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Single-Electron-Capture by O_2^+ Ions from O_2 and N_2 Gases

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Abstract

Using the time-of-flight technique, the absolute total cross sections for capture electron by O_2^+ ions colliding with O_2 and N_2 molecular gases have been measured for energies between 0.50 and 2.0 keV. These cross sections are found to be in the range of $1.06 - 2.54 \times 10^{-16}$ cm^2 and $0.67 - 2.08 \times 10^{-16}$ cm^2 for O_2^+ with O_2 and N_2, respectively. The present measurements indicate that the total cross sections are slowly increasing with increasing collision energies.

Keywords:

electron-capture, by slow O_2^+

1. Introduction

At collision energies below several thousand eV/amu, collisions in which multi-charged ions capture electron (s) from neutral atoms or molecules are characterized by large cross sections ($> 10^{-16}$ cm^2) [1-8], and therefore play an important role in any environment containing multi-charged ions and neutral species. Apart from the fundamental interest in a detailed understanding of the collision mechanisms involved, such electron-capture processes are important in the context of fusion plasma [9], astrophysics and atmospheric science [10,11], the design of controlled thermonuclear fusion devices [12] and are also important for testing theoretical predictions. Such processes have proven difficult to treat theoretically because the multi-electron systems cannot be described classically to a good approximation and the quantum-mechanical study of these multi-electron systems in the time-dependent field is very complicated [13]. Various empirical scaling-laws are well known in the intermediate- and high-energy regimes [13]. Scaling-laws do not exist for low-energy collision (i.e. < 2 keV/amu). The multi-electron configurations of projectile ions result in a rich and varied low-energy dependence which requires an explicit calculation for each collision-partner pair.

The work presented here focuses on the following reaction :

$$O_2^+ + O_2 \rightarrow O_2 + O_2^+ + \Delta E$$

between ionized ions such as O_2^+ with O_2 or N_2 gas (97 % of the atmosphere). The low-energy range data are needed for atmospheric plasma calculations involving heating processes, collisional ejection of atoms and molecules (atmospheric sputtering) and expansion of corona [14], an energy range where most scaling-laws break down. The primary focus of this study is to measure experimentally the total one-electron-capture cross sections for O_2^+ ions in collisions with O_2 molecular gas in the energy range of $0.50 - 2.0$ keV.

2. Experimental method

The experiment is carried out in the recoil ion source (RIS) apparatus shown in Fig. 1. The details of this (RIS) apparatus and the experimental method were discussed in the previous paper [1-3,15-17]. A collimated pulsed F^{4+} beam of energy 1 MeV/amu is directed into the (RIS) containing O_2 the molecular gas. The collisions that take place in the RIS between the fast F^{4+} pulsed beam and the gas molecules generate recoil (primary) ions that are extracted by the voltage gradient across the RIS electrodes. Upon exiting the RIS, these ions travel through the first acceleration unit, a seven-plate apparatus, which only the fifth plate is not grounded. This plate (Einzel lens) focuses and drifts the primary ions toward the secondary pressurized gas-target cell containing the O_2 molecular gas. After exiting the gas-target cell, the slow ions produced were extracted using a double-plate electrostatic analyzer and detected using a microchannel plate detector. The O_2^0 molecules passed straight through the analyzer onto the detector.

The initial charge states q of the recoil ions were determined by the time-of-flight (TOF) technique. The time it takes from the production of a recoil ion of

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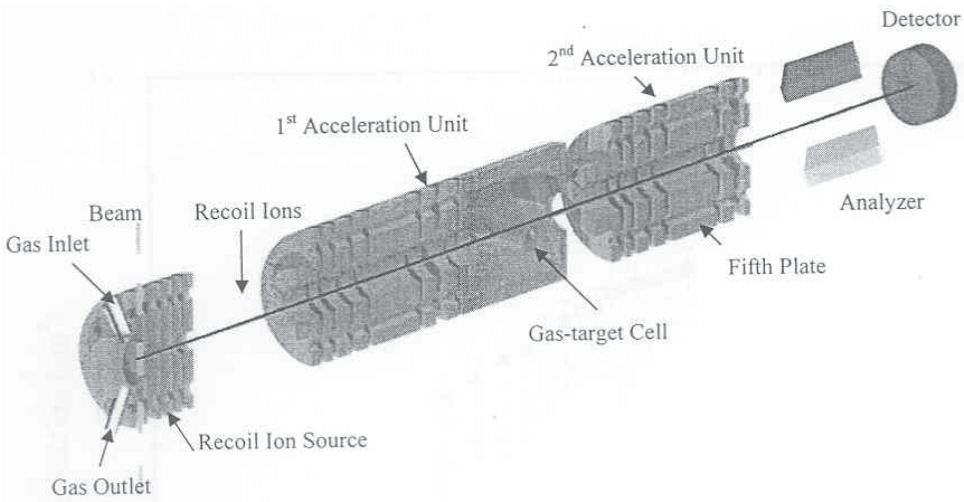

