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ALPHA-DEUTERON STRUCTURE OF THE ^{6}Li GROUND STATE[*]

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Abstract

We describe a simple pole model for the elastic scattering of α particles on ^{6}Li. We assume that the ground state of ^{6}Li consists of a deuteron weakly bound to an α particle. We calculate the angular distributions, and comparison with the experimental data yields a value for the coupling constant of the ^{6}Li-α-d vertex.

The structure of the ground state of ^{6}Li has been subject to detailed investigation, and the assumption that it consists of a deuteron weakly bound to an α particle was used in various ways. In the framework of the cluster model this allowed calculation of the ^{6}Li charge distribution, in good agreement with experimental data from electron scattering.[1] In a similar model predictions for the excited state of ^{6}Li could be obtained.[2] The formalism of the cluster model together with harmonic oscillator-type wave functions was also used to predict the cross sections for the quasi-free d-p scattering occurring in the reaction ^{6}Li(p, pd)^{4}He.[3] A comparison with experimental data[4] at 155 MeV proton energy proved this approach to be quite suitable. The angular correlations observed in this reaction were consistent only with the α particle and the deuteron being in a relative s state.

A recent experiment[5] investigated proton pairs from the reaction ^{6}Li(π^+, pp)^{4}He for 31-MeV pions. If the capture of the pion takes place on a quasi-free deuteron, the amplitude simply factorizes into a vertex function for the virtual decay of ^{6}Li into a deuteron and an α particle and into a vertex function for the quasi-free $d + \pi^+ \rightarrow p + p$ capture, divided by the propagator for the transferred deuteron. This factorization can be tested[6] by measuring the dependence of the cross section upon the Treiman-Yang rotation angle.[7] In the above experiment the cross section was found to be constant as a function of the Treiman-Yang angle for low-momentum transfers q, for which this first-order Feynman graph is expected to dominate, since the pole of the deuteron propagator occurs at a small negative value of q^2.

It was realized, however, that the substructures of ^{6}Li manifest themselves not only in the above-mentioned medium-energy reactions, but also in low-energy nuclear scattering. The angular distributions observed in the elastic scattering of α particles on ^{6}Li in the energy range from 2 to 4 MeV are strongly peaked in the backward direction.[8, 9] In this paper we wish to describe a simple model for the latter process. This model is a two-step process, involving the virtual decay of the ^{6}Li nucleus into a deuteron and an α particle, followed by the capture of this deuteron by the incoming α particle and the formation of the outgoing ^{6}Li nucleus. The reaction might, then, be expected to be dominated by a single pole in the transferred deuteron momentum, as given by the first-order Feynman graph.[10] We calculate the angular distributions, and comparison with the experimental data yields a value for the coupling constant for the ^{6}Li alpha-deuteron vertex.

Coulomb scattering being ignored for the moment, the amplitude for the single deuteron exchange illustrated in Fig. 1a can be written (for $\hbar = c = 1$)

as[10]

$$A = \frac{m_\alpha m_{^6\mathrm{Li}}}{m_\alpha + m_{^6\mathrm{Li}}} \quad \frac{g^2}{q^2 - 2m_d E_d} . \qquad (1)$$

Here q^2 is the momentum transfer at the ^{6}Li-α-d vertex, E_d is the kinetic energy of the exchanged deuteron, and $g \equiv g_{^6\mathrm{Li},\, \alpha,\, d}$ is the vertex function (averaged over the deuteron spin variable S_d) of the ^{6}Li -α-d vertex, which can depend on the momentum transfer. This amplitude has a pole in the unphysical region at negative values of q^2. For the energy region considered ($E_{\alpha;\,\mathrm{lab}}$ = 1.7 to 4.1 MeV), the values for the location of the pole range from - 0.17 to - 0.22 [F^{-2}]. Therefore, the largest contribution of this graph to the total amplitude is expected for low values of q^2 or in the backward direction of the scattered α particle.

The next possibly important graph, illustrated in Fig. 1b, describes the compound reaction via the intermediate ^{10}B nucleus, and it yields an isotropic angular distribution. Its contribution is important only in the neighborhood of strong resonances in the cross section. The known levels of ^{10}B in this energy region have small α-particle widths of 0.1 to 50 keV.[8, 11] Therefore, if only angular distributions at energies separated from the nearest resonance by several widths are taken into account, this graph does not contribute significantly to the cross section.

