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Ca INDUCED REACTIONS ON ^{141}Pr AND ^{150}Sm: NEW GOLD AND LEAD ISOTOPES ^{176}Au, ^{175}Au, ^{185}Pb

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Abstract: Reactions induced by a beam of ^{40}Ca ions on ^{141}Pr and ^{150}Sm have been studied between 180 and 290 MeV. From the characteristics of the (^{40}Ca, xn) excitation functions and from the systematics of α-decay, we deduce the existence of the following new neutron deficient nuclides: ^{176}Au ($E_\alpha = 6.26 \pm 0.01$ MeV and $T_{\frac{1}{2}} = 1.25 \pm 0.30$ sec and $E_\alpha = 6.29 \pm 0.01$ MeV), ^{175}Au ($E_\alpha = 6.44 \pm 0.01$ MeV) and ^{185}Pb ($E_\alpha = 6.40 \pm 0.01$ MeV and 6.48 ± 0.02 MeV). New information is obtained on the α-decay of ^{177}Au and ^{187}Pb.

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RADIOACTIVITY ^{175,176,177}Au, ^{185,187}Pb [from ^{141}Pr, ^{150}Sm(^{40}Ca, xn), ^{155}Gd(^{40}Ar, xn)]; measured E_α, $T_{\frac{1}{2}}$. He jet technique.
NUCLEAR REACTIONS ^{141}Pr, ^{150}Sm(^{40}Ca, xn), ^{155}Gd(^{40}Ar, xn), $180 < E < 290$ MeV; measured relative $\sigma(E, E_\alpha)$.

1. Introduction

In a previous paper [1]), we presented the identification of some new α-emitting isotopes in the region between Pt and Bi, which were obtained by (Ar, xn) reactions.

In that work, we pointed out the difficulties involved in the production of some very neutron deficient nuclei very far from the stability line. These nuclei are reached at the end of relatively long evaporation chains where fission is drastically competing at each step. The production cross sections become very small and decrease rapidly with the number of emitted neutrons. Taking into account these severe limitations, a possible way to reach unknown exotic nuclei is to restrict the length of the neutron evaporation chains by synthetizing a very neutron-deficient compound nucleus. In such cases, a judicious choice of possible target and projectile combinations is necessary. In this regard, ^{40}Ca beams seem more favourable than ^{40}Ar beams, because, for very close values of Z, the ratio N/Z of the projectile is equal to 1 for Ca compared with 1.2 for Ar.

We have studied the production of gold and lead isotopes in the reactions ^{141}Pr(Ca, xn)Au and ^{150}Sm(Ca, xn), in which the compound nuclei are 16 neutrons deficient relative to the stability line. Two gold isotopes with masses 176 and 175 and one lead isotope ^{185}Pb, have been found.

2. Experimental procedure

Targets of ^{141}Pr ($\approx$ 0.8 mg/cm^2 deposited on a 0.8 mg/cm^2 aluminium foil) and of ^{150}Sm (in oxide form, $\approx$ 1 mg/cm^2 deposited on a 0.75 mg/cm^2 nickel foil) were bombarded with a Ca ion beam recently available at ALICE in Orsay. The intensity of the beam was about 2×10^{10} p/sec ($\approx$ 40 nA of Ca^{13+}).

Recoil nuclei escaping from the irradiated target were collected by the He jet technique and their decay was measured and analyzed by classical α-spectrometry methods. The energy calibration was obtained with the active deposits of actinon and thoron. The α-decay energies were taken from the ref. [2]).

The excitation functions were determined by using aluminium foil degraders to reduce the energy of the incident Ca beam. The energy losses were evaluated with the aid of the range-energy tables of Northcliffe and Schilling [3]). The half-life determinations were made by repeating a cycle consisting of an irradiation time and a counting time in the multispectrum mode of a pulse-height analyser.

3. Results

3.1. GOLD ISOTOPES

Fig. 1 shows appropriate sections of the α-particle spectra obtained at 226 MeV (a) and 241 MeV (b). In part (a), ^{177}Au can be clearly identified by its two α-peaks at 6.11 MeV and at 6.13 MeV [ref. [1])]. A new α-peak is seen at 6.26 MeV with an asymmetry indicating a small component with a somewhat higher energy of 6.29 MeV. When the incident beam energy is increased, another unknown α-peak appears at 6.44 MeV (spectrum (b)).

