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Construction of a Charge-State Analyzer for Ion-Atom Collisions

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A simple and convenient charge-state analyzer has been constructed for atomic physics using accelerators. The electrostatic deflector and the position-sensitive detector were used for charge-state measurement. The performance of the analyzer constructed was examined in test experiment using $^{27}Al(p,p)$ reaction by 3.8475-MeV protons at 135°. The obtained two dimensional data of the energy and the position showed good agreement with the results of beam trajectory calculations based on a simple model.

KEYWORDS : Charge state/Electrostatic deflector/Position-Sensitive Detector/

I. INTRODUCTION

Recently many types of accelerator have been available to atomic physics studies. The level of research activity is growing substantially in such areas as the high-energy atomic collisions or the highly-charged ions atomic spectroscopy[1]. In order to study charge-transfer phenomena, a simple and convenient charge-state analyzer has been constructed. The design of the the charge-state analyzer, hereafter called as "Cstar", is based on electrostatic deflection system. The charged particles are deflected depending on its charge state. Therefore the use of a position-sensitive detector (PSD) enables us to measure several charge state of particles simultaneously and, moreover, to obtain two dimensional data of the energy and the position by using the PSD. The experimental techniques for the measurement of the charge-state fractions have been described by several authors[2]. In this paper, we report the detailed description of the design and construction of the Cstar, and also the performance of the Cstar being studied in $^{27}Al(p,p)$ reaction at 3.8475 MeV.

II. DESIGN AND CONSTRUCTION

The constructed charge-state analyzer (Cstar) is schematically shown in Fig. 1. The Cstar consists of three main systems with different functions, i.e., slit system, electrostatic deflector system and detector system. Whole system is housed in vacuum envelope of 100 mmϕ in diameter and 770 mm in length. In practical usage, the Cstar is connected to a scattering chamber in which ion-atom collisions take place. The scattering angle are selected among 45°, 90° or 135° in the

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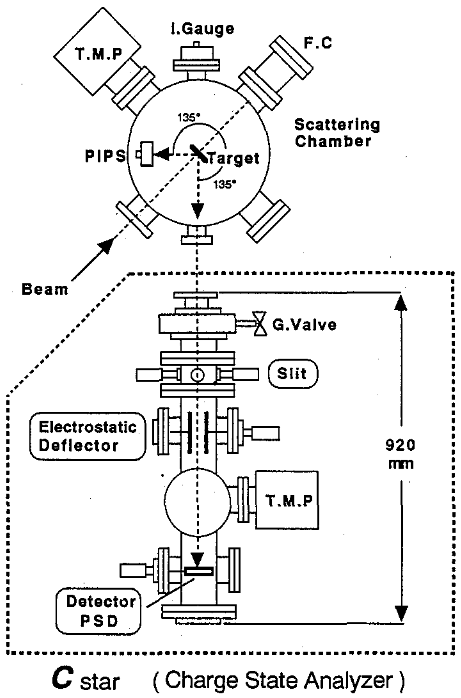

Fig. 1. Experimental set-up for charge-state measurement. The charge-state analyzer (Cstar) constructed by us is shown inside the dotted line.

present chamber.

II.1 SLIT SYSTEM

Shown in Fig. 2 is the slit system which was placed at the entrance of the Cstar as indicated in Fig. 1. A tantalum plate of 30 mm × 20 mm × 2 mm was used for each slit and mounted on a ceramic insulator. The current from the insulated tantalum slits can be monitored, if beams hit the slits. This slit system has a mechanism of changeable apertures, that is, it is possible to set any position in all directions (up, down, left and right) as shown in Fig. 2. For each slit, the setting range is −5 mm to +10 mm from the beam axis. The positioning of each slit is performed by a step of 0.05 mm with a rotary feedthrough having a mechanism of translating rotation to linear motion. As seen in the figure, the slit system consists of double slits which are 100 mm apart each other, thus providing well collimated particles.

