^{6}Li inelastic form factors in a cluster model

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Longitudinal and transverse form factors are calculated for the transition into the low-lying excited $T = 0$ and $T = 1$ states of ^{6}Li in the framework of the resonating group model. All form factors are reproduced simultaneously using three cluster wave functions. Meson exchange currents yield only minor corrections and do not lead to any specific structures at large momentum transfers.

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The structure and properties of the ^{6}Li nucleus are experimentally and theoretically well studied (especially form factors are of particular interest). For such a light nucleus microscopic calculations, starting from a nucleon-nucleon force, are feasible for a large variety of different models. Special interest is devoted to three-body α-np models often in the framework of Faddeev equations [1–4], but also shell model [5,6] and cluster model [7,8] calculations are affluent. In many cases only the ground-state properties of ^{6}Li are studied. Here we report an extension of Ref. [8] to all low-lying excited states of ^{6}Li in the framework of the resonating group model (RGM). We use completely antisymmetrized RGM cluster-wave functions in the form α-np and an effective nucleon-nucleon potential [9].

In Refs. [8,9] the ground-state wave function of ^{6}Li was calculated using the Ritz variational principle, allowing all possible combinations of S and D waves on the intercluster coordinates between neutron and proton and center of mass of n-p and α particle. For the $T = 0$ spin-orbit triplet $(3^+, 2^+, 1^+)$ such a variation is not possible anymore, because the lowest energy for this partial wave is just the α-deuteron threshold. Therefore, we used the parameters of the model space of our ground state and diagonalized the Hamiltonian in the corresponding spaces. The excitation energies are given in Table I. Obviously the agreement with experiment [10] is only fair due to the fixed width parameters. We refrained from changing the width parameters in order to reproduce the data, because there is no controllable way to do that.

In an α-deuteron scattering calculation the phase shifts for the $3^+, 2^+$ and to a lesser extent 1^+ vary rapidly in the neighborhood of the experimental energies (see Refs. [11,12] for potentials similar to ours). For $T = 1$ the situation is different, since the decay into the α-deuteron channel is forbidden by isospin. The $0^+T = 1$ state is bound, relative to the α-n-p threshold. Therefore, we again tried the Ritz variational principle to determine the wave function. Besides the obvious spin zero and pure S-wave component, we allowed P waves on the intercluster coordinates coupled to 1. For this model space we found a rather stable local minimum above the three-body breakup threshold with the parameters $\beta = 0.2838, \gamma = 0.1620, \delta_1 = 0.2609$, and $\delta_2 = 0.03624$ (see Ref. [9] for an explanation of these parameters). For the 2^+T=1 state these parameters were also used and we allowed all combinations of S, P, and D waves which could contribute.

The energies are given below (Table I). Since the calculated level order is not correct, we also allowed configurations of the ^{5}Li-n and ^{5}He-p in the $0^+T = 1$ wave function, gaining 0.7 MeV additional binding energy. As will be shown later, the effects of the wave function modification on the form factors had been quite small, so we will not give any details of the complicated wave function.

