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A NEW ELECTROSTATIC ON-LINE COLLECTION-SYSTEM

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Abstract

The working conditions of a new on-line electrostatic collection system are presented. The main characteristics are high efficiency (reaching 20%) and short delay time (down to the millisecond). The salient features of specific devices for measurements of absolute cross sections, recoil range distributions and angular distributions are given.

1. Introduction

The collection method presented here is of a non selective type. This method is not to be compared with the biggest high performance recoil spectrometers but better must be considered as a necessary complement of existing devices.

Our work has been to complete and modify the already known off-line electrostatic collection in order to realize on-line detection. It appears that the transport and the deposit of the activity on the surface of a detector can be easily performed with small devices. There is some relationship of this method with the helium-jet technique as the total efficiencies are comparable (the transport delay time being nevertheless one order of magnitude shorter in our device), but the main advantages of the electrostatic collection are simplicity, lightness and the possibility of a precise selection both in recoil energy and angular distribution. Then, known reaction mechanisms (fusion, deep inelastic ...) as well as new ones, that may occur in the range 20-100 MeV/n, can be studied by this method and this both for the exotic nuclei production and mechanism study per se.

2. Principles and off-line tests

All electrostatic experiments rely on two main basic principles : i) the recoiling nuclei are stopped in a gas, ii) at the end of the path an electrostatic field is applied. When the velocity vanishes (about 10^{-7}s after the nuclear interaction) the field ensures, in most of the cases, the presence of a remaining charge on the nuclei. An electric force is then created and provides the transport of the activity on a catcher, or in front of a detector.

The experimental devices built on these principles have been, up to now, focused on off-line measurements in which nuclei are first electrostatically deposited on parallel plates and then handly or mechanically transported in the detection area (see Fig. 1). Differential range of fission fragments[2] and evaporation residues[1-6] were studied with such devices. In the case of exotic isotope collection, there was only one group (Ghiorso et al[7,8] using this technique with on-line detection (discovery of element 103). At this time (twenty years ago) many experimental points remained obscure in the application of the main principles. Especially the total efficiency and the transport time were not measured. Furthermore the influence of important parameters such as the beam quality and intensity, the gas nature and pressure, the chemical properties of the collected nuclei, were only partially or not at all known.

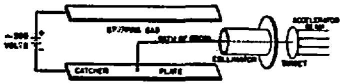


Fig. 1 Apparatus for differential range measurements by electrostatic collection (taken from Harvey[1]).

2.1. Measurements of the ion mobility in light gases

The ion velocity in an homogeneous electric field is well known[9] when the species concerned are He^{+}/He, N_2^{+}/N_2 ... i.e. for particular cases where ions come from the gas itself. We have then studied the ion mobility μ of ^{216}Po in N_2 and He. The pressure range was 0.02 to 1 bar and the electric field was varied correspondingly from $10^3 V\,m^{-1}$ to $10^5 V\,m^{-1}$. The $^{216}Po^{+}$ ions came from a ^{224}Ra source and were transported along parallel field lines up to the surface of an alpha detector. The three parameters P (pressure), E(electric field) and d (transport length) were varied and the loss of nuclei due to radioactive decay during the transport was determined for each (P, E, d) value ; other sources of experimental loss than decay rate were measured to be negligible. All results are well reproduced by the following formula which gives the mean velocity v :

$$v = \mu \frac{E}{P} \qquad (1)$$

with $\mu = (2.2 \pm 0.2)10^{-4}$ in N_2 and $(4.1 \pm 0.4)10^{-4}$ in He, if v, E and P units are $m s^{-1}$, $V m^{-1}$, and bar respectively. The width of the distribution is more difficult to obtain but can be roughly estimated to be half the mean value. One must notice that if the total transport length remains of the order of 0.1 to 1 m, the transport time can be as short as 1 ms. ($P = 50$ mbar, $E \sim 4\ 10^4 V\,m^{-1}$). An important point is then to minimize the distance between the stopping point of the nuclei and the detector.

2.2. The electrostatic field line configurations

The velocity is limited in the gas by the fluid friction. So there is no significant kinematic force perpendicular to the electric one. For the same reason, a magnetic field has a negligible effect if the pressure is greater than 1 mbar. So, trajectories of ions are directed by the electrostatic field lines.