Besides the single-pole graph of Fig. 1a, more complicated diagrams involving the α-d structure could be important. These are of the triangular type and are shown in Fig. 1c and 1d. Their singularities are far removed from the physical region compared with the single-pole graph, and they are neglected for our considerations. For an energy of the incoming α particle of 2.6 MeV, the pole for the quasi-elastic alpha-alpha scattering (Fig. 1c) is at -3.58 [F^{-2}], and for the quasi-elastic d-α scattering (Fig. 1d) at - 0.84 [F^{-2}].

For center-of-mass angles greater than 120 deg the cross section for Coulomb scattering is of the order of 10% of the measured cross sections. In a first approximation the unknown coupling constant g^2 can then be obtained by multiplying the square root of the experimental cross section with the denominator of the pole amplitude including the appropriate kinematical factors. The results for momentum transfers less than 0.4 [F^{-2}] are plotted in Fig. 2, where only the backward points from the angular distributions for all energies have been used. Within the limits of our approximation (10 to 20%) the independence of the form factors on the momentum transfer appears established. The relative normalization of the different angular distributions according to the authors in Refs. 8 and 9 is uncertain within a possible systematic error of about 10%. The statistical errors are small, being of the order of 0.8 to 4%. From this procedure we extract an average value for the form factor of

$$g^2 = 1.20 \pm 0.18.$$

In an attempt to fit the total angular distributions the amplitude for the point-Coulomb cross section multiplied by an arbitrary phase factor was added to the nuclear amplitude, Eq. (1). The following expression for the cross section was then compared with the data:

$$\frac{d\sigma}{d\Omega}_{c.m.} = \left| e^{i\psi} A_c + \frac{m_\alpha m_{^6Li}}{m_\alpha + m_{^6Li}} \frac{g^2}{q^2 - 2m_d E_d} \right|^2, \qquad (2)$$

with $A_c = -\bar{\lambda}\eta \exp(-i\eta \ln \sin^2\theta/2 + 2i\eta_0)/(2\sin^2\theta/2)$; $\eta = Z_1 Z_2 e^2/v$; $\exp(2i\eta_0) = \Gamma(1+i\eta)/\Gamma(1-i\eta)$; $\bar{\lambda}^2 = 2E_{\alpha,\mathrm{c.m.}}\, m_\alpha m_{^6\mathrm{Li}}/(m_\alpha + m_{^6\mathrm{Li}})$. In some fits we also allowed the vertex functions a dependence on the momentum transfer in the form $g^2 = a + bq^2$. Each angular distribution was fitted separately. The results are given in Table 1, and comparison with the experimental data in Fig. 3. The inclusion of a q^2 dependence does improve the fits considerably. However, the values for the coupling constant do not change by more than 15%, except for energies below 2.3 MeV. Since the binding energy of the deuteron in ^{6}Li is 1.47 MeV, the validity of our model is doubtful in the region, where the c.m. energies of the incoming α particle range from 1.02 to 1.38 MeV. On the other hand the constancy with respect to a q^2 dependence of the form factors for energies greater than 2.3 MeV, within the possible systematic errors of the data, gives enough evidence that our simple picture seems reasonable for these energies. The possible sources for the high values of χ^2 obtained, despite the fact that the general character of the angular distributions is represented very well by our fits, can be summarized as follows:

a. Inaccurate description by our parameterization of the total amplitude of the interference between the nuclear and the Coulomb amplitude around 90 deg.

b. Deviations from the point-Coulomb amplitude due to the finite size of the two nuclei.

c. Exclusion of higher-order graphs, such as those shown in Fig. 1c and 1d.

d. Contributions from compound resonances.

e. Underestimation of the experimental errors.

All these effects together can be estimated to be of the order of 10% of our total amplitude. According to the arguments for estimating our errors, we obtain for the average value of the square of the ^{6}Li-α-d coupling constant, without and with a possible dependence on the momentum transfer,

$$g^2 = 1.52 \pm 0.15,$$

$$a = 1.32 \pm 0.13; \quad b = 0.027 \pm 0.007\ [\mathrm{F}^2].$$

The lack of absolute cross-section measurements for reactions proceeding via a similar reaction mechanism--as, e.g., ^{6}Li(d, d)^{6}Li, ^{6}Li(d, α)^{4}He, or ^{6}Li(π^+, pp)^{4}He--does not at present allow a check on our value for the coupling constant g.

