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Gold and isotopically enriched platinium targets for the production of radioactive beams of francium

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Abstract

Au and isotopically enriched Pt targets are discussed for the production of radioactive Fr beams. Target foils, serving also as ionizers, have to be heated in order to enhance the diffusion of atoms to the surface for further extraction and injection into the electrostatic transport system.

Keywords: Francium; Gold; Heavy ion target; Platinium; Radioactive beam

1. Introduction

The alkali atoms have been the focus of most laser trapping of radioactive atoms due to their favorable composition of atomic level schemes. After creation via a nuclear reaction, the radioactive atoms must be quickly extracted from the target. The volatility of the alkali metals at elevated temperatures is very helpful for fast diffusion out of solid or liquid targets. Other factors, such as available beam particles and their energies, chemical properties and the cross section for the required reaction determine the choice of target – projectile combination.

2. Experiment

The Stony Brook group has concentrated on radioactive francium, the heaviest of the alkali elements, which has no stable isotopes. Its longest – lived isotope has a half-life of 21.8 min. The diagram of the experimental setup is shown in Fig. 1 [1]. More details about the ion transport system, cooling and the magneto-optical trap can be found elsewhere [2,3].

2.1. Au target

The isotopes $^{207-211}$Fr can be produced via the reactions ^{197}Au(^{18}O, xn)$^{215-X}$Fr and ^{197}Au(^{16}O, xn)$^{213-X}$Fr, with ^{18,16}O beam energies of 85–115 MeV from the Stony Brook Van De Graaff and superconducting LINAC.

Au was chosen as a target because it is monoisotopic, chemically clean, non-reactive (easy to

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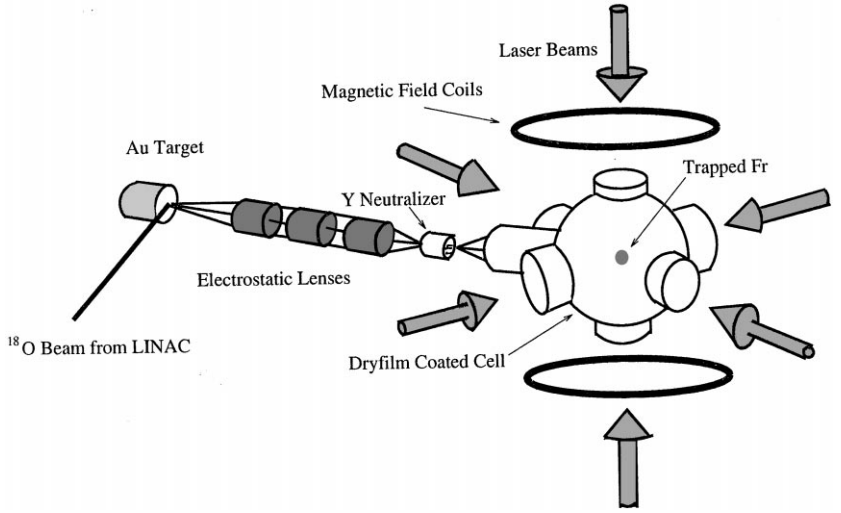

Fig. 1. Stony Brook apparatus for creating, transporting and trapping radioactive atoms.

handle), relatively inexpensive, and has the proper atomic number to produce francium with easily available beam particles. A 0.01 cm-thick Au foil was attached to the end of a 0.6 cm-diameter tungsten rod 5 cm long. Tungsten was chosen because it has a much lower tendency to alloy with Au than other refractory metals such as Ta or Mo. In order to ensure a good thermal contact with the rod, the foil was stretched on the face of the rod and tied with several turns of thin tungsten wire wrapped around the cylindrical surface. The rod and target were radiantly heated by a coaxial heater. The useful range of oxygen beam above the Coulomb barrier is about 30 mg/cm^2 and the recoil range of the reaction products is about 1 mg/cm^2. This gives an idea of the minimum target thickness requirement.

