Experimental determination of the internuclear separation of HD^+ ion micro-cluster

SHI Miangon, TANG Ayou, ZHU Zhousen, YANG Beifang, MIAO Jingwei

(Institute of Nuclear Science and Technology, Sichuan University, Chengdu 610064, China)

Abstract Measurements of zero-degree breakup fragment energy distribution from the Coulomb-Explosions of 1.50965 MeV HD^+ ion micro-cluster beam are reported. Mean value of the internuclear separation of HD^+ is found to be 0.125 ± 0.003 nm. A set of high-resolution experimental arrangement and improvement of the Van-de-Graaff accelerator are described briefly.

Keywords HD^+, Internuclear separation, Micro-cluster

1 Introduction

High-resolution measurement on the fragments resulting from "Coulomb-Explosion" of fast (MeV) ion micro-clusters with solids have yielded a wealth of interesting information on such topics as the wake field of the moving ion, breakup and reconstitution of ion micro-cluster, cluster energy loss, electron loss and capture, charge exchange and stereochemical structure.[1~3] Traditional experiment techniques for determing the stereochemical structure of neutral molecules are extremely difficult to apply to ion micro-clusters because of the problems in obtaining a sufficient spatial density of the ion micro-clusters to be studied.

For ion micro-cluster, it is worth while mentioning that the "Coulomb-Explosion" technique provided the direct experimental verification for long predicated triangular structure of H_3^+ for the first time[4]. During the last several years, our group perfomed many investigation in collision dissociation of energetic ion micro-clusters with solid and measured the stereochemical structure of H_2^+, D_2^+,H_3^+ and D_3^+.[5~6] We report here on a study of internuclear separation of HD^+. To our knowledge, the experiment reported here represents the first experimental determination of the geometry.

2 Experimental arrangement

The experiment was carried out on the multipurpose and high-resolution atomic collision arrangement at Institute of Nuclear Science and Technology, Sichuan University.[1] Fig.1 shows the experimental arrangement. A beam of HD^+ ions from 2.5 MeV Van-de-Graaff accelerator is selected by the 90° analyzing magnet, which is a new one builded in 1992. The major parameters of the new and old 90° analyzing magnets are listed in Table 1. So, it is possible to get more than 90 kinds of atomic and micro-cluster ion beams with the new magnet.

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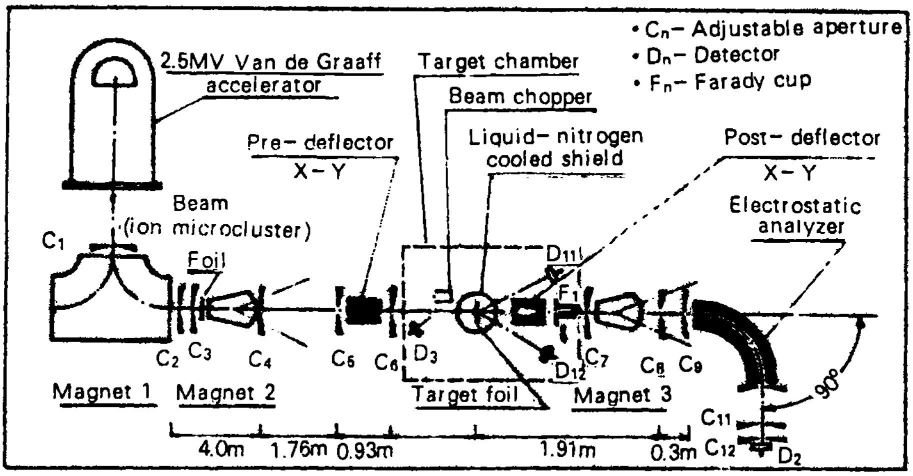

Fig.1 Schematic diagram of the experimental arrangement

Table 1 Major parameters of the new and old analyzing magnet

Parameter	New magnet	Old magnet
Bending radius/mm	850	500
Bending angle/(°)	90	90
Magnetic field/T	0.04~1.83	0.2~0.85
Mass number of analyzed ions	1~48	1~4
Stability of power supply	1.8×10^{-5}/8 h	4×10^{-5}/8 h
Weight/t	10	1.5

The gas of rf ion source is H_2(50%) and D_2(50%). A beam of HD^+ was defined by a pair of an adjustable collimators to be less than ±0.045 mrad. The intensity on target is $10^{-8}\sim10^{-10}$ A with cross section $20\times20(\mu m)^2$. A set of electrostatic x-y deflector plate placed upstream of the target is used to confine H^+, D^+, H° and D° from collisions with residual gas on 7 meters beam line between the 90° analyzing magnet and target.

