

Single electron detachment of carbon group and oxygen group elements incident on helium

Yongyi Huang^{a,b}, Guangwu Li^c, Yinghui Gao^{a,b}, Enbo Yang^{a,b}, Mei Gao^{a,b},
Fuquan Lu^a, Xuemei Zhang^{a,b,*}

^a *The Key Laboratory of Applied Ion Beam Physics, Ministry of Education, China*

^b *Shanghai EBIT Laboratory, Institute of Modern Physics, Fudan University, Shanghai 200433, China*

^c *China Institute of Atomic Energy, Beijing 102413, China*

Received 21 October 2005; received in revised form 8 February 2006; accepted 8 February 2006

Available online 10 March 2006

Communicated by B. Fricke

Abstract

The absolute single electron detachment (SED) cross sections of carbon group elements C^- , Si^- , Ge^- in the energy range of 0.05–0.29 a.u. (5 keV–30 keV) and oxygen group elements O^- and S^- 0.08–0.27 a.u. (5 keV–30 keV), incident on helium are measured with growth rate method. In our energy region, the SED cross sections of C^- , Si^- , S^- and Ge^- increase with the projectiles velocity, at the same time, O^- cross sections reach a conspicuous maximum at 0.18 a.u. Some abnormal behavior occurs in measurement of SED cross sections for the oxygen group collision with helium. Our results have been compared with a previous work.

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PACS: 34.50.Fa; 34.90.+q

1. Introduction

A great deal of atomic species form stable negative ions in the gas phase, and the fact that the other electrons do not completely shield the additional electron from the nuclear charge causes the non-zero binding energy, and less exciting states than atoms or ions [1,2]. Negative ions are relevant of a wide nature sciences and technology areas, such as research of biological tissue by ionizing radiation, the opacity of stellar atmosphere, the electric discharges in gases and breakdown phenomena, the chemical composition of the upper atmosphere, the technology of ion sources for tandem accelerators and the inertial confinement fusion approach to sustainable nuclear fusion based on the use of high-velocity high-current ion beams focused [3]. Thus the subjects with relevant negative ions have been extensively studied in the past few decades [4–10]. Electron detachment of negative ions in collision with a static gas target is known

to be one of the most fundamental processes, moreover, experiments of collision detachment for negative ions with static gases target are a kind of powerful tool to understand the nature about negative ions and the physics of negative-ion–atom interactions [11–13]. Studies about the group IV semiconductor elements are very popular in microelectronics and materials science field. A lot of work about carbon buckyballs, small silicon [14] and germanium [15] cluster anions have been reported. There are lots of papers on theoretic calculations of cluster structures and growth patterns as the number of atoms increase. The works of collisions involving atomic and small carbon, silicon and germanium cluster anions are relatively fewer. Luna et al. reported total cross section for group IV C^- , Si^- and Ge^- collisions with noble gases from 0.2 a.u. to 2.2 a.u., of course, with SED cross section which is dominant in the total cross sections [16]. In their velocity region, free-collision model (FCM) [17] describes well their results. In the intermediate-velocity under 0.2 a.u., experimental data of electron detachments and a sound model have not been found. One part of our present works are SED cross sections for group IV C^- , Si^- and Ge^-

* Corresponding author.

E-mail address: zhangxm@fudan.edu.cn (X. Zhang).

by helium in 0.05–0.29 a.u. velocity region. Zappa et al. reported the total absolute electron detachment cross sections of atomic anions of second and third periods incident on noble gases including group VI O^- and S^- in the 0.3–1.5 a.u. velocity region by helium in order to verify the validity of FCM model in the intermediate velocity region, with SED cross sections dominant in the total cross sections from their results [18]. Also the cross sections in the important intermediate velocity under 0.3 a.u. were not given in their paper. The other part of our works are SED cross sections for group VI O^- and S^- by helium in 0.08–0.27 a.u. velocity region. Our results show some abnormal phenomena especially in SED cross sections for O^- and S^- by helium.