An α-particle detector was used for isotopic identification (Fig. 2a and b), yield, and measurement of target efficiency. The Au foil was heated by the incoming beam (80–200 particle nA) and heater (800–900°C) to increase the diffusion of Fr atoms to the surface. The right combination of those factors increases the number of Fr atoms leaving the surface of the target, as shown in Fig. 4a at point C. Surface melting has been suggested as the explanation of the observation. Using a CCD camera, it was observed that for maximum release, the central portion of the Au foil was very close to the melting

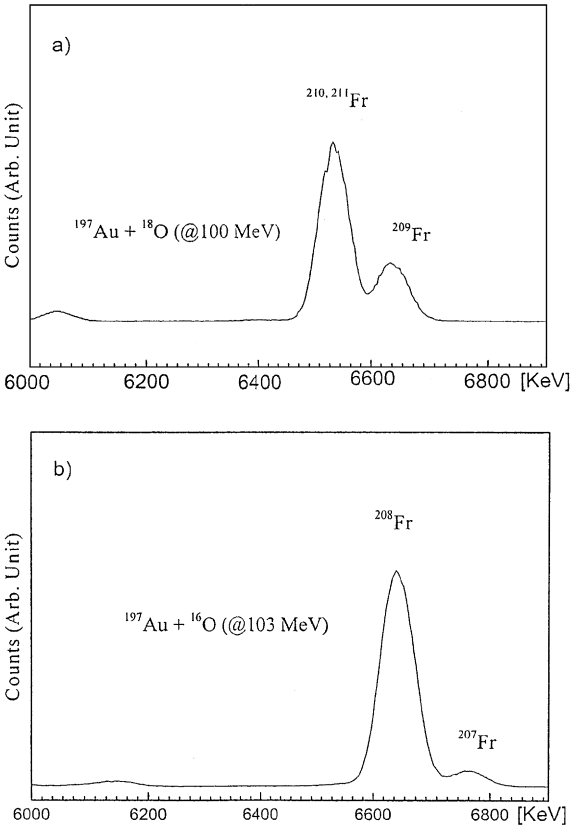

Fig. 2. Energy spectra of α-particles emitted from decaying Fr isotopes for ^{197}Au target and ^{18}O and ^{16}O beams.

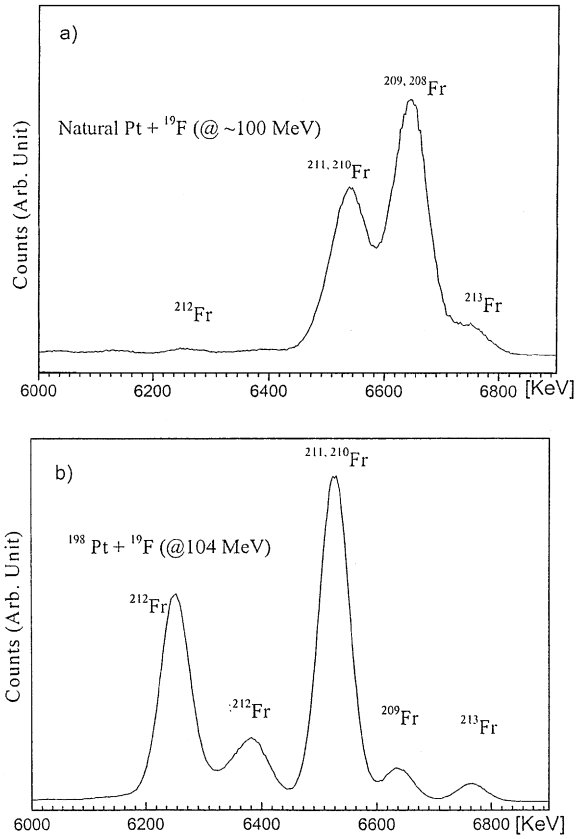

Fig. 3. Energy spectra of α-particles emitted from decaying Fr isotopes for ^{nat}Pt (a) and ^{198}Pt (b) targets and ^{19}F beam.

point, but we think remained solid. Other factors affecting target efficiency, including the competition between diffusion of Fr ions to the surface and production cross section of different isotopes (a function of beam energy), are discussed elsewhere [4,5].

2.2. Pt target

Several isotopes of Fr can also be produced via nuclear reactions where natural Pt is the target and ^{19}F is the projectile. As Pt has many stable isotopes, the available range of isotope that can be produced is greater than with Au, Fig. 3a. From the diagram it can be seen that the primary isotope of interest, ^{212}Fr, can barely be identified.

