Identification of heavy nuclei by combination of magnetic analysis time of flight and energy measurements

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Abstract.

The addition of a time of flight measurement to a ΔE-E telescope set up in the focal plane of a magnetic spectrometer improves the identification of very heavy ions. The ΔE silicon detector is 8μ thick. The time of flight is measured between a thin plastic scintillator at the entrance of the spectrometer and the ΔE detector, which gives a flight path of 3m. In order to compensate for the different lengths of the trajectories, the plastic is bent at 15° along the mean trajectory. In these conditions, one has obtained a time resolution of 0.7ns with a solid angle of $1.8\ 10^{-3}$sr (horizontal 2°, vertical 3°). In these conditions, preliminary results already give an unambiguous identification up to mass ≈100.

1. Introduction

New exotic nuclei are expected to be synthetized by heavy ions reactions and new accelerators with high energy and intensity beam will favor this production. Neutron rich nuclei can probably be obtained by transfer reactions and proton deficient nuclei by fusion between heavy nuclei. Then a good identification of the atomic number Z and the nuclear mass M of heavy products between 1 to 10 MeV/nucleon beam energy is crucial.

In this paper will be described a system allowing a good mass identification for the fragments emitted in the reactions Cu + heavy targets (Th, Au, Sn). The identification in Z is limited to Z = 40 by the capability of a ΔE-E telescope constituted by 2 silicon detectors.

2. Mass identification

1) Principle of the method

Experimental works have shown that a telescope E-ΔE in the focal plane of a magnet allows a mass identification of nuclei [1],[2]. The following relation

$$\frac{Z^2_{ef}}{M} = k\,\frac{E}{(B\rho)^2} \qquad (1)$$

where Z_{ef} is the charge state of the ion, shows that such an identification is possible for masses for which

$$\frac{\Delta M}{m} < \frac{\Delta E}{E} + \frac{2\Delta(B\rho)}{(B\rho)}$$

Usually, the measurement of the magnetic field value is good enough to be able to neglect the $\frac{\Delta(B\rho)}{B\rho}$ term. The mass identification is limited by the energy resolution of the solid state detector. This method gives a good identification for masses up to M ≈ 40. For heavier masses, the energy resolution is not sufficient. If a time of flight measurement is added, the relation

$$\frac{Z_{ef}}{M} = \frac{k'}{T}\ \left(\frac{1}{B\rho}\right) \qquad (2)$$

shows that if Z_{ef} is known, the precision of the mass measurement is given by the time of flight

$$\frac{\Delta M}{M} < \frac{\Delta T}{T} + \frac{\Delta(B\rho)}{B\rho}$$

Time measurements can be performed with a high precision, and the time of flight of ions can then be known with the needed accuracy, if the different trajectories of the nuclei in the magnet are known. To be able to determine Z_{ef}, it is not necessary to know very precisely the energy of the ion. This fact constitutes a very interesting property of the system, since, until now, the energy of heavy ions cannot be accurately measured.

The time signals are given by constant fraction discriminators behind a voltage sensitive preamplifier for the E detector, and behind a photomultiplier for the thin scintillator. All the electronics were made in the laboratory.

2) Experimental set-up

The magnet used is a double focusing dipole primitively designed for spectroscopy purposes. Its solid angle is of 4 degrees both horizontally and vertically. The energy of the ions is measured with ΔE-E silicon counters in the focal plane of the magnet. The ΔE counter is a 8.8μ ORTEC surface barrier detector. The time of flight is measured between the E counter and a thin plastic scintillator at the entrance of the magnet. The total length of the flight path is 309 cm. The scintillator foil of 140 μg/cm² thickness has a size of 25cm×8cm. It could be rotated from outside to correct the differences of trajectories lengths. Its angle with the ion beam direction was determined experimentally, using elastic scattering of ions on a gold target. The best time resolution which corresponds to the best possible correction of the outward and inward trajectories in the magnet was obtained for an angle of 20° with the ion beam direction. The solid angle has then to be reduced to 2° horizontally and 3° vertically. The thickness of the plastic scintillator seen by these ions is then 410 μg/cm². For copper ions, between 1 MeV/nucleon and 7 MeV/nucleon the energy loss varies from

19.4 MeV to 15.6 MeV [3]. The best time resolution achieved up to now is of 700 ps. With the accelerator Alice, the fastest ions to identify have a time of flight of 80 ns. The obtained time resolution would allow the identification of any mass produced with this accelerator, providing a good enough energy measurement. In fact, the limitation of the time resolution is due to the precision of the time determination in the plastic scintillator. The photomultiplier sees the scintillator through a small lucite guide concentrating the light on the photocathode. There is no contact between the light guide and the scintillator. In these conditions one cannot expect to collect more than a few photons per event, introducing fluctuations in the rise time and on the shape of the pulse given by the photomultiplier.

