Estimation of Relative Cross-Sections from Activation Analysis

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Introduction

The application of Charge Particle Activation Analysis (CPAA) is found extensively in the field of nuclear research for the determination of trace impurity amount in sample material and cross-section measurements related to Nuclear Astrophysics. The method involves qualitative and quantitative analysis of a sample after irradiation by charged particles or neutrons.

In the present work, the relative cross-sections of two exit channels of a reaction have been extracted by analyzing the decay of its long-lived reaction products. The experimental results have been compared with the predictions of statistical model code predictions.

Methodology

In a reaction, A_1 nuclei are bombarded with an energetic beam to produce A_2 nuclei. If these A_2 nuclei are radioactive having a decay rate λ, N_2 and N_1 are numbers of initial and final nuclei A_1 and A_2, respectively, the net production rate of A_2 is given by,

$dN_2/dt = R - N_2\lambda$

where $N_2\lambda =$ decay rate of A_2

$R=N_1\sigma\tau$ is the production rate of A_2, following the reaction with $\sigma =$ reaction cross-section, $\tau =$ incident particle flux.

After a certain time interval T, if we count the number of A_2 nuclei, whose decay rate is known, the reaction cross-section σ can be estimated provided N_1 and τ are known. In the present work, the ratio of the yields of two products of the same reaction has been determined to get their relative cross-sections. Thus the need for the exact quantity of the target nuclei and incident beam flux could be eliminated.

ISOTOPE	% Yield	Half-life
114-Te	0.2	15.22m
116-Te	0.4	2.49h
117-Te	2.7	62m
118-Te	12.7	6d
119-Te	14.8	16h
120-Te	15.4	stable
121-Te 121m-Te	**26.1**	**19.17d(g.s) 164.2d(m.s)**
122-Te	5.8	stable
123-Te, 123m-Te	**4.3**	**stable, 119.2d (m.s)**
124-Te	0.3	stable
125-Te	5.4	stable
126-Te	0.1	stable
Total	88.2	

Table 1. Percentage (%) yields of the Te isotopes as obtained from PACE4 [3] calculations (for 37 MeV alpha energy) and their half-lives [1].

Experiment, Analysis, and Results

A natural tin (Sn) foil of a thickness of 20.385 mg/cm^2 was irradiated with an alpha beam of energy 37 MeV obtained from the VECC cyclotron. The details of the irradiation experiment have been discussed in Ref [2]. The foil has been stored for one and a half years before decay gamma spectroscopy with high-resolution HPGe detector is done. The relative efficiency of the detector was determined using standard radioactive sources, like ^{133}Ba, ^{152}Eu, etc. The irradiated foil has been placed in the same position as the sources for acquiring decay gamma spectra shown in Fig.1.

Natural tin foil contains various stable isotopes of tin with A=112, 114-120, 122 and 124 with varying abundances. Using the statistical model code PACE4 [3], cross-sections of different product nuclei are obtained for bombarding alpha particle energies 37 MeV and 35 MeV (after energy loss in thick target). Most abundant products are $^{114\text{-}126}$Te~89%, $^{114\text{-}122}$Sb ~5% and $^{111\text{-}124}$Sn~4.6%. The relative percentage yields of different Te isotopes and their half-lives are listed in Table 1.

As the irradiation was done about 1.5 years ago, only long-lived isotopes (half-lives ~100 days or more) were observed in the spectrum. Decay gamma-rays from ^{121,123}Te meta-stable state and ground state decay are observed in the spectrum (Fig.1).

Observation of gamma rays from the decay of ground-state of ^{121}Te having a half-life of ~20 days, was confusing in the beginning. Later it was realized that about 11.4% of the population of the isomeric state (164.2 days) in ^{121}Te feeds the various higher levels in ^{121}Sb, whence it goes to the ground state of ^{121}Sb. The rest 88.6% makes transitions to its own ground state ($T_{1/2}$=19.17 days) by subsequent emission of 81 keV and 212 keV gamma rays. Thus the ground state decay of ^{121}Te populates 507 and 573 keV levels in ^{121}Sb finally reaching the ground state of ^{121}Sb. In the case of ^{123}Te, there is an isomeric state with a half-life of 119 days. From the isomeric state, it comes to the ground state (IT decay =100%), through two subsequent transitions 88 keV and 159 keV.

In the spectra (Fig. 1) of irradiated tin foil, we are able to observe all these transitions except the 81 keV of ^{121}Te and 88 keV line of ^{123}Te, because, they are M4 transitions and are highly converted. The conversion coefficients for these two transitions calculated using BRICC code [1] are found to be 1735 for the 81 keV transition and 1122 for the 88 keV transition.

Results and Discussion

The cross-section of ^{121}Te has been estimated to be ~7 times that of ^{123}Te after incorporating the necessary correction factors from the analysis of the experimental data. However, the statistical model calculation using the code PACE4 predicts this ratio as 6.

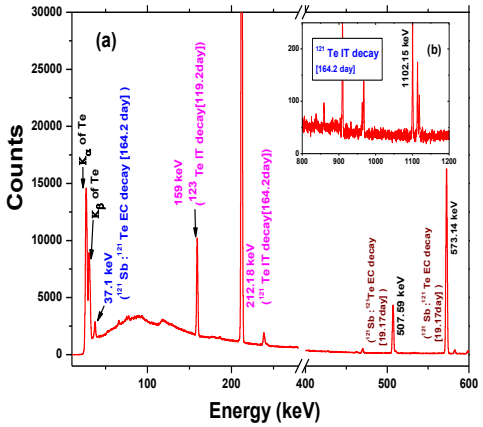

Fig.1 Gamma-ray spectra of irradiated Sn foil. (a) The spectra till 600 keV, (b) the higher energy part of the spectra.

The details of the analysis of the data and the estimation of experimental errors will be discussed. Apart from statistical errors in the area estimation, the other important source of error is the interpolated values of relative efficiencies. However, the primary source of error is in the estimation of the relative yield of the isomer compared to the ground state in the in-beam experiment, which will be discussed in detail.

Thus, this work demonstrates the strength of the activation analysis method in the determination of reaction cross-section from long-lived activities produced in the foil, even after a long interval of time after irradiation.

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