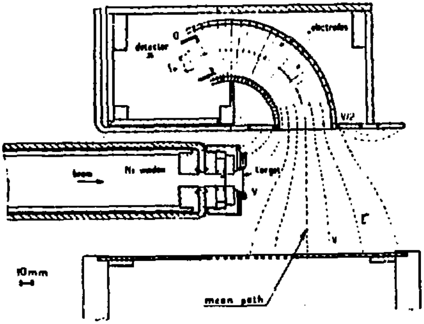


Fig. 2 Schematic view of the electrode configuration in an "in beam" collection

2.2.1. Boundary conditions determined by metallic electrodes

In this classic case the Laplace equation completely solves the problem. Within the restriction of non-crossing field lines it is possible to find an electrode disposition establishing the field along an arbitrary given line. In Fig. 2 is illustrated a standard case where the mean path is a straight line in the lower part and a circle in the upper part.

An important property of the $\Delta V = 0$ equation is that if the geometry of the electrodes is given, the relative intensity of the field along a field tube is determined by the section of this tube. This implies that in a focusing configuration as displayed on Fig. 2, the electric field is much lower in the convergent part. The total transport time is consequently increased and reaches 10 ms (in standard conditions) for this system.

2.2.2. Devices including insulators

If a continuously ionizing source (such as a beam or a radioactive source) is present in the electric field the equation $\Delta V = \rho(\vec{E})/\varepsilon_0$ is of an integral type. The charge density $\rho(\vec{E})$ is determined by the movement and recombination of the created free charges, themselves conditioned by the electric field.

We tried with some success to impose, in addition to the potential condition, a volume condition by the mean of an insulator (Fig. 3). On the surface of the insulator the charge density reaches an equilibrium state. The normal component of the electric field vanishes. Thus this boundary charge condition defines a field tube when potential constraints fail to do so. The system shown in Fig. 3 is charge equilibrated in a time varying from several minutes in presence of a 10^4 alpha s^{-1} source to few milliseconds when a beam goes through the device.

This system fails in two cases : i) if the ionizing source is too weak, ii) if the number of energetic ions directly implanted in the insulator is too high, for example, in the first degrees around the beam direction.

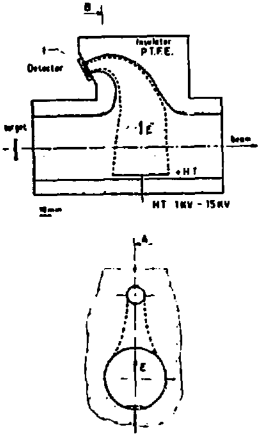


Fig. 3 Electrostatic device using a massive insulator

3. In beam collection of fusion residues and recoil range measurements

We have used the device shown in Fig. 2. The target and the Ni window are in the vicinity of the collection zone and have the same applied voltage as the lower plate. The detection being limited to alpha spectroscopy, the background is very low (less than 1 eventhour^{-1} MeV^{-1}) above 3 MeV when the surface barrier detector is placed behind a metallic screen and well protected from multiple scattering. This latter point justifies the circular field line created in the upper part by a succession of 17 electrodes. The nuclei are deposited onto the surface of the detector which defines the ground potential and constitutes the last electrode. The resolution is there still good, typically 30 keV with a 450 mm^2 detector. With this system we found optimum conditions for detecting isotopes with half-lives greater than 1 s which were : P = 250 mbar of N_2, V = 5 kV, beam intensity : 5 x 10^{10} part s^{-1}. The total efficiency (including the detection efficiency) is then 2% in the case of rare earth and francium isotope production.

This device enabled us to discover (in 1979) a new isotope ^{184}Pb[10] formed in the heavy ion fusion reaction (^{40}Ca + ^{148}Sm). The large detection efficiency (45%) allowed us to make α-α time delay coincidence between the new alpha line 6620 keV and the known 6120 keV line of ^{180}Hg. These parent-daughter relationships are of great interest, as emphasized by Hofmann et al[11] for the velocity filter, in the identification of new isotopes detected by non-selective collection methods.

For shortest half-lives the operating conditions must be changed, the pressure and voltage being reduced (100 mbar, 2.5 kV). The total efficiency is only 1%, for a 5 ms half-life (^{214}Fr). We must emphasize that the crossing of the beam through the device strongly reduces the efficiency since its value is 50% in off-line tests and corresponds to the detection geometry.

