

Excitation Functions and Isomeric Ratios for the Isomeric Pair ^{106m}Ag and ^{106g}Ag in the $^{107}\text{Ag}(\text{d},\text{t})^*$ Reaction

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Summary

Excitation functions and isomeric cross section ratios have been measured for the $^{107}\text{Ag}(\text{d},\text{t})$ reaction in which the isomeric pair $^{106m}/^{106g}\text{Ag}$ is produced. Thick-target yields have been determined for different irradiation times and as a function of deuteron energy. Stacked silver foils with aluminium foils as monitors were bombarded with deuterons up to 27 MeV and the activities of products measured with a calibrated Ge(Li) counter.

Zusammenfassung

Wirkungsquerschnitte sind gemessen worden für die Reaktionen $^{107}\text{Ag}(\text{d},\text{t})^{106m}\text{Ag}$ und $^{107}\text{Ag}(\text{d},\text{t})^{106g}\text{Ag}$. Die in dicken Proben induzierte Aktivität wurde als Funktion der Deutonenenergie bestimmt für verschiedene Bestrahlungszeiten. Sandwiches aus Silberfolien und Aluminiumfolien wurden mit 27 MeV Deutonen aktiviert. Die Aktivität der Produkte wurde mit einem geeichten Ge(Li)-Detektor bestimmt.

Résumé

On a mesuré les sections efficaces et leur proportion pour les réactions $^{107}\text{Ag}(\text{d},\text{t})^{106m}\text{Ag}$ et $^{107}\text{Ag}(\text{d},\text{t})^{106g}\text{Ag}$. Les rendements sont calculés en fonction de l'énergie des deutons pour des cibles épaisses et pour des durées d'irradiation différentes. Des feuilles d'argent en sandwich avec des feuilles d'aluminium furent irradiés avec des deutons de 27 MeV et les activités produites furent mesurées avec un détecteur Ge(Li) calibré.

Introduction

The knowledge of activation cross sections and their energy dependence is necessary if the limits of detection for a given element in activation analysis are to be calculated. Such excitation functions are also crucial to the development of the field of radionuclide production by charged particle bombardment. Although excitation functions do not lead to detailed understanding of nuclear reactions, they do contribute to the general picture of reaction mechanisms by their shapes and, specially, by the absolute magnitude of the cross sections. The yield ratio of the isomeric pairs in nuclear reactions leads to some theoretical predictions of the reaction mechanism producing the isomeric states. This paper reports the determination of absolute excitation functions and cross-section ratios for the $^{107}\text{Ag}(\text{d},\text{t})^{106m/g}\text{Ag}$ reaction. Thick-target yield as a function of energy were calculated for the production of ^{106m}Ag from deuterons on silver.

In spite of cross-sections having been measured for many charged-particle reactions [1-3], there exist few quantitative data of this kind for the (d,t) reaction [3-16].

A certain number of investigators [17] have previously reported the cross section ratios for $^{106m/g}\text{Ag}$ for (γ,n), ($\text{n},2\text{n}$), (p,p), (p,pn) and (He^4,n) reactions.

Experimental

a) Irradiations

Stacks of silver foils were irradiated with 27 MeV deuterons in the external beam of the Comisión Nacional de Energía Atómica (Argentine) Synchrocyclotron. The maximum uncertainty in the beam energy was estimated to be < 1 percent. Silver foils (99.999% pure), were cut and washed very carefully and placed between aluminium monitor

* (d,t) means: (d,t), (d,p2n) or (d,dn).

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Table 1. Cross sections and cross section ratio's for the reactions $^{107}\text{Ag}(d,t)^{106\text{m}}\text{Ag}$ and $^{107}\text{Ag}(d,t)^{106\text{g}}\text{Ag}$

E_D (MeV)	σ_m (mb)	σ_g (mb)	σ_m/σ_g
26.9	111 ± 15	191 ± 50	0.58
26.4	84 ± 5	98 ± 30	0.85
25.8	80 ± 1	108 ± 10	0.74
25.3	90 ± 5	95 ± 5	0.94
24.8	72 ± 1	78 ± 3	0.91
23.3	50 ± 2	49 ± 1	0.99
21.0	37 ± 2	41 ± 10	0.88
20.0	25 ± 7	24 ± 4	1.07
19.1	30 ± 2	25 ± 2	1.20
17.4	27 ± 5	20 ± 1	1.33
16.8	19 ± 1	19 ± 1	1.01
16.0	12 ± 2	18 ± 1	0.68
11.4	12 ± 5	14 ± 3	0.86

