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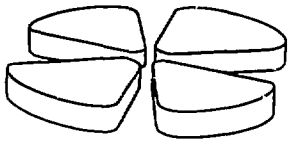

PRODUCTION AND ACCELERATION OF Ca-BEAMS WITH THE ECR SOURCE IN THE JINR-GANIL EXPERIMENT

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PRODUCTION AND ACCELERATION OF ^{48}Ca-BEAMS WITH THE ECR SOURCE IN THE JINR-GANIL EXPERIMENT

The results of production and acceleration of ^{48}Ca-beams with the ECR-source are described. For this purpose a special technique has been developed which allows the metal to be extracted from the oxide with the aluminium as an acceptor. The mean rate of consumption of ^{48}Ca was about 2 mg/h and the beam intensity was about 15 μA on charge state 6. The method for recuperation of used calcium is presented.

Heavy ion reactions are commonly used to produce nuclei in extreme states (e.g. superheavy, neutron-rich, strongly deformed nuclei, etc.). Some advantage in the synthesis of such nuclei is achieved when beams of exotic rare isotopes, such as ^{14}C /1/, ^{48}Ca /2/, are used. For instance, it is well known that in fusion reactions the neutron excess in the accelerated ^{48}Ca ions allows to decrease the neutron deficit in the synthesized nuclei in comparison to reactions induced by other ions. The use of ^{48}Ca at high energies offers wide possibilities for the production of neutron-rich nuclei in reactions of projectile fragmentation /3/. As an illustration, fig. 1 presents the calculated yields of neutron-rich nuclei as functions of the A/Z ratio of the projectile in reactions with a Ta target. This calculation has been performed on the basis of the model described in ref. /4/. It can be seen from the figure that the use of ^{48}Ca ion beams gives product yields 10^2-10^3 times larger than the ones obtained in reactions induced by ^{40}Ca or ^{40}Ar ions.

In order to study the stability and characteristics (mass excess, probability and halflives of β-delayed neutron emission of neutron-rich nuclei, produced in ^{48}Ca-induced reactions at energies of 44-55 MeV/nucleon, series of experiments were carried out by the JINR (Laboratory of Nuclear Reactions) - GANIL collaboration. As a result of these experiments on the LISE facility /5/, the stability of 25 new neutron-rich nuclei from oxygen to potassium was established and the halflives of some 10 isotopes were measured for the first time. The SPEG facility /6/ was used to measure the mass excess of these nuclei.

For the production of accelerated ions of the separated ^{48}Ca isotope an ECR source was used /7/. The beam was further accelerated by the three GANIL cyclotrons /8/.

There are some difficulties in producing ^{48}Ca ion beams of sufficient intensities by means of ECR sources. These difficulties are related to the following circumstances. First, ^{48}Ca makes up only 0.18% of the natural calcium mixture. Second, as an element of high chemical activity calcium is always met in compounds with other elements. The melting point of these compounds is high enough to prevent the use of ovens or crucible for the introduction of a working material containing calcium into the discharge volume of the ion source. Indeed, we tried to produce a beam of calcium directly from pure calcium oxide. The calcium oxide powder was compacted and put into the source in a tantalum crucible. The beam intensity between 40 and 10 μA of Ca^{6+} was got. The problem was that the beam was unstable because a lot of heat was needed for the crucible. Since the heat comes from the plasma, the crucible had to be introduced deep into it. This generated perturtations of the plasma and lead to instabilities of source. Thus in order to produce the calcium beam, a new technique had to be developed which allows the metal to be extracted from the oxide directly in the vacuum volume of the ECR source.

