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ρ-meson effective mass and electron scattering in medium nuclei

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The effects of the consideration of the ρ-meson effective mass, proposed in a number of previous papers, are investigated in medium nuclei by analyzing the electroexcitation of some low-lying magnetic states in ^{48}Ca. It is found that the simple consideration of m_ρ^*/m_ρ as a constant does not work properly in this nucleus, contrary to what happens in ^{208}Pb. If, in addition, the f_π^* is included as given by the *in-medium* scaling law established by Brown and Rho, the available experimental data can be reasonably well described, provided $m_\rho^*/m_\rho \approx f_\pi^*/f_\pi \approx 0.91$. This value differs notably from the one found for ^{208}Pb which is of 0.79. As predicted, f_π^* does not strongly affect the conclusions drawn in lead for the m_ρ^* calculations, the only effect being an increase of the quenching factor corresponding to the lower 12^- state at 6.43 MeV up to a value near 0.9. The results obtained show a rather clear dependence of the scaling with the nucleus considered.

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I. INTRODUCTION

A. The tensor part of the residual NN interaction

At present the investigation of the changes that environment modifications, such as density and temperature, produce in the different nuclear phenomena can be considered as one of the most challenging new directions in nuclear physics. Processes like relativistic heavy-ion collisions are expected to give information about how nuclear matter behaves at high temperature and/or high density. On the other hand, high-energy continuous wave electron scattering will show the properties of the individual hadrons when they are embedded in the surrounding matter which strongly interacts with them.

In principle one should be able to evaluate how the different observables change as the nuclear medium changes, provided the fundamental theory of the strong interactions is known. However, one can take advantage of the fact that these effects have nontrivial implications in nuclear processes at low energy and thus it is possible to obtain relatively clean information by analyzing some basic nuclear properties such as, e.g., excitation spectra, transition probabilities, and form factors for the scattering of hadrons and leptons.

As an example we mention here the enhancement of the ρ-exchange tensor interaction in the nuclear medium [1]. This modification is analogous to that of the isovector transverse form factor for electron scattering from nuclei and is basically due to the necessity of replacing the nucleon mass by the effective nucleon mass in the medium. This gives rise to a reduction of the tensor part of the nucleon-nucleon (NN) interaction and, as a consequence, the calculated electromagnetic form factors of low-lying magnetic states in ^{208}Pb are appreciably modified [1, 2].

Apart from the one just mentioned, some other mechanisms, such as core polarization effects [3] and the screening effects induced by two-particle–two-holes excitations [4], have been proposed to explain how the NN force changes by the presence of the nuclear medium. The common feature between all of them refers to a decrease in the strength of the tensor piece of the interaction.

However, the amount of this reduction has not been fully established yet. In effect, random phase approximation (RPA) calculations with a residual interaction which includes the $\pi + \rho$-exchange potential show [2] that the tensor piece must be reduced by a $\sim 30\%$ in order to obtain a simultaneous fit of the low-lying isoscalar 1^+ state and the two low-lying 12^- states in ^{208}Pb. Equally good fits are obtained [1, 2] if the tensor coupling of the ρ meson to the nucleon is enhanced by the factor $\frac{16}{9}$, suggested by Brown and Rho [1], without additional modifications of the pion terms.

On the other hand, RPA calculations similar to those of Ref. [2] bring the reduction factor to ~ 0.4 when the observed quenching factors in (e, e') and (p, p') experiments for the two 12^- states mentioned above and the 14^- state of ^{208}Pb are put into agreement [5]. Calculations performed in the same scheme, and with the same residual interaction, but for ^{48}Ca show [6] that a rather good description of the experimental information available can be accomplished if the reduction factor is taken to be $> 30\%$ and $< 60\%$. Despite the disparate values quoted for ^{208}Pb, these phenomenological investigations point out the necessity of the reduction we are discussing and, at the same time, provide a reasonable scheme to work out these aspects for different nuclei. Besides they are showing a possible dependence of the strength of the reduction with the nucleus considered.

B. Mass scaling

In this work we focus our attention in the density effect and more specifically in the *in-medium* scaling law proposed by Brown and co-workers [1, 7, 8]. This law is satisfied by the nucleon and scalar and vector mesons masses as

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$$\frac{m^*_\sigma}{m_\sigma} \approx \frac{m^*_N}{m_N} \approx \frac{m^*_\rho}{m_\rho} \approx \frac{m^*_\omega}{m_\omega} \approx \frac{f^*_\pi}{f_\pi} \tag{1}$$

and can be established [8] by starting from effective chiral Lagrangians in which the scaling property of QCD is taken into account. Here we want to investigate if this scaling provides a framework valid for different nuclei, as the simple *ad hoc* reduction of the tensor piece previously described does. In this respect it is worth pointing out that the introduction of m^* affects the tensor and spin-isospin pieces of the NN interaction. In fact the reduction in f_π and the enhancement of the ρ contribution by $\sim (m_\rho/m^*_\rho)^2$ lead to an overall decrease of the isovector tensor interaction while the strength of the spin-isospin interaction increases. It has been shown [5] that such effects produce non-negligible modifications in the nuclear reaction and structure aspects of the ^{208}Pb magnetic high-spin states, where evidences which support the need for m^* have been found. In fact the consideration of $(m_\rho/m^*_\rho)^2 = 1.6$ permits us to achieve a simultaneous description of the quenching factors of the two 12^- and the 14^- states of ^{208}Pb for both (e,e') and (p,p') experiments [5].

