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A STUDY OF NUCLEAR COLLISIONS OF 86 MeV/a.m.u. ^{12}C WITH HEAVY TARGETS BY COLLECTION OF THE HEAVY RECOIL NUCLEI

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The aim of the proposed experiment is twofold. We desire first to test with relativistic heavy ions the apparatus which until now has been used at Orsay on the Alice facility with heavy ions at energies around 6 MeV/a.m.u. and secondly get some insights into nuclear reactions induced by 86 MeV/a.m.u. ^{12}C using the possibilities of the recoil chamber.

I - EXPERIMENTAL METHOD

a - Device

The basic principle for the ion collection is the following. The recoil nuclei escaping from the irradiated target are first, in $\sim 10^{-7}$ sec, thermalised in a gas (N_2). Experimentally, it has been shown that at the end of their paths the ions are not completely neutralised. One then takes advantage of their remaining charge to collect them with an electric field on the surface of a solid state detector. The velocity along the second path is about 10^{+4} cm/sec at low pressure.

This method compared to the helium jet technique presents the following advantages i) it allows the knowledge of the recoil range distribution of the nuclear reaction products and therefore the energy distribution. ii) if the use of a low gas pressure is possible, it allows the detection of short lived nuclei. iii) it is easy to move.

The set-up is presented in fig. 1 with its initial collecting plates. Different electrostatic configurations have been used, as shown on fig. 2a-2b. Some others are still being tested (fig. 2c).

b - Tests already completed

The experimental procedure was first tested by using recoil nuclei that escaped from an α radioactive source of ^{224}Ra. Next the short live isotopes of Er (half periods of only a few seconds) produced in the compound nuclear reaction $^{40}Ar + ^{118}Sn$ have been collected.

We have shown that several parameters influence the efficiency and the speed of collection : i) the nature and pressure of the gas. ii) the values of the electric field and of the length of the second path. iii) the configurations of the electric field. iv) charge of the heavy ion beam.

The best conditions for collection are not still completely settled. At present we have obtained the following results :

1) With the use of electric configurations presented in fig. 2a and 2b the background of the solid state detector is very low even during the beam bursts.

2) The collection of α emitters directly on the surface of the detectors allows an energy resolution limited only by that of the detectors themselves. In fig. 3 is shown an α particle spectrum obtained in the reaction ^{40}Ar + ^{118}Sn.

3) The absolute efficiency of the system is an increasing function of the gas pressure in the chamber. We go from 0.7 % for P = 100 millibars to 6 % for P = 700 millibars. The reason for this evolution is not yet fully understood. It may be explained by the fact that as the gas pressure decreases the secondary ionisation in the chamber increases and the space charge induces a larger distortion of the initial electric field and consequently a defocalisation (with the ^{224}Ra source, i.e. without beam ionisation, the collection efficiency is around 95 %, independent of pressure, with the collection system shown on Fig. 2b). The efficiency is also a function of charge of the incident beam and decreases as Z increases. This last parameter has not yet been completely studied.

4) The collection time of the recoil nucleus is a decreasing function of the gas pressure. We get ≃ 1 sec for P = 700 millibars and around 10 ms for P = 100 millibars).

c - Conditions of collection with relativistic ^{12}C ions

The use of very energetic ^{12}C ions seems to be very well adapted to this technique as Z and dE/dx are very low. The primary and secondary ionisations will be certainly much lower than for ^{40}Ar ions at 6 MeV/a.m.u., and consequently the collection efficiency and collection times might be better.

Some other parameters are more critical : i) the maximum angular acceptance of the recoils is about 60° for the devices already tested. ii) the recoil energies have to be large enough to allow the nuclei to escape from the target. iii) the cross section values have to be around 0.1 mb for a flux of 10^{+11} ions/sec and a target thickness of 200 $\mu g/cm^2$.

II - USE OF THE RECOIL CHAMBER IN ^{12}C INTERACTIONS AT 86 MeV/a.m.u.

