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Z-IDENTIFICATION OF HEAVY IONS BY ENERGY LOSS IN FOILS.

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ABSTRACT.

A heavy ion Z-identification technique based on the measurement of the energy loss in solid absorbers has been investigated. The homogeneity characteristics of C, Al, Formvar and Mylar thin foils have been studied using α-particles. The Z-resolving power of selected absorbers has been measured using HI beams.

1. - INTRODUCTION.

With the operation of the 16 MV Tandem accelerator facility at the Laboratori Nazionali di Legnaro(1), a large number of heavy ion (HI) induced reactions may be investigated.

Composite system with $A \sim 100$ and specific energies in the range 1-2 MeV/amu can be produced using various target-beam combinations. By performing the complete identification (A, Z, E) of the heavy reaction products, it will be possible to study e. g. the production and structure of nuclei far from the stability line and details of the fusion reaction mechanism, as well as the competition with fission or deep-inelastic processes. From the experimental point of view, a detection system is needed to perform mass and charge spectrometry with resolutions $A/\Delta A \simeq 100$ and $Z/\Delta Z \simeq 40$.

We report here on the development of a Z-identification technique based on the measurement of the energy loss of heavy ions in a solid passive absorber.

This method was already successfully applied in the region $Z \sim 40$, $A \sim 100$, $E/A \sim 1$ MeV/amu at the recoil mass separator Lohengrin in Grenoble(2), achieving higher Z-resolving powers than with conventional ΔE-E telescopes using Silicon Surface Barrier Detectors (SSBD) or gas detectors.

The planned experimental arrangement for the experiments at LNL is shown in Fig. 1. The ionic mass identification is performed by measuring the time of flight (TOF) after the absorber (Δt_2) and the residual energy (E_{res}).

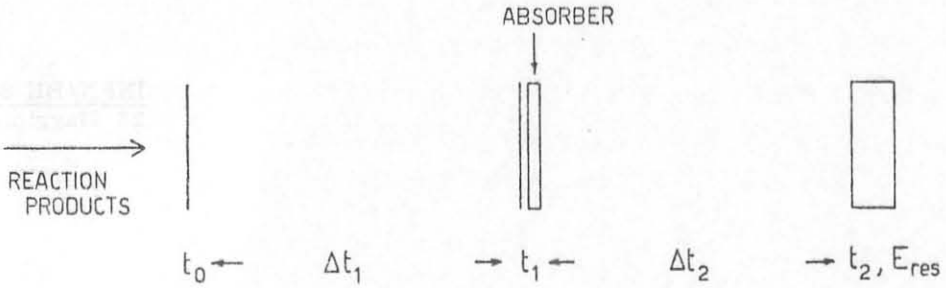

FIG. 1 - Planned experimental arrangement for mass and charge identification of heavy ions.

Deriving then the energy of the unslowed nucleus (E_{inc}) from the mass and the time of flight before the absorber (Δt_1), one gets the energy loss $\Delta E = E_{inc} - E_{res}$ achieving a complete identification (M, E_{inc}, $Z \sim \Delta E$).

The resolving power of a Z-identification system based on ΔE measurements is determined by the condition $\Gamma/\delta E_{res} < 1$, Γ being the detected energy width after the absorber and δE_{res} the difference in energy loss of two neighbouring isobars incident on the system with equal velocity.

It is clear, pushing the comparison with conventional ΔE-E systems, that the Z-identification by energy loss in solid passive absorbers using a double time-of-flight arrangement has its own drawbacks :

a) a larger number of detectors is needed (but not a larger number of signals and parameters are to be handled) ;

b) the solid angle is smaller, due to the second flight path.

However, the use of passive absorbers offers also major advantages : in fact, in conventional ΔE-E telescopes Γ is due to the characteristics of absorbers (energy loss straggling and material inhomogeneities) as well as to the ΔE detector resolution and the two contributions are hardly separated, because the absorber is the ΔE detector itself. In the present technique the two functions (energy absorption and energy detection) are separated. In this way the energy resolution of the system can be optimized (e.g. using time of flight techniques with long flight path) and it is also possible to choose the best absorber for any particular experimental situation.

As a first step of the experimental program, an extensive study of materials to be used as absorbers was done. In Section 2, the results on the homogeneity characteristics of C, Al, Formvar and Mylar thin foils are presented.