The research to define the procedure for reducing metallic calcium from the oxide, together with the choice of the most appropriate acceptor for this reaction, were carried out. Taking into account the characteristics of the ECR source a solution of the problem is offered and schematically shown in fig. 3. To obtain the oxide, powder of calcium carbonate was first heated to a temperature of 1200°C in open air and then a mixture of the oxide and an eventual acceptor was prepared. From the Table presented it

follows that aluminium is a suitable acceptor for the reduction of metallic calcium /9/. It is noteworthy that for aluminium the saturated vapour pressure is reached at a higher temperature than for calcium. The reduction process can be controlled as shown in fig. 3. A mixture of CaO and Al with a weight ratio of 3 :1 was heated in a crucible placed in a vacuum (10^{-4} mmHg). The evaporation rate was controlled by means of a quartz monitor, and consequently by XR -analysis of the material evaporated from the crucible and deposited on the collector.

The evaporation rate as a function of the mixture temperature is presented in fig. 4. From the figure it can be seen that a sudden rise of the material evaporation rate starts at a higher temperature than the aluminium melting point t^{Al}_{melt}. The chemical purity of the evaporated matter at crucible temperatures $t^{Al}_{melt} < t < t^{Al}_{evap}$ was controlled by means of XR-analysis of the material deposited on a brass catcher placed above the crucible. A photograph of the surface of the deposited layer made with an electronic microscope is shown in fig. 5. From an elemental analysis it follows that the grey material is the recovered metallic calcium (atomic contents 72.6% - Ca, 26.5% - O and 0.03% - Al) while the white material is calcium oxide.

For the ^{48}Ca beam production with the ECR source the mixture of CaO + Al was placed in a crucible first outgassed in vacuum at 500°C and then axially introduced into the source chamber with the help of a precise mechanism. The material consumption during the acceleration of $^{48}Ca^{+6}$ was controlled by increasing the UHF power by 2-5 W per hour. The charge states spectrum of ions extracted from the ECR source is presented in fig. 6. The consump-

tion rate of ^{48}Ca was 2 mg/h. The beam intensity extracted from the ECR source for ions with A/Z = 8 ($^{48}Ca^{+6}$, $^{40}Ca^{+5}$, $^{16}O^{+2}$), after the separation magnet, was about 15 μa. The beam intensity of $^{48}Ca^{+18}$ ions extracted from the last cyclotron with an energy of 44-55 MeV/nucleon was 150-250 nA.

In order to effectively use the ^{48}Ca isotope inside the discharge chamber a cylindrical W catcher was placed. After the experiment the ion source was cleaned out by washing the deposited ^{48}Ca with a 1% solution of HCl acid. The thus collected solution was kept for about 1-1.5 hours at a temperature close to the boiling point. As a result about 99% of the deposited calcium and some quantity of the source construction materials (Fe, Cr, Ni, Ti) were dissolved. Subsequently, after alkaline reactions this solution was neutralized to pH = 1 with the help of ammonia and filtered to separate the mechanical contaminants and hydroxides formed during the hydrolytic process. The calcium which remained in the solution was deposited by the excess of oxalic acid. The calcium oxalate was heated to 1000°C, which led to the formation of calcium oxide. The decribed chemical technique allows to regenerate for using in future experiments about 80% of the used calcium.

The experiments carried out lead us to conclude that the use of exotic beams such as ^{48}Ca offers new and unique possibilities for investigating the stability and other properties of nuclei far from the line of stability /3/.

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Table

Melting point compared to the temperature for different vapour pressures for some metals and also some of their compounds

Compound	t(°C) melt	T(°C) 10^{-2}	T(°C) 10^{-3} mm Hg
Ca	838	590	515
CaO	2580	2050	1890
Al	660	1140	1020
Al_2O_3	2046	1790	1600

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Figure captions

Fig. 1. Calculated yields of projectile fragmentation products as functions of the projectile A/Z ratio in the bombardment of a Ta target with ^{40}Ca, ^{40}Ar and ^{48}Ca ions at 55 MeV/nucleon.

Fig. 2. Scheme of the CaO + Al production process (1 - crucible made of Al_2O_3, 2 - heater, 3 - brass catcher, 4 - deposited layer, 5 - thermocouple).

