Fragmentation of C_{60} in close collision with fast carbon ions

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We have measured the mass distribution of fragment ions after the collision of C_{60} with fast carbon ions in different charge states. Close collisions were selectively measured using the coincidence method with the change of the projectile charge state. For the electron capture and loss by $C^{5+,6+}$ projectile ions, the multifragmentation was observed evidently. In L-electron loss channels of C^{2+}, we can see the peaks of the multiply ionized C_{60} ions and the multiply ionized fullerene-like fragment ions. We suppose that we can roughly classify the intermediate states of C_{60} through the fragmentation measurement in coincidence with the change of charge state for various projectiles.

Introduction

The interest is increasing recently in the fragmentation of C_{60} induced by collisions with atoms, molecules, ions, electrons, photons and C_{60} ions. The fragmentation processes leading to such even-numbered cluster loss were discussed well there. However, detailed studies of prompt multiple fragmentation have not been done enough.[1-4] Fragmentation pattern is thought to relate to the intermediate states before fragmentation. It should be important to find a tool of classification of intermediate states for detailed studies of fragmentation process. In fast ion impact experiment, a projectile energy loss is a direct information for internal energies of intermediate states. However, measurements of projectile energy loss less than a few keV are not realistic in MeV/u energy region. In this energy region, large energy transfer to C_{60} mainly results from strong Coulomb interaction between the projectile ion and electrons of C_{60} at small impact parameters. The collisions accompanying large energy transfer can be selected using coincidence measurements with the changes of the projectile charge states because the charge state change occurs predominantly when the projectile trajectories overlap with C_{60}. The fragment ion distributions in close collisions were measured in coincidence with the outgoing projectile charge state as well as total fragment ion distributions.

Experimental method

We measured the mass-to-charge ratio(m/q) of the fragment ions using a time-of-flight (TOF) method. A 15.6 MeV carbon ion beam from the heavy-ion linac at RIKEN (RILAC) passed through a C_{60} vapor target produced by an oven. We used a chopped beam to measure the total fragment ion distributions. In coincidence measurements with charge change of the projectiles, we used a continuous beam without beam modulation. The TOF spectrometer was located at 90° with respect to the beam axis. The C_{60} ions and the fragment ions produced in the collision region were extracted by an electric field. A couple of multi-channel plates (MCP) were used as the fragment ion detector. The final charge state of the projectile ion was analyzed by a dipole magnet located downstream of the collision chamber. The projectile ions with a selected charge state hit a 2-dimensional position sensitive parallel plate avalanche counter (PPAC). A multi-hit (8 hit) time-to-digital converter (multi-hit TDC) was used for mesurement of flight time. We have to note that, if plural fragment ions with the same mass-to-charge ratio are produced, our detection system cannot detect all the fragment ions because of electronics dead time.

Results and discussion

The TOF spectra of total fragment ion distribution are shown in Fig. 1. Peaks observed in these TOF spectra are catego-

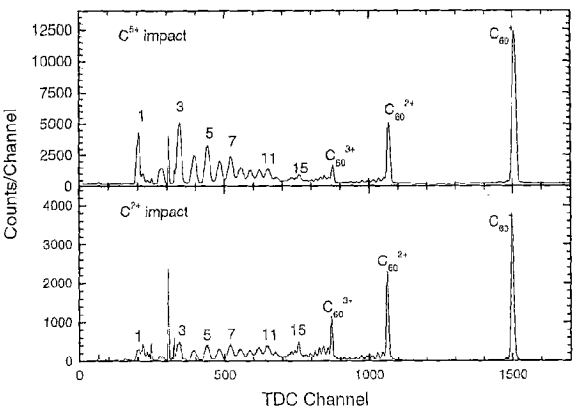

Fig. 1. TOF spectra for total fragment ion distribution in the collisions with $C^{2+,5+}$ at 15.6 MeV. The number above each peak shows the number of atoms in the fragment ion. The peak of $n = 15$ includes the peak of C_{60}^{4+}. We can also see the small peak for C_{60-2n}^{4+}.

