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Neutron induced reactions in antimony isotopes at 14 MeV

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Abstract. Neutron activation cross-sections in antimony isotopes were measured at an incident neutron energy of $14{\cdot}2 \pm 0{\cdot}2$ MeV. The versatile mixed powder technique and high resolution Ge(Li) detector gamma ray spectroscopy were employed. The measured cross-sections were compared with those reported in literature. The total (n, $2n$) cross-sections were compared with the estimates based on statistical theory. The experimental values were found to be smaller than the statistical theory estimates and the resulting diminution was attributed to the precompound effects in (n, $2n$) reactions at 14 MeV.

Keywords. Activation cross sections; mixed powder technique; statistical theory estimates; precompound effects.

1. Introduction

Due to the widespread availability of Cockcroft-Walton accelerators as prolific sources of monoenergetic neutrons, many fast neutron cross-sections are reported (CINDA 1976) around 14 MeV. During the last 25 years, techniques of measuring the activation cross-sections have steadily improved and the earlier GM counter detection of beta rays has been replaced by gamma detection by NaI(Tl) detector which was in turn replaced by high resolution Ge(Li) detector. Also, the mode of irradiating the sample and the monitor has been improved. Thus the versatile mixed powder technique (Venugopala Rao and Fink 1967) ensures the sample and the monitor to be exposed to the same flux of neutrons besides making possible the simultaneous counting of the activities produced in both, under identical geometry. Since the advent of high resolution Ge(Li) detectors, the spectroscopic data needed for the measurement of cross sections have also undergone a revision and now accurate tabulations are available.

These improvements have, of late, prompted a precision remeasurement of neutron activation cross-sections employing mixed powder technique and Ge(Li) detector gamma ray spectroscopy to clarify some mutual contradictions in the reported data and to clear up the anomalies in the systematics. The (n, $2n$) and (n, p) reactions induced in antimony isotopes are a case in point.

In the case of ^{123}Sb (n, p) ^{123}Sn reaction, there exist only two beta measurements (Levkovskii 1971 and Mavaddat *et al* 1974) reporting values which differ by a factor of five. In beta measurements, self absorption of beta rays within the target is the serious problem and it could give rise to differences of such order of magnitude. In gamma ray counting technique, this problem is less serious. But there are no reported gamma ray measurements for this cross-section even with a NaI(Tl) detector. This is presumably due to the fact that the characteristic gamma ray of the product nucleus ^{123m}Sn has a low energy of 160 keV and is likely to be masked by the strong compton background due to 197 keV gamma ray emitted by a reaction product due to the other isotope of antimony. On the other hand the chief virtue of a Ge(Li) detector is that the compton background of gamma rays is strongly suppressed and this together with the high resolution of the Ge(Li) detector makes possible the study of weak photopeaks in the presence of closely lying stronger ones. As for the self absorption effects, the correction factor is not only small for gamma rays but it can also be accurately estimated using a simulation technique in the efficiency measurements. For the above reasons a Ge(Li) detector is eminently suitable for cross-section measurements. There is another strong motivation for an accurate cross-section measurement of the above reaction. The product nucleus ^{123}Sn in this reaction is a magic nucleus with $Z=50$. The systematics of (n, p) cross-sections (Chatterjee 1964) in this region suggest a strong dip at $Z=50$ and this is indicated by the low value, $4{\cdot}6 \pm 1{\cdot}3$ mb, as reported by Levkovskii (1971). However, the latest measurement of $19{\cdot}7 \pm 6{\cdot}3$ mb by Mavaddat *et al* (1974) strongly contradicts this trend. As pointed out earlier, both these measurements were made using the beta counting method. It is therefore felt essential to remeasure the cross-section using the sophisticated Ge(Li) detector.

Similarly there are wide discrepancies in the reported values for the $(n, 2n)$ cross-sections of antimony isotopes. Therefore, in the present work a systematic measurement of neutron activation cross-sections in the isotopes of antimony has been undertaken using the high resolution Ge(Li) detector and versatile mixed powder technique.

2. Experimental

Neutrons were produced through $T(d, n)\alpha$ reaction at the 600 keV Cockcroft-Walton accelerator of Andhra University. The irradiations were performed at 90° to the incident deuteron beam such that the neutrons with energy, $14{\cdot}2 \pm 0{\cdot}2$ MeV, irradiate the samples. The neutron flux was of the order of 10^8 n/cm^2/sec. The constancy of the flux was monitored by an auxiliary BF_3 counter embedded in a paraffin block.

