NOTIZEN

Lack of Evidence for Shell Effects in the (n,p) and (n,α) Reaction Cross Sections at 14 MeV Neutron Energy

S. M. QAIM *

Institut für Anorganische Chemie und Kernchemie, Universität Mainz, Germany

(Z. Naturforsch. 25 a, 1977—1978 [1970]; received 2 October 1970)

The systematics of cross sections for (n,p) and (n,α) reactions induced by 14 — 15 MeV neutrons have been reinvestigated. No clear evidence for the existence of any proton shell effects in these two reactions was found.

The existence of shell effects in nuclear reactions induced by 14 — 15 MeV neutrons has been postulated by several workers [1–4], but the evidence presented has been rather weak. With the availability of more and better experimental data in recent years, a fresh look at this postulate seemed highly desirable. In case of (n,p) and (n,2n) reactions, the claim for the occurence of shell effects has already been recently repudiated [5, 6]; but for (n,α) reactions there seems to exist no evidence against the original claims [1, 2] that the cross section shows a minimum when the atomic number of the residual nucleus is a magic number. The present article describes briefly a reinvestigation of the systematics of the (n,p) and (n,α) reaction cross sections in the light of the latest experimental data. At 14 MeV neutron energy there appears to be no conclusive evidence for any significant proton shell effects in these two reactions.

Treatment of Data

The experimental cross section data for the (n,p) and (n,α) reactions at 14 MeV neutron energy were taken from recent compilations [7, 8] and research publications [9–13]. These were plotted by the method of CHATTERJEE [2, 3] against Z_R, the proton number of the residual nucleus. In order to eliminate the isotopic effect, the cross section value for the most abundant isotope of each element was used. If two or more isotopes of an element were of almost equal abundance, cross sections for all these, if available, were plotted. For certain elements, data were available only for one of the less abundant isotopes; these were, therefore, regarded as upper or lower limits depending on the position of the target isotope relative to the most stable isotope of the respective element. The partial cross sections for reactions leading to either the ground state or an isomeric state of the final nucleus were either omitted or, when their inclusion seemed very necessary, e. g., for isotopes near closed shells, they were taken as lower limits. When for any particular reaction several reported cross section values were available, in general a mean of the values in closest agreement was taken. The error limit for each mean value was established by taking an average of the corresponding quoted errors. Some of the old experimental data which appeared to be very inaccurate were discarded. For a few target nuclei, only single values were available; these were, therefore, treated with caution.

Systematics of the (n,p) *Reaction Cross Sections*

The systematic behaviour of the (n,p) reaction cross sections with respect to Z_R is shown in Fig. 1. The general trend in σ(n,p) for low atomic number elements with Z up to ≈ 20 is like that described by CHATTERJEE [3], although the postluated dips at $Z_R = 2$ and 8 cannot be confirmed. The σ(n,p) increases as a function of Z_R; however, with the exception of argon ($Z_R = 17$), the data for odd-proton residual nuclei and even-proton residual nuclei fall on two different slopes. The minima at $Z_R = 2$ and 8, postulated by CHATTERJEE [3], could be explained in terms of these even-odd effects. For medium and high atomic number nuclei, σ(n,p) appears as a continuously decreasing function of Z_R; the even-odd effects are not as marked as in the case of low Z nuclei. With the exception of a few isolated data, which are mostly based on single publications, most of the experimental values can be encompassed within an arbitrarily drawn broad band whose half-width corresponds to a deviation of approximately 40% from the (n,p) cross section value for a particular target. Considering that most of the experi-

* On leave of absence from Pakistan Atomic Energy Commission. Present address and Reprints request to Institut für Radiochemie, Kernforschungsanlage Jülich GmbH, *D-5170 Jülich*, Germany.

1 A. CHATTERJEE, Nucl. Phys. **47**, 511 [1963].
2 A. CHATTERJEE, Nucl. Phys. **49**, 686 [1963].
3 A. CHATTERJEE, Nucl. Phys. **60**, 273 [1964].
4 M. BORMANN, Nucl. Phys. **65**, 257 [1965].
5 D. G. GARDNER and S. ROSENBLUM, Nucl. Phys. A **96**, 121 [1967].
6 P. HILLE, Nucl. Phys. A **107**, 49 [1968].
7 R. W. FINK, Proc. Conf. uses of small accelerators for teaching and research, Oak Ridge, Tennessee 1968, 30.
8 J. CSIKAI, M. BUCZKÓ, Z. BÖDY, and A. DEMÉNY, Atomic Energy Review **7** (No. 4), 93 [1969].
9 N. TRAUTMANN, R. DENIG, and G. HERRMANN, Radiochim. Acta **11**, 168 [1969].
10 V. N. LEVKOVSKII, G. P. VINITSKAYA, G. E. KOVELS'KAYA, and V. M. STEPANOV, Sov. J. Nucl. Phys. **10**, 25 [1970].
11 W. LU, N. RANAKUMAR, and R. W. FINK, Phys. Rev. C **1**, 358 [1970].
12 L. HUSAIN, A. BARI, and P. K. KURODA, Phys. Rev. C **1**, 1233 [1970].
13 S. M. QAIM, J. Inorg. Nucl. Chem. **32**, 1799 [1970].

