A compact isotope identification telescope with a wide dynamic range*

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Abstract A compact $\Delta E - E$ telescope, used to complete the isotope identification for lighter projectile-like fragments in intermediate energy heavy ion collisions, is developed. By detecting the fragments emitted from 30 MeV/u ^{40}Ar induced reactions, it can identify isotopes of up to element aluminum (Z=13).
Keywords Isotope identification, Telescope, Heavy ion collisions, Argon-40 ion beams

1 Introduction

The reactions induced by heavy ions in intermediate energy region (10~100 MeV/u), especially around Fermi energy (~30 MeV/u), exhibit the characteristics of both mean field interaction and nucleon-nucleon interaction. In order to investigate the sources of the fragments, it is important to measure their energies (E), atomic numbers (Z) and mass numbers (A) simultaneously. Considering these observables together, more precise information on the reaction mechanisms will be revealed. For instance, the ratio of neutron number to proton number N/Z of the fragments is an effective probe to investigate the evolution of reaction mechanism from the low energy to high energy heavy ion collisions, since the equilibrium N/Z values of the fragments are sensitive to the reaction mechanisms[1,2]. Moreover, the nuclear temperature parameter can be extracted from the shape of the energy spectrum or the isotopic ratios of the reaction products. And the phase transition of nuclear matter can also be studied by the relation between the temperature and the excitation energy [3,4].

There are various methods[5,6] developed to obtain the E, Z and A of the reaction products, and each method takes its own advantages. Based on the commercial consideration and physical requirements, a compact $\Delta E - E$ telescope was arranged and tested.

2 The $\Delta E - E$ telescope system

2.1 The identification principle

The rate of energy loss of an ion passing through a medium is described by the well-known Bethe-Bloch equation[7]. By taking a simplified form, it can be expressed as

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = aZ^2(c^2/v^2)\ln \mid bv^2/(c^2 - v^2) \mid \quad (1)$$

where a and b are constants depending only on the detector material; v and c the ion velocity and the velocity of light, respectively; Z the atomic number of the ion. For non-relativistic particles $v^2 = 2E/M$ (this approximation is valid at the incident of 30 MeV/u), where E and M are the kinetic energy and mass of the particles, and since the logarithmic term in Eq.(1) varies quite slowly with the energy, Eq.(1) is further simplified as

$$\frac{\mathrm{d}E}{\mathrm{d}x} \propto AZ^2/E \quad (2)$$

In the actual case, the dx represents the thickness of the ΔE detector which keeps a constant for a given ΔE detector. A widely-used form for the particle identification by $\Delta E - E$ method is reached,

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$$E \cdot \Delta E \propto AZ^2 \quad (3)$$

Then the product $E \cdot \Delta E$ provides a measure of AZ^2 in this simplified case. In fact, ΔE and E are only the amplitudes of ionization signals from two successively arranged detectors in the telescope.

2.2 Construction of telescope

According to the principle mentioned above, a $\Delta E - E$ telescope was arranged and tested in an experiment. The constraints from physical requirements listed as follows are also considered. The requirements are a wide dynamical range, a low energy detection threshold, and a large solid angle. The telescope consists of three transmission types of surface barrier silicon detectors with thickness of 43.9 μm (ΔE_1), 580 μm (ΔE_2), and 3000 μm (ΔE_3) employed as ΔE detectors, and a CsI(Tl) crystal with thickness of 50 mm served as the residual energy (E_R) detector. The signals from the CsI crystal are extracted through a photodiode. The 43.9 μm and 580 μm ΔE detectors are developed by the solid detector group at Institute of Modern Physics, and the 3000 μm transmission type detector is from EG&G ORTEC Company, USA.

3 Results and discussion

Each detector used in the telescope was tested by the 5.486 MeV α particles from an ^{241}Am radioactive source. The energy resolutions for the detectors are 0.015 (43.9 μm), 0.01 (580 μm), 0.005 (3000 μm), and 0.03 (CsI).