'Specpure' natural antimony metal powder was thoroughly mixed with aluminium powder and the mixed powder was encapsulated in thin walled ($<0{\cdot}5$ mm thick) perspex discs of 3·3 cm in diameter and the thickness of the wafer was 1 or 2 mm. The following reactions served as monitors:

(i) ^{27}Al(n, α) ^{24}Na, $T_{1/2} = 15$ h, $\sigma = 115{\cdot}5 \pm 3$ mb (Robertson *et al* 1973)

(ii) ^{27}Al(n, p) ^{27}Mg, $T_{1/2} = 9{\cdot}5$ m, $\sigma = 72 \pm 5$ mb (Present work)

After the end of irradiation, the sample was transferred onto a 35 cc coaxial Ge(Li) detector (FWHM: 4·6 at 1332 keV) surrounded by lead blocks to minimise the background. Figure 1 shows a typical gamma spectrum of the irradiated sample recorded on a ND 512 channel analyser. Areas of the interested photopeaks were determined with the help of a computer programme which corrects for a linear

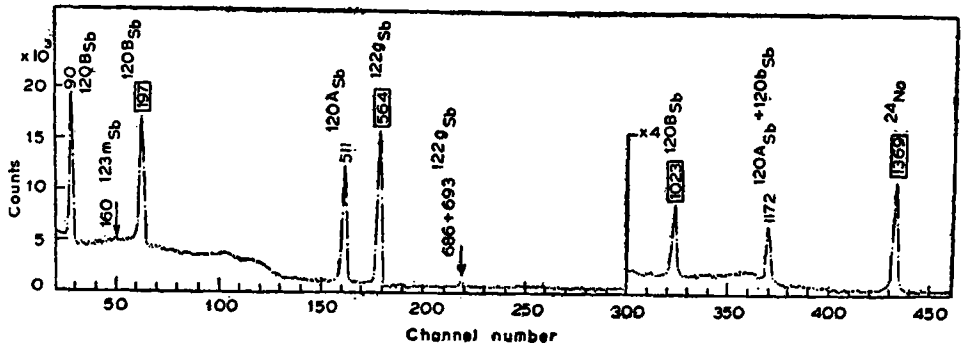

Figure 1. Gamma ray spectrum of irradiated (Sb+Al) powder sample (spectrum recorded 70 min after irradiation)

background and makes a Gaussian fitting of the photopeak. The relative photopeak efficiency of the detector, corrected for self absorption and scattering of gamma rays within the sample, was calibrated by the simulation technique, using standard radioactive sources, ^{75}Se, ^{133}Ba and ^{152}Eu, supplied by Bhabha Atomic Research Centre, Bombay.

The activation cross section, for the reaction was evaluated using the standard formula (Rama Prasad *et al* 1969).

2.1. *Errors*

The errors in the present cross-section measurements are the root-mean-square errors and are composed of the following: (i) the relative photopeak efficiency of the detector was estimated within an error $\sim 3\%$, (ii) the error on the determination of the photopeak areas was the standard deviation in counting statistics, (iii) the errors in weighing and mixing of the samples, duration of bombardment and transport of irradiated samples were negligible, (iv) spectra were recorded usually with less than 5% dead time in the multichannel analyser and hence the errors due to dead time losses were also negligible.

The errors in the monitor cross-sections, half-lives, and absolute gamma ray abundances were not included but the used spectroscopic data are shown in table 1. This is because any revision in the decay schemes and conversion coefficient values permits easy recalculation of the cross section in future.

3. Results and discussion

The cross-sections measured in the present work are given in table 1, together with those reported in literature. It can be seen that in the case of the first three reactions, the present experimental values agree closely with those of Lu *et al* (1970) who also employed the mixed powder technique and gamma ray counting with Ge(Li) detector. This fact reveals the superiority of the present technique of measurement in contradistinction to the beta counting with GM counter or gamma counting with NaI(Tl) detectors. It can be noticed from table 1 that the latter two methods are characterised by considerable spread in the reported values for the same cross-section upto a

