(3) The temperature dependence below 3.5°K is stronger in sample 5 than in sample 7.

$KMnF_3$ is a canted antiferromagnet over the temperature range investigated and has been described recently by a four-sublattice model by Minkiewicz and Nakamura.[12] Using this model, it is possible to calculate a T_{AE} of 0.3°K. It may be fortuitous, but $KMnF_3$ is the only antiferromagnet investigated thus far where the nuclear relaxation rate exhibits more than one intrinsic rate. Theoretically, the intrinsic relaxation rate for a magnetic material with a magnon energy gap should contain an exponential factor $\exp(-T_{AE}/T)$ for the temperature range $T < T_{AE}$. Experimentally, this rate has been observed[11,13] in two materials where this low-temperature dependence has predominated to temperatures above T_{AE}. The theoretical result implies that a power-law temperature dependence below T_{AE} is an impurity-dominated or nonintrinsic process. These nonintrinsic processes are independent of T_{AE} and will dominate the relaxation rate throughout the temperature range where the nuclear spin-impurity coupling is stronger than the nuclear spin-magnon coupling. There has been no theoretical or detailed experimental work on impurity relaxation processes in magnetic materials, so it is difficult to speculate on the form of their temperature dependences. However, a T^7 dependence has been observed[6-8] in a temperature region where one might expect an intrinsic exponential-dominated magnon rate. Prefaced with these remarks, it seems plausible that the low-temperature approximately exponential dependence, and the high-temperature T^5 dependence observed in $KMnF_3$ sample 5, are intrinsic rates, and the T^7 dependence is an impurity-dominated rate. This conclusion is further substantiated by the fact that sample 5 is known to have an impurity content less than 30 ppm (parts per million) and sample 7 could have an impurity content as large as 10 000 ppm.

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CLUSTER STRUCTURE OF EXCITED LEVELS IN He^6 AND Li^6†

D. R. Thompson and Y. C. Tang
School of Physics, University of Minnesota, Minneapolis, Minnesota
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The light nuclei He^6 and Li^6 have received a great deal of attention both theoretically[1-3] and experimentally.[4-6] In particular, the states with excitation energies (E_x) less than 2 MeV in He^6 and the states with excitation energies less than 6 MeV in Li^6 are known to have predominantly a cluster structure of an alpha cluster plus a two-nucleon cluster in triplet or singlet s state.[3] In this communication, we report the result of a calculation using the resonating-group method[7,8] which shows that there also exist levels in He^6 with $E_x > 2$ MeV which have predominantly a H^3-plus-H^3 cluster structure and levels in Li^6 with E_x between 3.5 and 10.5 MeV which have predominantly a H^3-plus-He^3 cluster structure.

Experimentally, there is some, but not definite, evidence[5,6] that there exist levels at 3.4 and 6.0 MeV in He^6 and a group of levels in the range from 6 to 10 MeV in Li^6. If these

levels do indeed exist, then their structure remains to be explained. In the intermediate-coupling model,[1] a group of P levels in Li^6 were predicted, but these levels have been shown to have excitation energies greater than 11 MeV and, hence, cannot be identified as the levels suspected experimentally to lie between 6 and 10 MeV. With a phase-shift analysis of the d-α differential scattering cross sections, Senhouse and Tombrello speculated that there might be the presence of 2^-, 1^-, and 0^- levels at 6.8, 7.8, and 9 MeV excitation in Li^6.[9] However, more extensive analysis by McIntyre and Haeberli failed to support this latter assertion.[10]

The resonating-group method in the one-channel approximation has recently been used to study scattering problems of He^3 on He^3,[11] H^3 on H^3, and H^3 on He^3,[12] and very good agreement with experiment has been obtained. Here, we extend these calculations to bound-state problems. In the one-channel approximation, the wave function is written as

$$\Psi = A\{\varphi_1\varphi_2 F(\vec{R}_1-\vec{R}_2)\xi(\sigma,\tau)\}, \tag{1}$$

where the operator A is an antisymmetrization operator and $\xi(\sigma,\tau)$ is a charge-spin function.[13] The functions φ_1 and φ_2 describe the spatial behavior of the two clusters and are written as

$$\varphi_1 = \exp[-\tfrac{1}{2}\alpha \sum_{i=1}^{3} (\vec{r}_i-\vec{R}_1)^2], \tag{2}$$

and

$$\varphi_2 = \exp[-\tfrac{1}{2}\alpha \sum_{i=4}^{6} (\vec{r}_i-\vec{R}_2)^2], \tag{3}$$

with $\vec{R}_1$ and $\vec{R}_2$ being the position vectors of the respective centers of mass of the two clusters. The constant α is chosen to be 0.36 F^{-2} which corresponds to a rms radius of 1.67 F for the nucleon distribution in H^3 or He^3.[14] The function $F(\vec{R}_1-\vec{R}_2)$, which describes the relative motion of the two clusters, is determined from a variational principle

$$\delta\int\Psi^*(H-E')\Psi d\tau = 0, \tag{4}$$

where E' is the total energy of the system and H is the Hamiltonian given by

$$H = \frac{\hbar^2}{2m}\sum_{i=1}^{6}\nabla_i^2 + \sum_{i>j=1}^{6} V_{ij}. \tag{5}$$