We have obtained excitation functions for the (Ca, xn) reactions producing the known isotopes ^{179,178,177}Au and for the new 6.26, 6.29 and 6.44 MeV α-peaks (fig. 2). The relative yields are not corrected for the α-branching ratios, which are not known. The curves for ^{179,178,177}Au show the expected behavior for nuclear reactions close to the fusion threshold (estimated to be at $\approx$ 53 MeV excitation energy).

The positions of the thresholds and of the maxima for the curves corresponding to the 6.26 and 6.29 MeV α-activities are very similar. We thus conclude that these two α-energies are associated with the decay of the same isotope. In addition, their shifts of $\approx$ 12 MeV in excitation energy with reference to the ^{177}Au curves lead us to assign these transitions to the α-decay of ^{176}Au produced by (^{40}Ca, 5n). Similarly the behavior of the yield of the 6.44 MeV peak indicates ^{175}Au as the isotope associated with it.

If we now look at the energy systematics by examining the α-particle energy E_α versus the mass number A (fig. 3), we observe that the measured α-particle energies for the Au isotopes are in agreement with the mass assignments of 176 and 175. This can be seen from the line drawn through all Au isotopes.

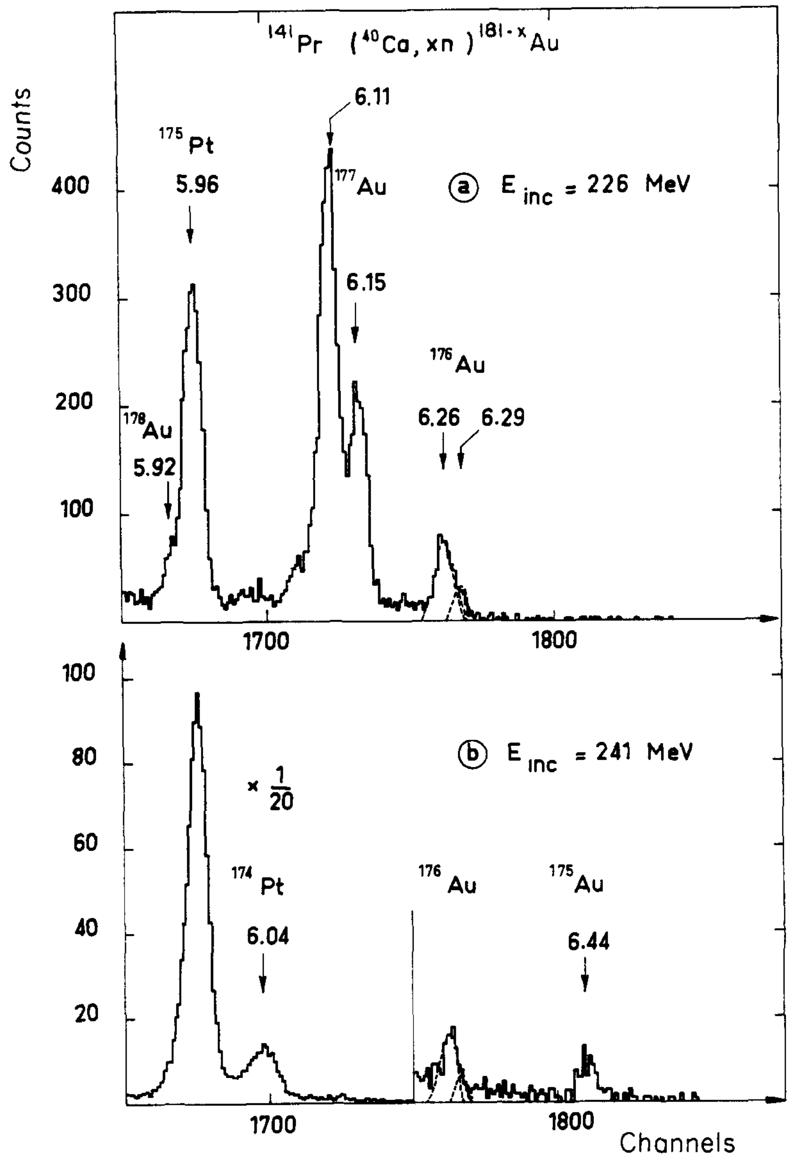

Fig. 1. Partial α-spectra obtained at 226 MeV (a) and 241 MeV (b) in irradiations of ^{141}Pr by ^{40}Ca ions.