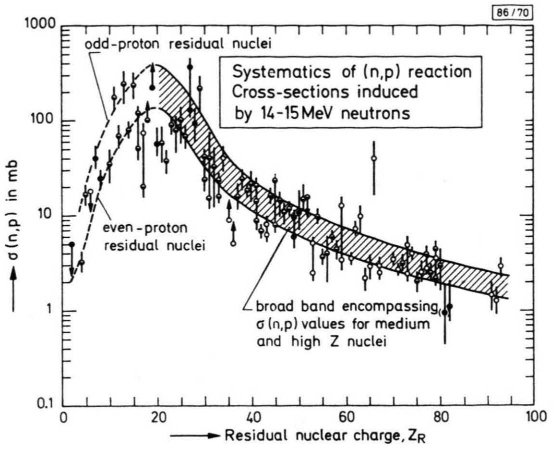

Fig. 1. Plot of 14 MeV (n,p) cross sections against proton number of the product nucleus, Z_R. Cross section data for normal nuclei based on several reports are shown as half-filled circles, and those based on single investigations as open circles. The fully-filled circles refer to the average cross section values for nuclei with closed proton shells either in the target or in the product, those shown in parentheses refer to these values based on single reports.

mental σ(n,p) values themselves contain errors of up to 30% and that data obtained at somewhat different neutron energies between 14.1 and 14.8 MeV are taken together, such a statement does not appear unrealistic.

Figure 1 thus describes broadly the systematics of (n,p) reaction cross sections and can be used for roughly predicting unknown cross sections. The whole trend is reminiscent of a giant excitation function covering the entire Z region. Apart from even-odd effects which probably influence σ(n,p) via the Q-value of a reaction, no abrupt changes in σ(n,p) in the region of closed proton shells, either in the target nuclei or in the residual nuclei, can be seen. In contradiction to the statement of CHATTERJEE [3], this suggests that shell effects do not make any significant contribution to this reaction at 14 MeV. This conclusion not only agrees with the remarks of GARDNER and ROSENBLUM [5], that for target elements in the range $6 \leqq Z \leqq 50$, shell effects are unimportant, but also extends to the entire Z region.

Systematics of the (n,α) *Reaction Cross Sections*

The cross section systematics of the 14 MeV neutron induced (n,α) reactions are shown in Fig. 2. One sees that, with the exception of the cross section value for beryllium ($Z_R = 2$), which is based on a single publi-

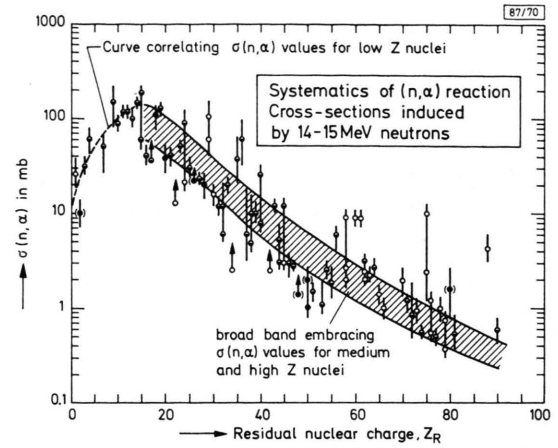

Fig. 2. Plot of 14 MeV (n,α) cross sections against residual nuclear charge, Z_R. Other details are the same as in Fig. 1.

cation, σ(n,α) values for all low atomic number elements fall on a single curve and increase as a function of Z_R, reaching a maximum value around $Z_R = 15$. In contrast to the (n,p) reactions, no even-odd effects are distinguishable. Beyound the maximum, however, the values become a continuously decreasing function of Z_R. Like σ(n,p), most of the σ(n,α) values for medium and high Z nuclei can be encompassed by a broad band the half-width of which corresponds to a deviation of approximately 40% from the cross section value of a particular (n,α) reaction. Maximum deviations from the band are shown by cross section values for Sm, Eu, Ir and Th (Z_R = 60, 61, 75 and 88, respectively). The data for these four cases are based on single publications, indicating the necessity of further measurements on these targets.

In Fig. 2, no sharp variations in σ(n,α) in the region of closed proton shells are to be seen. Closed proton shells, both in the target and daughter nuclei, therefore, do not make any major contributions to this reaction at 14 MeV. This conclusion is in direct contradiction to the statement of CHATTERJEE [1, 2] who has postulated strong shell effects. Although on the basis of present study small shell effects cannot be definitely excluded, much more complete and accurate experimental data are needed to prove or disprove such small effects.

Acknowledgements

The author thanks Prof. G. HERRMANN for his kind hospitality and encouragement, and the Alexander von Humboldt-Stiftung for financial support.