In what follows we investigate how the consideration of the *in-medium* scaling law affects the low-energy properties of medium nuclei. To do that we have studied the excitation spectrum and the (e,e') form factors for magnetic excited states in ^{48}Ca. In Sec. II the effects of the consideration of m^*_ρ are analyzed. In Sec. III we show the results obtained when both m^*_ρ and f^*_π are considered simultaneously as given by the scaling law. In Sec. IV we extend this calculation to the high-spin states of ^{208}Pb and discuss the consequences of the inclusion of f^*_π which, at least *a priori*, are expected to be small. Finally we give a summary and conclusions in Sec. V.

II. m_ρ SCALING

In previous works [9], an analysis of the magnetic excitation spectrum of ^{48}Ca has been carried out in the RPA framework using the Jülich–Stony Brook interaction [10] as residual interaction. This interaction consists of a zero-range part of Landau-Migdal type, which takes care of the short-range piece of the NN interaction, while the long-range component is given by the $\pi+\rho$-exchange potential. Some of the facts relevant for the present investigation and found in these calculations are:

(i) The RPA wave functions for the two lower 4^- states show configurations mixing of the two one-particle–one-hole (1p1h) dominant configurations which do not allow for reproducing the experimental (e,e') form factor [11]. This situation is completely similar to that observed in the high-spin 12^- states in ^{208}Pb which makes these states to be of special interest for our analysis.

(ii) The lower 2^- state appears to be inverted with respect to the 4^- states which is in a clear disagreement with the empirical finds [11, 12]. It has been shown that the excitation energy of this state is strongly affected by modifications in the tensor part of the NN interaction [6] and thus it can be expected that the consideration of m^* would produce a similar shift.

(iii) The state observed at 6.89 MeV, the assignment of which has not been experimentally resolved [11, 12], has been ascribed as a 2^- state after considering the effects of meson exchange currents (MEC) in the (e,e') form factor calculated with the wave function of the state obtained at 7.27 MeV in the RPA calculation [9]. The manner in which the introduction of m^* will modify this conclusion seems especially interesting because MEC contributions are linked to the NN interaction via the continuity equation.

(iv) The strong (e,e') transition to the well-known 1^+ state at 10.23 MeV has been nicely described [13] without the inclusion of Δ-hole configurations in the wave function, provided the full RPA wave function, and not only the dominant 1p1h component, is considered. Obviously changes in the residual interaction should modify the degree of mixing of the 1p1h components in the wave function which can give rise to non-negligible modifications of the form factor.

With all these facts in mind and following the strategy developed in Ref. [5] we define

$$\varepsilon = \left(\frac{m_\rho}{m^*_\rho}\right)^2 \tag{2}$$

and use a residual interaction given by

$$V_{\rm res} = C_0\,(g_0\,\boldsymbol{\sigma}^1\!\cdot\!\boldsymbol{\sigma}^2 + g'_0\,\boldsymbol{\sigma}^1\!\cdot\!\boldsymbol{\sigma}^2\boldsymbol{\tau}^1\!\cdot\!\boldsymbol{\tau}^2) + V_\pi + \varepsilon\,V_\rho(\varepsilon). \tag{3}$$

In this way both the range and the strength of the ρ-exchange potential are varied. Besides, we recover the Jülich–Stony Brook interaction for $\varepsilon = 1$. Two points deserve some comments. First no explicit density dependence of m^*_ρ/m_ρ has been considered, thus allowing for a clearer analysis. This means that we are considering for m^*_ρ/m_ρ some average value at the surface. Second we do not include any modification in the pion contribution. The *in-medium* decrease in this piece should not be large [1] and, to be conservative, we have ignored it in the first step.

Calculations have been performed for $\varepsilon = 1, 1.2, 1.6$, and 2. The values of g_0 and g'_0 used in each of them are the same fixed in Ref. [5] to reproduce the energies and B values of the two 1^+ states in ^{208}Pb. These values also give a good description of the experimental energies of the low 3^+ and 5^+ states in ^{48}Ca, as shown in Fig. 1. It is worth pointing out that the value $\varepsilon = 1.6$ is the one allowing us to explain the experimental data corresponding to the high-spin 12^- and 14^- magnetic states in ^{208}Pb in both (e,e') and (p,p'), simultaneously [5]. Thus we are interested to investigate if this value works also in ^{48}Ca. In Fig. 1 we compare the results corresponding to the magnetic excitation spectra obtained for these calculations with the experimental spectrum taken from Refs. [11, 12]. Concerning the points previously mentioned we must state the following:

(i) The energy of the lower 2^- is shifted towards higher values and the inversion with respect to the 4^- states disappears.

