Additivity of Cross Sections for Electron Loss from 6 A MeV Xe^{18+} in Molecular Targets

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It is often assumed that the cross section for a collision process involving the interaction of a fast ion with a molecular target can be approximated by adding up the individual cross sections for the constituent atoms of the molecule. This so-called additivity rule is generally hard to justify on theoretical grounds, but in the absence of experimental cross sections for molecular targets, it is usually the only alternative available. In the case of cross sections for electron capture and loss by hydrogen projectiles, additivity has been found to work quite well over a wide range of velocity [1, 2]. On the other hand, Wittkower and Betz [3] measured electron capture and loss cross sections for 12 MeV I^{5+} ions in a variety of molecular targets and found that the additivity rule over-predicted some of the cross sections by more than a factor of two. Therefore, these authors concluded that a collision between a heavy ion and a complex molecular target cannot be treated as a sequence of successive collisions with the individual atoms of the molecule. Nevertheless, it is interesting to note that an additivity rule (i.e., the Bragg rule) provides a reasonably accurate account of stopping powers for heavy ions traveling in solid materials composed of chemical compounds [4].

In conjunction with our investigation of the target Z-dependence of multiple electron loss cross sections, described in the preceding report, we have performed similar measurements for 6 A MeV Xe^{18+} ions in a variety of molecular gases for the purpose of investigating the question of cross section additivity with higher energy and more highly charged heavy ions than have been employed previously. The total electron loss cross sections per atom obtained in these measurements are shown

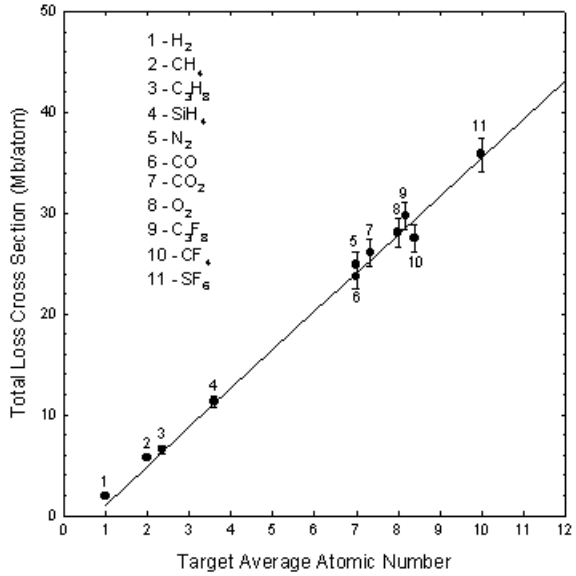

Figure 1: Total electron loss cross section (per atom) for 6 A MeV Xe^{18+} ions in various molecular targets as a function of the target average atomic number. The solid line shows the cross sections for atomic targets predicted by the noble gas results described in the preceding report.

in Fig. 1, plotted as a function of the target average atomic number. The per atom cross section is the cross section per molecule divided by the number of atoms per molecule, and the target average atomic number is defined as $\bar{Z} = \sum_i f_i Z_i$ where f_i is the fraction of atoms in the molecule that have atomic number Z_i. The solid line in Fig. 1 is the same line defined by the total electron loss cross sections for the monatomic targets He and Ne in Fig. 1 of the preceding report. It is evident that the per atom total electron loss cross sections for the molecular targets (a) increase linearly with target average atomic number, and (b) closely correspond to the predicted cross sections for atomic targets having $Z = \bar{Z}$. This latter observation means that the following additivity rule applies to the molecular data:

$$\sigma_{mol} = N\sigma(\bar{Z}), \qquad (1)$$

where σ_{mol} is the cross section per molecule, N is the number of atoms per molecule, and $\sigma(\bar{Z})$ is the cross section for an *atom* having an atomic number equal to the average atomic number of the molecule.

The usual form of the additivity rule is:

$$\sigma_{mol} = \sum_i n_i \sigma(Z_i), \qquad (2)$$

where n_i is the number of atoms in the molecule with atomic number Z_i. The validity of this rule was tested by using the linear relationship between the total loss cross section and the target atomic number, as defined by the noble gas data, to calculate the $\sigma(Z_i)$. The results are shown in Fig. 2, where the ratio of the measured cross section and the cross section calculated using equation 2 is plotted versus the total number of electrons per molecule.