These new α-decays cannot be associated with Pt nuclei because, first of all, they were not observed when we studied the ^{140}Ce(^{40}Ca, xn)$^{180-x}$Pt reactions. In addition, the systematics of α-decay confirms this conclusion. For instance, from systematics the 6.44 MeV α-peak could be associated with ^{171}Pt produced by a (Ca, p9n) reaction. The threshold of this reaction in which ten nucleons are emitted must be at an excita-

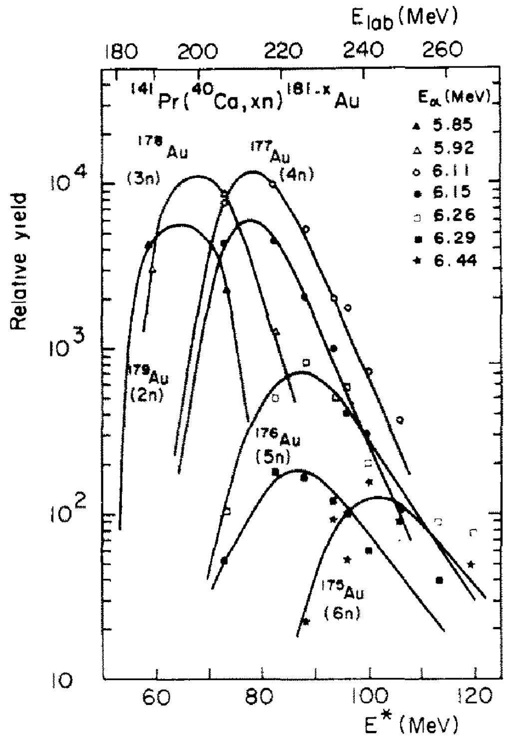

Fig. 2. Relative excitation functions for the reactions $^{141}Pr(^{40}Ca, xn)^{181-x}Au$.

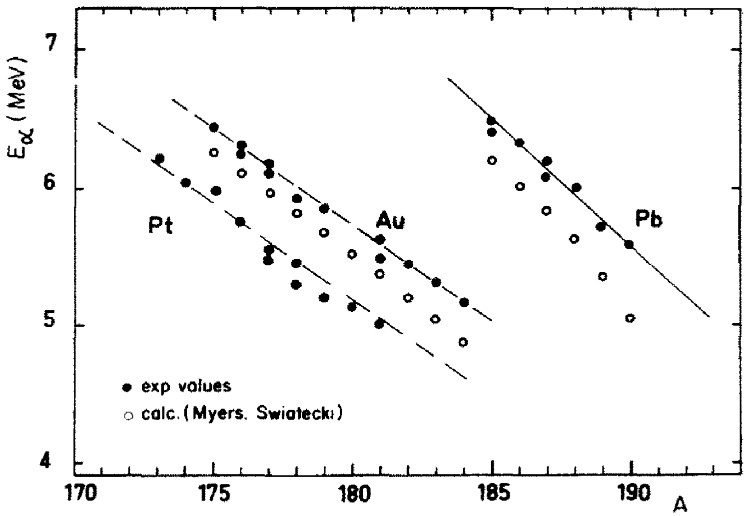

Fig. 3. Variation of α-particle energy E_α with the isotopic mass A for Pt, Au and Pb nuclei. Experimental values are shown. Calculated values by Myers and Swiatecki [5]) are also indicated.

tion energy of about 110 MeV. This energy is higher than the value at which the 6.44 MeV α-peak is first observed ($\approx$ 85 MeV) (fig. 2). Thus this possibility can be ruled out. For similar reasons the assignment to isotopes with $Z < 78$ must also be ruled out and the identification of the ^{176}Au and ^{175}Au isotopes produced by (Ca, 5-6n) reactions seems to us to be, therefore, very well established.