The region of incident energy around 86 MeV/nucleon is largely unexplored and even the qualitative aspects of nuclear reactions are poorly understood.

On the contrary,collisions between complex nuclei have been intensively studied in experiments both at high and low energy. In the low-energy regime reaction processes of fusion or inelastic collisions are correctly described with the concepts of potential of the interaction, friction, and diffusion. In the high-energy regime, nuclei undergo such violent collisions that the reactions proceed by independent collisions (two body friction) of the constituent particles. The nuclear fireball model gives good results for this high energy zone. The intermediate energy region will probably show transitional phenomena and numerous reaction mechanisms will be present.

Whatever mechanisms occur, most of the final heavy nuclei produced with ≃ 1,000 MeV incident ^{12}C will have masses lower than that of the target. In the case of fusion, the excited nucleus will evaporate 40 to 60 particles. In the case of the fireball model the projectile will sweep out a non negligeable fragment of the target. The remaining heavy partner is not expected to be very excited. This means that the A values of the observed residual nuclei can be very much the same in these two cases. On the contrary the N/Z value of the final nucleus may give some insights into the machanisms involved.

If a complete or partial fusion occurs in these interactions, the intermediate nucleus will be caracterised as follows : i) N/Z value not far from that of the stability line. ii) a very high excitation energy. This situation strongly favors neutron emission during the deexcitation process. Moreover, in the case of heavy targets, the ratio Γ_n/Γ_p (Γ_n and Γ_p are the probabilities of evaporating a neutron and a proton respectively) becomes less than unity only far from the stability line (15 to 23 neutrons away). This result is shown on Fig. 4 where the stability line and the region where $\Gamma_n/\Gamma_p \simeq 1$ are plotted. The accuracy in locating this line has been estimated from the uncertainty in the mass evaluation (dashed area). An excited nucleus will tend toward this line from either side by preferentially evaporating the appropriate nucleons. In the case of $Z \geqslant 68$ this line goes throught the zone of α emitters. So a complete or partial fusion mechanism between energetic ^{12}C ions and heavy targets will give evaporation residues caracterised by α emission and N/Z values ≃ 25 % lower than the N/Z value at the stability line.

If a mechanism occurs similar to that of the fireball model the target nucleus may lose nucleons in the same N/Z ratio, and leave the remaining heavy fragment with a low excitation energy. So the observed nucleus will have about the same N/Z value as the target.

These considerations suggest that in the case of heavy targets the N/Z values of the residual nuclei may be a good parameter to discriminate the major mechanisms involved. On the contrary, in the case of light targets, proton evaporation from the excited nucleus is highly competitive with the neutron emission. The reasons for this are firstly the low Coulomb barrier and secondly the presence near the stability region of the line $\Gamma_n/\Gamma_p = 1$. Consequently, regardless of the mechanism, the final product will have almost the same N/Z value.