Table 1. Neutron activation cross-sections in antimony isotopes

Reaction	$T_{1/2}$	E_r (keV)	θ	Activation cross-section (mb)			
				Present work (mb)	Literature value		
					σ	detector employed	ref.
$^{121}Sb(n,2n)^{120A}Sb$	15·9 m	1172	0·02	1169±70	750±188	G.M.	(a)
					1180±177	G.M.	(b)
					1056±79	G.M.	(c)
					935±90	NaI(Tl)	(d)
					1062±82	NaI(Tl)	(e)
					1244±80	NaI(Tl)	(f)
					1188±60	Ge(Li)	(g)
$^{121}Sb(n,2n)^{120B}Sb$	5·8 d	1023	0·99	430±26	611±58	G.M.	(d)
					597±35	NaI(Tl)	(f)
					432±105	NaI(Tl)	(e)
					427±20	Ge(Li)	(g)
$^{23}Sb(n,2n)^{122m+g}Sb$	2·7 d	564	0·66	1692±85	1245±311	G.M.	(a)
					1950±195	G.M.	(b)
					2280±200	NaI(Tl)	(f)
					1263±135	G.M.	(d)
					1542±80	Ge(Li)	(g)
$^{123}Sb(n,2n)^{122m}Sb$	4·2 m	75	0·17	527±40	1013±122	NaI(Tl)	(b)
					547±79	G.M.	(d)
					686±60	NaI(Tl)	(f)
$^{123}Sb(n,p)^{123m}Sn$	40 m	160	0·99	1·13±0·17	1·8±0·4	G.M.	(i)
					19·7±6·3*	G.M.	(j)

*Total cross-section for isomeric and ground states.

(a) Paul and Clarke (1953), (b) Khurana and Hans (1961), (c) Rayburn (1961),
(d) Bormann *et al* (1968), (e) Kanda (1968), (f) Minetti and Pasquerelli (1968),
(g) Lu *et al* (1970), (h) Mangal and Gill (1963), (i) Levkovskii (1971),
(j) Mavaddat *et al* (1974)

factor of two. Thus the cross-sections measured with the present technique may be taken as recommended values.

In the case of $^{123}Sb(n, 2n)^{122m,g}Sb$ reaction, Lu *et al* (1970) made no attempt to measure the isomeric state cross-section separately. This was done in the present work and the value compared with those obtained with other techniques. It can be seen from table 1 that the present cross-section for the reaction $^{123}Sb(n, 2n)^{122m}Sb$ not only agrees with the earlier beta measurement of Bormann *et al* 1968 but has a better accuracy.

In the case of $^{123}Sb(n, p)^{123m}Sn$ reaction, the present work offers the first Ge(Li) measurement of the cross-section using the versatile mixed powder technique. The present value of 1·13±0·17 mb is slightly smaller than the earlier beta measurement of 1·8±0·4 mb reported by Levkovskii (1971), who also measured the ground state cross-section to be 2·8±0·9 mb. It is noteworthy that the total cross-section for this reaction as measured by Mavaddat *et al* (1974) is 19·7±6·3 mb, which is rather

Table 2. Comparison of experimental results with statistical theory

Reaction	Experimental cross-section (mb)	Theoretical cross-section (mb)
^{121}Sb(n, 2n) ^{120}Sb	1599±75	1840
^{123}Sb(n, 2n) ^{122}Sb	1692±85	1861

quite large. The peculiarity of this reaction is that the product nucleus ^{123}Sn is magic with $Z=50$ and shell effects are expected. While the result of Mavaddat *et al* indicates a maximum in the systematics at this proton number, the present result as well as that of Levkovskii (1971) point out to a deep minimum in the systematics at $Z=50$, as predicted by Chatterjee (1964) on the basis of similar discontinuities at other magic nucleon numbers.

3.1. *Comparison with theory*

The total (n, 2n) cross-sections measured in this work were compared and are shown in table 2 with the estimates based on statistical theory (Blatt and Weisskopf 1952).

It can be seen from table 2 that in both the cases, the experimental cross-sections are lower than the theoretical estimates. This diminution can be attributed to the precompound effects in (n, 2n) reactions at 14 MeV. This is evidenced from typical calculations by Seidel *et al* (1976) who have shown that appreciable precompound effects can be anticipated in neutron induced reactions in as much as the excited compound system is raised to energies between 20–25 MeV, with 14 MeV neutrons. A typical feature of precompound emission is that the emitted nucleons carry away relatively large amounts of excitation energy. In (n, 2n) reactions, for example, it may result that after the first neutron emission in the pre-equilibrium phase, the residual nucleus may be left at such low excitation that a second neutron emission is energetically forbidden. This would detract from the (n, 2n) cross-section. In an activation measurement of (n, 2n) cross-sections where the product nuclei are identified, the evident result is a considerable decrease in the experimentally measured cross-section as compared to what is expected on the basis of pure evaporation from an equilibrium compound nucleus.

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