The half-lives of ^{177}Au and ^{176}Au were measured. The determinations were done for the two α-transitions (6.11 MeV and 6.15 MeV) of ^{177}Au. The same value, 1.3 sec, was obtained, indicating that these transitions are probably not associated with two isomeric states of ^{177}Au, but are due to the fine structure of ^{177}Au α-emission in its ground state. For ^{176}Au only the period of the 6.26 MeV α-decay was measured and the value 1.25 sec was obtained. The counting rates of the 6.29 MeV and 6.44 MeV (^{175}Au) activities were too low to permit any half-life measurements.

3.2. LEAD ISOTOPES

By (^{40}Ca, 3-4n) reactions on ^{150}Sm, lead isotopes with masses 187 and 186 are obtained. The 6.08 MeV and 6.32 MeV peaks from these two isotopes [4]) have been easily observed in our experiments using a Ca beam. The excitation function between 200 and 245 MeV for the formation of the two isotopes are shown in fig. 4. In the same energy range, the α-spectra indicate the existence of three new activities at 6.19, 6.40

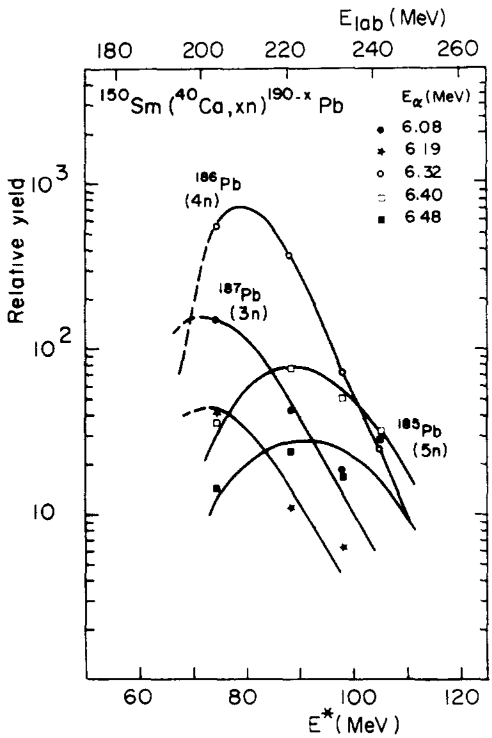

Fig. 4. Relative excitation functions for the reactions ^{150}Sm(^{40}Ca, xn)$^{190-x}$Pb.

and 6.48 MeV. The excitation functions for these three peaks are shown in fig. 4. The curves for the 6.40 and 6.48 MeV peaks exhibit the same behavior. Their maxima appear at an energy which is higher than the top of the (Ca, 4n) curve by about 12 MeV. This energy difference corresponds to the evaporation of an extra neutron. Thus we conclude that the 6.40 and 6.48 MeV activities are characteristic of the new isotope ^{185}Pb produced by the (Ca, 5n) reaction. This assignment is supported by the systematics of α-decay for the Pb isotopes, as shown in fig. 3. A similar analysis as the one developed for the Au isotopes leads us to rule out a possible assignment of the 6.40 and 6.48 MeV α-activities to the lighter elements thallium and mercury. If we compare the ^{141}Pr(Ca, xn) reactions (fig. 2) and ^{150}Sm(Ca, xn) reactions (fig. 4) as a function of available excitation energy, we observe a very clear similarity for the production of Au and Pb nuclei with regard to the number of emitted neutrons. The neutron binding energies in the two cases are very close to each other.