Table 2. Activity of $^{106\text{g}}\text{Ag}$ induced in thick and their silver targets by deuteron irradiation

Energy Range (E_1 E_2 MeV)	Thick-ness of the target (mg/cm ²)	Cross section (mb)	Saturation activity per MeV ($\mu\text{Ci}/\mu\text{A}$)	Saturation activity in thick target up to E_1 ($\mu\text{Ci}/\mu\text{A}$)	Activity in thick target per hour ($\mu\text{Ci}/\mu\text{Ah}$)
27-26	53.5	99	31×10^6	31×10^6	1.08×10^4
26-25	52.1	79	48×10^6	80×10^6	2.52×10^4
25-24	50.6	64	19×10^6	99×10^6	3.42×10^4
24-23	49.1	52	15×10^6	114×10^6	3.90×10^4
23-21	93.6	37	20×10^6	134×10^6	4.64×10^4
21-19	87.6	26	13×10^6	148×10^6	5.90×10^4
19-17	81.2	18	86×10^5	156×10^6	5.40×10^4
17-15	74.9	12	53×10^5	209×10^6	7.20×10^4
15-13	68.3	8	34×10^5	243×10^6	8.40×10^4
13-11	61.7	7	25×10^5	269×10^6	9.28×10^4

foils of known thickness. Since the excitation functions of the $^{27}\text{Al}(d,\alpha p)^{24}\text{Na}$ reaction [18] is well known, the yield of ^{24}Na in the aluminium foils relative to that of radioactive isotopes in the silver foils provides a means for obtaining absolute cross sections for the deuteron-induced reactions in silver.

The energy of the deuterons at the middle of each target foil was determined from range energy tables [19]. The uncertainty in the particle energy for each data point is due to the energy spread of the incident beam from the cyclotron (1%) and energy loss straggling. The energy straggling in the target was estimated to be about 0.5 MeV for the foil in which the deuterons had been slowed-down to 16 MeV [20]. Corrections for the energy spread in each foil due to uncertainties in the foil thickness and to energy degradation in the preceding foils, were not applied. Losses of reaction products by recoil were assumed to be negligible.

b) Counting and data treatment

After irradiation, the activities of each sample were measured without previous chemical separation because radioactive isotopes which might interfere with the measurements are not formed in appreciable amounts. The gamma spectra of each foil were obtained using a high-resolution Ge(Li) detector coupled to a 1024 channel pulse height analyzer.

The spectrometer was calibrated with standard gamma-sources of known activity.

Spectra were measured at time intervals suitable for identifying the nuclides $^{106\text{m}}\text{Ag}$ and $^{106\text{g}}\text{Ag}$ by their half-lives.

The count-rate in the 511 + 512 keV photopeak as a function of time combined with the published decay scheme data [21-23], provided the absolute activity of both isomers in each target foil from which the production cross section for both isomeric levels were calculated.

Since ^{106}Rh is produced by the $^{107}\text{Ag}(d,3p)$ and the $^{109}\text{Ag}(d,\alpha p)$ reactions, the subtraction of this nuclide

introduces a certain error in the determination of photopeak areas (roughly estimated as $\pm 15\%$).

The yield function of the (d,t) reaction for the irradiation of thick silver targets was calculated by numerical integration for different irradiation times. The computations were performed using the measured cross-sections [2,24].

Results and conclusions

Cross sections and cross section ratios were obtained as an average of data from three determinations. Table 1 shows this values for different deuteron energies. The listed errors are the greatest deviations from the average.

Errors in the cross section values are due to uncertainties of the individual quantities involved in their determination, as the absolute activity of the gamma ray, the deuteron flux, etc.

In the determination of the isomer ratios, errors in the beam intensity, target thickness, target uniformity and photopeak efficiency of the detector cancel. Apart from uncertainties in the decay schemes, the only errors involved are counting errors.

The excitation function for $^{107}\text{Ag}(d,t)$ has not been previously measured. We have compared our results with values calculated on the basis of systematics for charged particle reaction cross-sections [3].

The agreement is good, although the calculated figures are based on very few quantitative data for (d,t) reactions.

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In Table 1 the isomer ratios are listed as a function of energy. The dependence of the yield ratios of the isomeric states on energy does not show the general trend observed in other reactions [13–14]. Several factors influence the yield ratio of the isomeric pairs in nuclear reactions and these have been discussed by different authors [25–28]. In deuteron irradiations complications arise, since different processes such as total absorption of the deuteron or stripping compete. Activities obtained in thick targets are shown in Table 2.

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