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rized as follows: (1) Peaks due to singly, doubly, and triply (probably quadruply) charged C_{60} ions. (2) Peaks corresponding to C^{q+}_{60-2m}. The relative intensities of these peaks to the peaks of C^{q+}_{60} become higher with the charge q. (3) Peaks corresponding to singly charged small fragment ions C^{+}_{n} ($n = 1$ to 15). The peak intensities of the odd-numbered fragments are higher than the neighboring even-numbered fragments up to $n = 7$. These features of the total fragment ion distributions are qualitatively similar to the study using fast highly charged Xe impact by LeBrun et al.[2)]

Figure 2(a) shows the TOF spectra in coincidence with electron capture by projectile K-shell electron loss (C^{5+} to C^{6+}). Fullerene-like fragment ions are completely absent here. A similar TOF spectrum was observed for the electron capture by C^{5+} and C^{6+} projectiles. It is ruled out to argue that the residual C_{60} systems always dissociate to a neutral heavy fragment and small fragment ions in the overlap collision because the heavy fragment, which has a lower ionization potential than the small fragments, tends to carries more positive charges than the small fragments and because large clusters are generally more stable for Coulomb dissociation than small clusters. Therefore, we can conclude that multifragmentation is the dominant process.

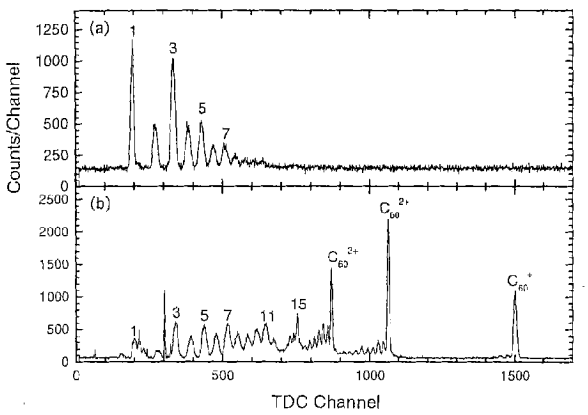

Fig. 2. (a) TOF spectra in coincidence with the projectile K-shell electron loss (C^{5+} to C^{6+}). (b) TOF spectra for the L-electron loss cases of C^{2+} projectile. The meaning of the number above each peak is the same as Fig. 1

In our impact velocity range, about 7.2 a.u., there is a large possibility of producing 1s-vacancy inside C_{60} in K-shell electron loss process and electron capture process by projectiles with a K-shell vacancy. Does the 1s-vacancy play an important role in the multifragmentation? Aksela et al. reported that the dominant fragment process was a neutral C_2 or C_4 emission following the photoexcitation and photoionization of the 1s-electron.[5)] We suppose that the 1s-vacancy production is not directly connected to the multifragmentation. In such close collisions, the recoil energy of a target carbon nucleus of close to the projectile trajectory should also be considered. According to a perturbation calculation, the probability of such process has a maximum around nearest inter nuclear distance of 0.2 a.u. (K-shell radius of carbon atom) and the recoil energy is about 2 eV. As estimated in Ref. 4, the internal energy of more than 210 eV is necessary for multifragmentation of neutral C_{60} system. Therefore, we think that only the recoil energy can little cause the multifragmentation.

Figure 2(b) shows the TOF spectra for the L-electron loss cases of C^{2+} projectile. The peaks corresponding to multiply ionized C_{60} ions and multiply ionized fullerene-like fragment ions become more intense here than in the total fragment distribution by C^{2+} impact, although the corrected intensity of C^{+}_{60} by the detection efficiency for singly charged fullerene-like ions is still larger than the intensities of multiply charged C^{q+}_{60}. Using the L-electron loss of C^{2+}, we can observe the fragmentation via the intermediate states whose internal energy is lower than in close collision with $C^{5+,6+}$ but higher than in the distant collision of C^{2+}

Summary

In summary, we performed selective measurements for close collisions using the coincidence method with the change of projectile charge states, as well as total fragment ion distribution measurements. For the charge change channel of $C^{5+,6+}$ projectile ions, the multifragmentation was observed evidently. In L-electron loss of C^{2+} projectile, the peaks of the multiply ionized C_{60} ions and the multiply ionized fullerene-like fragment ions are more intense than or as intense as the small fragment ions. In collisions with various fast projectile ions, using the coincidence method with charge transfer channel, it will be possible to perform selective study of relaxation processes from such various intermediate states.

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