The Construction of Charge-Spectrometer

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The charge-spectrometer was constructed for the observation of the ionic fragments and the charge distribution following nuclear transformation. The optimum condition to collect and accelerate the ions in the source volume was confirmed for the ^{86}Kr of β^- -decay. Then, the correction factors for charge 1, 2, were determined and it was known that the correction factor depended proportionally on the charge of ion.

1. Introduction

The charge-spectrometer was constructed to observe the positively charged fragments from molecular dissociation following nuclear transformation. Because of the unique characteristics of nuclear transformation, the primary atomic and molecular effects induced by this method of excitation and ionization may differ from the effects initiated by conventional external radiation;¹⁾ (1) shaking of the electron core of the atom as a result of sudden change in nuclear charge; (2) recoil of the daughter atom; (3) direct collision of the nuclear particle with an orbital electron; (4) shaking of the electron cloud as the result of the rapid change of the electrostatic field when orbital electrons are ejected; (5) the development of vacancy cascades by successive Auger events. These ionizations may sometimes yield multi-charged particles. When the radioactive atom is one of constituents of some molecule, the molecule is dissociated to the various ions as a result of excitation or multiple ionization following the nuclear transformation.

The charge-spectrometer which is one kind of the mass-spectrometers magnetically analyses the mass to charge ratios (M/e) of ions. In mass-spectrometry, ions dominantly charged with an electronic unit are analysed as to their mass numbers, while in charge-spectrometry ions are analysed mainly as to their charge numbers. The source volume which collects and focuses the ions produced by nuclear events is composed of the several guide rings and focusing grids. Although the radioactive gas must be contained in the source volume at low pressure enough to avoid mutual collisions of ions, molecules, and/or electrons, there must be sufficient partial pressure of the gas to be analysed.²⁾

In the present work, it has been designed for the guide rings and the accelerating grids to intensify the ion-current as far as possible. After testing on various forms and sizes of guide rings, the optimum condition to collect the ions effectively has been obtained and consequently been acquired correcting factors for each charge number.

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2. Experimental Apparatus

The charge-spectrometer constructed in this experiment was nearly the same by S. Wexler in Argonne National Laboratory,³⁾ and some modifications were performed to get more precise measurement. Fig. 1 shows the general view of this apparatus.

Fig. 1. General view of charge-spectrometer

2.1 Source Volume

The source volume was consisted of conic vessel of 16 litres in capacity, therein the radioactive gas was ionized through radioactive decay. It was evacuated with oil diffusion pump of 220 l/sec through the apex and with ion pump of 20 l/sec through the base, then the gas pressure in the source volume was monitored by ionization gauge.

In the source volume, cylindrical guide rings of 15 stages were arranged as shown in Fig. 2. The diameter of cylinders were 290mm, 270mm, and 30mm from the base to the apex, and to perform the higher collection efficiency the conically formed guiding electrode was adopted as the 15th. These guide rings which were set up with insulators were applied ca. 500 V from the first to the 15th.

The ions collected by guide rings were accelerated to several keV

through accelerating ring electrode on which transparent accelerating grid made of stainless steel gauze with 10mm radius semi-spherical form was attached. Finally, the ions were extracted from earth ring with the flat grid of 10mm in diameter.

The voltage applied to the accelerating grid determined the focusing point in front of the magnetic field. Before introduction of radioactive gas into the source volume, several conditionings such as guide ring voltage, accelerating voltage and calibration of detector were performed using the testing ion source.

This ion source which was made of tungsten filament was used not only for the surface ionization source of Na^+ , K^+ , Rb^+ , and Cs^+ , but for the electron impact source of ions of residual gas in the source volume. To determine the most reasonable condition for the focusing of ions and resolving power, the $^{85}\text{Rb}^+$ and $^{87}\text{Rb}^+$ ions were mainly used, and to analyse the residual gas or impurity in the sample gas, the electron impact mode was used.

Radioactive gas was introduced through the variable leak valve of which leak conductance was from 1×10^{-11} l/sec to 1 l/sec. The population of radioactive molecules in the source volume was measured by the ionization gauge and the scintillation detector. The scintillation detector was composed of the 1 inch $\phi \times 1$ inch NaI crystal, and it detected the Bremsstrahlung X-ray if the beta emitter was introduced.

