cell) does not produce enough ^{116}Pd to overcome the heavy gamma background when the detector is placed on delay line 2 just outside the irradiation shield. Further experiments will be carried on after the equipment has been moved to better facilities.

We are indebted to our colleagues at the Department of Nuclear Chemistry, in particular to Dr. J. O. Liljenzin for many helpful discussions, and to Mrs. E. Norman, Miss K. Borgström, and Mr. S. Wingefors for experimental aid. We also want to thank the Van de Graaff group at the Department of Physics for the loan of the Ge(Li) detector and Mr. P. Standzenieks for assistance with the operation of it. This work was supported by the Swedish Atomic Research Council.

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STUDY OF THE MECHANISM OF THE $(\alpha, 2\alpha)$ REACTION ON ^{6}Li

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(Received 13 July 1970)

The $(\alpha, 2\alpha)$ reaction on ^{6}Li has been studied at an incident energy of 42.8 MeV. At this energy, a sharp resonance in the free α-α scattering cross section is used to test the validity of the impulse approximation. The experimental results are analyzed with this model.

The cluster structure of light nuclei has been studied with knockout $A(a, ab)B$ reactions. The interpretation of these reactions supposes usually a quasielastic scattering mechanism, but only few experiments have been made to test this mechanism.[1]

Such experiments are analyzed with the plane-wave impulse approximation. If the particles are supposed spinless, the cross section can be written as

$$\frac{d^3\sigma}{d\Omega_a d\Omega_b dE_a} = P_b \mu \rho(q) \left(\frac{d\sigma}{d\Omega}\right)_{ab}, \qquad (1)$$

where P_b is the probability of finding a cluster b in the target nucleus, μ is the kinematic phase-space factor, $\rho(q)$ is the momentum distribution of the cluster, and $(d\sigma/d\Omega)_{ab}$ is the ab scattering cross section, in the c.m. system and off the energy shell. Many authors[1-4] replace this last cross section by the cross section taken on the energy shell. Then it can be taken either at the relative energy between the incident particle and the cluster before the reaction (form E_i) or at the relative energy after the reaction (form E_f).

We have studied the reaction $^6\text{Li}(\alpha, 2\alpha)d$ in order to test this model. The target, ^{6}Li, has a well-marked $\alpha + d$ structure and the free α-α scattering cross section is experimentally well known[5] and shows sharp resonances which should modulate the quasielastic cross section.

In particular, we thought that the resonance which appears at 19.8 MeV (c.m.) in the α-α scattering could be used to choose between the two possible forms E_i and E_f.

Our experimental geometry was coplanar and symmetric: The two detectors were at angles θ_1 and $\theta_2 = -\theta_1 = \theta$, and the detected α particles had the same energy $E_{\alpha 1} = E_{\alpha 2}$. In this case, the α-cluster momentum is given by

$$q = p_0 - 2p\cos\theta,$$

where p_0 and p are the momenta of the incident and detected α particles, and the α-α scattering cross section in formula (1) has to be taken at 90° c.m. For each form, E_i and E_f, the relative energy of the two α particles is a function of the

