References

1) G. E. Brown, Nucl. Phys. 57 (1964) 339;
2) C. F. Clement, A. M. Lane and J. R. Rook, Nucl. Phys. 66 (1965) 273, 293;
3) A. A. Lushnikov and D. F. Zaretsky, Nucl. Phys. 66 (1965) 35.

D3 Spectrometry of Charged Particles

N. CINDRO, *Institute "Ruđer Bošković", Zagreb*

D4 Possibility of Finding the α-Clustering Probability from (n, α) and (p, α) Studies

M. L. CHATTERJEE* and M. JURČEVIĆ, *Institute "Ruđer Bošković", Zagreb*

Knock-on and heavy particle stripping processes have been observed in (n, α) and (p, α) reactions. This necessarily implies a transfer of an α-cluster from the target in the initial state and the capture of a neutron or a proton in the final state by the core, which is usually not perturbed. As a consequence one can expect the single neutron or single proton states to be predominantly excited in such a process as in the corresponding (d, p) or (^{3}He, d) reactions. A test of these conjectures has been provided by the comparison of (d, p) and (n, α) reaction spectra leading to the same final nucleus.

Such comparisons have recently been made in the studies of ^{124,125,126,128}Te (n, α) (ref.[1]) and ^{93}Nb (n, α) (ref.[2]) reactions. The energy spectra both in (d, p) and in (n, α) processes showed considerable single neutron features. In the case of ^{103}Rh (n, α) and ^{115}In (n, α) reactions[3] the measured alpha energy spectra were compared with the calculated single neutron levels from the Nilsson model. Since the experimental energy resolution was not very good, the Nilsson neutron levels were smeared out to obtain a level density appropriate to that region. The agreement was fairly good. It was further observed that the best fit between the experimental spectra and the calculated neutron level sequence was obtained for only those values of the deformation parameter δ (which determines the Nilsson model sequence) which were expected from other experimental data and the systematics of the neighbouring nuclei.

The measured energy spectra were also compared with the statistical model calculation[1–3]. It was found that except in the case of ^{103}Rh (n, α), the energy distributions of alpha particles were far from being statistical. This probably shows that compound nuclear contributions are relatively small.

Very recently Kulišić et al.[4] also studied the (p, α) reaction on ^{115}In, ^{165}Ho and ^{209}Bi at 40 MeV. The results are at preliminary stage at present.

* On leave of absence from Saha Institute of Nuclear Physics, Calcutta, India.

Still the energy spectra show considerable single proton features indicating the importance of the knock-on mechanism.

These facts led us to a more detailed investigation towards the possibility of finding the α-clustering probability in even-even target nuclei by a study of (n, α) and (p, α) reactions and their comparisons with the corresponding (d, p) and (^{3}He, d) reaction data, which would lead to the same residual nucleus. We attempt here to derive an expression from the DWBA theory which would enable us to find the alpha clustering probability.

All expressions used below have been incorporated from Bassel et al.[5] (ORNL—3240). A short synopsis of the whole DWBA scheme pertaining to stripping and knock-on processes is given below. The symbols bear the same meaning as in ORNL—3240.

For any direct process of the form

$$a+A\rightarrow B+b$$

the DWBA differential cross section is[5]

$$\frac{d\sigma}{d\Omega}=\frac{\mu_a\mu_b}{\pi\hbar^4}\left(\frac{m_B}{m_A}\right)^4\frac{2J_B+1}{(2s_a+1)(2J_A+1)}\cdot\frac{1}{k_b^3k_a}\sum_{lsj}|A_{lsj}|^2\sum_m|\beta_{sj}^{lm}|^2;$$

$$\vec{j}=\vec{l}+\vec{s};\quad \vec{j}=\vec{J}_B-\vec{J}_A;\quad \vec{s}=\vec{s}_a-\vec{s}_b;\quad \vec{l}=\vec{L}_a-\vec{L}_b,$$

$$\beta_{sj}^{lm}=(-)^m\beta_{sj}^{lm}(\theta)=\sum_{L_aL_b}\Gamma_{L_bL_a}^{lm}P_{L_b}^m(\theta)f_{L_bL_a}^l,$$

$$f_{L_bL_a}^l=\text{radial integral},$$

$$\Gamma_{L_bL_a}^{lm}=i^{L_a-L_b-l}(2L_b+1)\sqrt{\frac{(L_b-m)!}{(L_b+m)!}}\langle L_b l 0 0|L_a 0\rangle\times\langle L_b, l, m, -m|L_a 0\rangle,$$

$$\sigma_{lsj}(\theta)=\frac{1}{\pi\hbar^4}\cdot\frac{m_B^5m_bm_a}{m_A^3(m_a+m_A)(m_b+m_B)}\cdot\frac{1}{k_b^3k_a}\sum_m|\beta_{sj}^{lm}|^2,$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp}}=\frac{2J_B+1}{2J_A+1}\cdot\frac{|A_{lsj}|^2}{2s_a+1}\cdot\sigma_{lsj}(\theta)\quad\text{mb/st.}\tag{1}$$

For (d, p) stripping (zero range) the form factor $=U_l(r)$ and

$$A_{lsj}=\sqrt{\frac{2s_a+1}{2s+1}}\sqrt{n}\cdot I(lsj)\cdot\sqrt{\nu}\cdot a(s)D_0,\tag{2}$$

where $\sqrt{\nu}\,a(s)$ = overlap of n and p in forming the initial deuteron, and is approximately equal to one.

An identical approach holds for (^{3}He, d) as well.