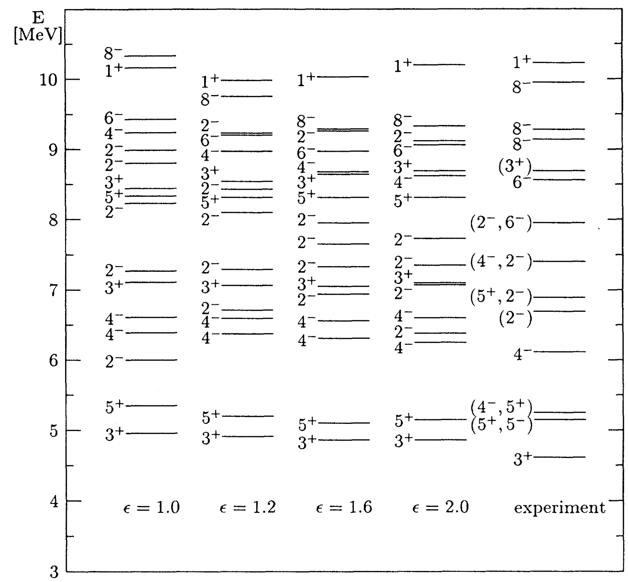

FIG. 1. Excitation energy spectrum of ^{48}Ca. The first four columns correspond to the RPA calculations performed for $\varepsilon = 1$, 1.2, 1.6, and 2, respectively, and considering only the effect of m_ρ^*. The last column shows the empirical data taken from Refs. [11, 12].

(ii) The two lower 4^- states do not change their excitation energies too much.

(iii) The energy of the 1^+ state remains practically unchanged. The same occurs for the remaining positive parity states. On the contrary the energy of the high-spin 6^- and 8^- states appears to be strongly ε dependent.

These results point out the fact that the modification of the NN interaction in the terms here considered allows for a better description of the magnetic excitation spectrum.

Now we proceed by investigating how the consideration of the ρ-meson effective mass affects the (e, e') form factors corresponding to the excitation of the magnetic states of interest. The results are shown in Fig. 2. Therein solid lines correspond to $\varepsilon = 1$, dashed lines to $\varepsilon = 1.2$, dotted lines to $\varepsilon = 1.6$, and, finally, dashed-dotted lines to $\varepsilon = 2$. All of them include the MEC effects corresponding to the so-called *seagull* and pionic currents [9, 14].

We start with the 2^- state lying at 6.89 MeV. As shown in Fig. 2(a), the calculations for both $\varepsilon = 1$ and 1.2 are given a rather good description of the data. We note here that for these two values of ε the MEC produce an enhancement of the squared form factor bigger than 80% [9] which ensures the agreement with the experiment. Values of ε other than the two mentioned are in full disagreement with the experiment, as we can see in Fig. 2(a). Other calculations not shown in this figure and performed for $\varepsilon > 1.2$ produce form factors completely out of range. Thus we can state that a modification of the NN interaction with a value $1 \leq \varepsilon \leq 1.2$ is needed. This differs notably from the value $\varepsilon = 1.6$ found in Ref. [5] as the right one for ^{208}Pb.

In what refers to the lower 4^- state [see Fig. 2(b)], the modification of the NN interaction produces the appearance of a scattering minimum $\sim 1.5\,\text{fm}^{-1}$. As a consequence, the data at the second peak are reasonably well described by the three calculations other than the one with $\varepsilon = 1$. However, the experiment is underestimated at the first scattering maximum, where the best situation