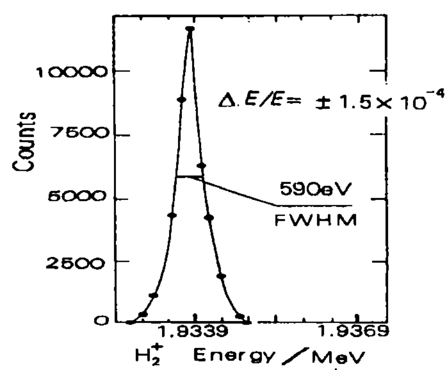

Fig.2 Incident 1.9338MeV H_2^+ beam energy profile recorded with the high-resolution arrangement

The high-resolution electrostatic analyzer (ESA) is used to measure the spectrum of incident HD^+ and emerging H^+ and D^+ from the target. The 90° sector ESA has a radius of 800 mm and across poles gap of 8 mm. A voltage of up to 60 kV can be applied. The power supply has a stability of $\pm1\times10^{-5}$/8 h. Depending on counting rate, one of the following is used for particle detection: a Au-Si surface barrier detector, a plastic scintillator, or a Faraday cup. The voltage stepping for the ESA and data taking are controlled by a microcomputer on line. The overall energy resolution of the detection system, as deduced from the measured energy distribution of a primary H_2^+ beam shown in Fig.2, is $\Delta E/E = \pm 1.5 \times 10^{-4}$.

3 Results and discussion

Using the high-resolution arrangement mentioned above, the following results are achieved by collision experiment of MeV level HD^+ with solid foil.

3.1 High-resolution spectrum of the HD^+ Coulomb explosion fragment

The H^+ and D^+ energy distributions yielded at 0° direction have been measured from the breakup of 1.50965 MeV HD^+ passing through a 3μg/cm^2 carbon foil, and the H^+ and D^+ energy distribution are shown in Figs.2 and 3, respectively.

The HD^+ issued from an rf ion source consists of an ion micro-cluster of H and D atoms and an electron, through the acceller-ation and selection of which the HD^+ beam incident ahead of target in the direction of its connected axis with H and D within 4π range has equidistributed probability, so it is certain that a group of HD^+ exists in an identical direction with the beam and axis. Owing to the cross section of electron loss is more than 4 orders of magnitude as compared with capture within this energy range, the bound electron fast stripped, HD^+ turns into two nude nucleus with positive charge, which are separated rapidly by Coulomb force. Generally, it is called "Coulomb explosion" of the cluster. As a result the HD^+ potential energy turns into the kinetic energy of the H^+ and D^+ fragments, the forward explosive H^+ or D^+ increase an energy, and backward explosive H^+ or D^+ decrease an energy. At 0° direction the energy distribution of H^+ and D^+ can be measured as the divergence of the initial HD^+ beam is small, the target is extremely thin and the resolution of the detector is extrmely high. Their spectrum shown in Figs. 3,4 not only reflects the existence of the Coulomb explosion of HD^+ ion micro-cluster in the foil, but also confirmes the existence of "wake effect" in the solid as predicted in the year 1948 by N. Bohr.[7]

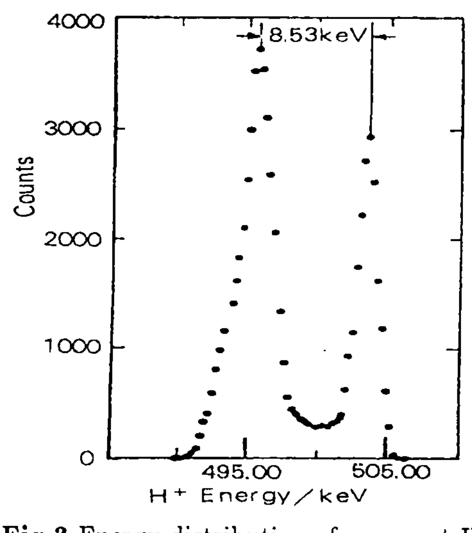

Fig.3 Energy distribution of emergent H^+ fragment in the direction of the initial 1.50965 MeV HD^+ beam passing a 3μg/cm^2 carbon foil

