THE (n, 2n) CROSS–SECTION FOR Na–23 BETWEEN E_n = 13.3—18.5 MeV

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ABSTRACT

The (n,2n) cross- section for ^{23}Na have been measured by the activation method in the energy range of $E_n = 13.3$—18.5 MeV. Monoenergetic neutrons were obtained from T(d,n) ^{4}He reaction at $E_d = 2.3$ MeV. The induced specific activities were detected by a coincidence counting setup. For comparison, the other measured, evaluated and calculated data from $E_n = 12$—20 MeV are also given.

Keywords: Neutron reaction ^{23}Na (n,2n) $E_n = 13.3$—18.5 MeV Natural target Activation cross- section

Ⅰ. INTRODUCTION

The activation cross- sections for ^{23}Na (n,2n) are important not only for practical use but also for theoretical study. First, they are necessary to radiation protection in fast reactor used Na as a coolant. From a theoretical point of view, the statistical theory can give good agreement with measured cross- section for median and heavy nuclei. But neutron induced reaction in light elements shows isolated resonance structure. This means the breakdown of the statistical conditions. The nucleus ^{23}Na is just in the "Intermediate zone" between the region of validity of statistical theory and the region of very light nuclei which require detailed treatment. There are three sets of experimental data in Na(n,2n) reaction[1-3], and each differs from the other by approximately a factor of two. It caused difficulty in use of these data. So we decided to measure it and to see which one is the best.

Ⅱ. EXPERIMENTAL PROCEDURE

1) Irradiation The general arrange ment for neutron irradiation is shown in Fig.1. The neutrons of $E_n = 13.3$—18.5 MeV were obtained by bombarding a T- Ti target with $E_d = 2.3$ MeV deuterons. The target was 2.65 mg/cm^2 in thickness. The deuteron beam was $I_d = 1$- 3μ A. The samples were suspended on a circle of 70mm radius. The centre of the circle was the geometrical centre of the beam. The

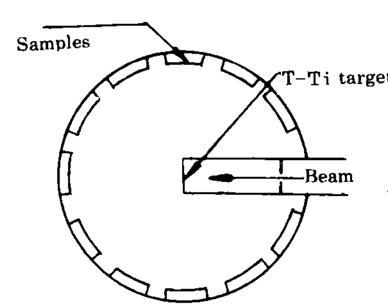

Fig.1 Irradiation arrangement

size of the beam spot was defined by an apperture of 3 mm diameter. The tritium target was mounted on a thin copper tube. The thickness of the tube is 0.1 mm. The neutron flux was determined by a calibrated long counter positioned in zero degree direction at 120 cm distance from the target before and after the samples were irradiated. A BF_3 counter in 40° was as monitor. The samples were irradiated about 60 hours.

2) *Sample* The sample consisted of natural NaF powder pressed firmly into a cylindrical shape. The dimension of the cyclinder was 1 cm in thickness and 2 cm in diameter. Nine samples were irradiated simultaneously. The angle of the samples respected to the beam were from 0° to 121°. The samples were mounted at both sides with respect to the beam direction to counteract a possible shift of beam centre.

3) *Activity determination* The induced specific activity of the sample was low and determined by a gamma- gamma coincidence spectrometer which consists of two scintillation counters both with 10 cm diameter and 10 cm thickness NaI(Tl) crystals and coupled to type GDB- 100 photomultipliers. The high voltage of PM tube was 800 volts. The photopeak of 0.511 MeV were fed into the coincidence unit. The resolution time of this unit was 2.5μ s. The coincidence counting efficiency of the spectrometer was determined with a standard ^{22}Na source. The activity of the source is 25.8 ± 0.1 kBq. The β^+ per decay 0.905[6] was used in this experiment. To eliminate difference in geometry and gamma self- absoption between the source and sample, the calibrated source was sandwiched in the brocks of sample material with different thickness and put in different position then took the average. The coincidence counting efficiency was $\varepsilon = 0.0735 \pm 0.0037$. The spectrometer was checked several times per day and no significant drift was found during the period of measurement. When samples were measured they were mounted in a plastic box. The thickness of the box was 1 mm.

Ⅲ. RESULTS

1) *Cross-section* Our result is listed in Table 1. The cross- section is given by

$$\sigma = N_c T_r \lambda / [N_s \varepsilon \Omega \eta L (1-\exp(-\lambda T_r)) \exp(-\lambda T_c) (1-\exp(-\lambda T_m)) K_1 K_2 P]$$

where N_c is the pure counts measured from the sample in period of T_m, λ decay constant of ^{22}Na, T_c delay time of the measurement after irradiation, T_r irradiation time of the sample, N_s the number of sample nuclei, ε coincidence counting efficiency of the spectrometer, P decay scheme correction, Ω solid angular sustended by sample to target, η neutrons in zero degree per monitor count, L monitor counts in the period of T_r, K_1 neutron attenuation correction in sample and K_2 angular distribution coefficient of TD neutron[6].