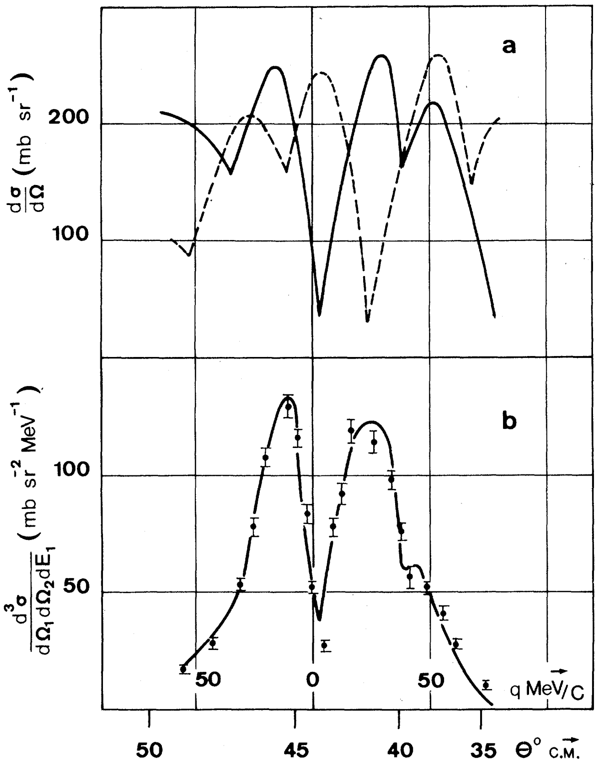

FIG. 1. ^{6}Li(α, 2α) at 42.8 MeV. (a) Experimental (α, α) scattering cross section, taken from Ref. (5) and averaged over 15 MeV/c to take into account the angular resolutions. Solid line, from E_f; dashed line, form E_i. (b) Experimental results. The solid curve is the fit obtained with the Hankel wave function (see text).

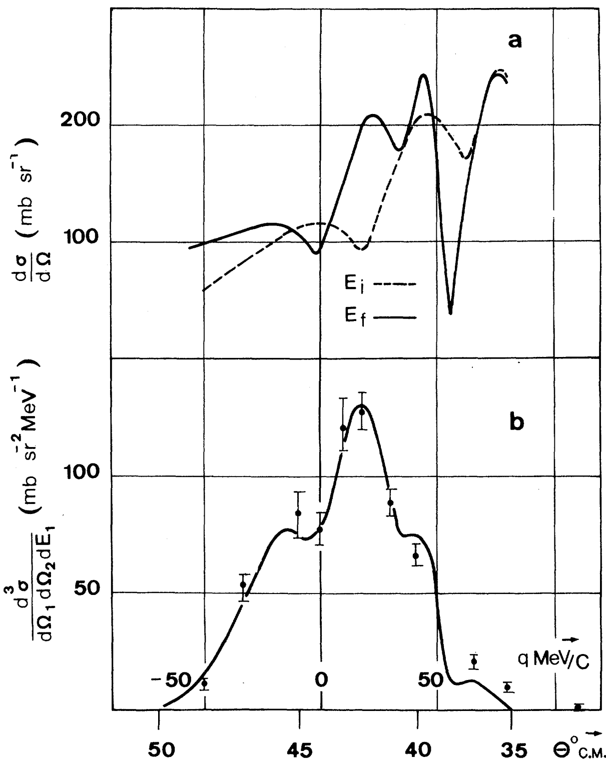

FIG. 2. ^{6}Li(α, 2α) at 55 MeV (see Fig. 1).

angle θ and consequently of q.

The experiment was performed with the Grenoble cyclotron, at an incident energy of 42.8 ± 0.2 MeV. (At this energy, the 19.8-MeV α-α resonance should appear near $q = 0$ in the form E_f and near $q = 25$ MeV/c in the form E_i.) The α particles have been detected in silicon surface-barrier detectors by a coincidence technique. The electronics was similar to that described elsewhere.[6] The ^{6}Li target (99% enriched) was self-supporting and its thickness was 1 mg/cm^2. The over-all energy resolution was about 500 keV.

Figure 1(b) shows the experimental results. As a comparison, Fig. 1(a) shows the experimental α-α cross section, plotted with the same abscissa, in the forms E_i and E_f. One can see a very sharp minimum in the (α, 2α) cross sections, which corresponds unambiguously to the 19.8-MeV α-α resonance in the form E_f and has no counterpart in the form E_i.

The results of the same experiment, made at an incident energy of 55 MeV,[4] are shown in Fig. 2. In this case, the position of the 19.8-MeV resonance is shifted to $q = 55$ MeV/c in the form E_f (and to a higher q in the form E_i) and its influence on the (α, 2α) cross section is not as easily seen because of the $L = 0$ shape of the momentum distribution $\rho(q)$ which has a small value for $q = 55$ MeV/c.