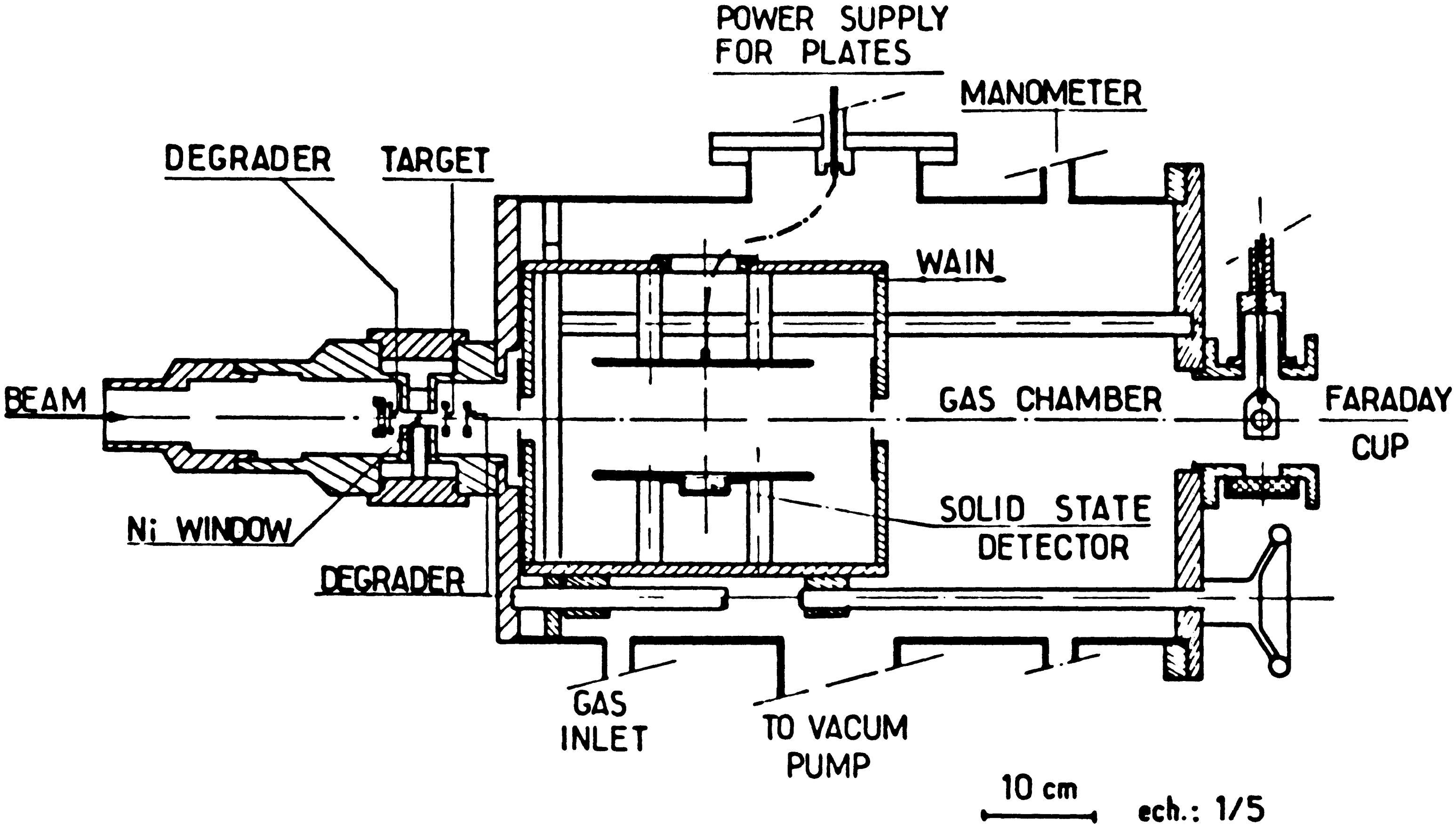
Our experimental method is able to give the N and Z values of the detected nuclei (using α spectroscopic techniques) and simultaneously the cross sections of formation and possibly the recoil energy. We expect to use heavy targets like Ho, Ta, Pb and Th to detect first the neutron deficient nuclei between $Z = 64$ and 80 and second the α-emitters of atomic number $Z > 82$ which will be produced if intermediate nuclei are formed with only small excitation. We can use also this chamber to detect new neutron deficient α emitters.

If lower beam energies are available measurements of the range of the residual nuclei (primarily of the fusion-like processes) will allow the study of the evolution of momentum transfer with incident energy.

Beam time requirement :

For the first experiments (i.e. tests of the chamber) we would require a run of about 9 eight-hour shifts. The device is ready for this first run.

For studies of nuclear reactions we ask for another run of 9 eight-hour shifts at 86 MeV/a.m.u., one or a few months later. If other energies are available with similar intensity we will ask for a few additional runs later.


