Coincidence studies of collisionally induced fission of C$_{60}^+$

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Abstract. A direct measurement of collisionally induced fission of C$_{60}^+$ has been performed. We have measured coincidences between various charged fragments resulting from collisions between C$_{60}^+$ and He atoms. The measurements show that C$_{60}^+$ not only emits C$_3$ units but also breaks up into larger, singly charged parts. In this paper, we report on coincidences between C$_n^+$ (2 ≤ n ≤ 9) and C$_m^+$ (42 ≤ m ≤ 48) fragment ions.

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Introduction

Since 1990, when it became possible to make macroscopic amounts of C$_{60}$ [1] research concerning C$_{60}$ has been very intense. However, the fragmentation process is still far from being understood. Several papers on the fragmentation of C$_{60}$ have been published. Multiphoton fragmentation has been reported by O'Brien et al. [2], collisionally induced fragmentation of keV C$_{60}$ ion beams with different gases by Hvelplund et al. [3], and low-energy collisions by Young et al. [4], Doyle and Ross [5] and Wan et al. [6]. These experiments show that the loss of an even number of carbon atoms is a very important destruction channel. More detailed information about the actual fragment distribution resulting from the break-up of a C$_{60}$ ion is still lacking. This was the motivation for making coincidence studies between fragments from collisions between C$_{60}^+$ and He. Gaber et al. have published a paper [7] which indicates that fission could be induced by laser light, but no direct measurement was made. A coincidence experiment can directly confirm that fission is a possible fragmentation channel. Here we consider coincidences between C$_n^+$ (2 ≤ n ≤ 9) and C$_m^+$ (42 ≤ m ≤ 48) when C$_{60}^+$ collides with a He atom.

Experimental setup

The studies are conducted with a 120 keV C$_{60}^+$ beam. The beam was produced in a standard plasma-ion source [8] by heating a C$_{60}$/C$_{70}$ mixture [9] to ~300°C in an insertion oven and subsequent bombardment of the cluster vapor with ~50 eV electrons. Afterwards the ions were electrostatically extracted and accelerated to 120 keV. The beam was then momentum-selected by a magnetic analyzer. By this arrangement, we were able to obtain a pure, monoenergetic C$_{60}^+$ beam. After leaving the magnet, the beam was passed through a 3 cm long gas cell. Then the beam entered an electrostatic analyzer which bent the fragments in a given direction, depending on their mass-to-charge ratio. Finally, the fragments were detected by two ceratrons 280 cm downstream from the gas cell. A schematic of the experimental setup is shown in Fig. 1. Data acquisition was performed by measuring the time between the arrival of different fragments to the two ceratrons by a Time-to-Amplitude converter (TAC). During a run, one of the detectors was kept at a constant position, while the other was moved across the fragment distribution. The signals were taken care of by standard NIM electronics and computer analysis.

Results

Helium was chosen as collision gas because earlier fragmentation studies of C$_{60}^+$ on He have shown that the cross section for electron capture in this gas is very low compared to other gases, see Fig. 2. The electron-capture cross sections are discussed in [10]. However, singly

Fig. 1. Experimental setup
charged ions around mass 44 (units of carbon) were still produced, so it was tempting to assume that they were produced by collisionally induced fission into two singly charged fragments.

In Fig. 3 is shown a typical spectrum of the time difference between arrival of two fragments (C$_2^+$ and $\sim$C$_{44}^+$) to the two ceratrons. The time scale on the axis should be noted. Normally, one would expect the time scale to be on a much smaller scale because the two fragments would have the same velocity due to conservation of momentum. But in this case, both of the fragments are singly charged, and they will repel each other in a Coulomb explosion after the break-up and thereby change their relative velocity. We have made numerical simulations of the shape of the TAC peak to find the energy release distribution. If $g(t)$ is the time-distribution function of the TAC peak and $h(t, e)$ is the distribution function of a fragmentation process with energy release $e$, then the distribution function of the release energies $f(e)$ must fulfil

$$\int_0^\infty f(e) h(t, e) \, de = g(t) \tag{1}$$

the function $h(t, e)$ is easily calculated by demanding momentum and energy conservation in the collision process. If one assumes that the fragments are isotropically emitted in the center-of-mass system, then the energy distribution $f(e)$ of the release energies will take the form as shown in Fig. 4. The shape of the TAC peak depends on the masses of the two fragments at the time of the repulsion. As an example, we considered the TAC peak, which has been obtained during a scan containing only C$_2^+$ in one of the detectors and fragments with a mass around that of C$_{44}^+$ in the other detector. The mean-energy release is around 1.5 eV. This energy is the same as the potential energy of two unit charges separated by 9.5 Å. The cage diameter of C$_{60}$ is 7.1 Å. This indicates that the two holes in the electron cloud are separated as much as possible within the cage structure. However, it is possible that part of the C$_2^+$ ions are produced as a C$_n^+$ ($n > 3$) in the fission process. The C$_n^+$ ($n > 3$) ions may then afterwards, but before the analyzer, emit neutral units and thereby generate C$_2^+$ ions. If this process is likely to occur, we have to change the parameters used in the calculations of the energy distribution.

Fig. 2. M/q (mass divided by charge) fragment distribution spectra resulting from interaction of 120 keV C$_{60}^+$ with He a, H$_2$ b, and Xe c.

Fig. 3. TAC peak. The time-of-flight distribution difference for C$_2^+$ in one of the detectors and fragments with a mass around that of C$_{44}^+$ in the other detector.