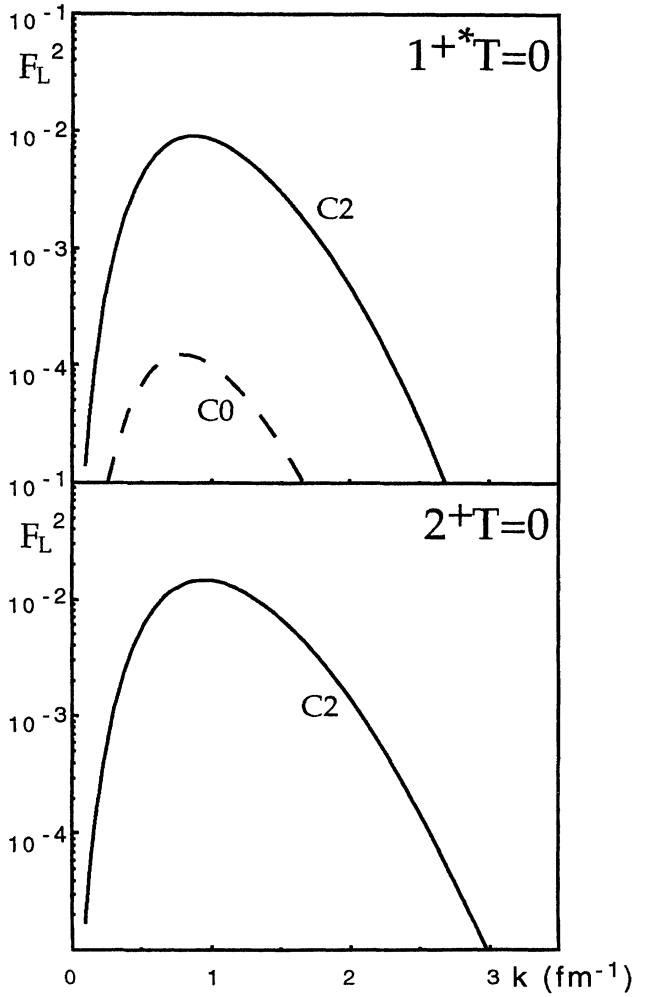

FIG. 1. Longitudinal form factors for the $1^{+*}T$=0 and 2^+T=0 state.

TABLE I. ^{6}Li energies (in MeV).

State	Calculated	Experimental
$1^+T=0$[a]	0	0
$3^+T=0$	3.33	2.18
$0^+T=1$	6.16, 4.46[b]	3.56
$2^+T=0$	4.86	4.31
$2^+T=1$	8.52	5.37
$1^{+*}T=0$	5.37	5.65

[a]Ground state.
[b]Complex wave function.

With these wave functions we now calculated electromagnetic transition form factors. For one-body operators we used the standard expressions for the charge density, convection current, and magnetization density [8]. For the meson exchange currents we used the prescription of Ohta [13]; details of the calculation in the RGM framework are given in Ref. [14].

Due to the finite size of the nucleons the form factors must be modified by the single nucleon form factor. This is done by multiplying all matrix elements with the

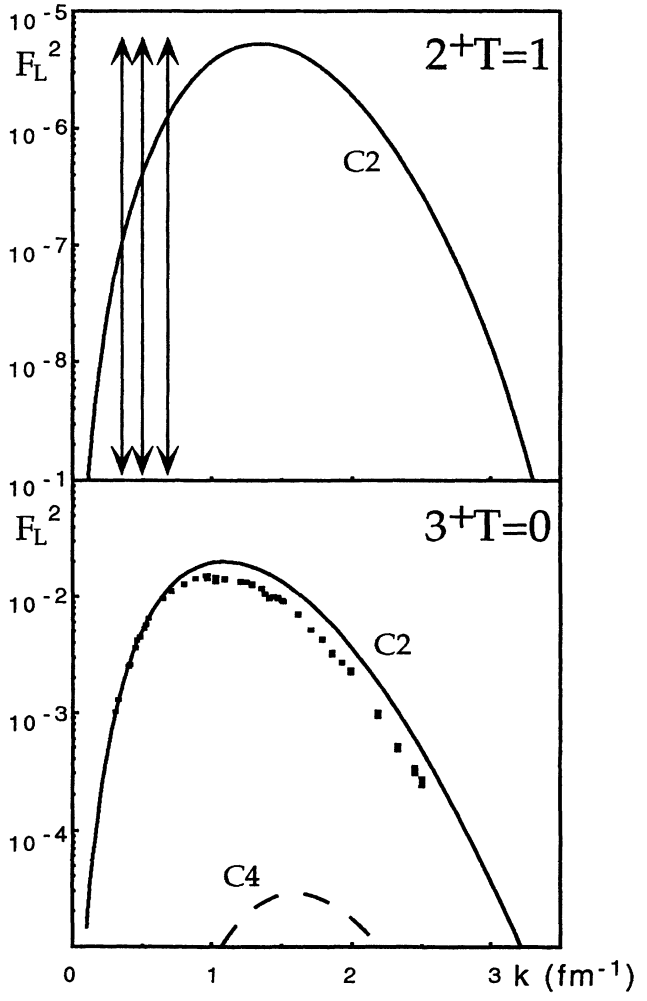

FIG. 2. Longitudinal form factors for the $2^+T = 1$ and $3^+T = 0$ state. Data (Ref. [16]).