3.1. Recombinaison and space charge effects

The ionization created by an heavy ion beam in a gas (at pressure about 100-1000 mbar) is very high, but the separation of these charges by an electric field is small due to the recalling field existing between positive and negative species. So recombination is a dominant mode. The ionization current between two parallel plates can be estimated by taking into account the equation of mobility (Eq. 1) for ions and electrons.

One finds that J, the density of the extracted current is given by the following equation :

$$J = K \, Ln \, (I_{BEAM}) \times \frac{V^2}{P \, d^{\alpha}} \qquad (2)$$

where α = 3. This current evacuates about two to four orders of magnitude less charges than those created by the beam. So the probability for a recoiling charged nucleus to be collected before neutralization is very small if it stays in the plasma. Fortunately the collision induced reionization occurs with a great probability and extraction from the plasma of long-life isotopes such as ^{151}Dy has been experimentally found to be in between 40%-100%.

In addition to this effect, in the interaction zone, the space charge regime has also a great influence in the transport. Inside a positive charge cloud moving under the influence of a primary electrostatic field, a repulsive component appears when the local charge density is too high. This effect is responsible of an important loss on the edges of the electrodes during the transport of the activity to the detector.

3.2. Measurements of recoil range distributions

All effects correlated to the space charge are of a particular importance when the aim of the electrostatic collection becomes to give a correct view of the recoil range distributions through an homogeneous field. Fig. 4 exhibits the system we have successfully tested first with a low energy fusion reaction and afterwards with the very energetic ^{12}C beam of CERN.

Previously experimenters checked carefully the symmetry between the beam and the two parallel plates. The space charge study shows that behind an apparent symmetry in the electrodes, the mobility of electrons and ions are so different ($\mu(e^-) \approx 10^3 \mu(+)$) that charge densities and electric fields exhibit strong differences between the elec-

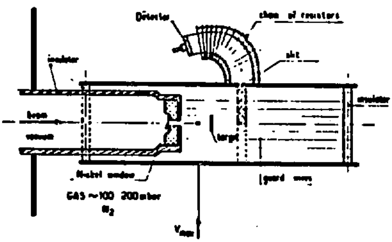
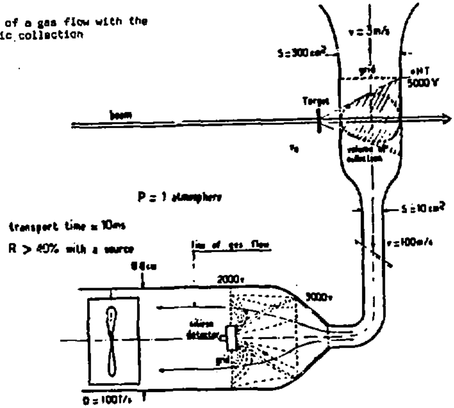


Fig. 4 Apparatus for differential range measurements by on-line electrostatic collection

Fig. 5 Combination of a gas flow with the electrostatic collection



tronic and ionic collection zones. An important consequence is that the potential of the metallic parts placed in the beam such as Ni window or target must have an applied potential close to the cathode one. Otherwise we have noticed a loss of *collection for small ranges (less than 3 cm)*, and some authors[3-4] mentioned a short-range tail due to a distorsion in the collection.

4. Addition of a gas flow to the electrostatic collection

A system like the one in Fig. 1 does not guarantee that the efficiency is independent of the half-live over a wide range. This is a problem to measure absolute cross-sections. In order to suppress multiple reionizations and recombinations as well as to compel the total transport time to be as small as possible, we used a system mixing *a gas flow and an* electrostatic collection (Fig. 5).

It must be noticed that this technique is quite different *from the helium-jet for two reasons* : i) the gas flow is insured by a small ventilator (power ≈ 20W, dimension : ϕ 80 mm) instead of a big pump. ii) the total flow rate of the evacuated gas in the collecting chamber is quite high : 10^5 cm^3 s^{-1} whatever the pressure is in the range 20-100 mbar. In an He-jet system the total flow rate is 10^2 cm^3 s^{-1} in the high pressure chamber if the operating pump evacuates 10 m^3 s^{-1} *at a 10^{-2} mbar pressure in the vacuum chamber.* The high flow rate insures the total removing of the gas receiving the activity in less than 20 ms (This time could still be easily lowered with a more powerful ventilator).