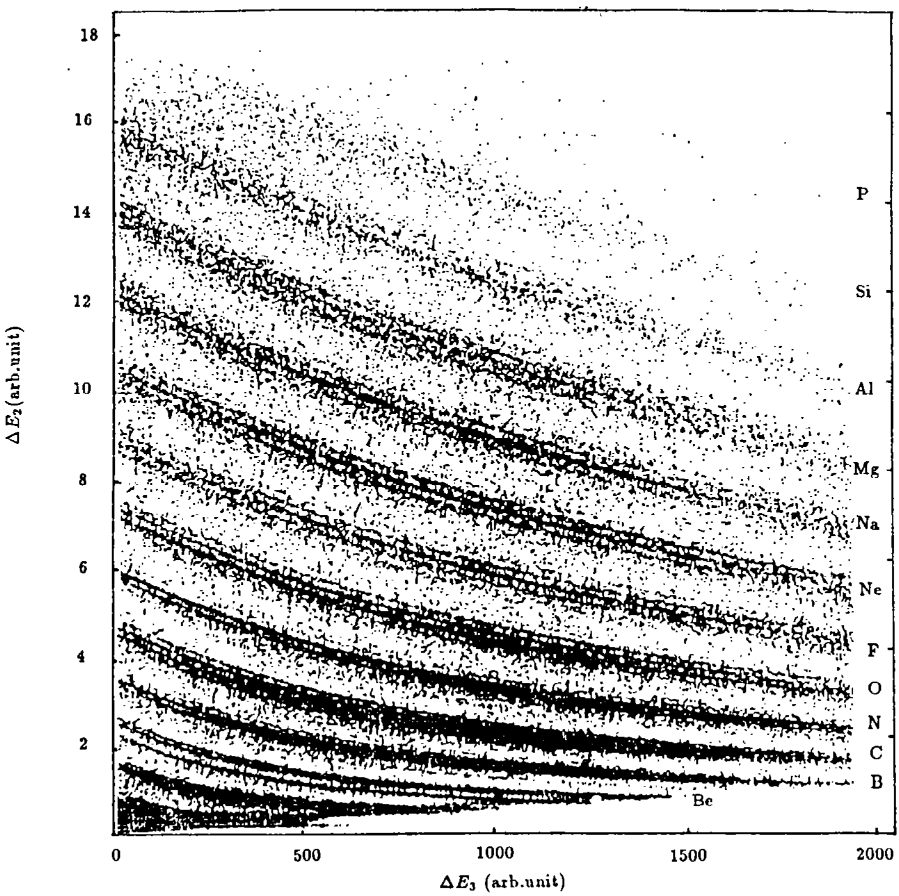

Fig.1 ΔE_2 vs ΔE_3 scatter plot from 30 MeV/u ^{40}Ar induced reactions detected at θ_1=9°

These values do not make any sense for the transmission detectors working under the ΔE detection mode. They only give a hint to the fragments depositing all their residual energies into the detectors.

The overall performances of this $\Delta E - E$ telescope can be revealed by detecting the fragments from the heavy ion induced reactions. The telescope was used in the experiments of 30 MeV/u ^{40}Ar beams bombarding the ^{58}Ni (1.5 mg/cm^2), ^{64}Ni (1.5 mg/cm^2), and ^{115}In (1.5 mg/cm^2) targets. It was mounted on the rotational support in the scattering chamber of TR4 experimental terminal of Heavy Ion Research Facility of Lanzhou (HIRFL). The distance between the target and the telescope is ~40 cm. It covers a solid angle of 1.7×10^{-4} sr. In order to inhibit the secondary electrons knocked out of the target by the beam from entering the telescope, an Al foil with thickness of 1.5 μm and two small rare earth Co magnets were mounted in front of the telescope during the experiment. To suppress the thermal noise, all the detectors were also cooled down below ~0°C.

Fig.1 depicts a typical scatter plot of ΔE_2 vs ΔE_3 obtained by the telescope in the experiment. By analyzing the data off-line, the particle identification (PI) of the telescope is presented in Fig.2. The particles lighter than He (including He) are suppressed by the hard ware cut during the experiment in order to decrease the dead time of the datum acquisition system. The isotope identification up to element aluminium (Z=13) has been achieved by the telescope.