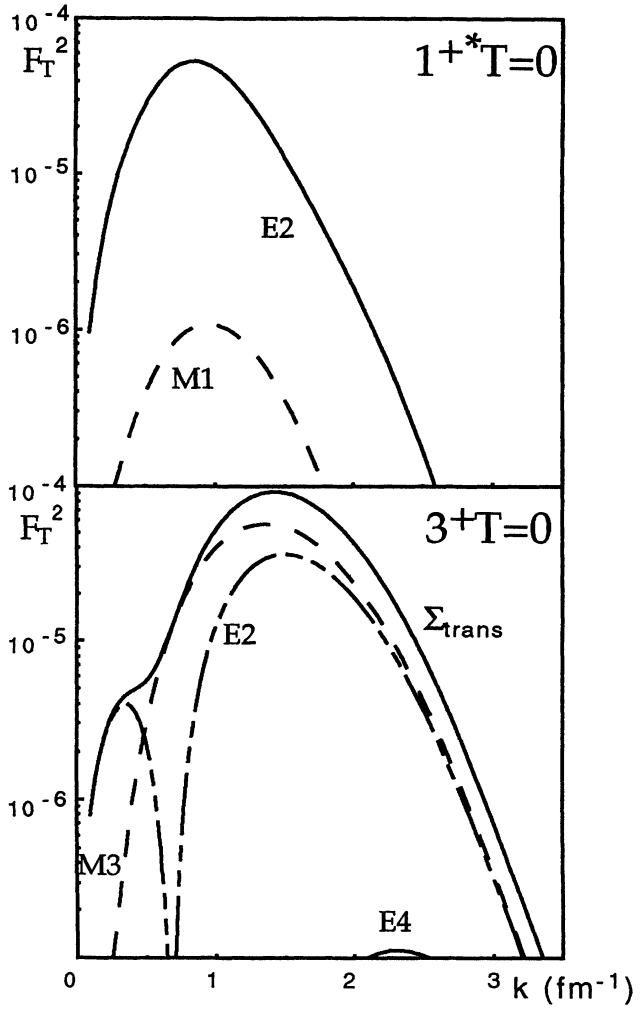

FIG. 3. F_T^2 for the $1^{+*}T=0$ and $3^+T=0$ state.

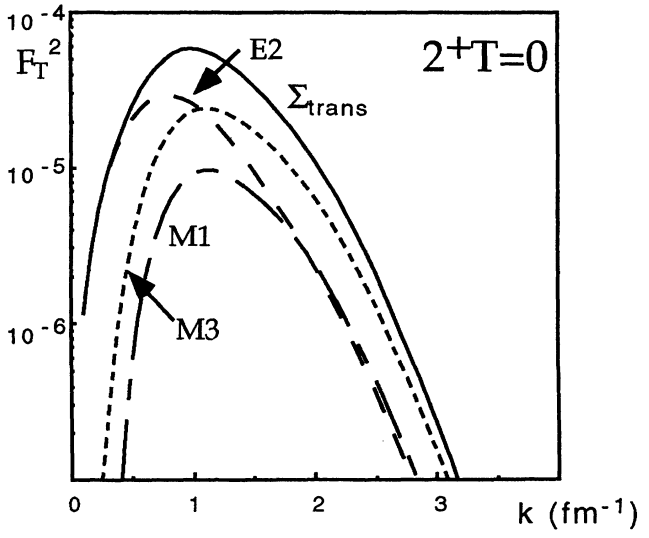

FIG. 4. F_T^2 for the $2^+T=0$ state.

nucleon form factors attained by the well-known dipole formula [15]. (This expression is misprinted in Ref. [8].)

$$f(k) = \left(\frac{1}{1 + \frac{k^2}{A_1}} \right)^2 \quad \text{with } A_1 = 0,71(\text{GeV}/\hbar c)^2 \ .$$

All details of the calculation are given in [14]. We mention in passing that the ground-state wave function reproduces the tiny quadrupole moment (see [9] but also the discussion in [7]) and the elastic form factors quite well only if the wave function is properly antisymmetrized.