II.2 DEFLECTION SYSTEM

The electrostatic deflection system[3] consists of a set of two-plate condenser in which charged particles move on parabolic trajectories as shown in Fig. 3. The two coper palates, each size of which was 40 mm × 150 mm × 2 mm, were used for the electrodes and were mounted on a block

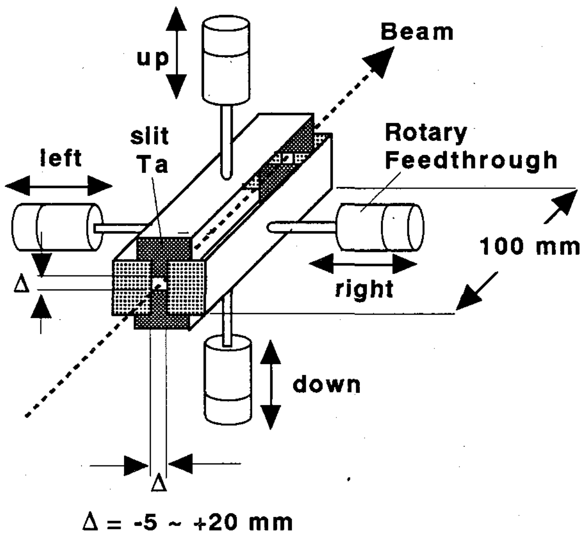

Fig. 2. Layout of the slit system in the Cstar.

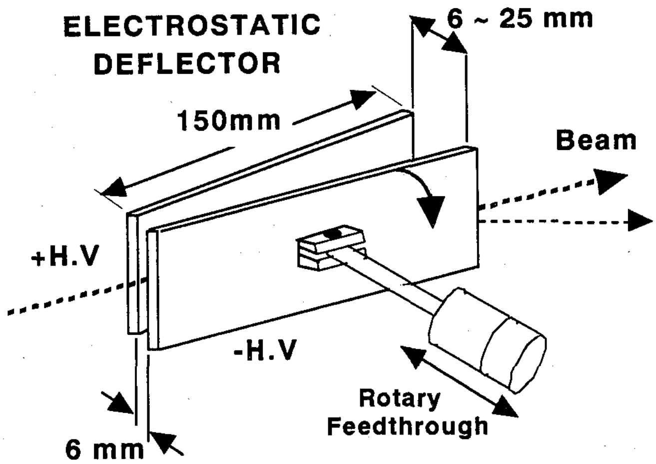

Fig. 3. Layout of the electrostatic deflector system in the Cstar.

of ceramics. The width of the gap for the beam entrance side of the deflector was fixed at 6 mm. The width for the exit was changeable from 6 mm to 25 mm by using a rotary feedthough. By this changeable device, it is possible to improve the focusing properties of the scattered particles to be analyzed at the detector position.

For the parallel-plate deflector system, the equation of charged particle motion can be solved analytically. The deflection (Y) of a charged particle at the PSD is given by

$$Y=\frac{qV}{E_k}\left\{\frac{l(2L+l)}{4d}\right\}, \qquad (1)$$

where q is the charge state of a particle, V is the high voltage of the electrostatic deflector, l is the length of the deflector, L is the distance between the deflector and the detector, d is the width of gap of the parallel plate, and E_k is the kinetic energy of the charged particle.

II.3 DETECTOR SYSTEM

We used position-sensitive solid-state detector (PSD) of ORTEC p-055-0847-500. The active area of the PSD is 47 mm in length and 8 mm in width. Due to the 500-μm thickness, the maximum limits of measuring energy are about 30 MeV for α particles and 8 MeV for protons.

The PSD gives both a signal proportional to the particle energy and simultaneously a signal proportional to the position of particles entering the PSD. The main advantage of this detector system is that entire charge-state spectrum can be recorded simultaneously, i.e., the effort of normalization for each charge state is unnecessary and measuring time is minimized. Moreover, two dimensional data of the energy and the position can be utilized for detailed study of charge-state structures of different particles such as protons and α particles. The distance between the end of the deflector and the PSD is about 220 mm. The PSD is fixed on a rotary feedthrough and its position moves from 0 to 36 mm from beam axis.

II.4 VACUUM SYSTEM

The Cstar was pumped by a turbo molecular pump of 360 l/s (LEYBOLD NT-360) and a rotary pump (ULVAC PVD-360). A fore-line trap (UFT-25M) was set between the turbo molecular pump and the rotary pump. A cold trap was also set between the Cstar and the turbo molecular pump. The operational pressure of the Cstar which was connected to the scattering chamber was 4.6×10^{-7}torr during test experiment, but this pressure was largely governed by that of the scattering chamber. We can believe that much better vacuum pressure, a few 10^{-8}torr, can be achieved when the cold trap equipped in the Cstar is utilized and the condition of the scattering chamber is improved.