Fig. 4 shows that the variation of the yield of the new α-peak at 6.19 MeV with excitation energy is similar to those of the 6.08 and 6.32 MeV peaks. The reason for this is that the incident energy is not too different from the fusion threshold ($\approx$ 190 MeV). It seems that the 6.19 MeV activity could be associated with the decay

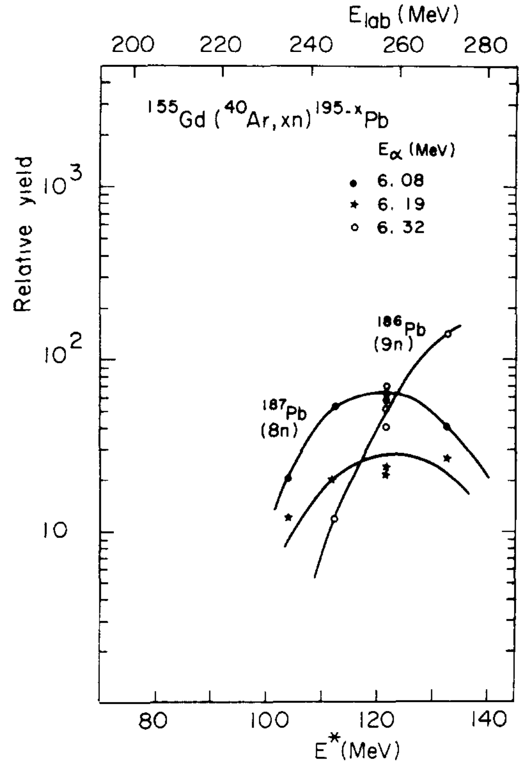

Fig. 5. Relative excitation functions for the reactions ^{155}Gd(^{40}Ar, xn)$^{195-x}$Pb.

of ^{187}Pb or ^{186}Pb, but the ^{150}Sm + ^{40}Ca experiments do not allow us to conclude this.

We have also studied the production of the isotopes ^{187}Pb and ^{186}Pb from the (^{155}Gd + ^{40}Ar) system. In this case, the (Ar, 8-9n) reactions occur far from the threshold for compound nucleus formation. Thus fig. 5 shows very distinct excitation functions between 230 and 280 MeV. The 6.19 MeV α-particle is also observed but, in this case, it clearly appears that the behavior of the 6.08 MeV and of the 6.19 MeV α-activities are very similar. Thus, we conclude that the 6.19 MeV α-activity is associated with the decay of ^{187}Pb, as is the 6.08 MeV α-activity. From figs. 4 and 5, we note that the same value is obtained ($\approx$ 2.5–3) for the ratio between the yields of the two α-activities.

Table 1 lists the decay characteristics for the very light isotopes of Au and Pb reported in this work.

TABLE 1

Summary of results on decay characteristics of Au and Pb isotopes

Isotope	E_α (MeV)	$T_{\frac{1}{2}}$ (sec)
^{177}Au	6.11±0.01 (65 %)	1.3 ±0.1
	6.15±0.01 (35 %)	1.3 ±0.1
^{176}Au	6.26±0.01 (≈ 80 %)	1.25±0.30
	6.29±0.01 (≈ 20 %)	
^{175}Au	6.44±0.01	
^{187}Pb	6.08±0.01 (≈ 73 %)	17.5±3.6 [a]
	6.19±0.01 (≈ 27 %)	
^{185}Pb	6.40±0.01 (≈ 72 %)	
	6.48±0.02 (≈ 28 %)	

[a]) From ref. [4]).

The use of a beam of ^{40}Ca ions has allowed us to produce three new isotopes, ^{176}Au, ^{175}Au, ^{185}Pb, which are 21 and 22 neutrons deficient relative to the line of stability.

We note that for the two gold isotopes, the mass tables of Myers and Swiatecki [5]) give a negative value for the proton binding energy. Thus the limit of the nuclear stability has been reached and proton emission is theoretically possible.

If we consider the lead nuclei, we may note that the α-decay of the 187 and 185 isotopes leads to ^{183}Hg and ^{181}Hg respectively. The α-transitions observed in our work may feed specific levels in these Hg isotopes. The region of the lightest mercury nuclei thus reached belongs to a mass region which is of great interest, and which is being extensively studied [6, 7]). As for Pt isotopes in the vicinity of $A = 186$ [ref. [8])], it has been shown that these nuclei are situated in a critical zone where some shape transitions appear, and where the stability of these shapes is still an open question.

In conclusion, we have shown the greater value of ^{40}Ca ions relative to that of ^{40}Ar ions in syntheses of very neutron deficient nuclei far away from the stability line. Other results will be presented soon for the region Pt-Bi.

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