The Z-resolving power of selected absorbers was then measured using HI beams ; Section 3 reports these results.

A brief discussion follows in Section 4, where a comparison is made between the achieved Z-resolving power and the needs of the planned experiments at the 16 MV Tandem facility at LNL.

2. - MATERIALS INVESTIGATION.

2.1. - According to theoretical estimates(3) and experimental results(4), the energy straggling at equal energy losses of the projectile increases with the nuclear charge of the energy absorber. The range of possible absorbers may thus be limited to low-Z, high homogeneity materials. Let us call Γ_{abs} (FWHM) the measured line broadening suffered by monoenergetic particle passing through the absorber; the comparison of Γ_{abs} with a reliable estimate of the energy loss straggling, gives us insight into the foil inhomogeneities.

2.2. - Carbon foils.

C-foils made by vacuum evaporation were used in Grenoble(2). The microscopic inhomogeneities of evaporated C-foils are related to the used parting agent(5). Macroscopic inhomogeneities, arising from the floating off procedure, can be avoided only selecting in planarity over a number of foils.

In a first measurement four stacks, made respectively of 1, 2, 3, 4 x 80 $\mu g/cm^2$ C-foils, were tested. A 2 mm diameter α-particles beam (E_α = 1.75 MeV) from the AN 2000 Van de Graaff accelerator hit the target (a 10 $\mu g/cm^2$ C-foils or the stack itself) and the scattered particles were detected at $\theta = 4^o$ by a TOF system. Two transmission time-detectors employing micro-channel plate electron multipliers were used(6).

The intrinsic time resolution was determined using beams in the energy range E_α = 1.1-1.75 MeV incident on the thin (10 $\mu g/cm^2$) target and the results was δt = 300-400 psec (fwhm), depending on the particles energy and corresponding to an energy resolution δE = 12-20 keV over the 50 cm flight path.

The measured Γ_{abs} for the C-stacks are reported in Fig. 2 together with the energy loss straggling prediction according to Tschälar(7). The agreement between experimental data

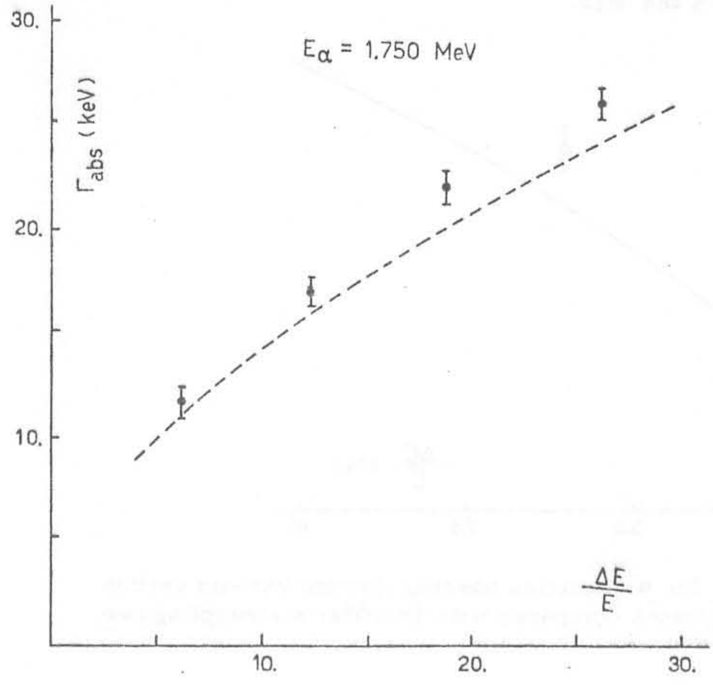

FIG. 2 - Experimental line broadening Γ_{abs} suffered by monoenergetic α-particles passing through various carbon absorbers (1, 2, 3, 4 x 20 μ/cm^2) compared with Tschälar's straggling predictions(7) (dashed line).

and calculated values is fairly good. A qualitative estimate of the inhomogeneity contribution Γ_{dis} can be made subtracting quadratically the calculated straggling from Γ_{abs}. The results are displayed in Fig. 3. In spite of the large uncertainties inherent to this procedure, a $\sim 3\%$ average value for the inhomogeneities is determined. The obtained results show the intrinsic good characteristics of the C-foils. Nevertheless the experimental procedure just described is very time-consuming and does not allow a fast screening of a large number of foils or stacks.