In Figs. 1 and 2 the calculated inelastic longitudinal form factors are displayed. The form factors for the $T = 0$ states are of similar magnitude and k dependence since in all cases the $C2$ is the dominant contribution. For the $2^+T = 1$ our result is some orders of magnitude smaller, for the $3^+T = 0$ state the calculation agrees well with the data [16]. For all other resonances there exist no data, either due to the width of the $T = 0$ states or the smallness of the longitudinal form factors for the $2^+T = 1$ state. For the $T = 0$ triplet states our results are similar to those of Ref. [3], whereas for the $2^+T = 1$ we disagree in magnitude and form.

In Figs. 3 and 4 the calculated transverse form factors are displayed together with the multipoles. $E2$ and $M3$ transitions are the dominant ones. Whereas the absolute magnitude agrees well with the findings of Ref. [3], the results for the various multipoles are quite different. Unfortunately there are no data to be compared with. Note that in our model meson exchange contributions are not possible for this transition due to the isospin zero of the initial and final states.

For the $T = 1$ states, however, such contributions are possible. In Fig. 5 we compared the calculation with experimental data for the $0^+T = 1$ state [16,17]. The one-body $M1$ operator reproduced the data quite nicely.

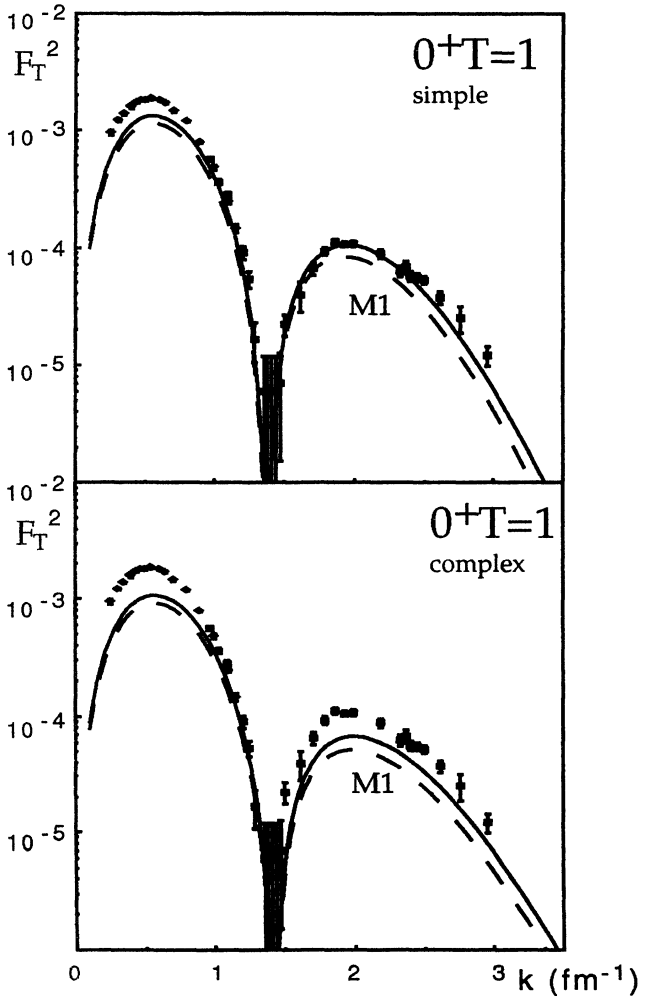

FIG. 5. F_T^2 for the $0^+T = 1$ state. Solid line: impulse-approximation; dotted line: including MEC's. Data (Refs. [16,17]).

