Shape of Dipole Radiative Strength Function for Asymmetric Nuclei

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The semiclassical method for description of the radiative strength function is used for asymmetric nuclei with $N \neq Z$. The theory is based on the linearized Vlasov-Landau equations in two-component finite Fermi liquid. The dependence of the shape $E1$ strength on the coupling constant between proton and neutron subsystems was studied.

1 Introduction

At the present time the properties of nuclei far from $\beta$-stability valley are widely investigated \cite{1, 2}. In this case the experimental data and theoretical predictions for photo-absorption and $\gamma$-emission processes are needed for the astrophysics and some applied problems. These processes can be calculated by the use of radiative strength (RS) functions. The RS function is determined by response function heated nuclei on external electromagnetic field. The semiclassical approach \cite{3, 4} gives the simple way to calculate the response function. It includes both self-consistence mean field and residual interaction. In this contribution the semiclassical Fermi-liquid model \cite{3, 4} is generalized to calculation response function in asymmetric nuclei with taking into account retardation effects \cite{6, 7} in collision integral. Note that the two-component Fermi-liquid system was investigated in the Ref. \cite{5}. But this model doesn’t include interaction $u^{\alpha\alpha'}$ between nucleon subsystems as well as difference between Fermi-energies of neutrons and protons. We avoid these simplification. The self-consistent mean field was taken with the use of separable interaction potential.

The nucleus is considered as a drop of two-component Fermi-liquid with phase-space distribution function $f^{(\alpha)}(\mathbf{r}, \mathbf{p}, t) = f_0^{(\alpha)}(\mathbf{r}, \mathbf{p}) + g^{(\alpha)}(\mathbf{r}, \mathbf{p}, t)$ ($\alpha = 1, 2$).
n for neutron and $\alpha = p$ for proton). Variations $g^\alpha$ of the distribution function in external field are determined by the system of the linearized Landau-Vlasov kinetic equations:

$$\frac{\partial g^\alpha}{\partial t} + \frac{p}{m_\alpha} \nabla g^\alpha - \nabla U_0^\alpha(r) \nabla p g^\alpha - \nabla (\delta U^\alpha(r, t) + \beta^\alpha Q^\alpha) \nabla p f_0^\alpha = J^\alpha \quad (1)$$

where $U_0^\alpha(r)$ is equilibrium component of the self-consistence mean field and $\delta U^\alpha(r, t)$ is deviation of the field. The external field $\beta(t)Q(r)$ has the following form $V_{ext}^L = \beta(t)Q_L(r)Y_{L0}(\hat{r})$, $Q_L(r) = r^L$, $\beta(t) = \beta_0 \exp[-i(\omega + i\delta)t]$ with $\beta_0 \ll 1$ and $\delta \to +0$.

Two equations of the system (1) are connected by the average field:

$$\delta U^\alpha(r, t) = \int d\mathbf{r}' u^{\alpha\alpha}(\mathbf{r}, \mathbf{r}') \int d\mathbf{p}' g^\alpha(\mathbf{r}', \mathbf{p}', t) +$$
$$+ \int d\mathbf{r}' u^{\alpha\alpha'}(\mathbf{r}, \mathbf{r}') \int d\mathbf{p}' g^{\alpha'}(\mathbf{r}', \mathbf{p}', t), \quad \alpha \neq \alpha'. \quad (2)$$

## 2 Self-consistent strength function

The Fourier transformation of the solution of the kinetic equation system (1) can be written in the next general form

$$g^\alpha(\mathbf{r}, \mathbf{p}, \omega) = g_0^\alpha(\mathbf{r}, \mathbf{p}, \omega) + \int d\mathbf{r}' \int d\mathbf{p}' \Omega^\alpha(\mathbf{r}, \mathbf{r}', \mathbf{p}, \omega) g^\alpha(\mathbf{r}', \mathbf{p}', \omega) +$$
$$+ \int d\mathbf{r}' \int d\mathbf{p}' \Omega^{\alpha'}(\mathbf{r}, \mathbf{r}', \mathbf{p}, \omega) g^{\alpha'}(\mathbf{r}', \mathbf{p}', \omega), \quad (3)$$

where $g_0^\alpha(\mathbf{r}, \mathbf{p}, \omega)$ is Fourier transformation of the solution (1) with $\delta U^\alpha = 0$, $J^\alpha = 0$. The function $\Omega^\alpha(\Omega^{\alpha'})$ coincide with $g_0^\alpha$ after replacing external field $\beta^\alpha Q^\alpha$ by the interaction $u^{\alpha\alpha}(u^{\alpha\alpha'})$ and the solution (3) can be rewritten as

$$g^\alpha(\mathbf{r}, \mathbf{p}, \omega) = \beta^\alpha(\omega) \int d\mathbf{r}' \int d\mathbf{r}'' \Omega^\alpha(\mathbf{r}, \mathbf{r}', \mathbf{p}, \omega) D^\alpha(\mathbf{r}', \mathbf{r}'', \omega) Q^\alpha(\mathbf{r}'') +$$
$$+ g_0^\alpha(\mathbf{r}, \mathbf{p}, \omega) + \beta^\alpha(\omega) \int d\mathbf{r}' \int d\mathbf{r}'' \Omega^{\alpha'}(\mathbf{r}, \mathbf{r}', \mathbf{p}, \omega) D^{\alpha'}(\mathbf{r}', \mathbf{r}'', \omega) Q^{\alpha'}(\mathbf{r}'') \quad (4)$$

with $D^\alpha(\mathbf{r}, \mathbf{r}', \omega)$ for the response function

$$\delta n^\alpha(\mathbf{r}, \omega) = \beta^\alpha(\omega) \int d\mathbf{r}' D^\alpha(\mathbf{r}, \mathbf{r}', \omega) Q^\alpha(\mathbf{r}') = \int d\mathbf{p}' g^\alpha(\mathbf{r}, \mathbf{p}', \omega). \quad (5)$$