Our 42.8 MeV experiment shows clearly that if, in formula (1), one uses the free α-α scattering cross section, one should take it in the form E_f, and confirms the theoretical result of Meboniya.[7]

With this choice of the interaction cross section, we tried to extract some spectroscopic information from our experimental cross sections. For these calculations, we assumed that the wave function of ^{6}Li could be written as

$$\psi(^6\mathrm{Li}) = P_\alpha^{1/2}\Phi_\alpha\Phi_d\,\psi(\vec{r}_\alpha - \vec{r}_d),$$

Φ_α and Φ_d being the internal wave functions of the alpha cluster and the deuteron in their ground states, and $\psi(\vec{r}_\alpha - \vec{r}_d)$ the relative-motion wave function of the alpha and deuteron clusters in ^{6}Li. The momentum distribution $\rho(q)$ is the square modulus of the Fourier transform of $\psi(\vec{r}_\alpha - \vec{r}_d)$.

In order to calculate $\rho(q)$ we chose three pos-

Table I. Comparison of information deduced from the 42.9- and 55-MeV experiments with different wave functions.

	$E_\alpha = 42.8$ MeV			$E_\alpha = 55$ MeV		
	q_0 MeV/c	x	P_α	q_0 MeV/c	x	P_α
HO 1	42		(7 ± 3) %	44		(8 ± 4) %
HO 2	70	0.26	(21 ± 10) %	72	0.26	(22 ± 11) %
Hankel			(11 ± 5) %			(11 ± 5) %

sible forms of $\psi(\vec{r}_\alpha - \vec{r}_d)$:

(1) We assumed that the α-d interaction is described by an infinite oscillator potential (HO 1). The alpha and deuteron clusters are supposed without internal structure so that the ground-state quantum numbers are $L=0$, $N=0$;

$$\rho(q) = \pi^{-3/2} q_0^{-3} \exp-(q/q_0)^2.$$

(2) The relative wave function is deduced from the shell model obtained from the harmonic oscillator (HO 2). It is then the sum of two harmonic-oscillator functions, whose quantum numbers are $N=0$, $L=2$, and $N=1$, $L=0$. As our experimental results can be fitted by considering only the $N=1$, $L=0$ function, we neglected the eventual contribution of the $N=0$, $L=2$ function. Then

$$\rho(q) = 6\pi^{-1/2} q_0^{-3}[1-\tfrac{2}{3}(q/q_0)^2]\exp[-(q/q_0)^2].$$

(3) We assumed that the relative α-d motion is described by a spherical Hankel function $h_0(iK_{\alpha d} \times |\vec{r}_\alpha - \vec{r}_d|)$, with a cut-off radius $R_A = 1.5A^{1/3}$ fm.[8]

$$\rho(q) = \hbar^{-3}\pi^{-2}K_{\alpha d}[q'^2 + K_{\alpha d}{}^2]^2[q'^{-1}\sin q'R_A + K_{\alpha d}{}^{-1}\cos q'R_A]^2,$$

where

$$q' = \hbar^{-1}q.$$

The second wave function is interesting because its parameter q_0 is related to the isolation parameter x,[9] defined as

$$x = q_0{}^2/\hbar^2 a,$$

where a is the oscillator width parameter for the α particle ($a = 4.7\times 10^{25}$ cm^{-2} [11]). This parameter can vary from the value 0 (extreme cluster model) to the value 1 (shell-model limit).

The Hankel wave function seems to be more realistic because of its good asymptotic form, the cut-off radius meaning that there is no clustering for $|\vec{r}_\alpha - \vec{r}_d| < R_A$.

A least-squares fit was used to obtain values of the clustering probability P_α with the three wave functions, and values of q_0 with the oscillator wave functions. (In the case of the Hankel function, the cut-off radius was not considered as a fitted parameter.)

Figures 1(b) and 2(b) show the fitted curves obtained with the Hankel functions. The other wave functions give quite similar results and the calculated curves have not been drawn, the differences being not observable on this scale.

We observed, as have other authors,[2,10] a shift of the center of the momentum distribution relative to the value $q=0$. This shift was +5 MeV/c at 42.8 MeV and 10 MeV/c at 55 MeV.