In order to estimate the neutron attenuation within the sample, the ^{63}Cu (n,2n) activation was used. The exitation curve of the reaction is rather similar to the Na (n,2n) reaction's. Two copper sheets, each in 0.2 mm thickness, one put in front of the NaF sample and the other in the backward. The diameter of these copper sheets were

Table 1

^{23}Na (n,2n) cross—section from E_n=13.3—18.5 MeV

E_n(eV)	Δ E_n (MeV)	σ (mb)	Δ σ (mb)
18.5	0.27	185	33
18.1	0.23	171.2	20
17.5	0.4	157.7	20
16.4	0.5	136.5	20
14.9	0.5	70	19
13.3	0.4	1.9	2

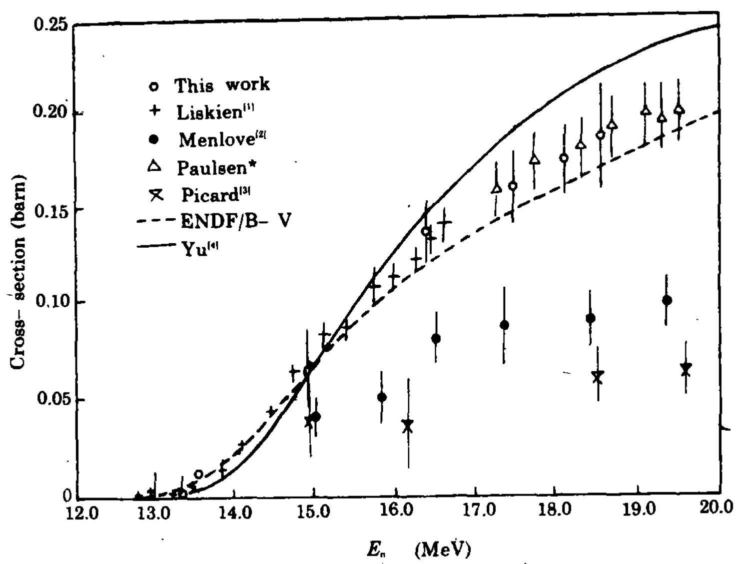

Fig.2 ^{23}Na (n,2n) cross—section

* Data taken from DNDF/B- V ^{23}Na evaluation instruction p.88, Paulsen is in same Lab. with Liskien. So we treat them as one data set

Table 2

Errors of the cross—section

1. Uncertainty of sample position	1.5%
2. Neutron flux measurement with long counter	6%
3. Neutron attenuation correction in sample	5%
4. Gamma coincidence counting efficiency	5%
5. Neutron angular distribution calculation	2%
6. Mass of sample less than	0.01%
7. Statistical errors of counting (according to the total counts) greater than	7%
Total greater than	13%

just the same with the NaF sample. After ten minutes irradiation the 0.511 MeV photon coincidence was recorded. The count rate of the sheet was proportional to the neutron flux in the place of the sheet. The average count rate of the two sheets was proportional to the average neutron flux in the NaF sample approximately. The ratio of average count rate and the front sheet count rate was used as neutron attenuation correction coefficient K_1. It was 0.901 ± 0.005 in our case.

2) *Uncertainty* The experimental error in the resulted cross- sections are also shown in Fig.2. They were calculated by compounding quadratically the uncertainties of the different factor which were listed in Table 2.

IV. COMPARISION

Fig.2 shows the result of this work. The other measured data are also shown in the figure. The dash line is the evaluated ENDF/B- V data. The solid line is the calculated result[4] which is based on the optical model, Hauser Feshbach and pre- equlibrium theory. From this figure we can find our result is very close to LisKien's and lower than Yu's calculation.

Y.N.Manokhin et al[7] have taken the IRDF data as their evaluation data but it was much lower than ENDF/B- V data.

Takashi Nakamura showed their result in a report recently[8]. They used a quasi- monoenergetic neutron source with energies from $E_n = 15$ to 35 MeV produced by the Be(p,n) reaction. They gave the average cross- section about 120mb between $E_n = 14$ to 19 MeV and about 210 mb between $E_n = 19$ to 24 MeV. Which is much close to our result.

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