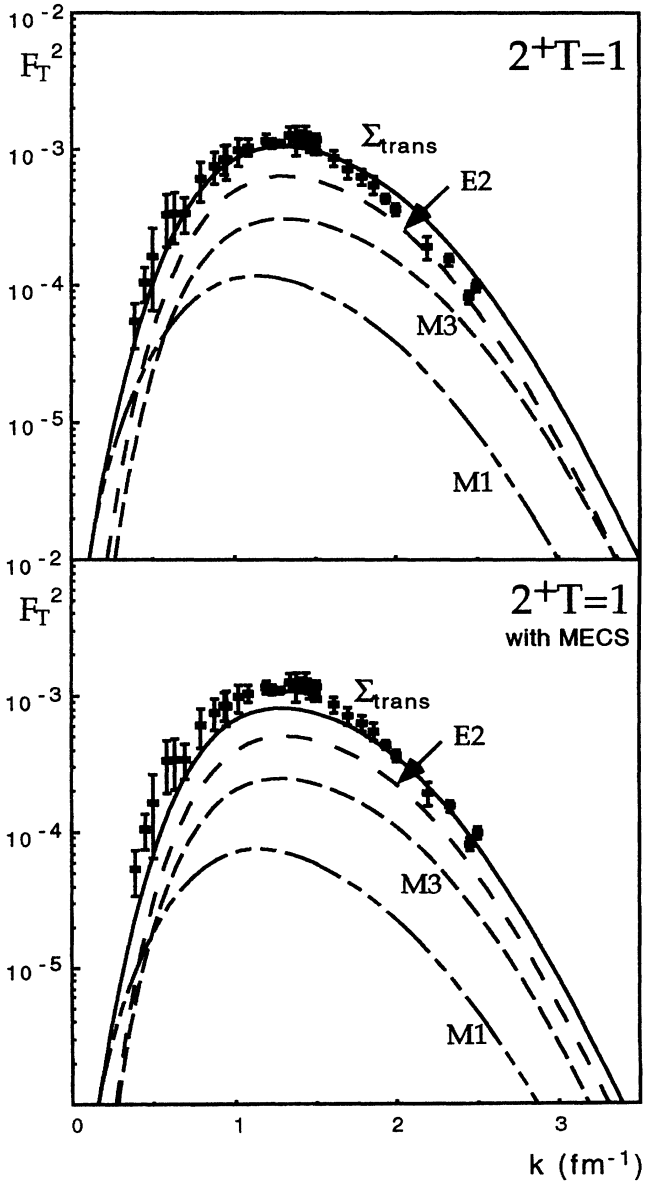

FIG. 6. F_T^2 for the $2^+T = 1$ state. Data (Ref. [16]).

The MEC's are only of minor importance, but reducing the calculated results and thus yielding a somewhat less agreement. Therefore we allowed for additional ^{5}Li-n and ^{5}He-p configurations in the $0^+T = 1$ wave function. The result was a further small reduction in the form factor similar to the MEC effects, and even less, but still satisfactory agreement with data (see Fig. 5). The reduction can be easily explained by the reduced overlap of the orbital wave function for the excited state with the ground-state one due to structures missing in the ground state. The inclusion of these structures into the ground state resulted in a totally wrong quadrupole moment. Since both wave functions reproduced the data much better than Ref. [3] we did not pursue this issue further (as pointed out in Ref. [18] the inclusion of additional structures may, in general, influence substantially the form factors. Here it resulted only in a totally wrong quadrupole moment). In Fig. 6 we compare transverse form factors of the $2^+T = 1$ state with data [16,17]. Again $E2$ and $M3$ are the dominant contributions, with MEC's playing only a minor role, but reducing the calculation by a few percent. Both calculations agree well with data.

In conclusion, one can say that our calculation reproduced consistently the measured elastic [8] and inelastic longitudinal and transverse form factors for all low-lying states of ^{6}Li. Meson exchange contributions yielded only minor effects and introduced no structure at larger momentum transfers.

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