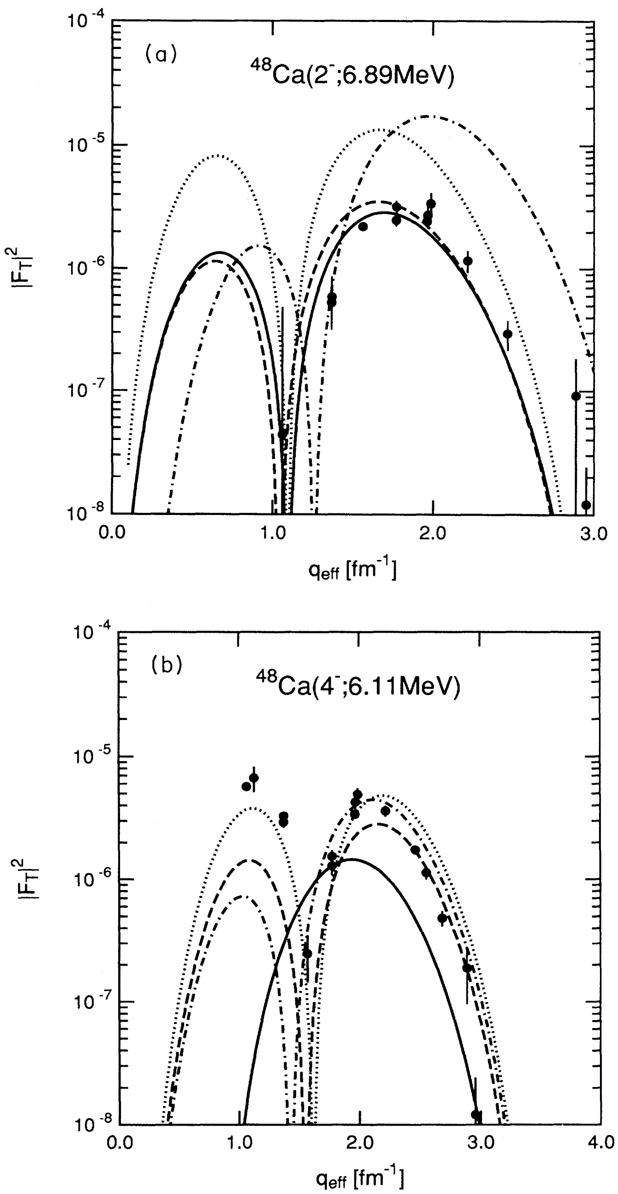

FIG. 2. The (e, e') form factors corresponding to (a) the second 2^- and (b) the first 4^- states obtained in our calculations are compared, respectively, with the experimental data of the states observed at 6.89 and 6.11 MeV [11]. Solid, dashed, dotted, and dashed-dotted curves correspond to $\varepsilon = 1$, 1.2, 1.6, and 2, respectively. MEC effects are included in the calculations. Only the effect of m_ρ^* has been considered.

is attained for $\varepsilon = 1.6$. Additional calculations performed for values around this one do not provide a better agreement with the experiment in this peak. In any case it is evident that the description of this state and the 2^- previously discussed cannot be found simultaneously for any value of the ε parameter.

This result differs notably from the one found in Ref. [6] concerning the tensor part of the NN residual interaction. Therein it is shown that a reduction $\sim 40\% - 50\%$ of this piece of the interaction should permit a good description of the experimental data for these two states, which is not possible by introducing the m^*_ρ.

Let us see finally what happens with the 1^+ state at 10.23 Mev. In Table I (columns 2–5) we give the amplitudes with which the dominant 1p1h components of the RPA wave function are contributing to the corresponding (e, e') form factor. As we can see the modification of the NN interaction produces simpler wave functions in which the bigger ε is, the more dominant the $\nu(1f_{5/2}, 1f^{-1}_{7/2})$ configuration becomes. The role of the nondominant 1p1h components is less important with increasing ε and, as a consequence, the corresponding (e, e') form factors show strengths which grow with ε at the first two peaks. In this situation the well-known "quenching" factor observed for this state, which appears to be q independent for $\varepsilon = 1$ [13], is not observed for the other values of ε, thus leaving room again for the contributions coming from the inclusion of the Δ-hole components in the wave function [15].

The main conclusion one can draw from the results of these calculations is that the *in-medium* scaling law seems to be strongly dependent with the nucleus, in what refers to the low-energy properties studied here. In this sense it is important to point out that the consideration of m^*_ρ works, in ^{208}Pb [5], in a similar way to that of the reduction of the tensor piece of the NN residual interaction. However, and contrary to what happens in this last case for ^{48}Ca [6], the introduction of the ρ effective mass is unable to explain the part of the empirical puzzle which is well established in this nucleus.

A number of reasons can be argued to explain the situation found for the consideration of the m_ρ scaling. First one must be careful with the fact of the consideration of m^*_ρ/m_ρ as a constant, that is at the surface. This could restrict the feasibility of the results to q values around 1.5–2 fm^{-1} and, as we can see in Fig. 2, a coherent description of the data discussed here can be obtained for $\varepsilon = 1.2$. On the other hand, neglecting the modification of the pion contribution via the f^*_π, which seems to not play any fundamental role in ^{208}Pb [5], could be of great importance in lighter nuclei as ^{48}Ca. We investigate this point in the next section.

III. ROLE OF f^*_π

Now we deal with the analysis of the effects produced by the simultaneous consideration of both m^*_ρ and f^*_π consistently with the *in-medium* scaling law of Eq. (1). With the definition of the ε parameter given in Eq. (2), the residual interaction we use in these new calculations can be written as

$$V_{\rm res} = C_0\,(g_0\,\boldsymbol{\sigma}^1\cdot\boldsymbol{\sigma}^2 + g_0'\,\boldsymbol{\sigma}^1\cdot\boldsymbol{\sigma}^2\boldsymbol{\tau}^1\cdot\boldsymbol{\tau}^2) + \frac{1}{\varepsilon}\,V_\pi + \varepsilon\,V_\rho(\varepsilon) \tag{4}$$

and, again, the Jülich–Stony Brook residual interaction is recovered for $\varepsilon = 1$.

