Doubly Differential Cross Sections for the Charge Exchange Process

Part II. Experimental Studies on the Resolution of Time-of-Flight Analyzer and Proposal for the Focusing Analyzer

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A new time-of-flight analyzer is developed for the doubly differential cross section studies on charge exchange process. Experimental results for the limit of energy resolution revealed the incidental effects of the sweeping voltage. According to the time-depending ion optics, the incidental effect of sweeping field introduces the spreads in energy, direction, and length of the pulsed ion packet depending on the voltage as far as the slit widths are finite. An example for multi-focusing time-of-flight analyzer is proposed.

1. Introduction

The energy resolution of time-of-flight type analyzer for neutral particle is usually limited to about $500 \cdot V/\Delta V$, that is about 2 eV FWHM when the initial energy V is around 2.00 KeV. We have reported in previous paper, Part I,¹⁾ a new type of time-of-flight analyzer for doubly differential cross section measurement, where the scattering angles of product neutral particles are determined precisely by means of the voltage applied at electrostatic cylindrical electrodes in front of the collision chamber. The resulted angular resolution

was found to be within 0.05° . However, the limit of energy resolution remained about 1 eV at 500 eV in spite of the time resolution is around 2 nano-sec. for $2 - 10 \mu$ -sec. flight time. This paper will report experimental studies on the effects of the sweeping voltage for the properties of the pulsed ion packet which are founded to be the main cause for the energy resolution.

2. Experimental

Details of the time-of-flight analyzer for the doubly differential cross section is reported in Part I of this report.¹⁾ It is essentially a Mattauch-Herzog type double

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Fig. 1. Geometry of the time-of-flight analyzer from sweeping field to collision chamber.

focusing mass spectrograph, equipped with an ion beam chopping field at the entrance of $31^\circ = \pi/4\sqrt{2}$ cylindrical electrostatic field, as well as with collision chamber at the exit of the cylindrical field. Also, a secondary electron multiplier type detector, which is mechanically rotatable around the center of collision chamber, is mounted at the end of a straight flight path, 490 mm. Fig. 1 is geometry and dimensions for part of the analyzer from the sweeping field to the collision chamber. The chopper electrodes length is 8 mm, and gap is 2.5 mm.

3. Results and Discussions

When the sweeping square voltage V_d is applied at the chopper electrode for the steady ion beam of Ar^+ , the "line width" for the pulsed ion packet is measured in the spread of time-of-flight at the detector. Fig. 2 is experimental result for the relation between the sweeping voltage, V_d and the flight-time spread in FWHM and FW ($\frac{1}{50}$) M. The line width reduces with V_d up to 20 volt range, however, it increase at higher voltage of V_d up to 100 volt, which is supplied by homemade high speed pulse generator. In spite of the primary

expectation, the resolution is deteriorated at higher sweeping voltage.

We have analyzed time-dependent ion optics for the incidental effects of the sweeping voltage for the pulsed ion packet formation. When an ion (mass m , charge e , initial velocity v_0 , and initial divergency in y -direction $\alpha = 0$) starts slit S_0 at the point y_0 at time $t = 0$, and passing through the sweeping field (electrode length is ℓ , and gap is d), and square voltage changes its porality at $t = t_1$, then the ion leaves slit S_1 of sweeping field at y_1 and α_1 at $t = \ell/v_0$,

$$y_1(t_1) = \frac{eV_d}{md} \left(\frac{\ell^2}{2v_0} - \frac{2\ell}{v_0} \cdot t_1 + t_1^2 \right), \quad (1)$$

and

$$\alpha_1(t_1) = \frac{eV_d}{mdv_0} \left(\frac{\ell}{v_0} - 2t_1 \right). \quad (2)$$

If the applied voltage at the cylindrical electrodes of radii R_1 and R_2 ($R_1 < R_2$) are $\pm V_E$, the velocity change of the ion along the median line is $\beta(V_E)$ relative to v_0 , and

$$\beta(V_E) = \sqrt{\frac{mv_0^2}{2eV_E} \ln(R_2/R_1)} - 1. \quad (2)$$

Than, the ion leaves the cylindrical field at y_2 and θ_2 respect to the median line at slit S_2 , which is entrance slit of the collision chamber,

$$y_2(t_1, V_E) = a_e \left\{ \frac{\alpha_1(t_1)}{2} + \left(1 - \frac{1}{\sqrt{2}} \right) \beta(V_E) + \frac{1}{\sqrt{2}} \frac{y_1(t_1)}{a_e} \right\}, \quad (3)$$

and

$$\theta_2(t_1, V_E) = \frac{\alpha_1(t_1)}{\sqrt{2}} + \beta(V_E) - \frac{y_1(t_1)}{a_e}, \quad (4)$$