The two-body potential V_{ij} is assumed to be purely central and of the form[11]

$$V_{ij} = -V_0\exp(-\kappa r_{ij}^2)(w + mP_{ij}^{\ r} + bP_{ij}^{\ \sigma} - hP_{ij}^{\ \tau}) + e^2\epsilon_{ij}/r_{ij}, \tag{6}$$

with $V_0 = 72.98$ MeV, $\kappa = 0.46$ F^{-2}, and ϵ_{ij} equal to 1 if particles i and j are protons, and zero otherwise. The constants w, m, b, and h satisfy the equations

$$w + m + b + h = 1, \tag{7}$$

and

$$w + m - b - h = 0.63. \tag{8}$$

We wish to mention here that the potential V_{ij} yields a good fit to the nucleon-nucleon low-energy scattering data. This is sufficient for our purpose, since it has been shown[2] that the level spectrum in Li^6 seems to be sensitive only to the low-energy property of the two-body potential. Hence, the results obtained with a nonsingular potential such as the one we use here should be quite reliable.

In this analysis, we have further written V_{ij} as

$$V_{ij} = y\,V_{\text{Serber}} + (1-y)V_{\text{Symmetric}}, \tag{9}$$

where V_{Serber} is given by Eq. (6) with $w = m$ and $b = h$, and $V_{\text{Symmetric}}$ is obtained from Eq. (6) with $m = 2b$ and $h = 2w$. According to the nucleon-nucleon scattering data, y should have a value close to 1. In our calculation, we have varied y slightly around 1 to achieve a best fit with the experimental scattering data of He^3 on He^3. In this way, a number of open and closed channels which have been omitted in our formulation are approximately accounted for. The best value of y, obtained from fitting the He^3-He^3 scattering data at low energies ($\lesssim 6$ MeV in the c.m. system), is equal to 1.25,[11] which is then the value of y used in this study. It should be emphasized that with y determined from the scattering data, there is no adjustable parameter in our bound-state calculations.

The results are listed in Table I, where E_S denotes the separation energy of the two clusters. Because of the use of a central force in our calculation, the ^3D level is not split. But the splitting can be estimated in the following way. In Li^6, we note that there are levels at 2.18, 4.6, and 5.7 MeV,[4,10] which can be identified as $^3D_3$, $^3D_2$, and $^3D_1$ levels. Thus, it is

Table I. Results of the bound-state calculation.

Nucleus	Level description L-S coupling terms	T	E_s (MeV)	E_x (MeV)
He^6	^1S	1	9.14	3.16
	^1D	1	6.10	6.20
Li^6	^1S	1	8.42	7.37
	^1D	1	5.40	10.39
	^3S	0	12.32	3.47
	^3D	0	7.61	8.18

reasonable to assume that the ^3D levels with which we are concerned are also split by about the same amount, i.e., 3 MeV. By further remembering that the expectation values of $\vec{l}\cdot\vec{s}$ are equal to -3, -1, and 2 for $J=1$, 2, and 3, the $^3D_3$, $^3D_2$, and $^3D_1$ levels of the H^3-plus-He^3 structure can then be estimated to have excitation energies equal to 7.0, 8.8, and 10.0 MeV, respectively.

A comparison with experiment is shown in Fig. 1. In this figure, only the ground states of He^6 and Li^6 have been plotted as a reference; other levels with $\alpha+d$ (or $\alpha+d^*$) cluster structure have been omitted for simplicity. Here, one sees that the resonating-group calculation does yield a group of levels which lie in the excitation region where, experimentally, there is some evidence for the existence of a number of excited levels. It is, of course, not possible at the present moment to make a positive identification; however, the close agreement between theoretical and experimental excitation energies does suggest that it is reasonable to identify the levels by the dashed lines drawn in the figure.

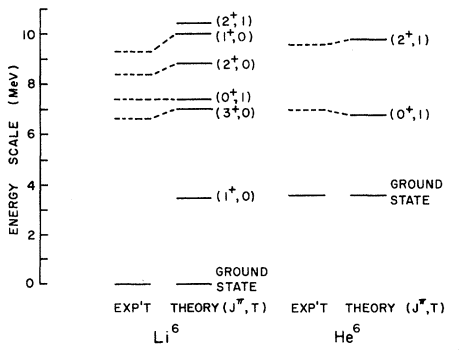

FIG. 1. Comparison of experimental and theoretical level spectra of He^6 and Li^6. The experimental levels are plotted with dashed lines to emphasize the fact that the experimental evidence is not definite.