As for the preceding case, we have carried out calculations for $\varepsilon = 1.2$, 1.6, and 2. Previously the values of g_0 and g_0' used in each of them have been fixed to reproduce the energies and B values of the two low-lying 1^+

TABLE I. Amplitudes $A_J(ph) = X_J(ph) + (-1)^J Y_J(ph)$ of the dominant 1p1h components of the RPA wave function corresponding to the 1^+ state and obtained for the different calculations performed by including only m^*_ρ and both m^*_ρ and f^*_π as discussed in the text. Only those amplitudes bigger than 0.05 in absolute value have been tabulated.

		m^*_ρ			$m^*_\rho + f^*_\pi$		
ε	1.0	1.2	1.6	2.0	1.2	1.6	2.0
E (MeV)	10.16	9.98	10.03	10.20	9.96	10.18	10.28
$\pi(2p_{1/2}, 1p^{-1}_{1/2})$	−0.098	−0.069					0.071
$\pi(2d_{5/2}, 1d^{-1}_{3/2})$			0.061	0.090		0.070	0.080
$\pi(1f_{5/2}, 1p^{-1}_{3/2})$	0.054						−0.092
$\pi(1g_{7/2}, 1d^{-1}_{5/2})$							−0.061
$\nu(3s_{1/2}, 2s^{-1}_{1/2})$	−0.066						−0.057
$\nu(2d_{5/2}, 1d^{-1}_{3/2})$	−0.153	−0.089			−0.057		−0.067
$\nu(1f_{5/2}, 1p^{-1}_{3/2})$							−0.079
$\nu(1f_{5/2}, 1f^{-1}_{7/2})$	−0.767	−0.848	−0.923	−0.930	−0.892	−0.926	−0.857
$\nu(2f_{5/2}, 1f^{-1}_{7/2})$	0.089	0.078	0.051		0.065		
$\nu(2f_{7/2}, 1f^{-1}_{7/2})$							−0.084
$\nu(1g_{7/2}, 1d^{-1}_{5/2})$				−0.055			−0.081
$\nu(1h_{9/2}, 1f^{-1}_{7/2})$				−0.069		−0.060	−0.099
$\nu(2h_{9/2}, 1f^{-1}_{7/2})$							−0.060

states of ^{208}Pb. In the next section we give some details concerning the results obtained in this nucleus.

The excitation energy spectra we have found for the new calculations are shown in Fig. 3, where the experimental spectrum and the one corresponding to $\varepsilon = 1$, which coincide with the same in Fig. 1, are included for comparison. In general we can state that the results are rather similar to those of Fig. 1. In particular the spectra for $\varepsilon = 1.6$ are very close in both cases. This points out that the inclusion of f_π^* in the calculations does not produce big effects at the level of the energies of the excited states. In any case differences are observed for the 6^- and 8^- states, the energies of which are shifted by ~ 0.5 MeV when ε goes from 1.6 to 2. This effect was not found in the calculations performed by including only m_ρ^* and can be ascribed to the consideration of f_π^*.

With this in mind we analyze if the inclusion of the effective pion coupling constant changes or not the results quoted in the previous section in what refers to the (e,e') form factors therein discussed. The corresponding results are shown in Fig. 4 where solid, dashed, dotted, and dashed-dotted curves have been obtained for $\varepsilon = 1$, 1.2, 1.6, and 2, respectively. As in the case of Fig. 2, the effects of MEC have been included in the calculations and, to be consistent, we have used f_π^* instead of f_π for these currents.

For the 2^- state at 6.89 MeV [see Fig. 4(a)] the calculations performed for $\varepsilon = 1$ and 1.2 provide a reasonable description of the experiment. On the other hand, the two remaining calculations show a certain disagreement with the data, even if the curve corresponding to $\varepsilon = 2$ (dashed-dotted) roughly describes the high-q ones. In any case, and for the values of ε of interest, no big changes are produced by the inclusion of f_π^* in what refers to this state.

However, the situation is quite different for the 4^- state lying at 6.11 MeV. As we can see in Fig. 4(b), and similarly to what we found when only m_ρ^* was considered, the three calculations done for $\varepsilon > 1$ describe rather well the data at the second peak. The main difference now is that also the first peak can be explained provided ε is taken to be 1.2 or 1.6, while the result corresponding to $\varepsilon = 2$ still underestimates the data at this scattering maximum.

These results allow us to state that the simultaneous consideration of both m_ρ^* and f_π^* permits a rather good description of these states for $\varepsilon \sim 1.2$. It is worth pointing out that the agreement found in this case is similar to that obtained in Ref. [6], where the tensor piece of the interaction was reduced "by hand" by a factor between 30% and 60%. As noted therein, this reduction factor