In knock-on (p, α) or (n, α): $a+A\rightarrow B+b$; $a+(C+b)\rightarrow(a+C)+b$ with zero range approximation

$$|A_{lsj}|^2=\text{Const. } S_A\cdot S_B\cdot G_\Sigma^2. \tag{3}$$

$$\text{Form factor}=U_{l_a}\left(\frac{m_A}{m_C}r\right)U_{l_b}\left(\frac{m_B}{m_C}r\right);$$

$$S_A=n_b\,|I_{AC}(l_b a_b j_b)|^2,$$

$$S_B=n_a\,|I_{BC}(l_a s_a j_a)|^2,$$

$$V_{ab}^\Sigma=\langle(s_a s_b)\Sigma,\ M\,|\,V_{ab}\,|\,(s_a s_b)\Sigma,\ M_\Sigma\rangle,$$

$$V_{ab}^\Sigma=-G_\Sigma\,\delta(\vec{r}_b-\vec{r}_a).$$

The constant in Eq. (3) involves Clebsch-Gordan, Racah and 9-*j* coefficients, complicated by the following coupling scheme

$$\vec{J}_A=\vec{J}_C+\vec{j}_b,\quad \vec{j}_b=\vec{l}_b+\vec{s}_b,$$

$$\vec{J}_B=\vec{J}_C+\vec{j}_a,\quad \vec{j}_a=\vec{l}_a+\vec{s}_a.$$

The angular momentum transfers are

$$\vec{j}=\vec{J}_B-\vec{J}_A=\vec{j}_a-\vec{j}_b=\vec{l}+\vec{s}.$$

$$\vec{l}=\vec{l}_a-\vec{l}_b;\quad \vec{s}=\vec{s}_a-\vec{s}_b.$$

Examining Eq. (3) and looking at the angular momenta couplings we see that only when the core and the target both have 0^+ spin the transfers l, s, j in (n, α) or (p, α) knock-on processes correspond to those of the captured neutron or proton in the final state, and thus the final state is definitely a single neutron or a single proton state. When, however, the core and the target have non-zero spins, the transfers l, s, j may not always correspond to pure single neutron or single proton states in the final nucleus, as evident from the complicated coupling schemes. So for simplicity we consider only a 0^+ target and a 0^+ core.

When such single particle states are excited by a (p, α) or an (n, α) knock-on process on an even-even target, we concentrate on such an isolated single particle state. From the DWBA fit of the angular distribution we can extract A_{lsj} using Eq. (1) and consequently from Eq. (3) $G_\Sigma^2 S_A S_B$, i.e. the product of the spectroscopic factors for the (core + alpha) configuration of the target, the (core + n or p) configuration of the residual nucleus, and the square of the interaction strength G_Σ^2. As evident, the final state configuration is identical to that obtained from the (d, p) or (^{3}He, d) stripping reaction on the core for the (n, α) or (p, α) knock-on process. Thus from (d, p) and (^{3}He, d) data on appropriate targets and looking at the same single particle state correspondingly excited in (p, α) or (n, α), we can extract the single neutron or the single proton reduced width S_B. G_Σ can in principle be determined from the two nucleon scattering data; in the case of (n, α) and (p, α) knock-on processes G_Σ could be obtained from the scattering of a neutron or a proton on ^{4}He nuclei. Thus S_B and G_Σ being known, S_A can be obtained from Eq. (3). S_A stands for the alpha clustering reduced width of the target, i.e. the probability of finding the even-even 0^+ target ground state as an even-even 0^+ core plus an alpha in the S state of relative motion.*)

However, the possibility of extracting the α-clustering probability from Eq. (3) is subject to the assumption of zero-range approximation being valid. The use of this approximation in (n, α) or (p, α) knock-on processes is still questionable.

Acknowledgement

We are indebted to Drs. N. Cindro, I. Šlaus and V. Valković for helpful discussions and encouragement. We are also grateful to Dr. P. Kulišić for sending us the preprints of their (p, α) work before publication. One of us (M.L.C.) is particularly grateful to the Scientific Council of the Institute „Ruđer Bošković“ for the kind hospitality extended to him.

References

1) M. L. Chatterjee, N. Cindro, M. Jurčević, P. Kulišić and J. Tudorić-Ghemo, Proceedings of the International Conf. on Clustering Phenomena in Nuclei, Bochum 1969 (to be published); M. Jurčević, P. Kulišić and J. Tudorić-Ghemo, to appear in Fizika;
2) P. Kulišić, to be published;
3) Đ. Veselić and J. Tudorić-Ghemo, Nucl. Phys. **A110** (1968) 225;
4) P. Kulišić et al., private communication;
5) R. H. Bassel, R. M. Drisko and G. R. Satchler, ORNL—3240 (1962).

---

*) This scheme can be further clarified by the example of the following reactions proposed to test our conjecture:

1) Reaction pair (n, α) and (d, p) for single neutron final state:

Knock-on ^{20}Ne(n, α)^{17}O: $n + (^{16}O + {^4}He) = (^{16}O + n) + {^4}He$

Stripping ^{16}O(d, p)^{17}O: $d + {^{16}}O = (^{16}O + n) + p$

2) Reaction pair (p, α) and (^{3}He, d) for single proton final state:

Knock-on ^{20}Ne(p, α)^{17}F: $p + (^{16}O + {^4}He) = (^{16}O + p) + {^4}He$

Stripping ^{16}O(^{3}He, d)^{17}F: ${^3}He + {^{16}}O = (^{16}O + p) + d$

It may be noted that in the (n, α) and (d, p) reaction pair the final nucleus ^{17}O has the same single neutron parentage in both processes for identical states excited by (n, α) and (d, p). Similarly for (p, α) and (^{3}He, d) pair the final nucleus ^{17}F has single proton parentage.