A more simple method, using a radioactive source and a silicon detector measuring directly the energy broadening caused by the absorber was used for the tests described in the following. Fig. 4 displays a second set of experimental Γ_{abs} values on C-stacks made of 2, 4, 6, 10 x 80 $\mu g/cm^2$ foils.

The agreement with the calculated straggling values is rather poor. The increase of the inhomogeneity contribution may be related to the large area ($\sim$7 mm diameter) investigated.

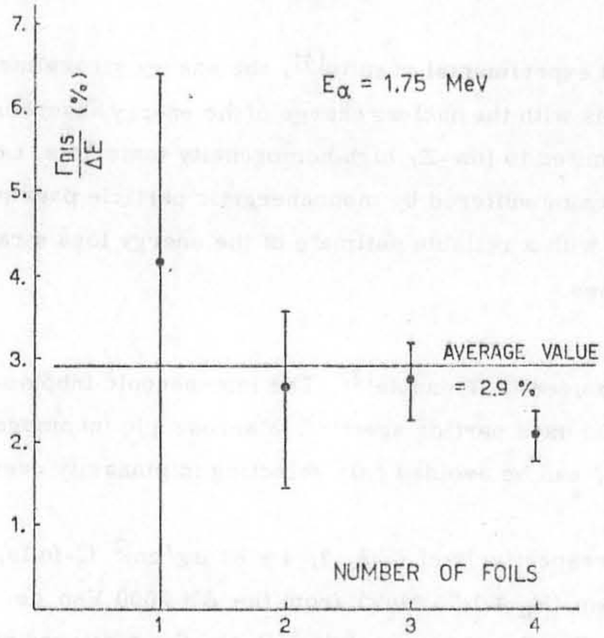

FIG. 3 - Estimated inhomogeneity of carbon stacks.

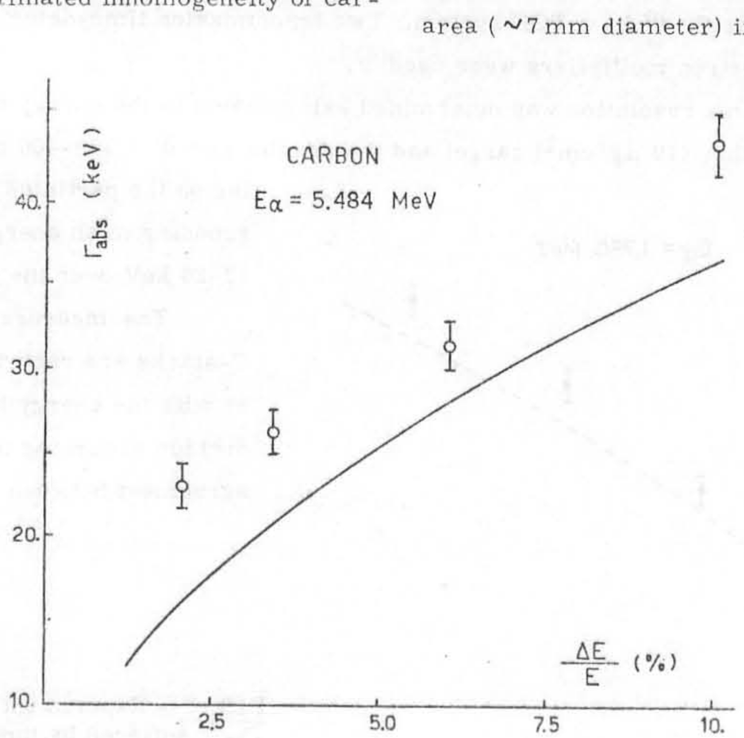

FIG. 4 - Experimental Γ_{abs} for α-particles passing through various carbon absorbers (2, 4, 6, 10 x 80 $\mu g/cm^2$) compared with Tschälar's straggling predictions[7] (full line).

2. 3. - Aluminium foils.

Three samples made of 1, 2, 3 x 1 μm thick commercial aluminium foils were tested. The results are reported in Fig. 5 together with the Tschälar prediction[7] and experimental data from ref. (8).