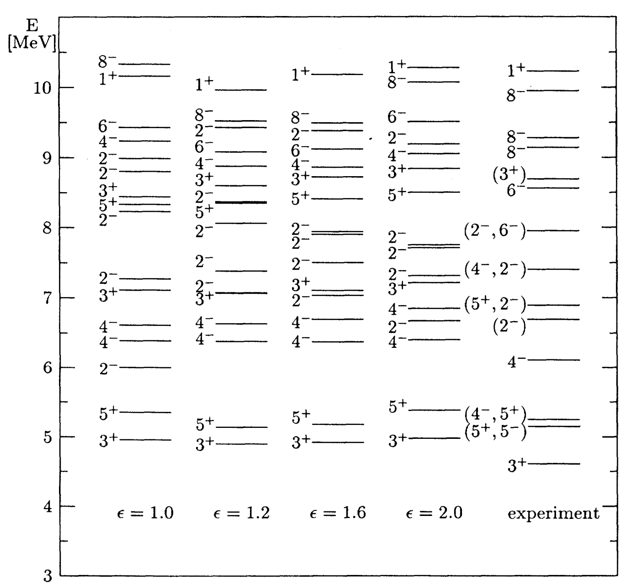

FIG. 3. Same as in Fig. 1 but for the simultaneous consideration of both m_ρ^* and f_π^* in the calculations.

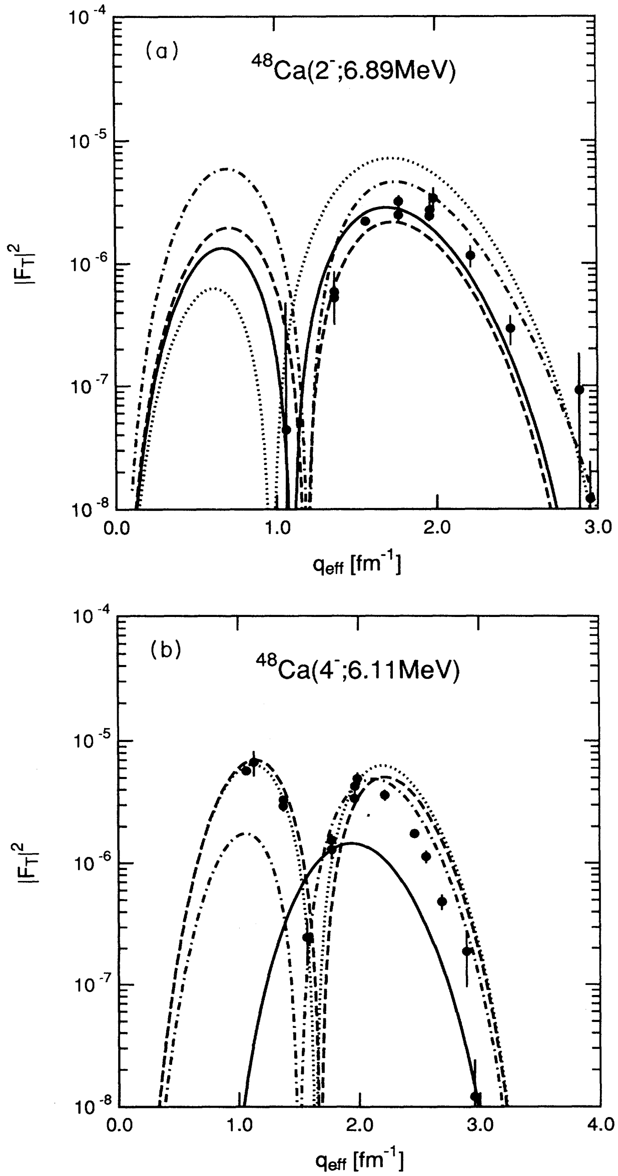

FIG. 4. Same as in Fig. 2 but for the simultaneous consideration of both m_ρ^* and f_π^* in the calculations.

shows a certain dependence on the nucleus considered, because 60% is needed in ^{208}Pb [5]. This dependence appears now in a more clear manner when the value 1.2 for the ε parameter is compared with the $\sim$ 1.6 quoted in Ref. [5] for lead.

Finally we come back to the 1^+ state lying at 10.23 MeV. In Table I (columns 6–8) we also give the amplitudes of the dominant 1p1h configurations of the RPA wave functions obtained for the different values of ε. As we can see, the calculated excitation energies are close to those found with m^*_ρ only and the same is valid for the amplitudes corresponding to $\varepsilon = 1.2$ and 1.6. However, the results for $\varepsilon = 2$ differ notably in both calculations, thus following our findings concerning the excitation spectra. In any case, similar conclusions to those quoted in the previous section can be drawn for $\varepsilon = 1.2$.

IV. ROLE OF f^*_π IN ^{208}Pb

Now we will study the influence of the inclusion of f^*_π in the ^{208}Pb nucleus. It has been predicted [1] that the π part of the interaction should not be modified too much by the medium in the lead region and in order to see if this is so, we have analyzed how the consideration of the effective pion-nucleon coupling constant modifies the results concerning the observed quenching factors for the high-spin states which were investigated in detail in Ref. [5].