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References

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1. K. Wildermuth and W. McClure, Cluster Representations of Nuclei, Springer Tracts in Modern Physics, Vol. 41, 1966, p. 115 and references therein.
2. T. I. Kopaleishvili, I. S. Vashakidze, V. I. Mamasakhlisov, and G. A. Chilashvili, Nucl. Phys. 23, 430 (1961).
3. D. F. Jackson and L. R. B. Elton, Proc. Roy. Soc. (London) 85, 659 (1965).
4. C. Ruhla, M. Riou, M. Gusakow, J. C. Jacmart, M. Liu, and L. Valentin, Phys. Letters 6, 282 (1963).
5. R. L. Burman and M. E. Nordberg, Jr., Phys. Rev. Letters 21, 229 (1968).
6. I. S. Shapiro, V. M. Kolybasov, and G. R. Augst, Nucl. Phys. 61, 353 (1965).
7. S. B. Treiman and C. N. Yang, Phys. Rev. Letters 8, 140 (1962).
8. V. Meyer, R. E. Pixley, and P. Truoel, Nucl. Phys. A101, 321 (1967).
9. W. Auwaerter, V. Meyer, and P. Truoel, to be published.
10. I. S. Shapiro, Nucl. Phys. 28, 244 (1961). For a review, see also I. S. Shapiro, "Some Problems of the Theory of Nuclear Reactions at High Energies," in Varenna 1966 International School of Physics "Enrico Fermi" XXXVIII, and references therein; H. J. Schnitzer, Rev. Mod. Phys. 37, 666 (1965).
11. F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. 78, 1 (1966).

Table 1. Results of the fits to the experimental cross sections of Refs. 8 and 9, using formula (2) with and without q^2 dependence of the form factor.

E (MeV)	g^2	$d(g^2)$	ψ (rad)	$d(\psi)$ (rad)	χ^2	a	d(a)	b (F^2)	d(b) (F^2)	ψ (rad)	$d(\psi)$ (rad)	χ^2	Number of data points
1.7	1.68	0.11	-0.49	0.14	3072	0.78	0.05	0.156	0.006	0.20	0.03	53	5
2.0	1.46	0.05	-0.72	0.09	1006	1.00	0.04	0.097	0.005	-0.14	0.03	34	6
2.3	1.54	0.07	-0.74	0.03	1411	1.22	0.02	0.058	0.003	-0.34	0.02	41	7
2.6	1.58	0.02	-0.73	0.02	1900	1.35	0.02	0.034	0.003	-0.50	0.02	341	14
2.9	1.48	0.03	-0.73	0.06	901	1.35	0.03	0.027	0.004	-0.48	0.07	211	7
3.1	1.46	0.03	-0.62	0.07	1564	1.23	0.05	0.029	0.004	-0.40	0.05	320	7
3.7	1.49	0.04	-0.87	0.07	152	1.28	0.02	0.027	0.003	-0.56	0.04	15	7
3.9	1.55	0.07	-0.95	0.07	83	1.35	0.07	0.025	0.007	-0.67	0.09	41	7
4.1	1.52	0.03	-1.15	0.06	134	1.36	0.07	0.021	0.007	-0.84	0.11	81	7

Figure Captions

Fig. 1. Feynman graphs illustrating possible reaction mechanism for the direct interaction in $^6\mathrm{Li}(\alpha,\alpha)^6\mathrm{Li}$.

(a) pole graph; (b) quasi-compound process; (c) and (d) triangular graphs involving the α-d structure of ^{6}Li ground state.

Fig. 2. The $^6\mathrm{Li}$-α-d form factor as a function of q^2, including only backward points from the angular distributions of Fig. 3, and neglecting the Coulomb amplitude.

Fig. 3. Angular distributions for $^6\mathrm{Li}(\alpha,\alpha)^6\mathrm{Li}$ for different energies. Experimental points are taken from Refs. 8 and 9. The dashed curve represents the fits using formula (2) with a constant form factor; the solid curve, with a linear dependence of g^2 on q^2.