Fig. 1 A schematic diagram shows the experimental arrangement.

mass m to its detection by the detector is proportional to $(m/q)^{1/2}$. The recoil ions were analyzed after their passage through the O_2 gas using the electrostatic analyzer. In the present experiment, the yield of O_2^0 molecules produced through single-electron-capture by the O_2^+ ions and the total yield of parent ions was used to determine the total cross sections. A separation between the O_2^+ ions and O_2^0 molecules could only be achieved when the fifth plate of the second acceleration unit was not grounded.

3. Result and discussion

3.1 Result

When making cross-section measurements the pressure in the target cell is chosen to ensure single collision and the total cross section for the single-electron-capture is then evaluated from the mathematical formula [1,3]:

$$\sigma = \frac{N_t^0}{N_t n \varepsilon l}$$

where N_t^0 is the total number of the neutral events, N_t is the measured number of incident ions, n is the number of gas particles per cm^3 in the collision target-cell and is related the measured pressure p in Pa according to $n = 2.45 \times 10^{14} p$ (at 22°C), ε is the detection efficiency of detector and l is the geometric length of the target cell (l = 2 cm). For the efficiency of the channel-plate detector, we used the product of the active area ratio of the first channel-plate from the manufacturer's manual and the transmission of the grids at the entrance of the detector (ε = 34 %). The total number of the neutral events N_t^0 is determined by applying a transverse field on the analyzer to deflect the ions away after they pass through the second acceleration unit, allowing only the neutral products to impact the detector [16]. The measured total single-electron-capture cross sections are shown in

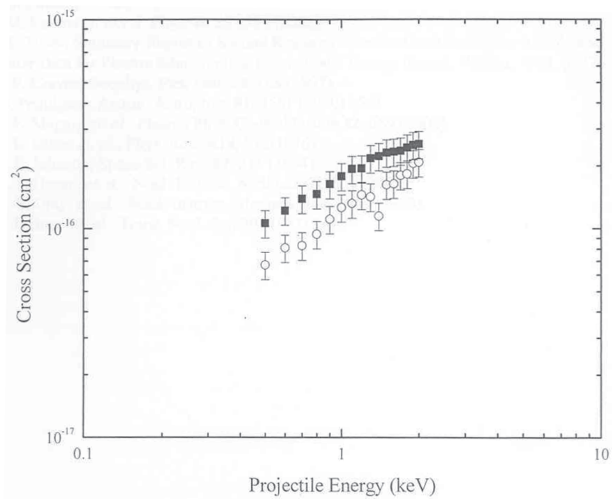

Fig. 2 The present measurements of the total single-electron-capture cross sections for $O_2^+ + O_2$ (■) and our previous measurements for $O_2^+ + N_2$ collisions (○) are shown.

Fig. 2.

3.2 Experimental uncertainty

The total absolute uncertainty of the cross section was obtained as the quadrature sum of counting statistics (~10 %) and systematic uncertainties (~7 %) of all measured quantities (n, ε and L). The total absolute uncertainty of cross section was estimated to be ~15 %. The data, including the total uncertainty are shown in Fig. 2.

3.3 Results and conclusion

Measurements of total cross sections for single-electron-capture were obtained at laboratory energies between 0.5 and 2.0 keV. The energy dependence of these cross sections for O_2^+ ions colliding with O_2 and N_2 [2] gases are shown in Fig. 2. These measurements show a monotonic increase in the cross sections with increasing energy. At low collision energies, this behavior is typical of single-electron-capture cross sections between singly-charged ions and neutral atoms or molecules for which capture is usually favored only between atomic ground states. This may be attributed to the fact that there is only one exoergic channel available for the reaction with reasonable crossing radius.

In the measurement reported here, we measured the total cross sections for single-electron-capture from O_2 and N_2 gases by slow O_2^+ ions, such measurements are not found in the literature. These cross sections are of sufficient accuracy to be used to further refinement of the predictions of the theoretical models.

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