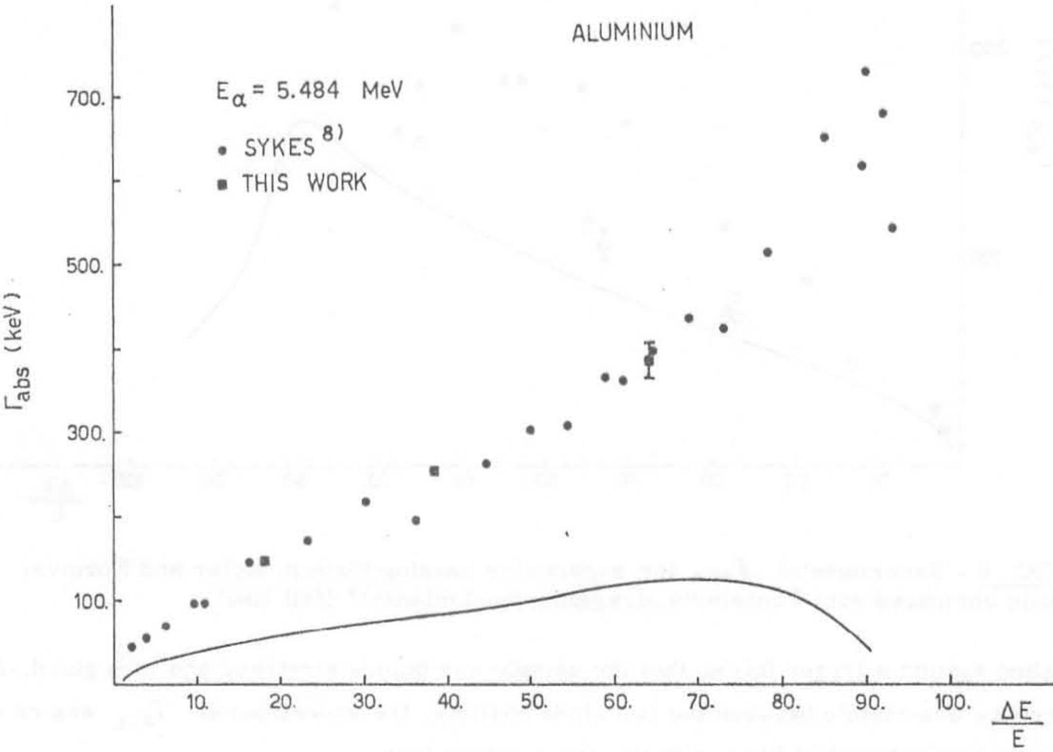

FIG. 5 - Experimental Γ_{abs} for α-particles passing through commercial aluminium foils compared with Tschälar's straggling predictions[7] (full line).

The experimental data are systematically higher than the prediction values. The anomalous straggling of the commercial Al-foils can be related to gross non-uniformity or microscopic pin-holes[8].

2. 4. - Plastic foils.

Four stack made of 1, 2, 3, 4 x 6 μm thick commercial Mylar foils and two samples made of a number of thin (20-40 $\mu g/cm^2$) home-made Formvar foils[9] were tested. In Fig. 6 the experimental data are compared with the Tschälar prediction[7] and the data from refs. (8, 10). The rather good agreement between experiments and predictions indicates the good homogeneity of these plastic materials.

The mechanical properties of Mylar and Formvar foils, allow an easy mounting on the frame, so that gross non-uniformities can be avoided. This feature has been evidenced performing a specific test. Two series of samples were prepared using different mounting procedures and tested. In the first case the Mylar was directly glued on the frame, in the second case the frame

