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Absolute detection efficiencies for keV energy atoms incident on a microchannel plate detector

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ABSTRACT

The absolute detection efficiencies of a microchannel plate detector (MCP) were determined experimentally for neutral hydrogen, carbon, and tungsten atoms with impact energies of 0.5–4.5 keV. We measured detection efficiencies using our recently developed method, which uses coincidence counting between neutralized incident ions and ionized target atoms in single-electron capture collisions. The obtained detection efficiencies showed similar impact-energy and mass dependence to those of rare gas atoms (Ne, Ar, Kr, and Xe), measured previously using our method. The detection efficiencies increased with increasing impact energy and converged to the open area ratio (~50%) of the MCP used. The efficiencies at fixed energies decreased as the mass of the incident atom increased. The absolute detection efficiencies obtained for H, C, W, Ne, Ar, Kr, and Xe atoms could be scaled according to the average electron emission yield estimated using the formulas for electronic and nuclear stopping powers.

1. Introduction

The microchannel plate (MCP) detector is frequently used to detect keV-energy ions and neutrals. The absolute detection efficiency (ADE) of the MCP detector is known to depend on the incident energy and charge state for the individual ionic species. Knowledge of the ADE is therefore necessary in order to determine the absolute number of particles incident on the MCP. Here, the ADE is defined as the ratio of the number of detected particles to the number of particles impinging on the MCP.

For ions, the ADE of the MCP detector is generally obtained by consecutively measuring the ion beam current from a Faraday cup and the count rate of the pulses from the MCP detector. However, previous ADE data for neutral atoms are scarce, mainly because of the difficulty in measuring the incident neutral beam current. We developed a new method that enables the determination of the ADE for neutrals at keV energies [1]. This method uses single-electron capture collisions of ions with gas targets. The neutralized incident ions and singly ionized target atoms are detected with two identical MCP detectors in the coincidence mode. The number of detected coincidence events is not equal to the number of detected target ions because of the ADE of each MCP detector. The ADE of the MCP for the neutralized incident ions is then provided by the ratio of the number of coincidences to the number of target ions. Using this method, we determined the detection efficiencies for rare gas atoms (Ne, Ar, Kr, and Xe) with energies of 0.5–4.8 keV [2].

In this work, we measured the absolute detection efficiencies for hydrogen, carbon, and tungsten atoms to investigate the ADEs for atoms that are lighter or heavier than the previously measured atoms. The range of impact energies is 0.5–4.5 keV. Additionally, this report describes a scaling relation for all the data obtained by us thus far. This scaling is useful for the rapid evaluation of the ADE of MCP detectors for various atoms having keV energies.

2. Experiment

2.1. Measurements

The experimental setup and procedures are fundamentally similar to those used in our previous work [1]. Only a brief description is given here. Further details are provided for a few important points of interest to the present experiment. The present MCP detectors are the same as those used in our previous experiments.

The H^+, C^+, and W^+ ions are produced, respectively, from H_2, CO or $W(CO)_6$ gas with a Nier-type electron-impact ion source. $W(CO)_6$ gas is obtained from vacuum sublimation at room temperature. The ion beam accelerated to energies of 0.5–4.5 keV is mass analyzed and collimated using two 1-mm-diameter apertures. The collimated ion beam is impinged on a target gas effused from a cylindrical nozzle, as presented in Fig. 1. After passing through the target, neutrals produced by charge transfer collisions and incident ions are separated electrostatically. They are then measured

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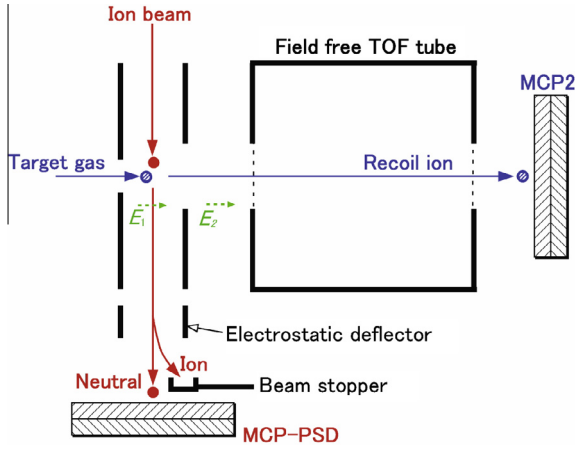

Fig. 1. Schematic showing the experimental setup. For an explanation of the lettering, see the text. The extraction electric field E_1 is 2 V/mm. The acceleration electric field E_2 is 1.5 V/mm.

using a position-sensitive MCP detector (MCP–PSD) that enables us to distinguish neutrals from the incident ions. The MCP–PSD is located so that the neutrals enter the center of the MCP at normal incidence. Specifications of the MCP (chevron configuration) are as follows: the quality diameter is 40 mm; channel diameter, 25 μm; channel pitch, 32 μm; bias angle, 8°; and minimum open area ratio, 50%.

