Giant Resonance Splitting in Asymmetrical Nuclei

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The isovector giant dipole resonance (IVGDR) splitting observed in the isospin conjugate photonuclear (γ, n) and (γ, p) reactions is often explained as a phenomenon of the nuclear asymmetry within the isospin shell model (ISM) [1]. However, the splitting of the giant resonances into two or more peaks is a more general effect and it is observed in many near *spherical* neutron-rich nuclei. In the present work we suggest a more general explanation of the splitting of both the isoscalar and the isovector modes in spherical neutron-rich nuclei within the Fermi-liquid-drop model (FLDM) [2] based on the collisional Landau kinetic theory and extended to two-component asymmetric nuclei.

In the linear approximation in the asymmetry parameter $X = (N - Z)/A$, both the isoscalar and the isovector sound modes are independent of each other having the sound velocity $s_\pm = s\ (1 \pm \Delta)$, where $s = \omega / v_F k$ is the dimensionless zero sound velocity in symmetric nuclear matter, v_F is the Fermi velocity of the nucleon, $\Delta = (2/3)(1 + F'_0)X$ and F'_0 is the Landau's isovector scattering amplitude. We have shown that the isospin asymmetry leads to the splitting of the GDR into the main peak, $\hbar\omega^{(m)}$, and the satellite, $\hbar\omega^{(s)}$. The energy of both resonances is given by

$$\hbar\omega_-^{(s)} \approx \hbar\Omega \sqrt{\frac{10}{3\,(1 + 2\xi(9 - 7F'_0)/3G_1)}}\ ,$$

$$\hbar\omega_-^{(m)} \approx \hbar\Omega \sqrt{\frac{10}{3\,(1 + 2\xi(3 + F'_0))}}\ , \qquad (1)$$

where $\Omega = v_F/R_0 \approx \varepsilon_F / A^{1/3}\hbar$, $\xi = \varepsilon_F / b_s^- A^{1/3}$ and b_s^- is the isovector contribution to the surface tension coefficient. The resonance energy of the main peak, $\hbar\omega_-^{(m)}$, is close to being proportional mainly to $A^{-1/3}$ through $\hbar\Omega$ but the quantity $\hbar\omega_-^{(m)} \cdot A^{1/3}$ increases slowly with A because of the additional $A^{-1/3}$-dependence of ξ . We point out that this A-dependence of the isovector giant dipole-resonance (IVGDR) energies agrees with the experimental data, Fig. 1. For a large enough particle number A, one obtains a simpler estimate for the energy splitting $\hbar\omega_-^{(s)} - \hbar\omega_-^{(m)} \approx (10/3)^{3/2}\, \varepsilon_F^2 F'_0 / b_s^- A^{2/3}$. The magnitude of the splitting decreases with the increase of the particle number A and the surface tension parameter b_s^- or with a decrease of the Landau interaction constant F'_0. That means that the splitting effect in our FLDM depends significantly on the effective volume (F'_0) and surface (b_s^-) isovector interactions and does not depend on the neutron excess $N - Z$. These results show essentially a new IVGDR splitting effect compared to the traditional ISM explanation.

We have also performed a calculation of the response of the asymmetric nucleus to the isovector external field and the corresponding contribution of both the main, $m_1^{(m)}$, and the satellite, $m_1^{(s)}$, resonances to the model independent sum rule $m_{GDR} = (3/4\pi)(\hbar^2/2m)(N/A)A$. The dependence of