Fig. 3. Scheme of the experimental check for the metallic calcium reduction process.

Fig. 4. Evaporation rate of the CaO + Al mixture as a function of temperature.

Fig. 5. Photograph of the surface layer of the reduced metallic calcium.

Fig. 6. The charge state spectrum of ions from the ECR source. The y-axis represents the ion intensity.

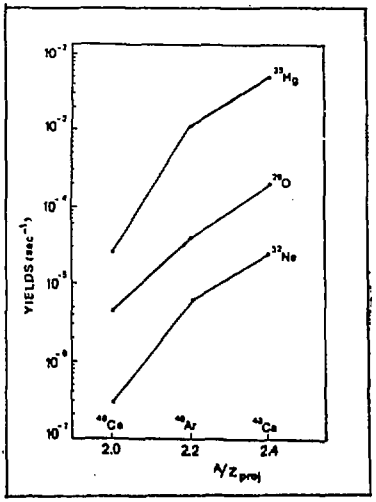

Fig. 1

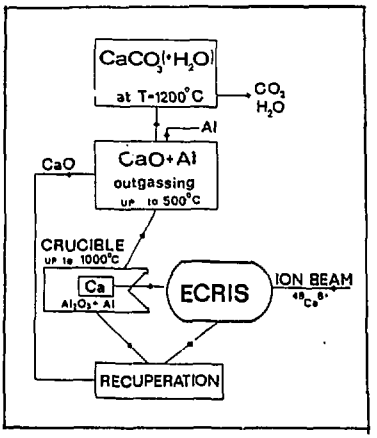

Fig. 3

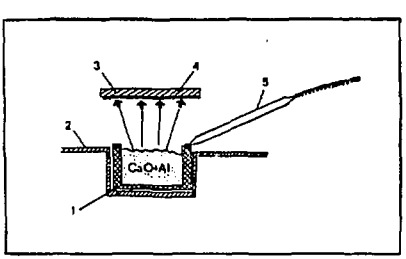

Fig. 2

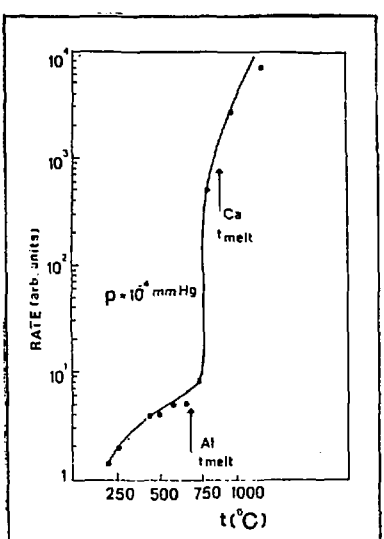

Fig. 4

Fig. 5

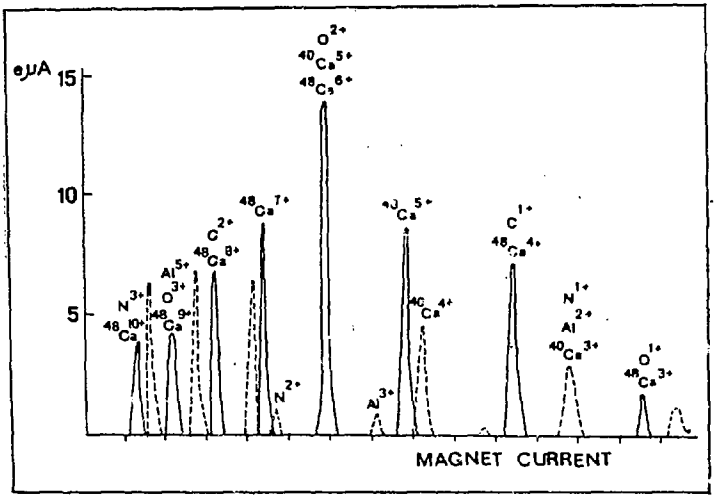

Fig. 6