Before going with this particular point we will briefly comment on the modification produced by f^*_π in the parameters of the zero-range piece of the interaction. As mentioned above, the g_0 and g'_0 parameters have been fixed in order to reproduce the energies and B values of the two low-lying 1^+ states in ^{208}Pb. The results obtained as a function of ε values are shown in Fig. 5. Therein dashed (solid) lines correspond to calculations performed with (without) the inclusion of f^*_π. As we can see the main effect produced by the inclusion of the effective pion-nucleon coupling constant is to compress the curves of g_0 and g'_0 towards smaller values of ε. The almost constant behavior of g'_0 with ε is not modified too much, while for g_0 the minimum, which appears at $\varepsilon \sim 2$ if only m^*_ρ is included, is shifted by $\sim$ 0.5 when f^*_π is added. Thus f^*_π imposes an additional reduction of g_0 for $\varepsilon < 1.6$ and an increase of it for larger values of the ε parameter.

Now we deal with the quenching factors observed in the (e, e') form factors corresponding to the high-spin 12^- and 14^- states. To investigate the effect of f^*_π we have calculated the ratio

$$R = \frac{|\,F(q)\,|^2_{m^*_\rho}}{|\,F(q)\,|^2_{m^*_\rho + f^*_\pi}}$$

of the squared form factors evaluated with, $|\,F(q)\,|^2_{m^*_\rho+f^*_\pi}$, and without, $|\,F(q)\,|^2_{m^*_\rho}$, the consideration of f^*_π at the first scattering maximum, where the quenching factors for these states are measured. The results are given in Fig. 6. As we can see, the effect of the inclusion of f^*_π

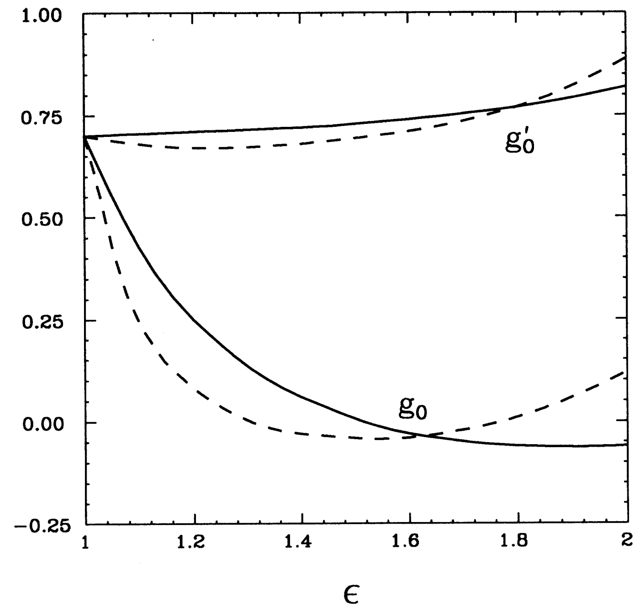

FIG. 5. Parameters of the Landau-Migdal piece of the interaction used in our calculations as a function of ε. Solid lines correspond to calculations performed considering m^*_ρ only. Dashed lines also include f^*_π.

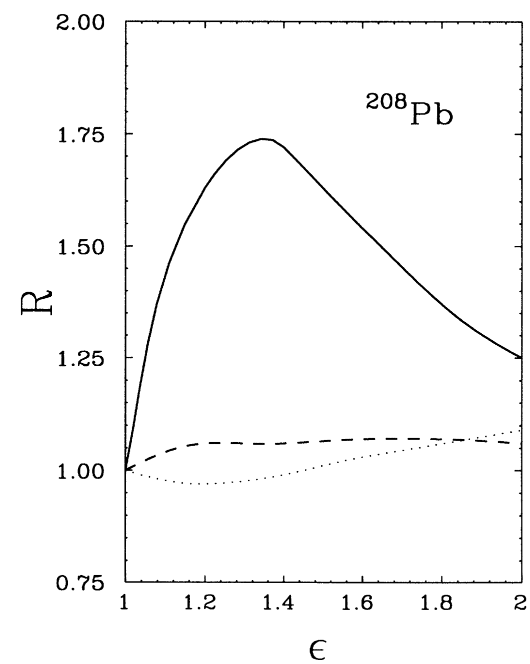

FIG. 6. R ratio of the (e, e') squared form factors calculated by considering m^*_ρ only and also including f^*_π for the three high-spin 12^- (solid line), 14^- (dashed line), and 12^- (dotted line) states in ^{208}Pb, lying at 6.43, 6.74, and 7.06 MeV, respectively.

in the 14^- (dashed line) and 12^- at 7.06 MeV (dotted line) is, at most, 10%, a value which can be considered of the same order of the error estimated for the measured quenching factors [5]. On the contrary, larger values are observed for the lower 12^- state (solid line). In fact the R ratio is maximal, $R \sim 1.75$, for $\varepsilon \sim 1.4$ and in the particular case of $\varepsilon = 1.6$, the value determined in Ref. [5] as the one working for this nucleus, $R \sim 1.5$. Despite this, the modification is not at all negligible in this state, it only produces a change in the slope of the actual quenching factor, which moves, e.g., from ~ 0.6 to ~ 0.9 for $\varepsilon = 1.6$, without any additional effect, at least in the (e, e') process we are discussing.