Here, $\delta n^\alpha(\mathbf{r}, \omega)$ is nucleon density variation in external field. The system of integral equations for response function $D^\alpha$ is obtained with the use of (3) and integration (2) over momentum $\mathbf{p}$.
The strength function of nuclear response \( S_L(\omega) \) determines the RS function and can be found in the following form

\[
S_L(\omega) = C_L^{(p)} S_L^p + C_L^{(n)} S_L^n, \tag{6}
\]

\[
S_L^\alpha(\omega) \equiv -\frac{1}{\pi} \text{Im} \frac{\chi^\alpha + \chi^\alpha(\varepsilon - k^\alpha \chi^\alpha)}{(1 - k^\alpha \chi^\alpha)} - (k^\alpha \chi^\alpha)2\chi^\alpha \chi^\alpha'. \tag{7}
\]

Here, \( \chi^\alpha = \int dr \int dr' Q_L(r) D_{L}^{\alpha,0}(r, r', \omega) Q_L(r') \). The separable interaction potential \( u_{L}^{\alpha\alpha'}(r, r') = k^\alpha \alpha' (L) Q^\alpha(r) Q^\alpha'(r') \) was used. The values of the coefficients \( C^{(\alpha)} \) were found from the energy weighted sum rule; \( C_1^{(p)} = 2N/A, C_1^{(n)} = 2Z/A \) for dipole electric external field.

The collision integral in equation (6) is taken in relaxation times approximation with allowing for retardation effects [6, 7], \( J^\alpha = g^\alpha(\tau(\omega)) \).

Here, \( \tau(\omega) \) is frequency and temperature dependent relaxation time. As a result the \( \chi^\alpha \) takes the following form [3, 4]

\[
\chi^\alpha = \frac{8\pi^2}{2L+1} \sum_{n=-\infty}^{L} \sum_{N=-L}^{L} |Y_{LM}(\frac{\pi}{2}, \frac{\pi}{2})|^2 \times \int d\varepsilon \frac{\partial n_{\alpha}(\varepsilon)}{\partial \varepsilon} \int d\lambda \lambda \omega_{\alpha}^\alpha(N) T^\alpha |Q_{LM}^\alpha(n, N)|^2 \frac{\omega - \tilde{\omega}^\alpha(n, N)}{\omega^\alpha(N)}. \tag{8}
\]

Where, \( n_{\alpha}(\varepsilon) \) is equilibrium distribution function, \( \omega_{\alpha}(N) \) – eigenfrequencies in subsystem \( \alpha \) without residual interaction, \( Q_{LM}^\alpha(n, N) \) – matrix elements. Resonance frequency \( \tilde{\omega}^\alpha(n, N) \) is obtained as a solution of the following equation:

\[
\omega - \frac{i}{\tau^\alpha(\omega)} = \omega_{\alpha}^\alpha(N). \tag{9}
\]

3 Calculations and conclusions

The dipole photo-absorption RS function \( \tilde{f}_{E1}(\epsilon_\gamma \equiv \hbar \omega) \) is connected with the strength function \( S_{L=1}(\omega) \) and photo-absorption cross-section \( \sigma_{E1}(\epsilon_\gamma) \) in the following way [10]:

\[
\tilde{f}_{E1}(\epsilon_\gamma) \equiv \frac{\sigma_{E1}(\epsilon_\gamma)}{3\epsilon_\gamma(\pi\hbar c)^2} = \frac{4\pi}{9} \frac{e^2}{(\hbar c)^3} \cdot S_{L=1}(\omega), \quad \epsilon_\gamma \equiv \hbar \omega. \tag{10}
\]

The photo-absorption strength functions for \(^{208}\text{Pb}\) are shown in Fig. 1. They were calculated with the different values of the coupling constants \( k^{np} \) and infinite wall potential was taken for mean field. The experiment data was taken from Ref. [8]. The Fermi-energies were calculated as in Fermi gas
model. The constants $k^{nn}$ and $k^{pp}$ were equal $k = k^{nn} = k^{pp} = 113/A^{5/3}$.

The calculations show that the resonance peak is shifted to higher energies with increasing in $k^{np}$ and amplitude of the peak is decreased. The width of the peak is increased.

The photo-absorption strength functions for the isobars with $A = 208$ are shown in Fig. 2. The resonance amplitude decreases and its width grows with asymmetry coefficient $I = (N - Z)/A$. The energy of peak maximum is slowly dependent on $I$. The width of the RSF is proportional to the $I^2$. An additional low-energy peak appears at large asymmetry coefficient.

The numerical analysis of RS function for asymmetric nuclei shows that the RSF shape does not change strongly for the nuclei with $|I| \leq 0.25$ and due to this the one-component models of the RSF with modified width could be used.

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Fig. 1: The RS function for $^{208}\text{Pb}$ calculated at different values of the coupling constant $k^{np}$.
Fig. 2: The radiation strength function for isobars with $A = 208$