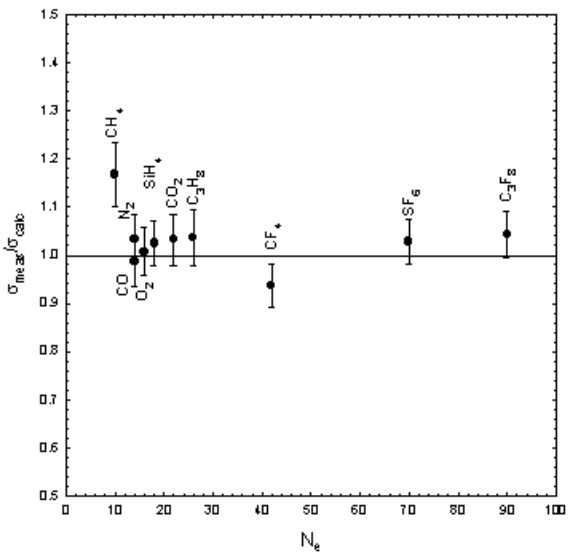

Figure 2: Ratio of the measured cross section and the cross section calculated using the additivity rule expressed by equation 2, plotted as a function of the total number of electrons per molecule.

Except for the H_2 (not shown) and CH_4 targets, the additivity rule yields total electron loss cross sections that agree with experiment to within 6% or less.

In Fig. 3, the multiplicity dependence of the electron loss cross section is compared for targets having nearly the same average atomic numbers. This figure shows that even the electron loss cross sections for specific Δq are remarkably similar for targets within the same $\bar{Z}$ group. However, judging from the comparisons shown in

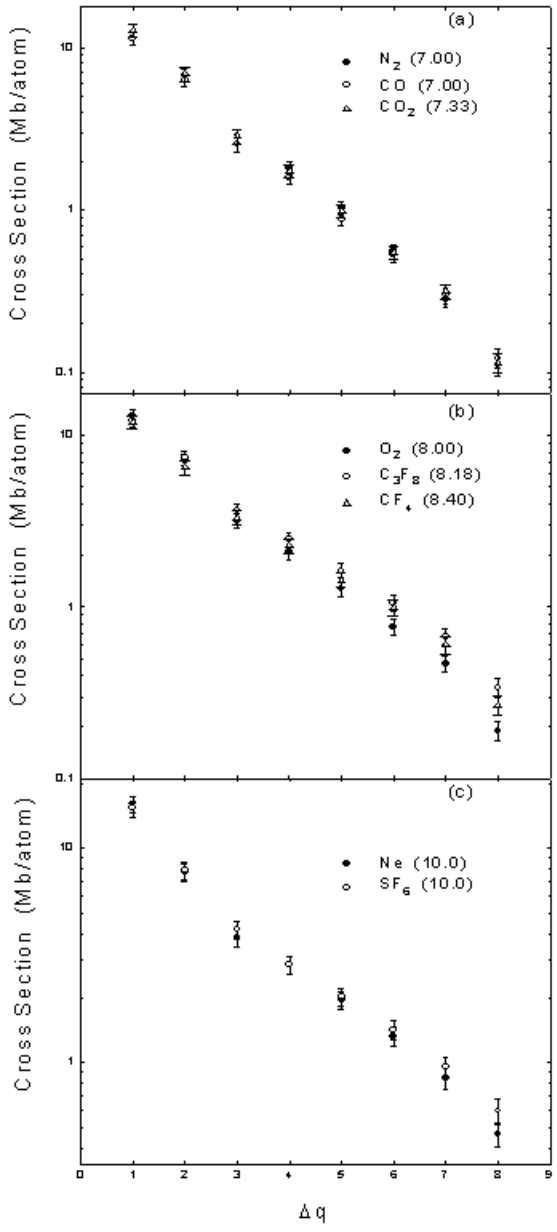

Figure 3: Comparison of cross sections for the loss of Δq electrons in targets having nearly the same average atomic numbers. The numbers in parentheses are target average atomic numbers.

Fig. 3(b) and (c), it appears that the larger molecules have slightly enhanced cross sections for high multiplicity collisions.

We conclude that cross-section additivity works extremely well for electron loss from heavy ions in the present energy and charge regime. This implies that the target molecules act as assemblies of individual atoms and that alterations of electron densities and ionization energies due to molecular bonding have a negligible influence on the electron loss cross sections.

References

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