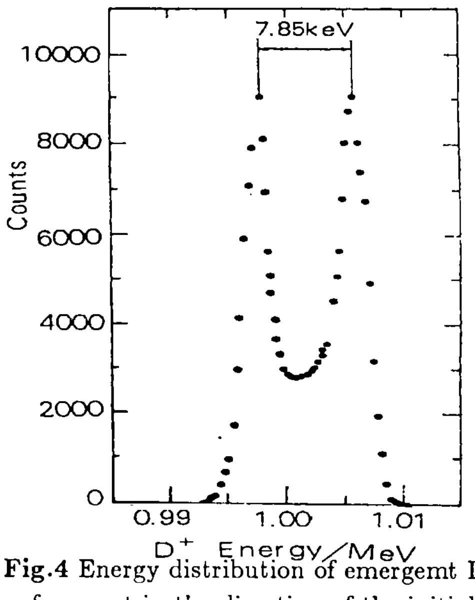

Fig.4 Energy distribution of emergemt D^+ fragment in the direction of the initial 1.50965 MeV HD^+ beam passing a ~3μg/cm^2 carbon foil

3.2 Contamination of H_3^+ in HD^+ initial beam

Since ion source is provided with the equal gas of H_2 and D_2, even if using magnet analyzer with high resolution it can not be sorted HD $^+$ and H_3^+ with identical ratio of the charge and mass. For this reason, we carried on an investigation in HD^+ and H_3^+ formation mechanism and controlled the parameter of ion source to give satisfaction to the condition of HD^+ formation and to give inhibition to the condition of H_3^+ as far as possible, concerning the study of it will be discussed in other paper.

3.3 Experimental measurement of HD^+ internuclear separation

It can be seen from Figs.3 and 4 that double peaks have energy separations of ΔE_H^+=8.53 keV and ΔE_D^+=7.85 keV in the H^+ and D^+ energy distribution, respectively. The lower energy trailing fragment in Fig.2 has a high intensity due to the wake effect. Although in principle, both H^+ and D^+ energy distributions can be applied to measure HD^+ internuclear separation $< r >$, it was not used, considering the contamination of H_3^+. In practice, only incident energy of HD^+ initial beam and ΔE_D are used to obtain more reliable $< r >$ of HD^+. We neglect the very small corrections due to the effects of wake, difference in the energy lost, and multiple scattering. The measured value $< r >$ HD^+ equalled to be 0.125±0.003 nm

3.4 Isotopic effect on the stereochemical structure of ion micro-cluster

The HD^+ internuclear separation together with H_2^+ and D_2^+ internuclear separation measured formerly are listed in

Table 2 Internuclear separation of H_2^+, HD^+ and D_2^+ ion micro- clusters

	H_2^+ [1,6]	HD^+	D_2^+ [1,6]
$< r >$/nm	0.119±0.003	0.125±0.003	0.132±0.003

Table 2. Within the quoted errors, the values of $< r >$ for H_2^+ and H_3^+ are the same as those obtained by others.[2,4] The larger magnitude of $< r >$ over r_0 in all case is attributable to the fact that the beam ions are vibrationally excited.

By comparision of these internuclear separation, the isotopic effect on stereo chemical structure of the diatomic ion micro-cluster is observed to be larger than the expected magnitude as given. Two factors enter into consideration probably. One is the higher vibrational excitation for HD^+ and D_2^+. This requires drastically different ion sourse parameters for the D_2^+, HD^+ and H_2^+, which was not the case. The other is the longer lifetime of vibrational state for D_2^+ more than HD^+ and HD^+ more than H_2^+ which are expected on the basis of $t \propto \frac{1}{\nu}$ and $\nu \propto \frac{1}{\sqrt{\mu}}$, where t is the lifetime of vibrational state, ν is the vibrational frequency, and the μ is the reduced mass of diatomic micro-cluster. The long flight path between the ion source and the target(~14 m) can result in a highter vibrational population for D_2^+ more than HD^+, and HD^+ more than H_2^+, even if D_2^+, HD^+ and H_2^+ excited the ion source with the same excitation.

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