We measured the same efficiency for two isotopes whose half-lives were 30 ms and 150 ms (source tests). In on-line tests we found for a 36 s half-live (^{213}Fr) an efficiency twice the value *for a* 5 ms *half-live* (^{214}Fr). *These results* are consistent with the mechanical caracteristics

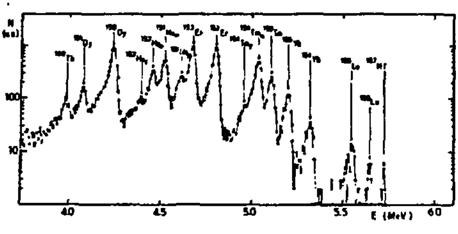


Fig. 6 Alpha spectrum obtained with an equal efficiency for all half-lives *of the produced* isotopes (from ^{151}Dy, $T^{1/2}$= 17 mn to ^{155}Lu, $T^{1/2}$= 70 mn)

of the ventilator predicting a total transport time in the range 10-15 ms.

This point is very crucial in the interpretation of results obtained with the ^{12}C beam at 1 GeV at CERN. It appears on Fig. 6 that exotic nuclei as far from the stability line as ^{157}Hf ($T^{1/2}$ = 120 ms) and ^{155}Lu ($T^{1/2}$ = 70 ms) could be seen ; and we can state that the non-detection of more exotic isotopes is only due to a too low production yield since ^{158}Hf ($T^{1/2}$ = 25 ms) and ^{158}Ta ($T^{1/2}$ = 37 ms) have half-lives greater than 20 ms.

The electrostatic design is arranged with the gas flow in order to insure that : i) near the target and during the transport, electric forces are small compared to fluid forces, ii) near the detector the force situation is reversed by expanding the gas while the electric field is enhanced in a focussing configuration. The total efficiency is entirely controlled by recombinations occuring in the plasma zone. All neutralized atoms are lost for the further electrostatic deposit on the detector. The intensity of the extracted current can be approximated by the following expression :

$$J = k\,\mu \frac{\left(V + \frac{v_0\, d\, P}{\mu}\right)^2}{P\, d^3} \qquad (3)$$

where v_0, d and V are the gas velocity, the electrode separation and the electrode voltage respectively. The extracted current only slightly changes when the beam intensity or energy or nature is varied. On the contrary, the total number N_p of ion-electron pairs is strongly dependent of these parameters :

$$N_p = \alpha\, I_{beam}\, P \left(\frac{dE}{dx}(E)\right) \qquad (4)$$

$\frac{dE}{dx}(E)$ being the stopping power of the beam in the gas. The efficiency proportional to the ratio J/N_p is then given by the following relation if

$V < \frac{v_0\, d\, P}{\mu}$:

$$\frac{J}{N_p} \approx k' \frac{v_0^2}{\mu \times d \times I_{beam} \times \frac{dE}{dx}(E)} \qquad (5)$$

The better conditions for this system are energetic beams (low dE/dx), low intensity beams and high fluid velocity. So we have obtained a total efficiency of 15% using the 10^{10} part s^{-1} 12C beam at 1 GeV (transport efficiency ≈ 45%). The counting rate is almost independent of the beam intensity above 10^{10} part s^{-1}, increasing by a factor of two for a tenfold increase of the beam intensity.

An interesting development of this system could be its use behind an electromagnetic recoil separator, even a crude one, as a residual 10^{7}-10^{9} part s^{-1} beam would not hinder the collection.

5. Out of beam collection and on-line angular distributions

The crossing of the beam through the collecting section is the only cause of the problem appearing in the system presented just before. We have then developed devices in which the beam is out of the electrostatic field. As the number

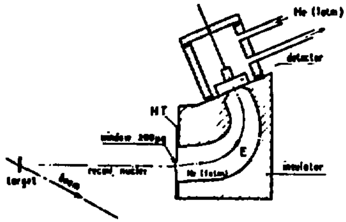


Fig. 7 The on-line angular distribution "detector"

of diffused particles can reach 10^8 part s^{-1} without any influence on the collection, the forbidden solid angle is reduced to the beam emittance, that is less than 1° aperture.

