
Identification of Iron Isotopes using CR-39 Track Detector

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Abstract

In order to study the mass identification for iron-group isotopes, we have exposed a stack of CR-39 sheets to ^{56}Fe ions with an energy of 500 MeV/nucleon. A preliminary result showed the mass resolution of CR-39 for iron isotopes to be 0.35 ± 0.11 amu. It was found that the most significant contributions to the mass dispersion were “thickness measurement error” and “depth measurement error” in the present mass identification measurement.

1. Introduction

Measurements of elemental and isotopic abundances, such as iron-group isotopes, in Galactic Cosmic Rays (GCRs) provide rich information of the origin and acceleration and propagation of GCRs. The flux of the particles is very low and the excellent mass resolution is required to observe the individual isotopes in GCRs. Solid state nuclear track detectors (SSNTD) are very promising for the large-scaled observation of these nuclei in space. Moreover, since the plastic track detectors, such as CR-39, respond essentially to only low energy δ -rays ejected by the “distant collisions” in ionization energy loss. We expect that the CR-39 track detector has a better resolution of performance, if we reduce any contribution of experimental ambiguity to mass dispersion. Hayashi et al. [1] reported that the CR-39 track detector had a mass resolution of 0.34 ± 0.14 amu for ^{56}Fe nuclei by the experiment in 1982. After that, the properties of CR-39 have been improved in its quality and performance of particle identification. Therefore, we intend to re-investigate in detail the mass resolution of the CR-39 track detector for iron-group isotopes. In this paper, a preliminary result of mass resolution of CR-39 for iron nuclei is presented.

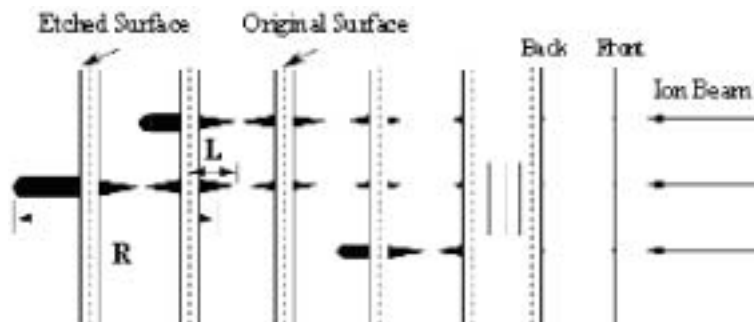


Fig. 1. Schematic view of etch-cones in CR-39 sheets.

2. Experimental procedure

2.1. Principle of mass identification

A swift charged particle passing through SSNTD leaves a trail of damage which is called “latent track”. If the detector is etched in a suitable etchant, the latent track is preferentially etched at a rate of V_t . The etching produces a conical “etch-pit” along a particle’s path in SSNTD, because the bulk etch rate of V_b is smaller than V_t . The etch rate ratio, $V \equiv V_t/V_b$, is a function of the restricted energy loss (REL) of incident particles. V is also a function of the charge and velocity of the incident ion. The range of ion of a definite charge at a given velocity is proportional only to the mass of the ion. Therefore, in the case of SSNTD, the mass identification of the ions can be achieved using the so-called “ L - R pairs” [2], where L is the cone-length of etch-pits on each detector plate and R is the residual range for the ion (see Fig.1). In general, this “ L - R ” technique is analogous to the ΔE - E technique in electronic detectors [3].

L is calculated from the measured values, the sheet thickness, depth from the surface to the cone-tip and the amount of bulk etch. R is also calculated from the sheet thickness, the depth of cone and the cone-length.

2.2. Irradiation and measurements

A stack of CR-39 was exposed to 500 MeV/n ^{56}Fe ions at the incident zenith angle of 30° from the HIMAC accelerator at NIRS. The stack consisted of 90 sheets of CR-39, each of a size of $50\text{mm} \times 50\text{mm} \times 0.9\text{mm}$. The etching was carried out in 7N sodium hydroxide solution at 70°C for 10 hour. The amount of bulk etch from the single surface of the sheet was $22.6\mu\text{m}$ on an average. In this experiment, CR-39 plates (trade name: BARYOTRAK) manufactured by Fukuvi Chemical Industry, Japan were used. This detector material was polymerized from the special high-purity monomer. Therefore, the surface quality after the etching is very clear due to a uniform polymerization. We measured the pairs of the cone-length L and the residual range R of along the particle trajectory

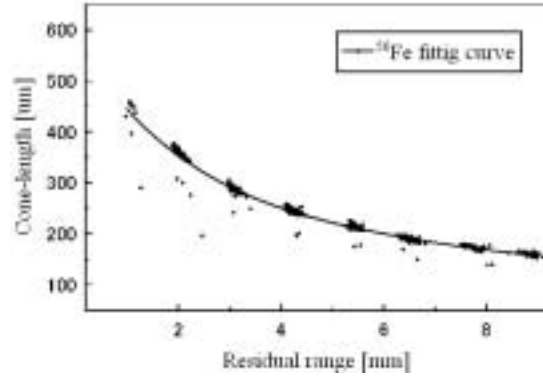


Fig. 2. Cone-length *vs* Residual range for L-R pairs.

recorded in the front 10 sheets from the stopping point.