One salient feature contained in Fig. 1 is that there is a level found theoretically at 3.47 MeV in Li^6 which has not been reported experimentally. This is, perhaps, not too surprising. Recently, Young et al. have cited a number of pieces of evidence which show that the ground state of Li^6 has a significant admixture of the H^3-plus-He^3 configuration.[15] This means that if we had done a coupled-channel calculation involving both the $\alpha+d$ and the H^3+He^3 channels, the level found here at 3.47 MeV would turn out to have a larger excitation energy. Thus, it is conceivable that this particular level might actually occur in the excitation region of 4 to 5 MeV, at which the presence of other broad levels would make its detection difficult.[16] Similar consideration should, of course, be applied to the other levels reported here. However, there is experimental evidence[15,17] which indicates that relatively little of the H^3+He^3 configuration is contained in the first ($^3D_3$, $T=0$) and second ($^1S_0$, $T=1$) excited states of Li^6.[18]

In conclusion, we have found by the method of resonating-group structure that there exist levels in He^6 at 3.2 and 6.2 MeV which have predominantly a H^3+H^3 cluster structure and levels in Li^6 with excitation energies in the range from 3.5 to 10.5 MeV which have predominantly a H^3+He^3 cluster structure.

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[18]The first excited state of Li^6 is unbound, which means that the alpha and the deuteron clusters are expected to be spatially quite far apart. On the other hand, it is found from our calculation that the states with H^3+He^3 cluster structure are all rather tightly bound. This indicates that there is a poor spatial overlap between the wave function describing a H^3+He^3 system and that describing an $\alpha+d$ system. Thus, one expects that there would be only a small admixture of the H^3+He^3 configuration in the first excited state of Li^6. A similar argument should also hold for the second excited state of Li^6, since here, the alpha and the d^* clusters are only very lightly bound.

ABSOLUTE SPECTROSCOPIC FACTORS FOR (d,p) REACTIONS ON HEAVY DEFORMED NUCLEI*

R. H. Siemssen† and J. R. Erskine
Argonne National Laboratory, Argonne, Illinois
(Received 15 March 1967)

A reanalysis of a previously reported experiment on the reaction $W^{182}(d,p)W^{183}$ still shows a serious discrepancy in the absolute spectroscopic factors if we use distortion parameters that fit the elastic-scattering data. Similar deviations exist for (d,p) reactions on other rare-earth and actinide nuclei.

In a recent investigation of the reaction $W^{182}(d,p)W^{183}$ at 7.5- and 12-MeV bombarding energy[1] (hereafter referred to as I), the measured spectroscopic factors were found to be about twice the best theoretical values. (A single-particle rotational model which included the effects of Coriolis band mixing and of pairing correlations was used to calculate the theoretical spectroscopic factors.) The differences in the spectroscopic factors were observed if the experimental spectroscopic factors were extracted with distorted-wave Born approximation (DWBA) calculations with measured distortion parameters. If, on the other hand, "average" optical-model parameters were used, the agreement between the measured and the predicted spectroscopic factors was found to be good. The "average" potentials, however, do not fit the elastic scattering on tungsten, and there is therefore no a priori justification to use these potentials for the DWBA analysis. As was also pointed out in I, similar discrepancies in the absolute spectroscopic factors seem to exist for (d,p) reactions on the actinide nuclei, in particular, for the reaction $U^{238}(d,p)U^{239}$ at 12-MeV bombarding energy. The same discrepancy was recently observed by Sheline et al.[2] and is also present implicitly in the study of Iano and Austern.[3] The discrepancies of a factor of 2 to 3 in the spectroscopic factors are in contrast to the situation in light- and medium-weight nuclei (as well as for Coulomb stripping on lead), where the agreement with theory is usually to within 20%.[4]

In the optical-model analysis[1] of the deuteron scattering on W^{182} at 12 MeV, a serious ambiguity in the deuteron optical potentials was discovered. With this ambiguity, the imaginary potential W could be varied continuously from 5 to 30 MeV without significantly affecting the quality of the fit so long as the parameters a, a', and V were correspondingly readjusted. It was also found that the scattering data could not be satisfactorily fitted with a set of average geometrical parameters ("set B" from the work of Perey and Perey[5]). These ambiguities in the deuteron potential and the failure to obtain a fit with the average geometrical parameters of Perey and Perey lead one to suspect that the "true" optical-model param-