Measurement of activation cross section of (n, p) and (n, α) reactions in the energy range of 3.5 to 5.9 MeV using a deuterium gas target

Masataka FURUTA [1,*], Itaru MIYAZAKI [1],
Hiroshi YAMAMOTO [1], Michihiro SHIBATA [2], Kiyoshi KAWADE [1]

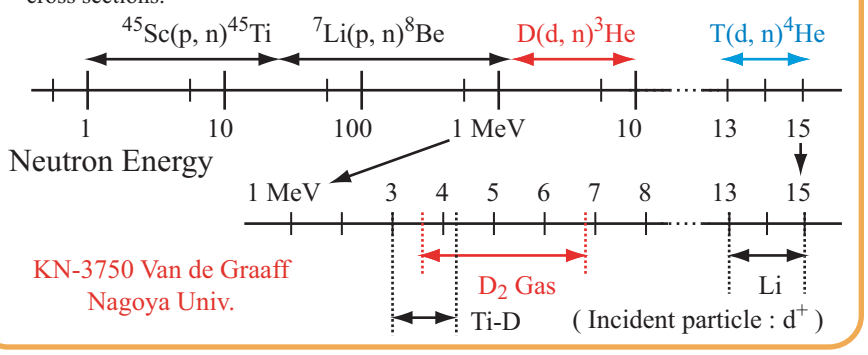
[1] *Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan.*
[2] *Radioisotope Research Center, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan.*

Abstract

Activation cross sections of (n, p) and (n, α) reactions were measured by means of activation method in the neutron energy range of 3.5 to 5.9 MeV using a deuterium gas target. The irradiated target isotopes were ^{27}Al, ^{28,29}Si, ^{41}K, ^{51}V, ^{61}Ni, ^{65}Cu, ^{64,67}Zn, ^{69}Ga, ^{79}Br, ^{92}Mo and ^{93}Nb. The values of the ^{29}Si (n, p) ^{29}Al, ^{67}Zn (n, p) ^{67}Cu, ^{69}Ga (n, p) ^{69m}Zn, ^{79}Br (n, p) ^{79m}Se, and ^{69}Ga (n, α) ^{66}Cu reactions were obtained for the first time. For the corrections of neutron irradiations, neutron spectra and mean neutron energies at the irradiation positions were calculated. A systematics of the (n, p) reactions at the neutron energy of 5.0 MeV in the mass range between 27 and 92 were proposed for the first time. The systematics can predict the cross sections within an accuracy of a factor of 1.6.

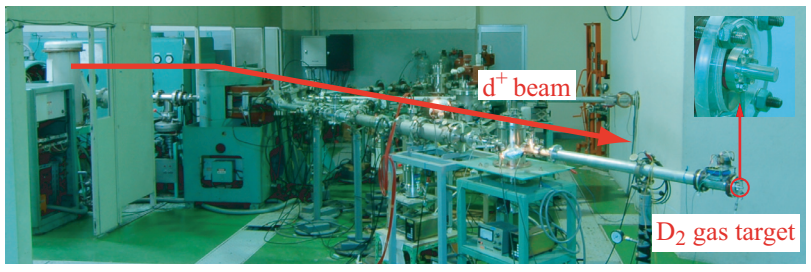
1. Introduction

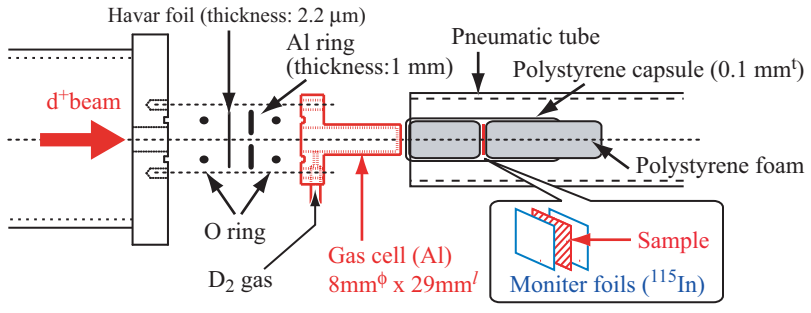
A lot of experimental cross section data have been reported in the neutron energy of around 14 MeV. On the other hand, there are insufficient data around 5.0 MeV because there are few appropriate neutron sources for the measurement of cross sections.