The system shown on Fig. 7 is only an example of this kind of disposition. The target and the beam are in a vacuum chamber while the collecting chamber is reduced to a little cell in which the electrostatic field is used to focalise the activity onto the detector. The background is very low, since the direct scattering cannot reach the detection zone (Fig. 8). The total efficiency has been measured to be in the range 20%-40% and the conditions of the collection appear to be very similar to off-line conditions. The time transport is therefore given by the velocity measured in off-line tests. The efficiency of collection is about 100% for the charged recoiling nuclei. But depending on the chemical nature of the collected nuclei, on the stopping gas and on the electric field, a fraction of the entering ions is neutralized in the last part of the slowing down path. Due to the exclusion of the plasma, a further reionization of neutral atoms is impossible. The proportion of 1+ or 0 charge states in the eV-keV energy range is not well known. Experimental data[1,2,6] indicate that in H_2,He,N_2, most of the elements remain still charged at the end of the

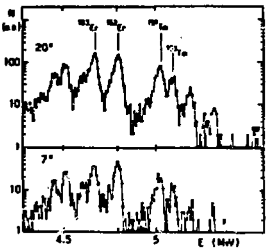


Fig. 8 Alpha spectrum obtained at 7° and 20° in the laboratory system in the reaction of ^{12}C at 1 GeV on ^{181}Ta

stopping path ; the exceptions are rare gases and halogens which are mainly neutralized. In the case of rare earths our measurements indicate a 40% greater probability for the 1+ charge state than for the 0 one. If the stopping gas has a too low ionization potential (Ar, CH_4, ...) the situation may become very different and even elements having a low ionization potential like Cs may be almost totally neutralized[12].

We have up to now obtained on-line angular distributions of neutron-deficient isotopes produced in the reactions of the CERN ^{12}C beam on heavy targets. A typical spectrum is shown on *Fig. 5. This kind of differential measurements has* not yet been achieved in a wide angular range (2°-90°) by any other method and corresponds to one of the more promising configuration of the electrostatic collection. Similar systems well suited for isotope production, fusion or deep inelastic reactions, are now developed with the goal to collect all nuclei emitted outside a forward cone having a 1° aperture.

6. Conclusion

The electrostatic collection presents very interesting characteristics. This method is simple, versatile and can be used for different purposes : absolute cross sections measurements, recoil range distributions, angular distributions. The high efficiency (reaching 20%) and the short delay time (down to the ms) allowed exotic nuclei detection. The electrostatic transport in gases offers two *methods of focalisation ; the gas flow and the* electric field itself in which the mean delay time is of the order of 10 ms and could be easily lowered to 1 ms.

It is important to notice that the rapid methods of collection are not universal. For example the recoil spectrometers only collect the fusion residues with high efficiency. In other cases (Lohengrin, Josef) an additional low collection (multicapillary He-Jet system, tape transport) is useful. The other very quick methods as mass spectrometry are restricted so some elements, alcalines for example, and hardly detect half-lives shorter than 100 ms when the mass of the isotope exceed 100. The high efficiency collection in the 5 ms-100 ms half-live range, almost independent of reaction mechanism and collected elements, is especially important since in many cases the last known exotic isotopes have precisely half-lives about 100 ms.

References

1) B.G. Harvey, Ann. Rev. Nucl. Sci. 10 (1960) 235

2) M. Pickering and J.M. Alexander, Phys. Rev. C6 (1972) 332

3) L. Bryde, N.O. Lassen and N.O. Roy Poulsen, Mat. Fys. Med. 33 (1962) n° 8

N.O. Lassen, N.O. Roy Poulsen, G. Sidenius and L. Vistisen, Mat. Fys. Med. 34 (1964) n° 5

4) J.M. Alexander, J. Gilat and D.H. Sisson, Phys. Rev. 136 (1964) 1289

5) J. Gilat and J.M. Alexander, Phys. Rev. 136 (1964) 1298

6) N.T. Porile and I. Fujiwara, Phys. Rev. 176 (1968) 1166

7) A. Ghiorso, T. Sikkeland, A.E. Larsh, R.M. Latimer, Phys. Rev. Lett. 6 (1961) 473

8) A. Ghiorso, J.M. Nitschke, J.R. Alonso, C.T. Alonso, M. Nurmia, G.T. Seaborg, E.K. Hulet, R.N. Lougheed, Phys. Rev. Lett. 33 (1974) 1490

9) A. Dalgarno in Atomic and molecular processes edited by D.R. Bates (1962), Academic Press New York and London

10) J.P. Dufour, A. Fleury, F. Hubert, Y. Llabador, M.B. Mauhourat, Z. Physik A294 (1980) 107

11) S. Hofmann, W. Faust, G. Munzenberg, W. Reisdorf and P. Armbruster, Z. Physik A291 (1979) 53

12) S.D. Kramer, C.E. Bemis, J.P. Young and G.S. Hurst, Opt. Lett. 3 (1978) 16