. Thus, ions extracted from the interaction region were produced by a field whose value has large uncertainty. A possible solution to this problem has been explored by using ion optics to image the laser interaction region onto a 2D-PSD (Figure 3).

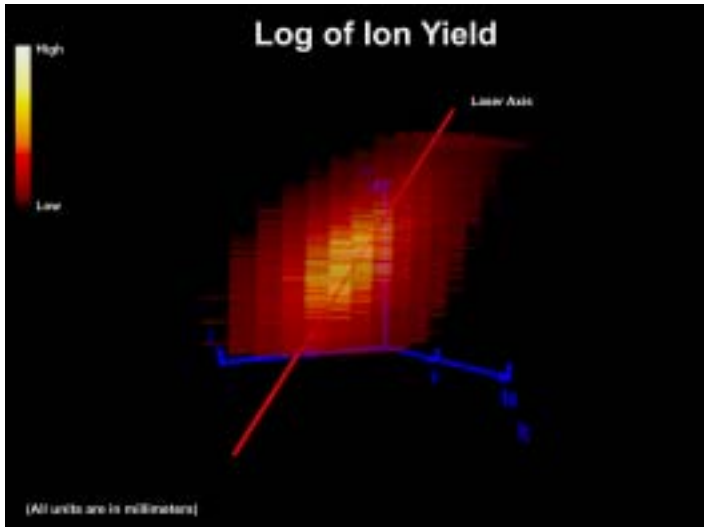


**Figure 3 Photo-ion yield from a Rb target as a function of position. The log of the yield is represented in false color. The red line indicates the path of the ionizing laser.**

The apparatus consisted of the MOTRIMS momentum spectrometer, to which potentials were applied which were appropriate to spatial, rather than momentum, imaging. With two dimensions provided by the PSD, and the third dimension provided by the ion the time-of-flight, a 3-D image of the ionization region was built up, event by event. The spatial variation of the laser beam intensity was separately measured with a scanning CCD camera. Thus, with knowledge of the target thickness, one could deduce, through a single image of thousands of events, the absolute ionization rate as a function of laser intensity, for a range of intensities. In principle, one could

introduce any number of atomic or molecular gasses or vapors into the chamber for ionization studies. In this test case, ionization of Rb atoms in vapor supplied by the "getter" source used in MOT experiments was studied. The target thickness was directly measured from absorption studies which made use of one of the diode lasers normally tuned for trapping. Laser pulses of approximately 25 fs were used to ionize the Rb. The various parts of the technique (ion imaging, target thickness measurement, and laser profiling) were each found to work beautifully. In the future, all three components will be combined in a single measurement of absolute ionization rates for Rb in the ground state. We also plan to use our trapping lasers to optically pump the Rb into a particular orientation; ionization rates will then be measured as a function of the angle between the orientation axis of the atoms and the polarization axis of the ionizing laser.

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