V. Conclusions

The cross sections for single and double electron capture have been measured for several different collision systems, with projectile energies ranging from a few eV to a few hundred eV. These very low energy measurements were made possible by using the **CRYEBIS** combined with the **OPIG**. The projectile ions generated from the **CRYEBIS** offered a large range of different ion species and charge states, allowing for a broad survey of different types of collision systems. The **OPIG** made it possible to slow the ions down, and simultaneously confine the ions in the direction transverse to the original ion beam axis, which facilitated performing very low energy collisions.

In general, both the single and double electron capture cross sections measured in this series of experiments were nearly constant in the range of energies studied. At energies less than 5 qV/amu, the cross section behavior for some systems did increase slightly with decreasing energy. In a few cases, the double capture cross sections slightly decreased at energies less than 5 qV/amu. The Langevin model predicts that the cross section at very low energies should increase in a proportion that is inversely related to the velocity of the projectile ion, and this can be used as an argument to explain why the cross sections increase at energies less than 5 qV/amu. However, it should also be pointed out that the energy spread of the ions produced from the **CRYEBIS** is approximately 4-5 qV/amu as well. This spread in energy, may influence the cross section trends at energies less than 5 qV/amu and, at the very best, makes the definition for exactly what the energy of the collision is, more difficult to determine. The data presented in this work are near the low energy limit of what can be done experimentally. A multiply charged ion source with a lower energy spread and new techniques in ion

deceleration are necessary to push the low-energy limit. Lower energy measurements with better ion beam energy resolution may bring new insight to effects of the dipole and quadrupole moments of the potential of the target as discussed in chapter 3.

There are a few different theories of varying sophistication that have been considered for comparing to the experimental results. Due to the rather dull tendency for the cross sections which change very little over the range of collision energies studied, it was found that more sophisticated models were not necessary in predicting the cross section behavior, and in many cases, did not compare as well as more simple models such as the Müller and Salzborn scaling law and the classical over-barrier model. An extended version of the classical over-barrier model was used for a theoretical comparison to the data. Even though the over-barrier model is a somewhat rudimentary model, it has been quite successful at predicting cross sections at higher energies in the past, and holds up well even at energies as low as the ones studied in these experiments. Due to the fact that the cross sections change so little over the entire energy range studied, it can be concluded that the capture process is occurring through an over-barrier type of transition which is independent of the collision energy. The classical over-barrier model was fairly successful at predicting the single electron capture cross section, but was often over-estimating or under-estimating results by as much as a factor of 3. The over-barrier model was quite useful as an interpretive tool in so far as it can be used to understand that the charge transfer process is an over-barrier type and does not depend on the collision energy.

The double electron capture cross sections were typically an order of magnitude less than the single electron capture cross sections. Like the single electron capture cross

sections, they also exhibited very little change as a function of collision energy. While it is possible to calculate the double capture cross sections from theory, such as with the classical over-barrier model, it is difficult to use the calculated cross sections for comparison with the measured double capture cross sections. The main difficulty that arises when trying to compare theoretical double capture cross sections with the measured double capture cross sections from this work is that there is no clear way to include transfer ionization into the model. In the experiment, it is the net single and net double electron capture cross sections that are measured. As stated previously, in the experiment, any double capture followed by electron emission through the Auger process is measured as a single capture event, so the measured (net) double electron capture cross section will be smaller than what is predicted by theory, even if the theory did match exactly with the double electron capture cross section before transfer ionization is considered. This also changes the measured total single capture cross section, but since the single capture cross sections are generally an order of magnitude larger than the double capture cross sections, it is likely that the "true" single cross sections differ from the net single capture cross sections by a fairly small fractional amount.

The cross sections for nearly every system measured exhibited no dependence on the collision energy; the $N^{(7-9)}$ on H_2 systems gave cross sections that changed with collision energy below 5 eV/amu. The double capture cross sections varied much more than the single capture cross sections. These results could be erroneous and possibly due to the fact that the energy spread of the ion beam influenced the results which somehow gave a changing cross section value. However, this explanation is unlikely because this effect was not observed for the other systems studied. Furthermore, each of these

systems was repeated a few weeks apart and all of the ion beam optics were redone with no appreciable change in the results. It's also possible that the center of the cut-off curve was not accurately determined. This is a more likely scenario, since the "hump" (which was used as a marker to indicate where the zero energy is defined from) was less pronounced for these measurements than for most of the other measurements. However, it's not likely that the center of the cut-off, or zero energy point, was more than 1-2 volts off from the true center. In any case, the results from these systems are provocative and further investigation would be useful to shed light onto the situation.