Where a_e is radius of median line in the

Fig. 2. Experimental results for the line width, in nano-sec, of projectile ion Ar^+ in FWHM and $\text{FW}(\frac{1}{10})M$ at 1.00 KeV at different sweeping voltage, V_E , and the calculated result according to time-depending ion optics.

sector cylindrical field, $\pi/4\sqrt{2}$. If the slit S_2 is very small, less than 0.1 mm, the ion enters into the collision chamber when $y_2(t_i, V_R) = 0$, then the $t_1(V_R)$ and $\theta_2(t_i, V_R)$ are fixed by the applied voltage, V_R . Therefore, when V_R is fixed at certain value and the direction for the detector is fixed at θ_2 , the t_1 for the detected ions are dependent on the θ_2 value. This condition brings the spread in starting points of the ions in a pulsed ion packet, and introduce the spread in the flight path for each ion which belongs to identical packet. Details of the time-depending ion optics, including the fringing effects characteristic to the

sweeping field, will be published in separate paper.

According to our experimental results for charge exchange collision processes, the line widths for projectile ions are almost identical to the widths for product neutral particles, if the scattering angle is less than 4° , energy loss is less than 1 % of translational energy of projectile, and mass of projectile is less than or equal to mass of target molecule. Then, information for the line width of product neutrals are acquired in the study of line width for projectile ions.

Solid curve in Fig. 2 is the calculated

Fig. 3. Experimental result for the minimum line width, in eV, of projectile ion Ar^+ in FWHM, $FW (\frac{1}{10}) M$, and $FW (\frac{1}{50}) M$ for different initial energy, E_0 .

result for the line width estimated according to the time-dependent ion optics, and it is fairly in good agreement with the experimental results. The line width is proportional to width of slit S_1 , and it mainly depends on the "writing speed" of the ion beam at slit S_2 at the range 5 ~ 20 volt for V_d . The time interval of ion packet in the collision chamber also depends on the widths of S_0 , S_1 , as well as S_2 . For the 20 ~ 100 volt range of V_d , the fringing effects at the sweeping field is

mainly responsible for the line width increase with V_d , because both the time-dependent fringing effects at the entrance and the exit bring accelerations along flight path of an ion.

Each minimum line width in Fig. 2 is plotted in Fig. 3 in energy scale for different initial energy of projectile Ar^+ ion.

It may be concluded that the resolution of the time-of-flight analyzer for doubly differential cross section depends on the incidental effects of sweeping field as far

Fig. 4. An example of the focusing time-of-flight analyzer. From main slit to entrance of toroidal electric field; 98 mm, from exit of the field to detector; 2110 mm, chopper; 10 mm length and 2.5 mm gap, Main slit width less than 0.10 mm, S_2 0.30 mm, and S_3 0.40 mm. The toroidal electric field; radius of median line $a = 100$ mm, $k = \sqrt{2-c} = 0.960$ where $c = a/r$ and r is radius of equipotential surface at median line, and deflection angle $\phi = 285^\circ$ with the Matsuda plates M_1 and M_2 and cylindrical electrodes E_1 and E_2 .

as slit widths are finite, and that it is improbable to improve the resolution by increasing the flight path length because the aberrations increase too for longer flight path.

Several types for focusing time-of-flight analyzer are proposed by combining straight flight space with sector fields.²⁾ We have analyzed the first order focusing properties of time-of-flight analyzer including the incidental effects of the sweeping field. Fig. 3 is an example of the focusing time-of-flight analyzer.

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References

- 1) N. Nose, *Mass Spectrosc.*, **31**, 173 (1983).
- 2) W. P. Poschenrieder, *Int. J. Mass Spectrom. Ion Phys.*, **6**, 413 (1971); *ibid.*, **9**, 357 (1972).

Keywords

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