In order to increase the production efficiency of radioactive ^{212}Fr, the target material must be replaced with one isotopically enriched in ^{198}Pt.

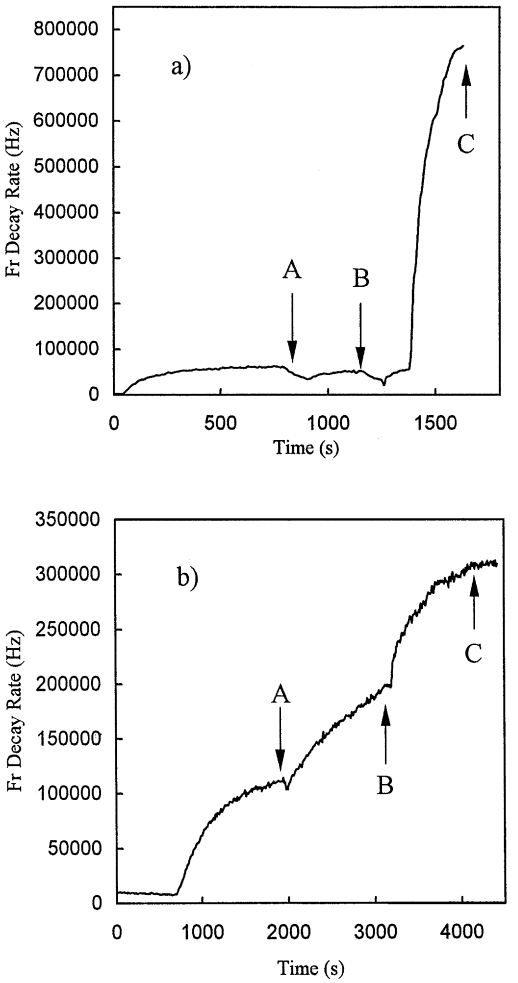

Fig. 4. Francium α-particle decay rate at the catcher in the ion transport system versus time. At points A–C the system reaches an equilibrium for the given combinations of beam current and heater temperature: (a) ^{197}Au target with ^{18}O beam; (b) ^{198}Pt target with ^{19}F beam.

The cost and availability of material required modification of the method by which the target was prepared. A thin (5 mg/cm^2), 4 mm × 4 mm piece of Pt, enriched in the 198 isotope to 95.71%, was spot welded (25–30 spots) to a thicker (300 mg/cm^2) ^{nat}Pt foil. These layers were additionally rolled together and then mounted on the tungsten rod in the same way as the Au. Fig. 3b shows the increase in the desired ^{212}Fr atoms.

In the current set up, the target heater is limited to 800–900°C, while the melting point of Pt

is 1767°C. Target heating is mainly due to the incident ^{19}F, particle beam. We can control the beam intensity to maintain steady temperature of the target close to the melting point. Fig. 4b shows an increase of the Fr ion production versus time. The decay rate reaches equilibrium at point A for a given beam current and target temperature. At the higher beam currents the equilibrium points are at B and C. At C we observed a beginning of the phase transition (surface melting) of the Pt on the face of the rod.

3. Targets as ionizers

The work functions of both Au and Pt (5.1 and 5.65 eV, respectively) are higher than the ionization potential of Fr (4.07 eV). Therefore, atoms leaving the target are in the ionic form and can be subsequently extracted into the electrostatic transport system. High release efficiency is very important for target ionizer performance. Quantitative measurements were carried out at the end of the transport system, so the α-particle detector measures the efficiency of the target and ion transport system combined.

4. Conclusion

The "near liquid" target provides the highest diffusion rate and the cleanest surface, which allows the Fr atoms to move fast enough (with respect to their half-life) to get to the surface, become ionized, and escape. Operating the target/ionizer assembly in the continuous fashion for partially molten Au or Pt seems to be the essential condition for the highest Fr ion extraction. We found that Au targets with oxygen beams are more efficient for Fr isotope production than Pt targets with fluorine beam. We could measure up to 3.6×10^6 Fr atoms/s for the Au foil and about 6.0×10^5 Fr atoms/s. for the Pt foil.

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