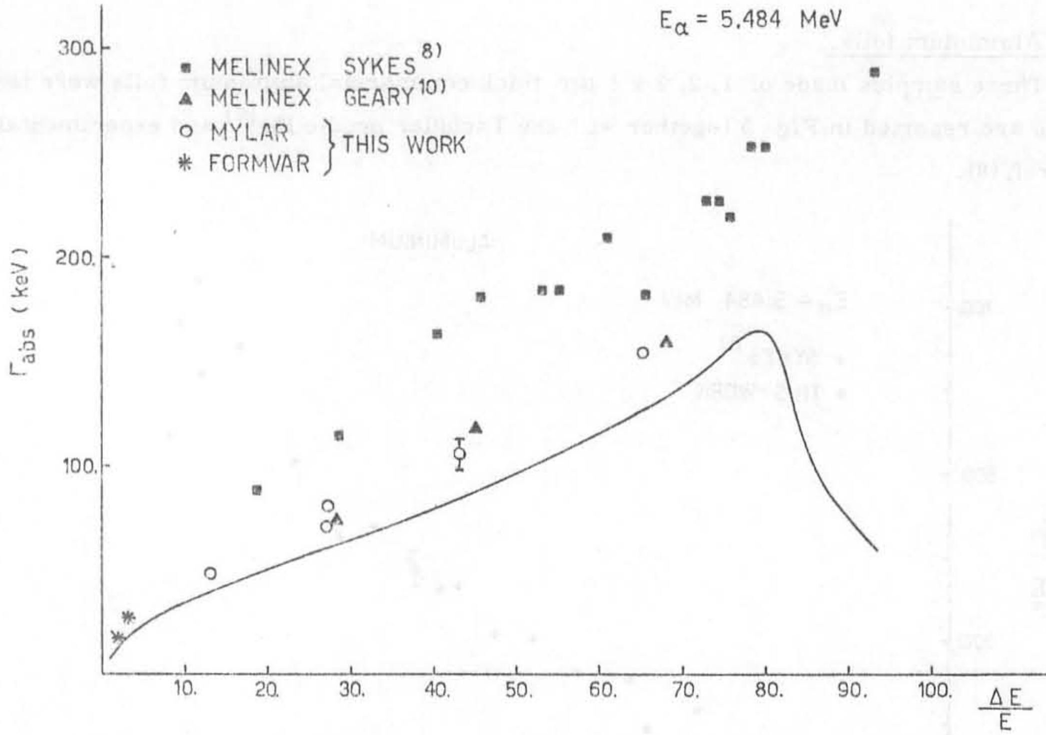

FIG. 6 - Experimental Γ_{abs} for α-particles passing through Mylar and Formvar foils compared with Tschälar's straggling predictions(7) (full line).

was pushed against a larger foil so that the sample was before stretched and then glued. Although no difference was visible between the two kinds of films, the experimental Γ_{abs} was on average 12 % higher for unstretched films with the same energy loss.

2.5. - Conclusions.

The present results show that carbon and Mylar foils can be used as absorbers for Z-identification. The use of both materials has some advantages: the C-foils are intrinsically homogeneous but gross non-uniformities can be present due to the floating off procedure. They are also rather fragile and unconfortable to handle. On the other side they can be made with the wanted thickness.

Mylar films have a good homogeneity and mechanical properties allowing the preparation of high planarity absorbers. Only a few thicknesses are commercially available restricting their practical use. Formvar films look promising to overcome the Mylar disadvantages and the technique to make routinely these films is currently under investigation at LNL.

3. - EXPERIMENTAL DETERMINATION OF THE Z-RESOLVING POWER.

The Z-resolving powers of Carbon and Mylar absorbers were determined using 8 MeV $^{12}C^{++}$ and $^{14}N^{++}$ beams from the 7 MV CN Van de Graaff accelerator.

The carbon absorber was made of $6 \times 80\ \mu g/cm^2$ foils, the Mylar absorber of $2 \times 2.5\ \mu m$ foils ($\simeq 750\ \mu g/cm^2$).

The ions scattered by the absorber itself were detected at $\theta = 4^o$ using a Silicon detector. The energy calibration was performed with α, C, N beams and a thin ($\sim 10\ \mu g/cm^2$) carbon scatterer. An instrumental energy resolution $\delta E \sim 100$ keV (fwhm) with 8 MeV C, N beam energies was measured.

The results obtained are displayed in Table I, which reports the energy loss ΔE and the measured line width Γ including the instrumental resolution, for the different ions. Preliminary measurement with ^{241}Am α particles are included for comparison.