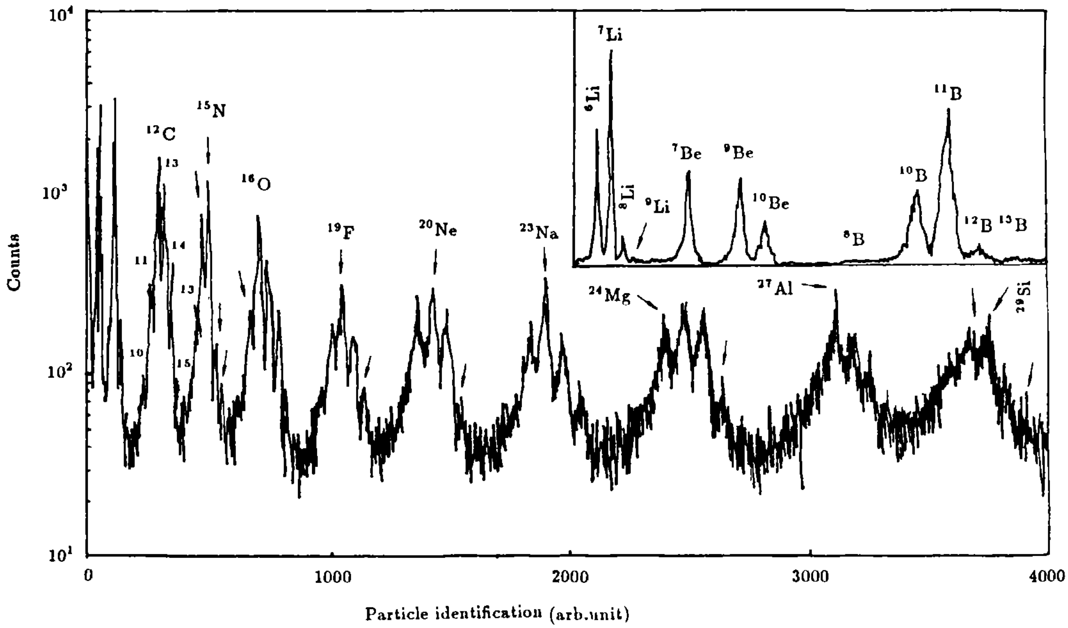

Fig.2 The particle identification (PI) spectra obtained from a measurement at θ_l=9°for ^{115}In target
At the right-top of the figure, an enlarged nuclide distribution of elements Li, Be and B is presented at linear scale

In principle, the isotope identification ability by using this method is limited by the AZ^2 values of different elements which can easily be calculated. It is obvious that overlap of AZ^2 values for neighboring elements may appear for all the elements of Z >5. This may not be held in actual case since the observed distribution of the isotopes populated is not so broad for each element in an experiment. If only 5 or 6 isotopes centered around the stable nuclide(s) for each element are observed in the reactions, this method still works up to $Z \sim 16$.

Except for the limitation induced by the AZ^2 values, the isotope identification power of this kind of telescope is mainly governed by the resolution of ΔE and E detectors. Here a simple estimation can be made. For a given Z value, the mass resolution of $\delta A/A$ linked to the E and ΔE resolutions simply follows the error relation,

$$\frac{\delta A}{A} = \sqrt{\left(\frac{\delta(\Delta E)}{\Delta E}\right)^2 + \left(\frac{\delta E}{E}\right)^2} \qquad (4)$$

Usually the E resolution of less than 0.01 is easily achieved by a thick surface barrier silicon detector. In PI spectra, assuming both shapes, the peak of each isotope and the isotope distributions of each element, following Gaussian shape, then the highest resolved mass numbers A corresponding to different ΔE resolutions are presented in Fig.3 with the fixed E resolutions of 0.01 and 0.005. Normally, the ΔE resolution of $\delta(\Delta E)/\Delta E = 0.015 \sim 0.020$ can easily be reached. The highest value of mass number A which can be identified by this method ranges from 45 to 32 respectively under the estimation.

Considering the results presented in Fig.3 together with the AZ^2 limitation, we can roughly derive the following conclusion. The best isotope identification power for $\Delta E - E$ method is up to element Z=16 (mainly limited by the overlap of the AZ^2 values). The result of our telescope has achieved up to element Z=13.

Moreover, taking the advantage of a large solid angle relative to the time-of-flight technique, the angular distributions among the range of 5° ~19° (at 2° steps) were measured for three targets. It would not be available to complete this measurement by a time-of-flight system in a reasonable beam time period.

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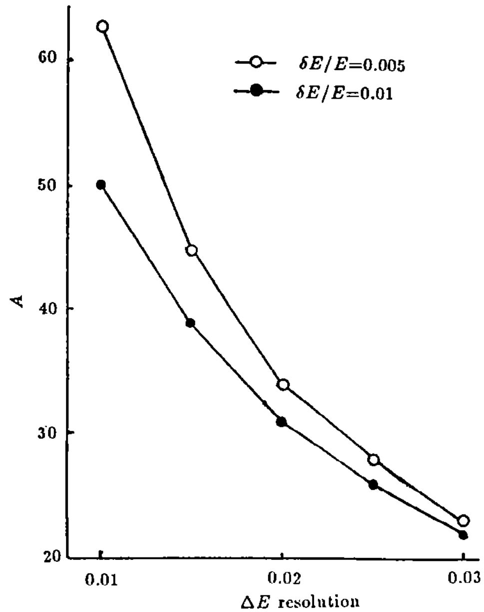

Fig.3 Dependence of maximum A values on the resolutions of ΔE detection

References

1 Di Toro M, Gregoire C. Z Phys, 1985; A320:320.

2 Guerreau D, Borrel V, Jacquet D *et al.* Phys Lett, 1983; 131B:293

3 Natowitz J B, Hagel K, Wada R *et al.* Phys Rev, 1995; C52:R2322

4 Suraud E, Gregoire CH, Tamain B. GANIL P89-04, 1989

5 Coffin J P, Engelstein. Treatise on heavy-ion science, Vol.7. New York:Plenum Press, 1984; 275

6 Dufour J P, Del Moral R, Emmermann H *et al.* Nucl Instru and Meth, 1986; A248:267

7 Livingston M S, Bethe H A. Rev Mod Phys, 1937; 9:261