III. TEST EXPERIMENT

The performance of the Cstar was examined in ^{27}Al(p,p) and ^{27}Al(p,α)^{24}Mg reactions. The proton beams were obtained from the 8-MV tandem Van de Graaff accelerator at Kyoto University. The measurements were performed at the proton energy 3.8475 MeV at scattering angle 135°. The beam energy calibration was carefully carried out by using the 3.8520-MeV resonance in ^{27}Al(p,α)^{24}Mg reaction. The target used was a self-supporting ^{27}Al foil with the thickness of 11 μg/cm^2. The slits were set +1 mm to left and right direction; the horizontal aperture was 2 mm, and +5 mm to up and down direction; the vertical aperture was 10 mm.

The obtained typical energy spectrum is shown in Fig. 4. We observed the elastic scattering of protons by ^{12}C, ^{16}O and ^{27}Al and the inelastic scattering (P_2) by 2nd excitation of ^{27}Al, and α particles (α_0) from ^{27}Al(p,α)^{24}Mg reaction. For the position calibration of the PSD, the PSD was moved 10 mm from beam axis. The length of 1 mm on PSD corresponds to 1.7 channel at position spectrum, that is, 0.59 mm/ch. In the lower side of Fig. 5, the position spectrum of elastic protons by ^{27}Al and α particles are shown. The base width of the position peak was about 16 channels. Thus, for example, it is necessary to separate 16 channels (9.4 mm) at least for the difference of peak position between the H^{1+} and H^0 particles. The required deflection were obtained by supplying a high voltage of 15 kV for electrostatic potential. The peak position shifted by using the deflector system is shown in the upper side of Fig. 5. In case of H.V = 0, H^{1+} and He^{2+} formed one peak at the 65 channel, on the other hand, in case of H.V = 15 kV, H^{1+} and He^{2+} are separated each other due to the difference of the energy and the charge state.

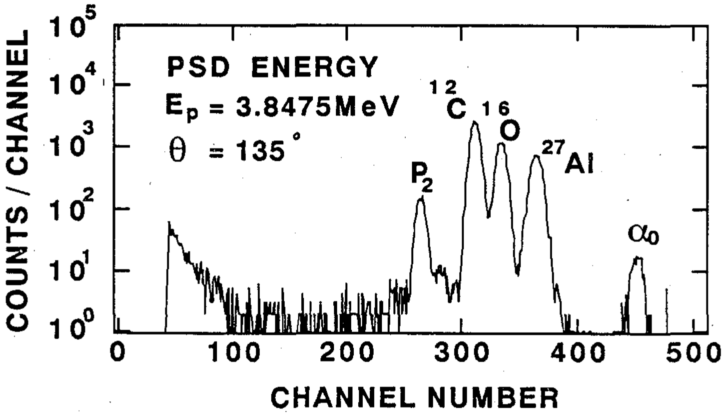

Fig. 4. Typical energy spectrum obtained with the PSD in the ^{27}Al(p,p) and ^{27}Al(p,α)^{24}Mg reactions. ^{12}C, ^{16}O and ^{27}Al indicate the elastic protons. P_2 shows inelastic protons by 2nd excitation of ^{27}Al, and α_0 indicates the α particles from ^{27}Al(p,α)^{24}Mg reaction.

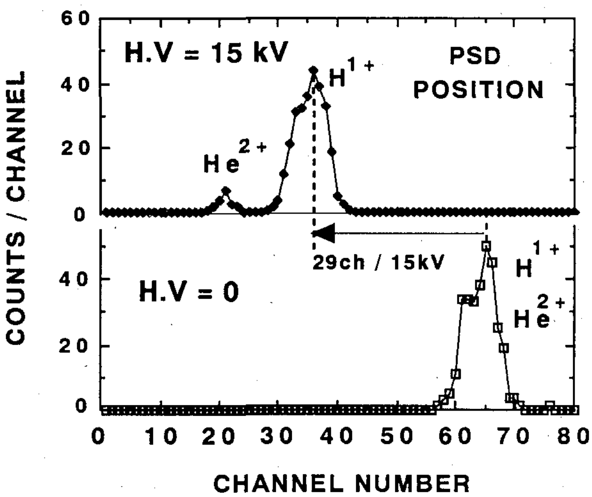

Fig. 5. The position spectra of protons and α-particles with and without the high voltage of 15 kV for the electrostatic deflector.