2. Experiment

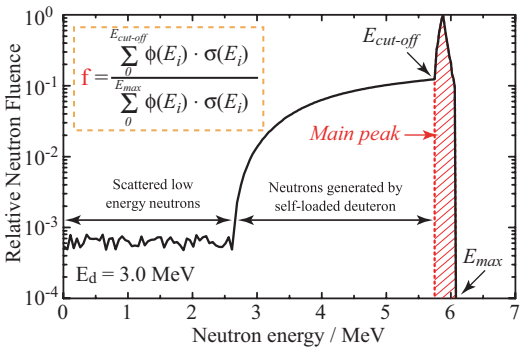
Neutron irradiation facility	:	KN-3750 Van de Graaff at Nagoya Univ.
Accelerating voltage	:	1-3.5 MV
Beam currents	:	~ 1 μA
Neutron target	:	Deuterium gas target
Neutron flux ^{115}In(n, n')	:	~ 2 × 10^6 cm^{-2}·s^{-1}





An expanded view around the gas target assembly. The target chamber consists of a small cell made of aluminum and filled with D_2 at 1.62 x 10^5 Pa. The samples were sandwiched between two indium foils of 10 x 10 mm square and 0.2 mm thick, and were put in the sample cartridge. The indium foils of the ^{115}In(n, n')^{115m}In reaction work as a neutron flux monitor.

3. Correction of background components



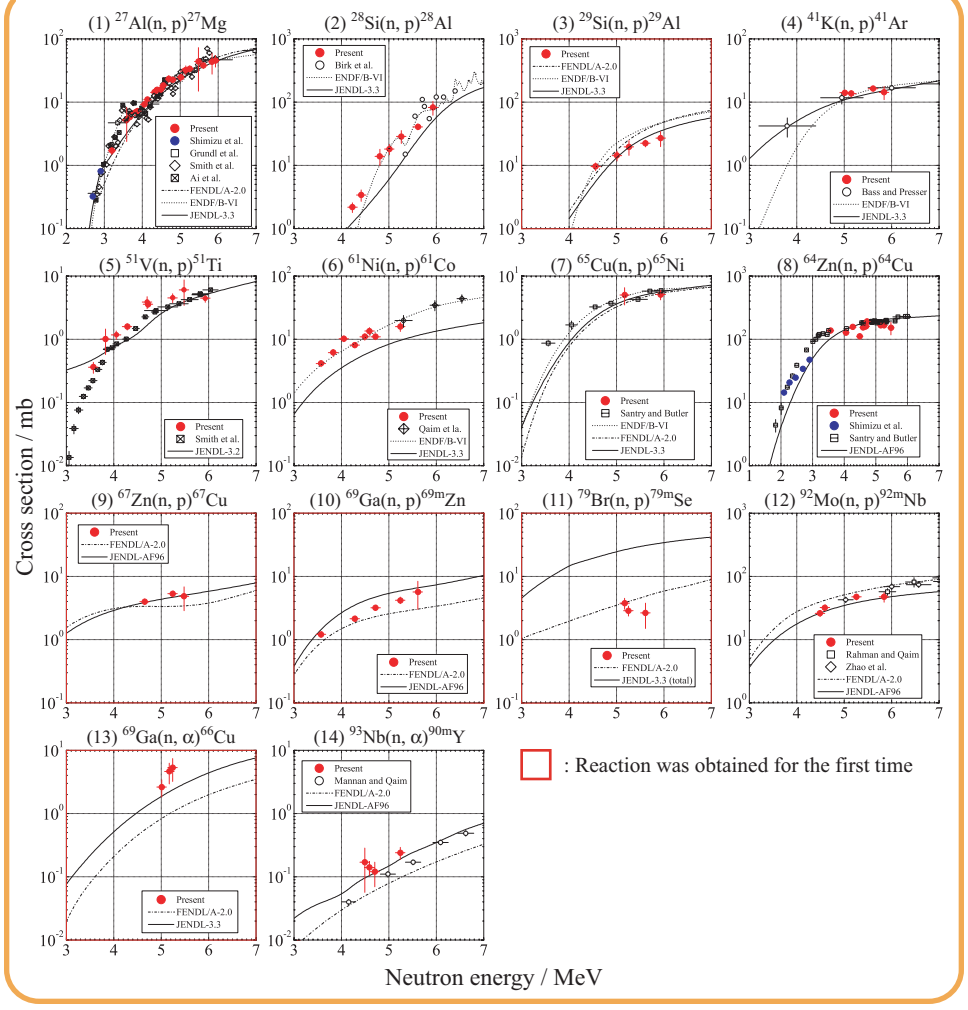
Calculated neutron spectra at 20 mm from the end of a cell of a deuterium gas target for primary deuteron energy of 3.0 MeV. The Monte-Carlo simulation is used. $E_{cut\text{-}off}$ is neutron cut-off energy separating main peak and background components; E_{max} is maximum energy in the emission neutrons; $\phi(E_i)$ and $\sigma(E_i)$ are neutron flux and cross section when emission neutron energy is E_i.