Table I shows the different parameters deduced from our fits. One can remark, for each cluster wave function, the constancy of these parameters, within the experimental errors, at both energies.

A comparison of the width of the momentum distribution which we obtain (full width at half-maximum: 70 MeV/c) with those published in the literature[2,3,10,12] shows a very good agreement. The same comparison of the clustering probabilities is not so easy because of the influence of the choice of the relative wave function on the value of P_α, as can be seen in Table I. However, most of the values are in fair agreement if one considers the experimental uncertainties.

These results confirm the validity of the analysis method. One should not, however, be too confident in the absolute values of the clustering probabilities because of the neglected distortion effects.

The authors want to thank Professor Yoccoz, Professor Longequeue, Dr. Chabre, and coworkers for their kind hospitality.

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PARTICLE-VIBRATION DOORWAY RESONANCE IN Pb^{209}

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With no free parameters the particle-vibration model is used to describe the $\frac{1}{2}^+$ doorway resonance observed in Pb^{209} at 500 keV with a width of 58 keV. We find that the $(2g_{9/2}, 4^+)$ state which occurs at nearly the experimental energy has a width of about 1 to 2 times the measured value.

While the idea of a particle-vibration weak-coupling model has been widely used with good results, continuum levels have not been studied to any great extent. Mottelson[1] has, in fact, emphasized a need for the evaluation of radial matrix elements when the one-particle state is at a known energy in the continuum. The purpose of this paper is to show that the particle-vibration model provides a good explanation for an s-wave resonance observed in Pb^{209} by Farell et al.[2] The weak-coupling model has been quite successful in describing inelastic scattering exciting vibrational states in the Pb region.[1,3] Since this $\frac{1}{2}^+$ resonance is not very high in the continuum, it is reasonable to expect an extension of the successful predictions of the particle-vibration model for bound states. An additional impetus for this work is the interpretation in Ref. 2 of the s-wave resonance as a possible doorway state leading to complex structure in adjacent nuclei. The doorway concept has become rather important in recent years.[4]

Specifically, Ref. 2 observed the high-resolution elastic scattering of neutrons from $Pb^{206,207,208}$ yielding resonances in $Pb^{207,208,209}$. In Pb^{209} only one $\frac{1}{2}^+$ resonance is observed in the energy range from 0 to 1.7 MeV above the neutron threshold. This occurs at about 500 keV (4.38 MeV above the Pb^{209} ground state) with a width of 58 keV. The experimental cross sections for the Pb^{207} and Pb^{208} compound nuclei show much fine structure in the general region of 500-keV incident neutron energy. In particular, there are 11 s-wave resonances in Pb^{207} up to the inelastic threshold (800 keV), the sum of whose reduced widths compares remarkably well with that of the single s-wave resonance in Pb^{209}.

The usual doorway mechanism is that of the two-particle–one-hole (2p-1h) state. However, while it is possible to form a large number of $\frac{1}{2}^+$ 2p-1h states in Pb^{209}, prior to mixing there are none as low as 500 keV. In fact there are none below 1 MeV and only a few between 1 and 2 MeV. Shakin[5] has suggested that a possible explanation of the Pb^{209} resonance is the coupling of the 4^+ collective core vibrational state at 4.31 MeV[6] in Pb^{208} with the $2g_{9/2}$ zero-energy single-neutron level. Since the 4^+ state probably has 2p-2h components, the decay to the Pb^{208} ground state would just go through the ground-state correlations, and Stein[7] indicates that these are non-negligible. The proposed particle-vibration state nearly coincides in energy with the observed resonance, and according to Auerbach and Stein[8] loses only a few percent of its strength in mixing with the bound $4s_{1/2}$ single-neutron level. It is conceivable that other excited core-plus-neutron levels mix with the $(2g_{9/2}, 4^+)\frac{1}{2}^+$ state; however, these are fairly far away. [The closest configuration is $(1i_{11/2}, 6^+)$ at 5.2 MeV relative to the Pb^{209} ground state, and other available particle-vibration states are even high-