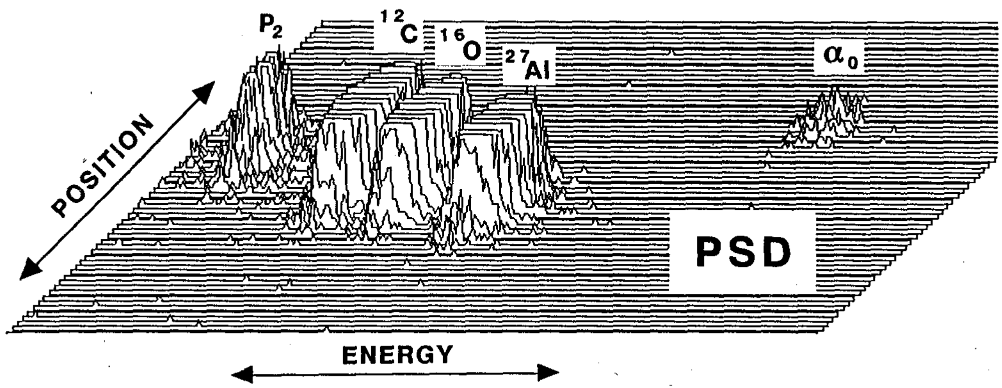

Fig. 6. Two dimensional spectrum of the energy and the position observed for the electrostatic deflector with the high voltage of 15 kV. The peak height more than 200 counts/channel^2 is cut out.

Figure 6 shows the two dimensional spectrum corresponding to the channel numbers from 250 to 500 in the energy spectrum of Fig. 4. In this figure, the peak height more than 200 counts/channel^2 is cut out in the display. Although the charge states for the peaks labeled as ^{12}C, ^{16}O, ^{27}Al and P_2 are same as 1+, the locations of theses peaks are slightly different due to their kinetic energies.

As shown in Fig. 7, we derived the position spectra by setting windows on energy channels corresponding to ^{12}C, ^{16}O, ^{27}Al, P_2 and α_0 events, respectively. We calculated the deflection (Y) using Eq. (1) and the results are shown as solid curve in the upper side of Fig. 7. Solid dots show the measured deflections for each events. We found a good agreement between the measured and calculated results. In the position spectrum, one channel corresponds to the particle energy of about 100 keV for singly ionized particles.

IV. CONCLUSIONS

Throughout the test experiment, the charge-state analyzer (Cstar) developed succeeded in measurement of charge state of protons and α particles in ^{27}Al(p,p) and ^{27}Al(p,α)^{24}Mg reactions. In the present system, the Cstar can be operated under the condition

$$E_k[\mathrm{MeV}]/q<5, \qquad (2)$$

in H.V = 15 kV setting, where E_k is the energy of charged particles in unit of MeV and q is the charge-state number. Thus if Eq. (2) gives the value less than 5, it is possible to measure the charge-state fractions with well separated position peaks. On the position spectrum, one channel corresponds to 0.59 mm in length and also 100 keV for energy. The present analyzer (Cstar) constructed provides us a satisfactory performance from the practical point of view. It is expected that focusing property at the position of the PSD can be improved by using a non-uniform

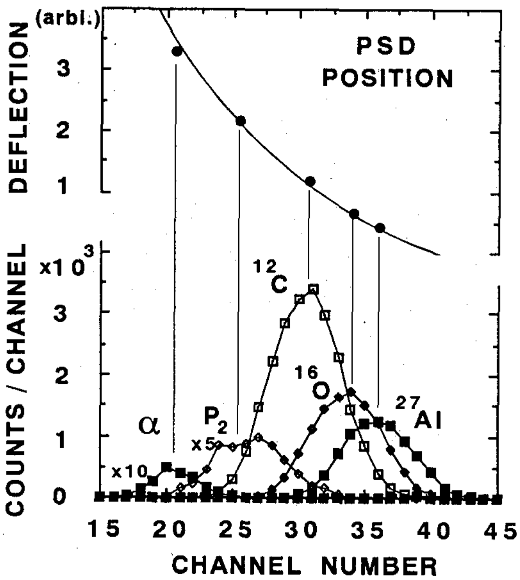

Fig. 7. The position spectra for each elastic proton scattering by ^{12}C, ^{16}O and ^{27}Al, inelastic scattering (P_2) by 2nd excited state of ^{27}Al, and α particles (α_0) from $^{27}Al(p,\alpha)^{24}Mg$ reaction, respectively. In upper side of the figure, full circles indicate measured deflections with the high voltage of 15 kV. Solid curve shows the results of the calculation with Eq. (1).

electrostatic field which can be provided by our deflection system.

V. ACKNOWLEDGMENTS

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