V. SUMMARY AND CONCLUSIONS

In this work we have analyzed how the *in-medium* scaling law followed by the masses of the nucleons and scalar and vector mesons affects nuclear processes at low energy in medium nuclei. In particular the magnetic excitation spectrum of ^{48}Ca as well as the (e, e') form factors corresponding to the electroexcitation of three states which are reasonably well known from the experiment, have been used to focus the discussion. It has been found that the simple consideration of m_ρ^*/m_ρ as a constant does not permit a good description of the empirical information in this nucleus, contrary to what happens in ^{208}Pb. This situation is amended if, in addition, one considers the effective pion-nucleon coupling constant, which also obeys the *in-medium* scaling law established by Brown and Rho [1, 7, 8]. In that case the available experimental data can be reasonably well described by using $m_\rho^*/m_\rho \approx f_\pi^*/f_\pi \approx 0.91$, a value which shows a notable difference with the one found for ^{208}Pb in Ref. [5].

We have also studied if the additional inclusion of f_π^* produces any modification concerning the results obtained for the high-spin states of ^{208}Pb when only m_ρ^* is considered in the calculations. In this respect, the only effect to note is an increase of the quenching factor corresponding to the lower 12^- state at 6.43 MeV, which reaches a value near 0.9 for $\varepsilon = 1.6$. Though non-negligible, this enhancement only affects the slope of the quenching factor and thus it is not expected to strongly modify the conclusions drawn in lead for the m_ρ^* calculations. In this sense the prediction concerning the small *in-medium* decrease of f_π in the lead region [1] can be considered as plausible.

In any case, the results obtained point out a rather strong dependence of scaling with the nucleus considered. First, the mandatory necessity of f_π^* to explain the data in ^{48}Ca and not in ^{208}Pb and, second, the large difference between the values of the ε parameter working in both nuclei, ~ 1.2 for calcium and ~ 1.6 for lead, seem to clearly support this idea.

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[1] G.E. Brown and M. Rho, Phys. Lett. B **237**, 3 (1990).
[2] G. Co' and A.M. Lallena, Nucl. Phys. **A510**, 139 (1990).
[3] K. Nakayama, Phys. Lett. **165B**, 239 (1985).
[4] S. Drożdż, J.L. Tain, and J. Wambach, Phys. Rev. C **34**, 345 (1986); J.L. Tain, G.P.A. Berg, I. Katayama, S.A. Martin, J. Meissburger, J.G.M. Römer, and J. Wambach, *ibid.* **35**, 1288 (1987).
[5] N.M. Hintz, A.M. Lallena, and A. Sethi, Phys. Rev. C **45**, 1098 (1192).
[6] J.E. Amaro and A.M. Lallena, Mod. Phys. Lett. A **7**, 3029 (1992).
[7] G.E. Brown, C.B. Dover, P.B. Siegel, and W. Weise, Phys. Rev. Lett. **60**, 2723 (1988); T.L. Ainsworth, G.E. Brown, M. Prakash, and W. Weise, Phys. Lett. B **200**, 413 (1988); G.E. Brown and M. Rho, *ibid.* **222**, 324 (1989).
[8] G.E. Brown and M. Rho, Phys. Rev. Lett. **66**, 2720 (1991).
[9] J.E. Amaro, thesis, Universidad de Granada, 1990; J.E. Amaro and A.M. Lallena, Nucl. Phys. **A537**, 585 (1992); J.E. Amaro and A.M. Lallena, J. Phys. G **19**, 99 (1993).
[10] J. Speth, V. Klemt, J. Wambach, and G.E. Brown, Nucl. Phys. **A343**, 382 (1980).
[11] J.E. Wise, J.S. McCarthy, R. Altemus, B.E. Norum, R.R. Whitney, J. Heisenberg, J. Dawson, and O. Schwentker, Phys. Rev. C **31**, 1699 (1985).
[12] Y. Fujita, M. Fujiwara, S. Morinobu, T. Yamazaki, T. Itahashi, H. Ikegami, and S.I. Hayakawa, Phys. Rev. C **37**, 45 (1988).
[13] J.E. Amaro and A.M. Lallena, Phys. Lett. B **261**, 229 (1991).
[14] A.M. Lallena, Ph.D. thesis, Universidad de Granada, 1984; J.S. Dehesa, S. Krewald, A.M. Lallena, and T.W. Donnelly, Nucl. Phys. **A436**, 573 (1985); S. Krewald, A.M. Lallena, and J.S. Dehesa, *ibid.* **A448**, 685 (1986); A.M. Lallena, *ibid.* **A489**, 70 (1988).
[15] A. Härting, W. Weise, H. Toki, and A. Richter, Phys. Lett. **104B**, 261 (1981); T. Suzuki, S. Krewald, and J. Speth, *ibid.* **107B**, 9 (1981); M. Kohno and D.W.L. Sprung, Phys. Rev. C **25**, 297 (1982); W. Weise, Nucl. Phys. **A396**, 373c (1983); A. Härting, M. Kohno, and W. Weise, *ibid.* **A420**, 399 (1984); K. Takayanagi, K. Shimizu, and A. Arima, *ibid.* **A481**, 313 (1988).