# Cluster-Cluster Collisions and Cluster-Complex Formation of Helium Clusters with Size-Selected Metal Cluster Ions

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**Synopsis** We have built up a merged-beam apparatus of size-selected metal cluster ions and $He_N$ in a pulsed mode. By use of this apparatus, we demonstrate the production of the cluster complexes in the collision of cobalt cluster ions. The production efficiency of the cluster complexes is measured as a function of the relative velocity of the collision, and the incorporation process is explained on the basis of the electrostatic interaction and the hard-sphere interaction.

Chemical reactions on inorganic clusters have been widely studied since it is expected that the clusters are promising catalysts. To understand and adjust the reactivity of the clusters, it is indispensable to elucidate the structures of the adsorbed molecules, the relevant electronic structures of the clusters, and so on. Infrared photodissociation spectroscopy of messenger-tagged clusters is a useful technique to examine their structures. Though Ar is usually used as a messenger, naturally He is more reliable because He has less influence on the clusters, and gives a fine spectrum.

He nanodroplet isolation spectroscopy is one of the ultimate methods, and this was applied to cluster-adsorbate systems like HCN-$Mg_n$, which were produced in He clusters by using pickup cells. Recently we have developed a merged-beam apparatus to inject a mass-selected cluster ion into a He cluster for the spectroscopy [1]. This cooling technique is applicable to the wide-range of the cluster ions.

Further, we found that this process includes interesting dynamics, that is, collision, deceleration and capture of a cluster ion in a He cluster. The dissociation of the He cluster and the evaporation of He atoms from the cluster-cluster complex also occur.

Figure 1 shows a typical mass spectrum of $Co_5^+He_n$ obtained in the collision of $Co_5^+$ with $He_N$ at the relative velocity of ~$10^3$ m/s. The intensities of $Co_5^+He_n$ gradually decrease with the increase of $n$. We found that this distribution was roughly represented by a log-normal function. Considering that the size distribution of $He_N$ follows a log-normal function, this agreement may indicate that the sequential release (evaporation) of He atoms occurs after the incorporation of $Co_5^+$ into $He_N$.

Total yield of the cluster complexes were measured in the collision between $Co_2^+$ and $He_N$ as a function of the relative velocity, $v_{rel}$. The total yield increases rapidly with the decrease of $v_{rel}$ in $v_{rel} < 300$ m/s. This suggests that the attractive interaction between $Co_2^+$ and $He_N$ plays an important role in this velocity region. The charge-induced dipole interaction, that is, the attractive interaction between the charge of $Co_2^+$ and the dipole of He atoms in $He_N$ induced by $Co_2^+$, dominates the long-range interaction in the production of the cluster complex, $Co_2^+He_n$. In $v_{rel} > 300$ m/s, the total yield of $Co_2^+He_n$ once levels off. This indicates that a hard-sphere collision occurs. In the higher relative velocity region ($v_{rel} > 1000$ m/s), the complex intensity decreases again. Probably this is because only $Co_2^+$ that collides with $He_N$ at a sufficiently small impact parameter can stop at the inside of the helium cluster. At a grazing collision, $Co_2^+$ can break through $He_N$.

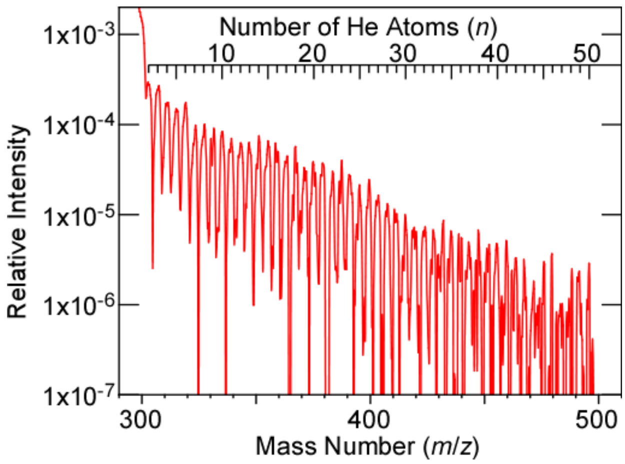


**Figure 1.** Mass spectrum of $Co_5^+He_n$.

## References

[1] H. Odaka *et al.* 2017 *Eur. Phys. J. D, submitted.*

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