Magnitude of the correction of background components

Reaction	background / %
^{27}Al (n, p)	11-71
^{28}Si (n, p)	28-83
^{29}Si (n, p)	24-52
^{41}K (n, p)	12-42
^{51}V (n, p)	23-75
^{61}Ni (n, p)	19-54
^{65}Cu (n, p)	31-60
^{64}Zn (n, p)	8-35
^{67}Zn (n, p)	14-37
^{69}Ga (n, p)	22-45
^{79}Br (n, p)	10-33
^{92}Mo (n, p)	18-50
^{69}Ga (n, α)	38-74
^{93}Nb (n, α)	18-40
^{115}In (n, n') [(a)]	20-31

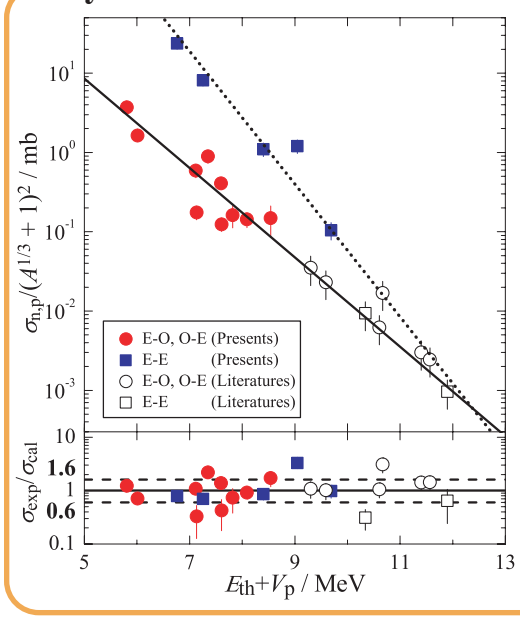
(a) Standard reaction used in this work

4. Results



: Reaction was obtained for the first time

5. Systematics



The systematics of the (n, p) reaction at a neutron energy of 5.0 MeV

[Solid line : even-odd, odd-even]

$$\sigma_{n,p} = 5.59 \times 10^3 (A^{1/3}+1)^2 \times \exp\{-1.30(E_{th}+V_p)\}$$

[Dotted line : even-even]

$$\sigma_{n,p} = 1.38 \times 10^7 (A^{1/3}+1)^2 \times \exp\{-1.93(E_{th}+V_p)\}$$

The relationship between $\sigma_{n,p}/(A^{1/3}+1)^2$ and $(E_{th}+V_p)$, where $\sigma_{n,p}$, A and $(E_{th}+V_p)$ are the cross section of the (n, p) reaction at an energy of 5.0 MeV, the mass number and sum of the threshold energy and the Coulomb barrier, respectively.

6. Conclusion

We measured the cross section data of twelve (n, p) reactions and two (n, α) reactions in the neutron energy range of 3.5 to 5.9 MeV by using the D_2 gas target. The systematics of the (n, p) reaction at a neutron energy of 5.0MeV were proposed for the first time on the basis of our data with simple parameters. It can predict cross sections of the (n, p) reaction within accuracy of a factor of 1.6 in the mass range between 27 and 92.

References

[1] T. Shimizu, H. Sakane, M. Shibata, K. Kawade, T. Nishitani, Ann. Nucl. Energy 31, 975 (2004).
[2] T. Shimizu, H. Sakane, M. Shibata, K. Kawade, T. Nishitani, Ann. Nucl. Energy 31, 1883 (2004).
[3] T. Shimizu, H. Sakane, S. Furuichi, M. Shibata, K. Kawade, H. Takeuchi, Nucl. Instr. Methods A527, 543 (2004)
[4] T. Shimizu, I. Miyazaki, K. Arakita, M. Shibata, K. Kawade, J. Hori, T. Nishitani, Ann. Nucl. Energy 32, 949 (2005)
[5] V. N. Manokhin, INDC(CCP)-398 (1996)
[6] M. Furura, T. Shimizu, I. Miyazaki, M. Shibata, K. Kawade, Ann. Nucl. Energy, submitted.