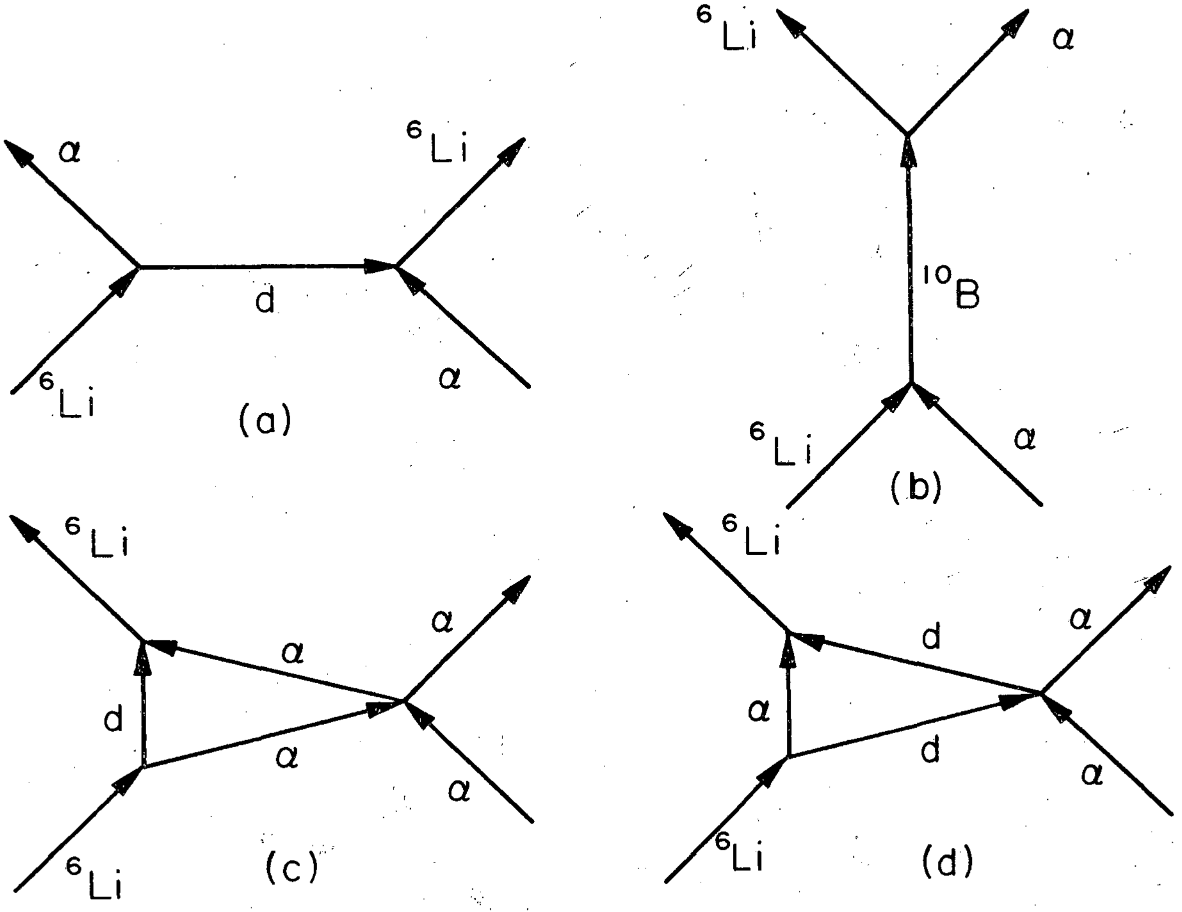

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Fig. 1

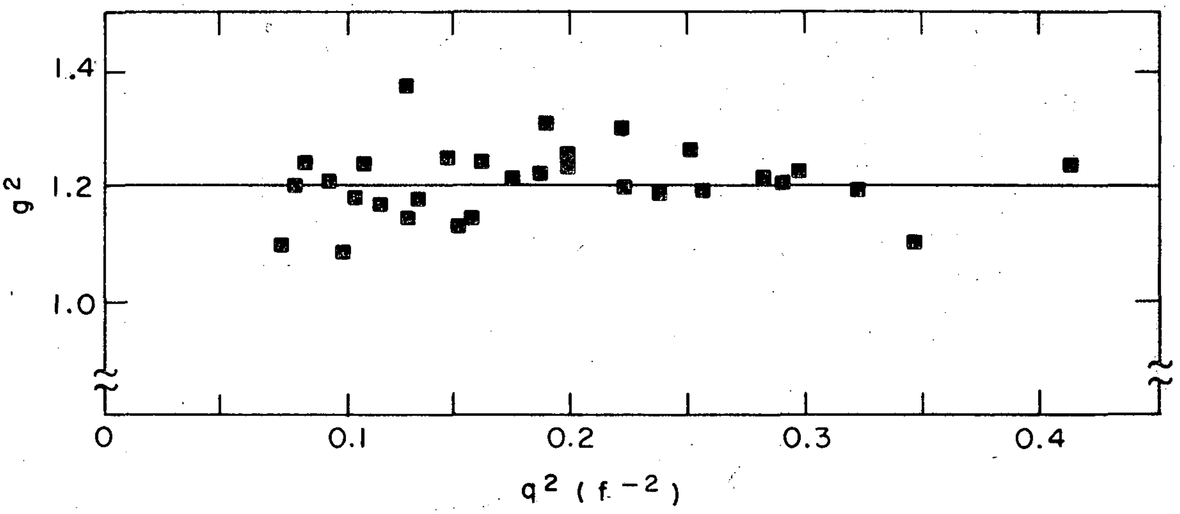

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Fig. 2