The target ions produced by charge transfer collisions (recoil ions) are analyzed using a standard time-of-flight (TOF) technique that satisfies the time-focusing condition [3]. The recoil ions are extracted perpendicular to the incident beam direction by an electric field. After further acceleration and passage through the field-free region, the ions are detected using a second MCP (MCP2) detector. A time-to-amplitude converter (TAC) is started by the signals from the MCP2 and stopped by the delayed signals from the MCP–PSD, which yields a TOF spectrum of the recoil ions in coincidence with the particles detected by the MCP–PSD. The signals from the MCP–PSD are recorded simultaneously with the signals from the TAC using the event-by-event mode (LIST mode). This enables us to obtain the TOF spectrum of the recoil ions in coincidence with the neutralized incident ions in an off-line analysis. The number of recoil ions detected by the MCP2 is recorded using a counter.

Single-electron capture cross sections of ions at low energies become large for collision partners having a similar ionization potential I_p [4]. For this reason, Ar, Xe, and NO (I_p = 15.8, 12.1, and 9.3 eV) were selected, respectively, as the target gases for the collisions of H^+, C^+, and W^+ ions (I_p = 13.6, 11.3, and 7.6 eV). However, for W^+ + NO collisions, the recoil ion (NO^+) peak could not be observed clearly in the TOF spectrum because of the small cross section of the ions. To obtain better statistical data, a W^+ ion beam that was a few hundred times more intense was impinged on the NO gas. The ion beam was then intercepted by a beam stopper that was newly introduced in front of the MCP–PSD. This process prevented distortion of the position spectrum that might be caused by pile-up and considerable dead time of the LIST-mode data-acquisition system.

2.2. Evaluating the absolute detection efficiency

The evaluation procedure was described in detail in an earlier report [1]. In short, the number of recoil ions detected by the MCP2, R, is given as

$$R - R_B = tdI\sigma X, \tag{1}$$

where R_B is the number of background signals, t is the transmission of the TOF tube, d is the ADE of the MCP2 for recoil ions, I is the number of incident ions, σ is the single-electron capture cross section, and X is the target atom thickness. The number of recoil ions in the TOF spectrum (the number of coincidence events), C, is given as

$$C - C_{AC} = tdI\sigma X, \tag{2}$$

where C_{AC} is the number of accidental coincidences and D denotes the ADE of the MCP–PSD for incident neutrals. By combining Eqs. (1) and (2), D can be written as

$$D = \frac{C - C_{AC}}{R - R_B}. \tag{3}$$

The C_{AC} is determined by a linear fit to the flat background outside the recoil-ion peak in the TOF spectrum.

The output pulses from the MCP detectors are discriminated by constant fraction discriminators (CFD) for the suppression of electronic noise. True MCP pulses that do not reach the CFD threshold level cannot be recorded, which causes the underestimation of the ADE. We estimated the calibration factor η by extrapolating the pulse-height distribution (PHD) of the MCP–PSD from the threshold level to zero. The factor η is given as the ratio of the peak area of the PHD above the threshold to all peak area including the estimated region below the threshold. The obtained values of η for H^0, C^0, and W^0 increase from 98 ± 2%, 91 ± 2%, and 93 ± 7%, respectively, at the lowest impact energies (0.5 keV for H^0, C^0 and 0.6 keV for W^0), and attain more than 99 ± 1% at energies greater than 1 keV for H^0, 2 keV for C^0, and 3 keV for W^0. The ADE for the neutrals is ultimately evaluated using the following equation:

$$D = \frac{1}{\eta}\left(\frac{C - C_{AC}}{R - R_B}\right). \tag{4}$$

3. Results

3.1. Absolute detection efficiencies

Fig. 2 shows the TAC spectrum of the recoil-ions measured for 2-keV W^+ + NO collisions. The vertical lines in the upper part represent flight times of typical residual gases and fragment ions from dissociative electron capture of NO. The peaks from residual gases and the fragments cannot be observed clearly, which indicates that $W^+ + NO \rightarrow W^0 + NO^+$ is the main neutralization process for W^+. Similar TAC spectra were obtained for H^+ + Ar and C^+ + Xe collisions: only a singly ionized recoil-ion peak was observed in the spectra.

Fig. 3 shows the ADEs for neutral H^0, C^0, and W^0 as a function of the impact energy. Dashed curves are provided as a guide to the

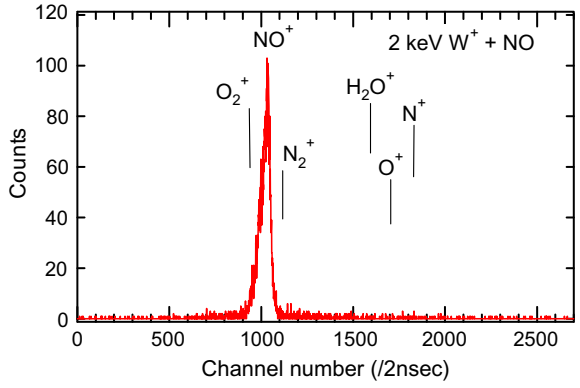

Fig. 2. TAC spectrum in 2 keV W^+–NO collisions. Larger channel numbers correspond to shorter flight times of the recoil ions.