POWER SUPPLY
FOR PLATES
MANOMETER
DEGRADER
TARGET
WAIN
BEAM
GAS CHAMBER
FARADAY
CUP
Ni WINDOW
SOLID STATE
DETECTOR
DEGRADER
GAS
INLET
TO VACUM
PUMP
10 cm
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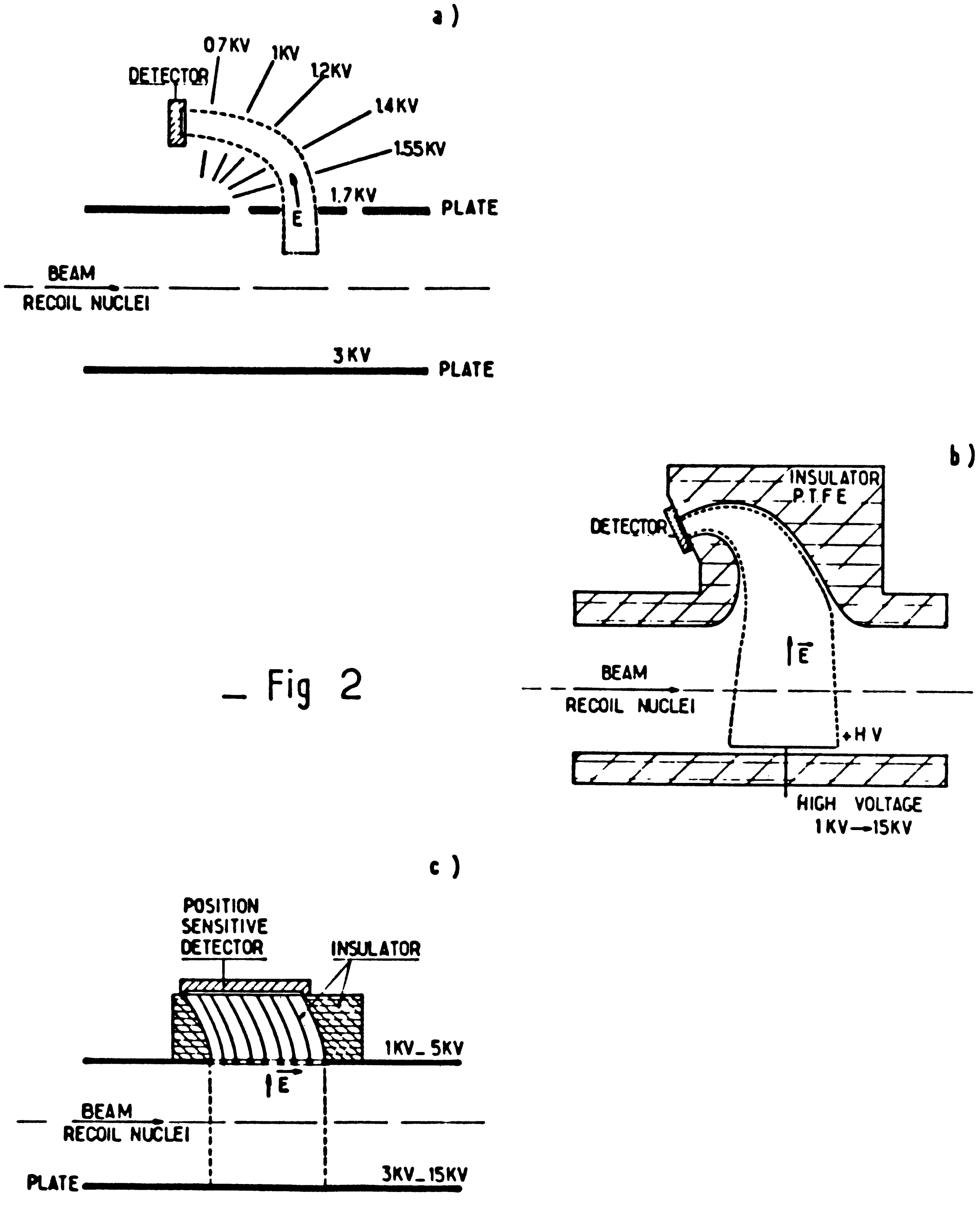
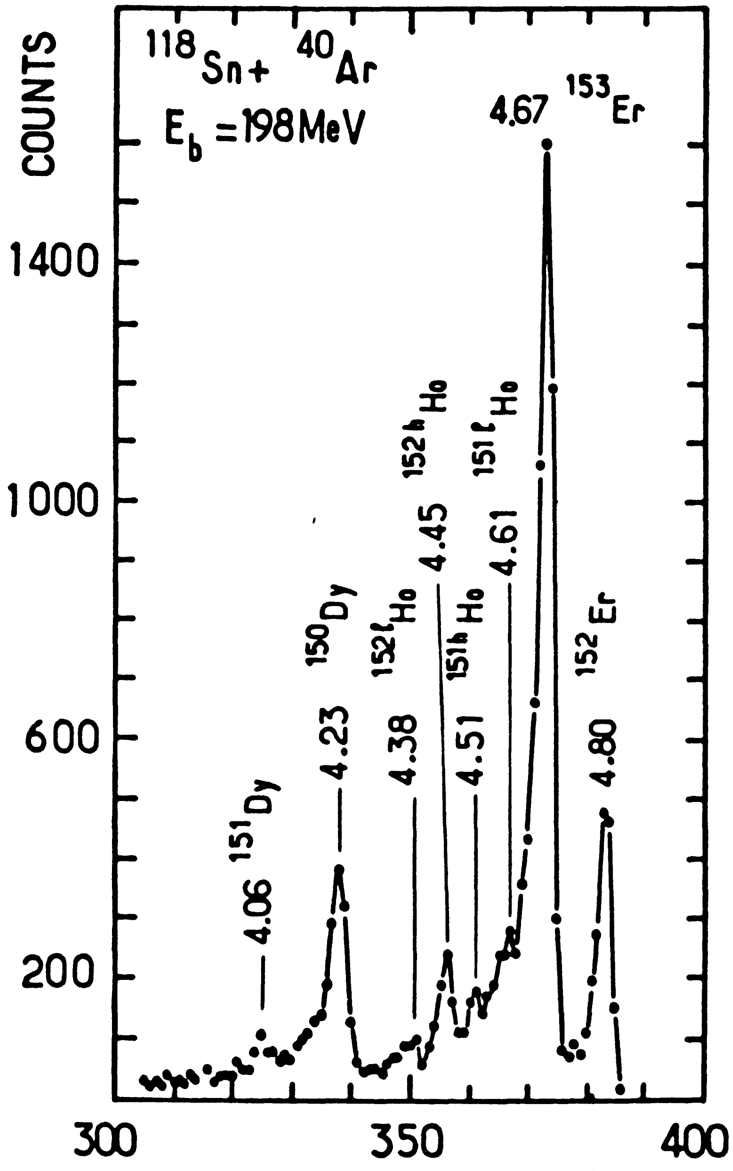
— Fig. 1 —


a)
0.7KV
1KV
1.2KV
1.4KV
1.55KV
1.7KV
DETECTOR
E
PLATE
BEAM
RECOIL NUCLEI
3KV
PLATE
b)
INSULATOR
P.T.F.E
DETECTOR
E
BEAM
RECOIL NUCLEI
+HV
HIGH VOLTAGE
1KV→15KV
c)
POSITION
SENSITIVE
DETECTOR
INSULATOR
1KV_5KV
E
BEAM
RECOIL NUCLEI
PLATE
3KV_15KV

_ Fig 2



^{118}Sn+ ^{40}Ar
E_b =198MeV
COUNTS
1400
1000
600
200
4.06 ^{151}Dy
4.23 ^{150}Dy
4.38 $^{152\ell}$Ho
4.45 ^{152h}Ho
4.51 ^{151h}Ho
4.61 $^{151\ell}$Ho
4.67 ^{153}Er
4.80 ^{152}Er
300
350
400
CHANNEL

— Fig. 3 —