2.2 Analyser

To analyse the M/e of ions, the magnetic analyser of mass-spectrometer was applied. The orbital radius of ion was 300mm and the maximum strength of magnetic field was 5k Gauss. If it was used with conventional ion source

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Fig. 2 Diagram of the major components of the charge-spectrometer

of the mass-spectrometer, the resolving power of this magnetic analyser was more than 2500. The strength of magnetic field by which the M/e of ions could be known was measured with Hall generator whose out put voltage was measured by the digital voltmeter. By this device, the strength of magnetic field was precisely determined down to less than 1 Gauss.

2.3 Detector System

Pulse counting method with the continuous channel electron multiplier was used for the ion detection as had been shown in the previous paper.⁴⁾ The signals obtained from the multiplier were stored in a memory core of a multi-channel analyser. The counting rate of this detector system was 100 %, if the applied voltage to the electron multiplier was more than 3 kV. The charge spectra were finally registered by a digital printer or the Polaroid camera. (See Fig. 3) Although the counting rate of back ground depended on the gas pressure in the detector, they were reduced to 1 c. p. s. or so.

2.4 Gas Pressure

Gas pressure in each part of the charge-spectrometer was shown in Table 1. The apparatus was evacuated by oil diffusion pumps with dryice-alcohol-traps and by ion pumps ultimately to the order of 10^{-7} Torr.

Fig. 3. An example of spectrum of residual gas in source volume.

3. Results and Discussions

3.1 Calibration of the Apparatus

Fig. 4. shows the collection efficiency as a function of applied voltage on the guide rings using nonactive Kr as sample gas. The maximum collection efficiency of ions could be acquired at the condition that the focusing voltage was 3 kV and the applied voltage on the guide rings was more than 450 V.

3.2 Charge Distribution Following β^- -decay of ^{85}Kr

The examination and the calibration of this charge-spectrometer were carried out by determining the charge distribution of ^{85}Rb following β^- -decay of ^{85}Kr .

If the mass was known beforehand

Table 1. Gas pressure in Torr. in each part of the charge-spectrometer.

	Source volume	Analyser	Detector
Before			
introduction	5×10^{-7}	3×10^{-6}	8×10^{-8}
of R. I. gas			
After			
introduction	2×10^{-5}	7×10^{-6}	8×10^{-7}
of R. I. gas			

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Fig. 4. Collection efficiency as a function of applied voltage on the guide rings, in three cases of focusing voltage; 2.0, 3.0 and 3.6 kV.

as the β^- -decay of ^{85}Kr to ^{85}Rb , the charge distribution was simply determined. Varying the collecting and accelerating voltages under the constant strength of the magnetic field, the charge number n in the M/ne was directly determined. It was essential for the collecting and accelerating voltages to be equally efficient from charge to charge. This was ensured by making the collecting and accelerating voltage inversely proportional to the charge number. In the analysis of ionic species following molecular decomposition, however, it was not possible to apply the above mentioned technique. Then, the measured values should be corrected as to the charge discrimination effect.

Fig. 5 shows the raw values of

Fig. 5. Charge-spectrum of ^{85}Rb .

counting rate obtained by this charge-spectrometer for charge 1~4 of ^{85}Rb . Relative intensities of charges 2, 3 and 4 were higher in this measurement than the reported values by Snell and Pleasonton⁵⁾ or the theoretically⁶⁾ assumed values. In Table 2, the percent abundances in this experiment were represented in the third column in comparison with the Snell and Pleasonton's in the fourth column. The differences of the values between these two columns issued from the fact that the collection efficiencies of ions with each charge were not constant in the present experiment, since the ions were collected and accelerated in the constant electric field for every charge. The charge discrimination factors for charge 2, 3 and 4 were represented in the fifth column of Table 2 where the data in 3rd and 4th columns were normalized as to charge 1 and ratios for each charge were taken. This values indicated that for example the collection efficiency for charge 2 was 4.4 times larger than charge 1. Fig. 6 shows the charge dis-

Table 2. Charge abundances of ^{85}Rb and their charge discrimination factors.

Charge	Counts/Min.	Percent abundance	Percent abundance by Snell *	Charge discrim. fact.
1	152	39.6	79.2	1.0
2	91	23.8	10.9	4.4
3	64	16.7	3.91	8.5
4	75	19.6	3.12	12.3

* Ref. (5)

Fig. 6. The linear dependence of charge discrimination factors on charge numbers.

crimination factor for each charge, where linear relation with the charge number can be seen. Consequently the collection efficiency depended exclusively on the charge number.

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