3) Results

Some iron isotopes identified by this method are presented. On fig.1, a E-ΔE matrix is represented with windows corresponding to the 20+, 21+, 22+ charge states determined for energy calibrations. Figure 2 shows the mass identification given by the time of flight corresponding to those 3 windows.

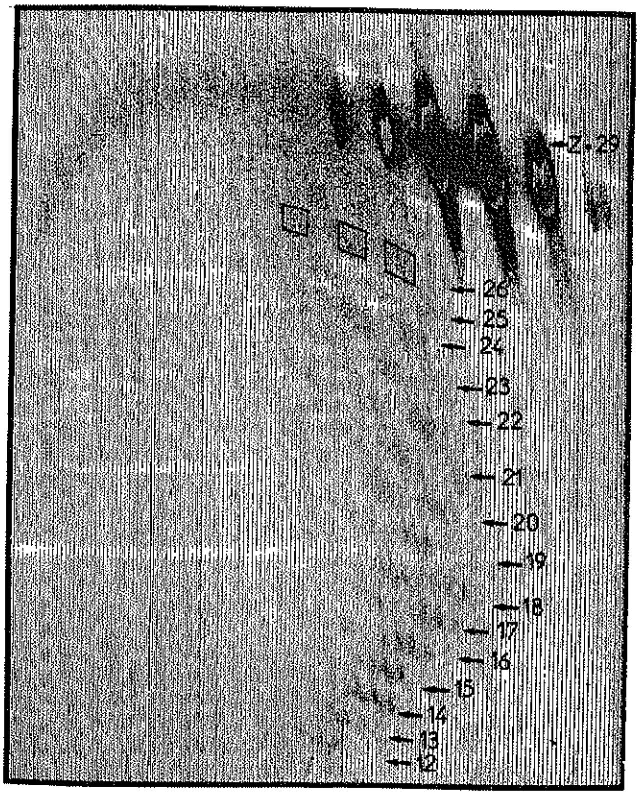

Fig.1. Bidimensional spectrum of a E-ΔE matrix obtained in the ^{65}Cu+^{124}Sn reaction. Fe^{20+},Fe^{21+},Fe^{22+} windows are represented.

Identification of masses up to 100 and atomic number up to 40 was achieved. For the identification of heavier masses, it is necessary to improve the energy definition in the E counter, and for the identification of the atomic number, to obtain a better energy resolution in ΔE measurements.

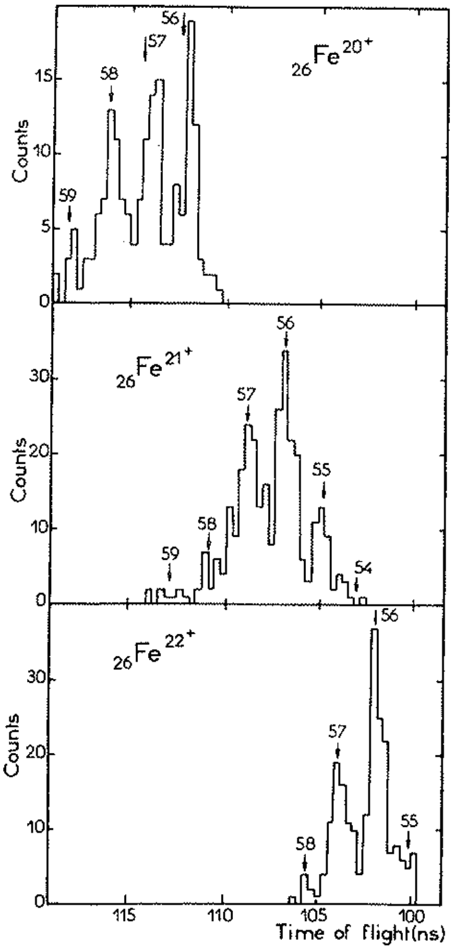

Fig.2. Time of flight spectra corresponding to the 3 windows represented on fig.1.

3. Conclusion

The method described above, allows the determination of the mass of any heavy ion for which the energy resolution of the E counter is known with enough accuracy (namely 1%). This precision of the energy measurement can be much lower than the one needed in a direct determination of a heavy mass with a time of flight and a E counter. Furthermore, the time of flight can be measured on a long flight path without any loss of the solid angle. One can also notice that a magnet allows measurements to very small angles.

Our experiments have been done with a simple dipole available at the laboratory. For these types of measurements the high resolution of this magnet is not necessary. The dispersion has only to be good enough to allow a determination of $\frac{\Delta(B\rho)}{B\rho} \sim \frac{1}{1000}$. It should be suitable to use a magnet able to cover a larger solid angle of about 10^{-2} steradian, and for which the corrections on the trajectories would be as small as possible.

References

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