Calculated properties of *M*1 excitations in ^{40}Ca and ^{48}Ca

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(Submitted 24 April 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **40**, No. 1, 31–33 (10 July 1984)

The properties of the low-lying $M\,1$ resonances in ^{40}Ca and ^{48}Ca are calculated from a microscopic model which incorporates $1\,p1\,h$ configurations and complex configurations of the type "$1\,p1\,h\ +$ a phonon." A good agreement with experiment is found.

The structures of the low-lying $M\,1$ and giant Gamow-Teller resonances in nuclei have been discussed very extensively in recent years. The physical problems which arise here are extremely general in nature: the role of a Δ isobar and of one-meson exchange, refining the properties of the spin and spin-isospin forces, possible effects of other types of nuclear forces (spin-orbit and tensor forces), and the effect of configurations more complicated than the particle-hole configurations ($1p1h$) which are taken into account in the ordinary random phase approximation.[1]

Of major interest in connection with these problems is the explanation for the strong $M1$ transitions from the ground state to the 1^+ excited state with an energy ~ 10 MeV in ^{40}Ca (Ref. 2) and ^{48}Ca (Ref. 3), which were detected in (e, e') experiments comparatively recently.(1) These transitions may be thought of as the excitation of at least part of a low-lying $M1$ resonance in these nuclei. The $M1$ resonance in ^{40}Ca is the most interesting, since a low-lying $M1$ resonance could not exist for the magic nucleus ^{40}Ca according to the random phase approximation, while experimentally an unexpectedly strong transition is observed. Consequently, an explanation of the effect for ^{40}Ca should be sought primarily in complex configurations, primarily $2p2h$ configurations. The calculations in Refs. 2 and 6 are extremely phenomenological and only distinctly related to the existing theory of giant resonances. We need to study the effect of $2p2h$ configurations in a common framework for the two nuclei. This approach gives us a good opportunity to find a systematic explanation of the data and to test the calculation method for nuclei of two types: nuclei in which an $M1$ resonance is and is not possible in the ordinary $1p1h$ approach. Other interesting information which can be extracted from these calculations is the extent to which these nuclei are magic.

Kamerdzhiev[7] has derived a microscopic model which simultaneously incorporates $1p1h$ configurations and configurations of the type "$1p1h$ + a phonon." This model generalizes the theory of finite Fermi systems[8] to the case of complex configurations of this type. It makes systematic use of the Green's-function method; the quasiparticle-phonon interaction in the kernel of the integral equation for the density matrix is taken into account with an accuracy to the square of the amplitude for the creation of low-lying phonons. This accuracy is completely acceptable for magic nuclei. An important circumstance here (important also for explaining the $M1$ resonance in our calculations) is the simultaneous account of two types of diagrams which reflect "$1p1h$ + a phonon" configurations: diagrams with "insertions" corresponding to a complication of the one-particle Green's functions due to mixing with phonons and diagrams with a "transverse" phonon, corresponding to the incorporation of a new (retarded) interaction due to the exchange of low-lying phonons.

A circumstance which makes it possible to carry out calculations for ^{40}Ca, in contrast with most approaches of this general type (i.e., approaches which make use of "$1p1h$ + a phonon" configurations[7]), is that in the model of Ref. 7 the equation for the density matrix is formulated in the standard representation of one-particle wave functions, and RPA phonons are not used as doorway states.

Our calculations use a one-particle model developed for a Woods-Saxon potential, whose parameters were varied to obtain the best fit of the known experimental one-particle levels in ^{40}Ca and ^{48}Ca. Each nucleus was assumed to be doubly magic. We took into account in each case the two lowest-lying collective electrical phonons, with the experimental parameters [$E(3_1^-) = 3.74, E(5_1^-) = 4.49$ MeV, $\beta(3_1^-) = 0.36$, $\beta(5_1^-) = 0.10$ in ^{40}Ca and $E(2_1^+) = 3.83$, $E(3_1^-) = 4.51$ MeV, $\beta(2_1^+) = 0.16$, and $\beta(3_1^-) = 0.17$ in ^{48}Ca]. Parameters describing the spin interaction of the quasiparticles and the values of the local charges were taken from the calculations of Ref. 10, which

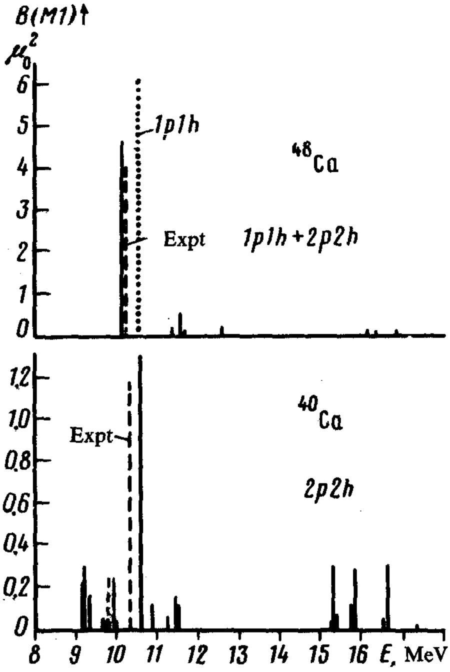

FIG. 1. The low-lying $M1$ resonance in ^{48}Ca and ^{40}Ca calculated with allowance for complex configurations of the "$1p1h$ + a phonon" type. Only the levels with $B(M1)\uparrow \geqslant 0.05\,\mu_0^2$ for ^{48}Ca and with $B(M1)\uparrow \geqslant 0.01\,\mu_0^2$ for ^{40}Ca are shown. The dotted line shows the results of a calculation for ^{48}Ca in the theory of finite Fermi systems.

were carried out in the theory of finite Fermi systems[8] and which use a similar one-particle model: $g = 0$, $g' = 0.8$, $C = 360$ MeV·fm^3, $\xi_s = 0.1$, $\xi_1 = -0.03$. The effective phonon charge e_q' was ignored in these calculations. The corrections to the one-particle energies found by removing from the phenomenological energies the "impurity" of mixing with phonons have a noticeable effect, improving the agreement with experiment. The reader is referred to Refs. 7 and 11 for more details.

As can be seen from Fig. 1, we achieved a good agreement with the experimental data available for each of the nuclei. The calculations also predict a large number of low-intensity 1^+ levels, whose measurements would be of considerable interest, particularly at energies below those of the intense 1^+ levels which are observed. In ^{40}Ca about 70% of $\Sigma B(M1)\uparrow$ is distributed among such levels. The resultant calculated values are $\Sigma B(M1) = 4.3\,\mu_0^2$ for ^{40}Ca and $5.9\,\mu_0^2$ for ^{48}Ca [the random-phase approximation with the same parameter values leads to ^{48}Ca $B(M1)\uparrow = 6.1\,\mu_0^2$].

Although the calculations use essentially no new or adjustable parameters, and the agreement with experiment is good, it would be worthwhile to use the same approach to study the effects which have been ignored as discussed above. Presumably, however, complex configurations of the "$1p1h$ + a phonon" type should play an important role in explaining the properties of the $M1$ and, apparently, Gamov-Teller resonances.

1) For more-detailed references to other experiments which confirm the results on ^{48}Ca and for theoretical efforts to explain these data, we refer the reader to Refs. 4 and 5, for example. Experiments and calculations based on the many-particle shell model for ^{40}Ca are cited in Refs. 2 and 6.

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Translated by Dave Parsons
Edited by S. J. Amoretty