In our measurements we make use of growth rate method, which has been widely used in experiments of electron detachments for negative ions in collision with atoms and molecules [8]. A series of experiments on atomic collisions have been done in our laboratory [19–24] with this method. When passing a pure incident ion or atom beam through the collision chamber with such low gas pressures that single collision regime is ensured, the growth rate of new charge state fractions can be typically given as a quadratic function of target thickness [25,26]:

$$F_0 = \frac{I_0}{I_{\text{total}}} = \sigma_{-10}\pi + \frac{1}{2}[\sigma_{-11}\sigma_{10} - \sigma_{-10}(\sigma_{-10} + \sigma_{-11} + \sigma_{01} + \sigma_{0-1})]\pi^2, \quad (1)$$

where I_0 is the product neutral current, I_{total} is the total current that equals I_0 plus I_{-1} surviving energetic negative ions current and I_1 positive ions current, σ_{ij} is the cross section for the charge-changing process $i \rightarrow j$ and π denotes the target thickness defined by $\pi = nl = (0.726 \times 10^{17} \text{ T}^{-1})pl$, where n is the target gas density, T is temperature (in K), p is pressure (in Pa), l is the distance that the beam has traversed in the gas (effective scattering length, in cm). SED cross sections will be extracted

from (1), with I_0/I_{total} measured varying target thickness π , which is the so-called growth rate method.

2. Experiment

A schematic diagram of our experiments set-up is shown in Fig. 1. Since they are already described elsewhere [19], only a brief description will be given here of the setup and of the method employed.

Negative ions are produced in a cesium-sputtered negative-ion source (CSNIS), extracted, magnetically mass selected, focused and collimated before entering a differentially pumped 6 cm long collision chamber, in which the pressure is measured with MKS gauge. Primary ions and neutral atoms produced by collisions pass through a pair of electrostatic deflection plates, and are detected by the particle detector consisting of a converter plate and a channeltron.

An important characteristic of our set-up is that a single-particle detector is employed for both neutral atoms and ions. The particle detector is operated in the counting mode and the particle (ions and atoms) detection efficiencies remain equal to unity up to a count rate of about 10^4 cps in our velocity region (5–30 keV) [27]. The counting rate needs to be kept about $1\text{--}2 \times 10^3$ cps in the measurements. There is a square-wave signal with amplitude of 300–500 V to modulate the electrostatic deflection field between the deflection plates. All particles including the anions, the neutral atoms and the positive ions detached are detected with the electrostatic field zero, and *only* the neutral atoms are detected with the field strong enough to deflect the charged ions (survived energetic anions and detached positive ions).

SED can be extracted from the measured I_0/I_{total} and p . Fig. 2 displays a typical growth rate curve, which shows the fraction of neutral atoms versus gas pressure of Ge^- collision with helium at 0.09 a.u. velocity (15 keV).

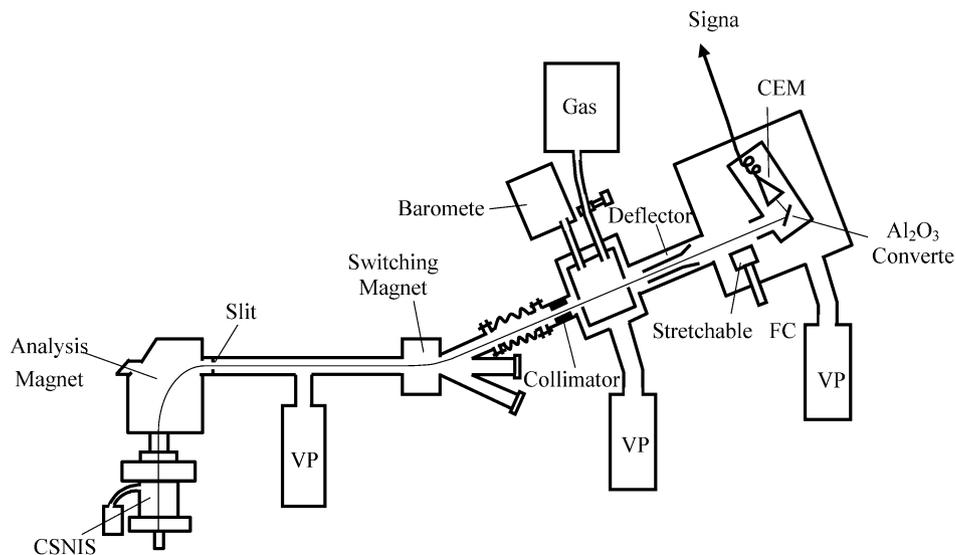


Fig. 1. Schematic of the experimental setup. CSNIS, VP and CEM represent Cs sputtering negative ions source, vacuum pump and channel electron-multiplier (channeltron) respectively.

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