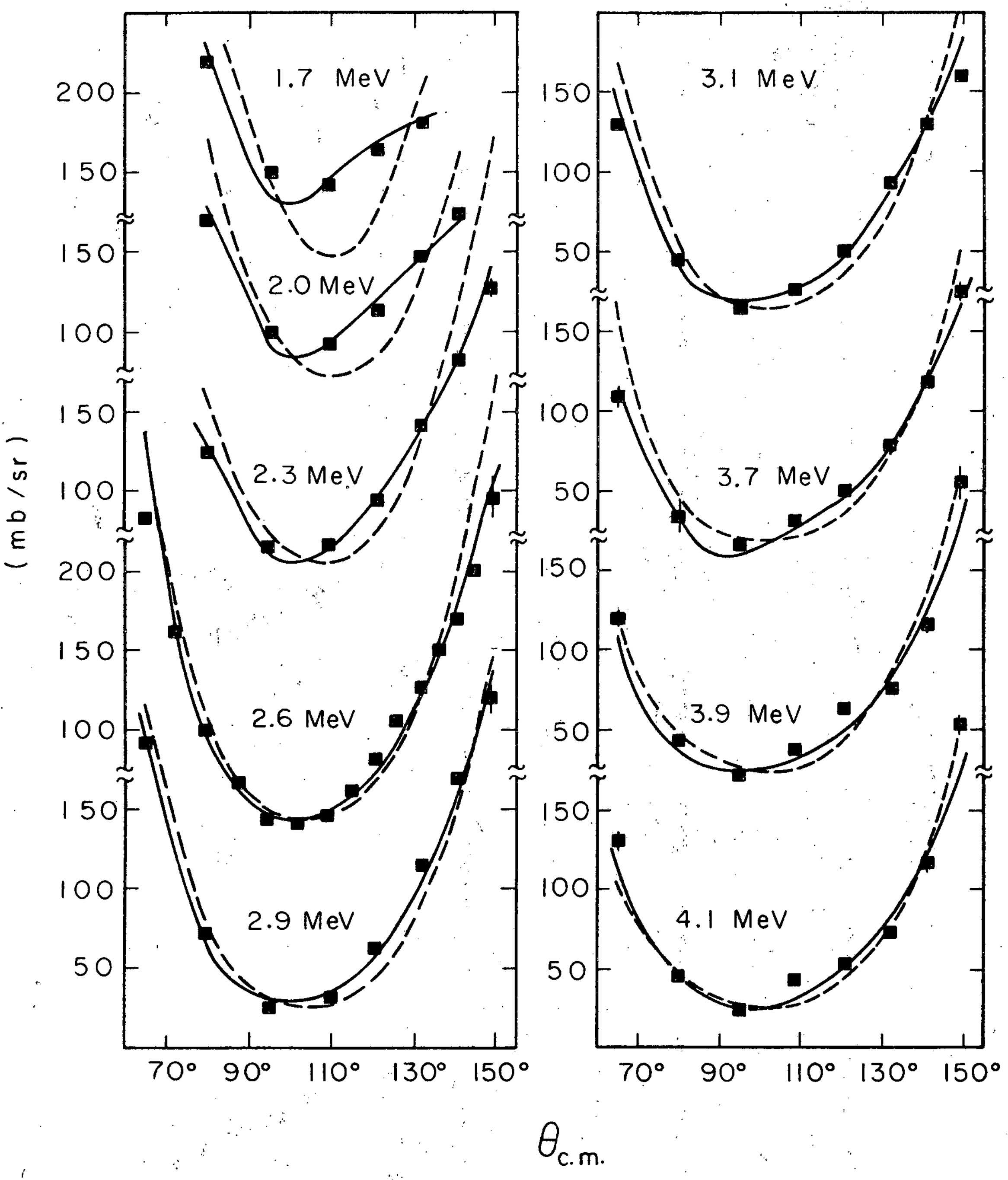

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Fig. 3

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