L was calculated from the value of the depth of cone tip obtained by focusing down of the microscope. R was measured from the stopping point to the center of L . In this experiment, we obtained 567 “ L - R pairs” from 50 incidence particles observed only at the “front” surfaces. Fig. 2 is the scatter plot of “ L - R pairs”. A dominant chain of the data points belongs to iron tracks, while some cones scattered in the lower part are considered to be fragmentation products of incident particles in the stack. The solid line in Fig. 2 is the fitted curve for ^{56}Fe tracks.

3. Results

For each cone, a mass value M_i is determined from Formula (1), where L_i is the cone-length of each track and L_{56} is the cone-length of the fitted curve at each residual range R_i , *i.e.* $L_{56} = f(R_i)$.

$$M_i = 56 \frac{L_i(R_i)}{L_{56}(R_i)} \quad (1)$$

$$\overline{M} = \frac{\sum_i (\Delta L_i)^2 M_i}{\sum_i (\Delta L_i)^2} \quad (2)$$

$$(\overline{\sigma}_i)^2 = \frac{\sum_i (\Delta L_i)^4 (M_i - \overline{M})^2}{\sum_i (\Delta L_i)^4} \quad (3)$$

$$\overline{N} = \frac{\sum_i (\Delta L_i)^2}{(\Delta L_i)_{\max}^2} \quad (4)$$

$$\sigma_M = \frac{\overline{\sigma}_M}{\sqrt{\langle \overline{M} \rangle}} \quad (5)$$

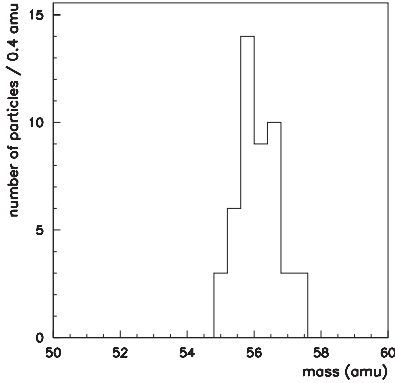


Fig. 3. Distribution of weighted mean mass \bar{M} for iron tracks.

Table 1. Contributions to mass dispersion

Measurement or Parameter Error	Magnitude [amu]
• Thickness measurement error	0.19 (5.56%)
• Depth measurement error	0.10 (2.01%)
• Surface position measurement error	0.02 (0.81%)
• Bulk etch-amount error	0.02 (0.46%)
cone-length calculated error(ΔL)	0.07
residual range calculated error(ΔR)	0.20
Total contribution	0.22

The weighted mean mass \bar{M} is obtained by averaging the measured mass value M_i for each cone (see Formula (2)). Fig. 3 shows the distribution of \bar{M} for iron tracks. Then the deviation for individual particle is calculated from Formula (3). The mean value σ_M of the deviation of \bar{M} for each iron track is 0.56 ± 0.17 amu. Since the average of reduced cone number N for one particle is give as 2.5 ± 0.8 tracks from the Formula (4), the mass resolution is estimated to be 0.35 ± 0.11 amu from the Formula (5).

4. Discussion

We have evaluated the magnitude of contributions of the measurement errors to the mass resolution from each measurement error values as shown Table 1. ΔL and ΔR were calculated from these four parameters, and the errors of mass were calculated from the equations in section 3. The most significant contributions in mass resolution were estimated to be “thickness measurement error” and “depth measurement error”.

“Thickness measurement error” due to the inaccuracy of measurement of CR-39 sheet thickness is the most critical value for estimation of the mass resolution, since this error is accumulated to the value R . If we would measure locally the sheet thickness with an accuracy to $\pm 1.0 \mu\text{m}$, for example, the thickness value in the proximity of the etch-pit will be selectively used for the analysis, then this error will be reduced to about 0.03 amu. And then, because “depth measurement error”, 0.10 amu (an accuracy of the focusing to about $\pm 4.0 \mu\text{m}$) depends on the optical microscope (object lens) system, it is necessary to improve an accuracy of the depth measurement. If we use a newly developed high-speed microscope which have the automated microscope system with an accuracy of the focusing to $\pm 1.0 \mu\text{m}$, so this error will be reduced to about 0.02 amu. Thus, eliminating these errors as much as possible, we expect that the mass resolution will be improved to about 0.20 amu at least.

5. Conclusion

In the preliminary experiment, we obtained that the mass resolution of CR-39, BARYOTRAK, for iron nuclei was 0.35 ± 0.11 amu. In spite of poor statistics, our result agrees with the resolution (0.34 ± 0.14 amu) that previously has been reported [1]. Due to the poor statistics, it is impossible to discuss the performance for identification of iron isotopes at this stage, but we expect that CR-39 track detector has a better resolution of performance, if we can reduce any contribution of experimental ambiguity to mass dispersion. In order to improve the statistics and the accuracy of the depth and thickness measurements, we have started new experiments using a newly developed high-speed microscope which is equipped by a line-sensor and able to scan a wide area of the detector plate very speedily. This measuring system enable us to analyze a large number of etch cone with high precision in a short time. Therefore, we expect that the mass resolution will be improved to about 0.20 amu. Moreover, both of ^{55}Fe and ^{56}Fe ions have been irradiated to a same CR-39 stack from HIMAC. From the analysis of this stack, mass resolution of CR-39 track detector for ^{55}Fe and ^{56}Fe will be experimentally decided.

References

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