TABLE I

Particles	Energy	Carbon absorber				Mylar absorber			
		ΔE (MeV)	$\Delta E/E$ (%)	Γ (keV)	$\Gamma/\Delta E$ (%)	ΔE (MeV)	$\Delta E/E$ (%)	Γ (keV)	$\Gamma/\Delta E$ (%)
α^*	5.48	0.436	8.0	37	8.4	0.596	10.9	49	8.3
^{12}C	8.00	3.49	43.6	176	5.0	5.57	69.6	245	4.4
^{14}N	8.00	4.58	57.2	189	4.1	6.62	82.7	157	2.4

* ^{241}Am Source

The experimental data are believed to be within 5 % overall accuracy.

The Z-resolving power can be obtained as :

$$Z/\Delta Z = Z\ \delta E_{res}/\Gamma$$

were δE_{res} is the difference in energy loss between isobars with charge Z, Z - 1 and Γ is the energy width of the detected ions.

Using the data of Table I and correcting the ^{12}C results with the aid of the Northcliffe and Schilling[11] tabulation to account for the different energy loss of ^{14}C and ^{12}C, the following conclusions can be drawn :

at $Z = 7$ $\quad Z/\Delta Z = 46 \pm 4$ for the Mylar absorber,

$\quad Z/\Delta Z = 40 \pm 4$ for the Carbon absorber.

A further experiment with a Mylar absorber was done at the MP Tandem in Munich.

A 258 MeV ^{60}Ni beam was used, impinging on a ^{118}Sn (110 $\mu g/cm^2$) target.

The elastically scattered ions were detected at $\theta = 60^o$ (the corresponding energy was 147.2 MeV) by a TOF system using a MCP detector as start and a SSBD as stop. The measured time resolution of the system was Δt = 200 psec (fwhm). The absorbing stack was placed between the target and the start detector, and was made of 2 x 6 μm Mylar foils. Testing the stack with a ^{241}Am α-particles the following results had been obtained:

$$\Delta E = 1.47 \text{ MeV} \quad (\Delta E/E \sim 27\%), \qquad \Gamma_{abs} = 76 \text{ keV} \quad (\Gamma_{abs}/\Delta E \sim 5.1\%).$$

The in-beam results obtained with ^{60}Ni are:

$$\Delta E_{exp} = 76.5 \pm 3.8 \text{ MeV} \qquad (\Delta t = 10.20 \text{ nsec}),$$

$$\Gamma_{exp} = 1.74 \pm 0.09 \text{ MeV} \qquad (\delta \Delta t = 0.400 \text{ nsec}).$$

These numbers have been compared with the prediction of a computer program(12) calculating the energy loss and the energy loss straggling of heavy ions. The calculated value are:

$$\Delta E_{calc} = 73 \text{ MeV} \qquad (\Delta E_{exp}/\Delta E_{calc} = 1.05),$$

$$\Gamma^{str}_{calc} = 1.20 \text{ MeV}.$$

Adding to the calculated straggling the instrumental time resolution, a contribution due to the finite solid angle of the set-up and a 1 % inhomogeneity of the Mylar absorber, we have:

$$\Gamma_{calc} = 1.82 \text{ MeV} \qquad (\Gamma_{exp}/\Gamma_{calc} = 0.96).$$

The agreement between experimental data and calculation is fairly good: it seems therefore reasonable the use of a calculated value for the isobaric difference in energy loss to estimate the Z-resolving power. A $\delta E^{calc}_{res} = 3.14$ was calculated for the isobars A = 60, Z = 28, 29; this implies:

$$Z/\Delta Z = 50 \quad \text{at} \quad Z = 28.$$

4. - CONCLUSIONS.

Z-identification techniques with a high resolving power are important tools in studying Heavy Ion induced reactions. Good intensity ^{32}S and ^{58}Ni beams will be soon available at the 16 MV Tandem facility at LNL with sufficient energy (up to 6.5 and 4.5 MeV/amu respectively) to overcome the Coulomb barrier with medium weight nuclei targets. A detection system is therefore needed to perform in-beam mass and charge spectrometry of heavy reaction products with resolutions $A/\Delta A \gtrsim 100$, $Z/\Delta Z \gtrsim 40$.

The results here presented show that such a Z-resolving power can be achieved using the passive absorber technique with Mylar (or Carbon) foils. A higher Z-resolving power seems to be possible using plastic absorbers(13).

The in-beam test of the whole identification system is planned for the near future at the XTU Tandem facility.

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