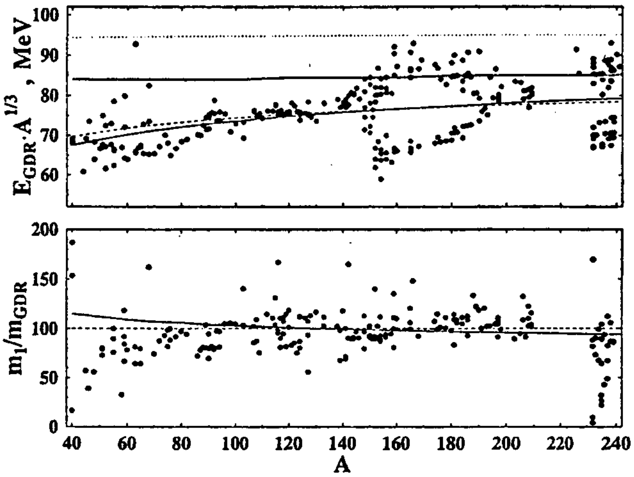

Figure 1. Giant dipole resonance energies E_{GDR} multiplied by $A^{1/3}$ (top) and depletion m_1 of the model-independent EWSR m_{GDR} (in percent, bottom) for certain isotopes versus the particle number A; the full points are the experimental data from the Web page http://depni.npi.msu.su/cdfe/; solid and broken (fat) lines are the main GDR resonances and their satellites found from our FLDM for $F_0' = 1.2$, $b_s^- = 110$ MeV, $\epsilon_F = 40$ MeV, $r_0 = 1.1$ fm; points and seldom broken lines correspond to those from (1).

the IVGDR characteristics on the asymmetry parameter for several isotopes of the Ca nucleus is presented in Fig. 2. The main ($E_{GDR} = \hbar\omega_-^{(m)}$) and satellite ($E_{GDR} = \hbar\omega_-^{(s)}$) GDR energies, their relative strength $m_0^{(1)} = m_1^{(1)}/m_1^{(2)}$ and the depletion of the EWSR, m_1/m_{GDR}, versus the asymmetry parameter X are compared with the experimental data and ISM estimates. As seen from the top figure of Fig. 2 the splitting magnitude in our FLDM does not depend on the neutron excess $N - Z$ and there is a good agreement with the experimental data (squares and triangles). Its slow decrease with the asymmetry parameter X is explained in our case by the A dependence in Eq. (1). This is in contrast with another splitting effect predicted by the ISM which shows an increase of the energy splitting of the GDR with the isospin quantum number $T_z = (N - Z)/2$. The satellite strength ratio $m_0^{(1)} = m_1^{(s)}/m_1^{(m)}$ in the middle of Fig. 2 is small and increases linearly with the asymmetry parameter X in contrast to both the opposite ISM behavior $m_0^{(1)} \approx 1/T_z$ and the case of the deformation in dynamic collective model with $m_0^{(1)} \approx 1$.

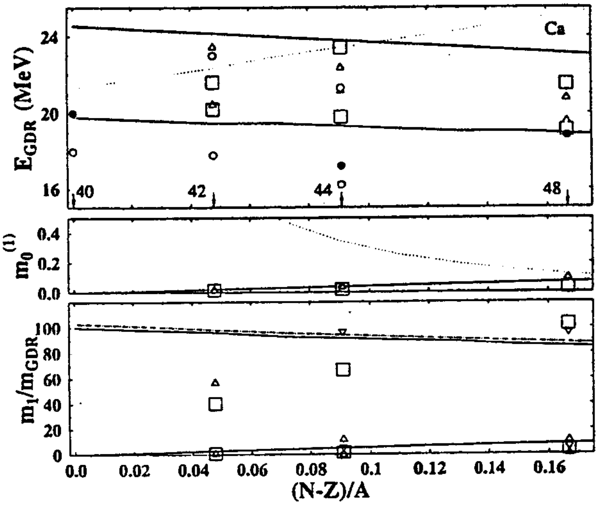

Figure 2. Energies E_{GDR} (top), EWSR depletion m_1/m_{GDR} (bottom, in percent) and satellite strength $m_1^{(s)}$ divided by the main peak one $m_1^{(m)}$ (middle) for the Ca isotopes versus the asymmetry parameter $X = (N - Z)/A$; full and open circles show the experimental data from the Web page http://depni.npi.msu.su/cdfe/; squares and triangles are obtained from the cross sections for the corresponding (γ, n) and (γ, p) reactions of Ref. [1]; dots in the top and middle present the ISM [1]; solid (point-dashed) and fat broken (short broken) in the bottom show the analytical (exact integral) EWSR depletion.

References

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