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CALCULATION OF GIANT Eλ-RESONANCES OF HIGH MULTIPOLARITY IN DEFORMED NUCLEI

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Киселев М.А. и др. **E4 - 11121**

Расчеты гигантских $E\lambda$ -резонансов высокой мультипольности в деформированных ядрах

Исследованы силовые функции $b(E\lambda; 0^+ \to \lambda^\pi)$ для возбуждения мультипольных резонансов с $\lambda = 4,5,6$ и 7 в четно-четных деформированных ядрах. Сделаны заключения о возможных энергетических областях нахождения гигантских электрических резонансов высокой мультипольности.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Kiselev M.A. et al. **E4 - 11121**

Calculation of Giant $E\lambda$ -Resonances of High Multipolarity in Deformed Nuclei

The strength functions $b(E\lambda; 0^+ \to \lambda^\pi)$ for the excitation of multipole resonances with $\lambda = 4,5,6$, and 7 in doubly even deformed nuclei are investigated. The conclusions are made about possible energy regions of finding the giant electric resonances of high multipolarity.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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1. INTRODUCTION

Much progress has recently been achieved in the experimental study of giant quadrupole and octupole resonances in atomic nuclei [1-3]. The semimicroscopic and microscopic description of these resonances has been performed for some nuclei [4-10]. Now the problem is whether the giant $E\lambda$ -resonances with multipolarity $\lambda \geq 4$ exist or not. There are some experimental indications for the existence of giant resonances with high multipolarity [11-13]. The collective 4^+ states have been observed at energies (1-3) *MeV* [14] what indirectly testifies to a possible existence of giant resonances with $\lambda = 4$ at higher energies. Some theoretical papers [6,15] have considered the giant resonances of high multipolarity in spherical nuclei.

In this paper the one-phonon states with $\lambda = 4,5,6,7$ and the strength functions $b(E\lambda; 0^+ \to \lambda^\pi)$ are calculated for deformed nuclei. A possible existence of giant $E\lambda$ -resonances with multipolarity $\lambda \geq 4$ is studied. The values of the isoscalar $\kappa_0^{(\lambda)}$ and isovector $\kappa_1^{(\lambda)}$ constants of the multipole-multipole interaction required for the description of phonons within the quasi-particle-phonon nuclear model [16] are discussed.

2. THE DETAILS OF CALCULATION

The calculations have been performed in the random phase approximation within the general semimicroscopic approach [17]. The secular equations and expressions for the one-phonon state wave functions when the isoscalar and isovector forces are simultaneously taken into account are given in ref.[18]. Similar calculations of the giant resonances with $\lambda=1,2$ and 3 in deformed nuclei have been performed in refs.[7,19].

The model Hamiltonian includes the average field as the Saxon-Woods potential, the pairing interactions and multipole-multipole forces. The parameters of the Saxon-Woods potential are taken from fers.[20]. In this paper we take into account the single-particle levels in a wider energy interval from - 36 *MeV* to +40 *MeV*. A great number of single-particle levels are found in the region with positive energy and are quasidiscrete. So, for the rare-earth nuclear region 48 levels of 104 single-particle neutron levels and 83 levels of 132 proton ones are with $E>0$. For the actinide nuclear region 155 neutron (59 with $E>0$) and 175 proton (114 with $E>0$) single-particle levels are taken into account. The pairing constants G_N and G_Z are determined from the pairing energy. For the rare-earth region in the zone with $A=165$ they are equal to $G_N=0.11$ *MeV* and $G_Z=0.1285$ *MeV*, and for the actinide region in the zone with $A=239$, $G_N=0.072$ *MeV* and $G_Z=0.088$ *MeV*.

To determine the regions of location of the giant resonances with $\lambda\geq 4$, we calculate the strength functions for the $E\lambda$-transitions from the ground state to the excited states $I^{\pi}K$ with $I=\lambda$. The strength functions can be written as

$$b(E\lambda\,;\,0^{+}0\to I^{\pi}K)=\sum_{i}M^{2}(\omega_i)\rho(\omega-\omega_i), \qquad (1)$$

where the summation is over the one-phonon states. Here ω_i is the energy of one-phonon state i, $M(\omega_i)$ is the $E\lambda$-transition matrix element, and

$$\rho(\omega-\omega_i)=\frac{1}{2\pi}\,\frac{\Delta}{(\omega-\omega_i)^2+(\Delta/2)^2}.$$

The averaging parameter Δ is taken to be equal to 0.5 *MeV*.

When calculating the strength functions $b(E\lambda;0^{+}0\to I^{\pi}K)$ one should consider the transitions to the rotational states. For each value of λ one should calculate the transitions to the rotational states with $I=\lambda$, $\pi=(-1)^{\lambda}$ and $K=0,1,\ldots,\lambda$ and then sum these functions at each excitation energy. The strength function $b(E\lambda\,;0^{+}\to\lambda^{\pi})$ is determined as follows:

$$b(E\lambda\,;\,0^{+}\to\lambda^{\pi})=\sum_{K=0}^{\lambda}b(E\lambda\,;\,0^{+}0\to\lambda^{\pi}K). \qquad (2)$$

In these calculations we neglect the $E\lambda$-transitions to the rotational states $I^{\pi}K$ for which $I>\lambda$ since they give a small contribution due to their incoherence. For instance, for the multipolarity $\lambda=4$ we take into account the transitions to the states with $I^{\pi}K$ equal to $4^{+}0$, $4^{+}1$, $4^{+}2$, $4^{+}3$ and $4^{+}4$ constructed on the band heads with $\lambda=4$. The $E4$-transitions to the $4^{+}0$ and $4^{+}2$ states built on the band heads with $\lambda=2$ and $K=0,2$ are neglected.

It is most difficult to choose the constants of the multipole-multipole interactions with $\lambda\geq 4$. In our calculation as the isoscalar constant $\kappa_0^{(\lambda)}$ we take the estimate obtained from the condition of equivalence of the density and nuclear potential variations[21]:

$$\kappa_0^{(\lambda)}=\frac{4\pi}{2\lambda+1}\,\frac{m\omega_0^2}{A\langle r^{2\lambda-2}\rangle}, \qquad (3)$$

and as the isovector constant $\kappa_1^{(\lambda)}$ the estimate obtained from the expression for the isovector part of the nucleon-nucleon potential[21]:

$$\kappa_1^{(\lambda)}=-\frac{\pi V}{A\langle r^{2\lambda}\rangle}, \qquad (4)$$

where $V=120$ *MeV*.

The estimate(3) for $\kappa_0^{(\lambda)}$ is obtained for the spherical oscillator potential. It is rather rough for deformed nuclei. However, the comparison of $\kappa_0^{(\lambda)}$ for $\lambda=2$ and 3 with the constants $\kappa_{exp}^{(2)}$ and $\kappa_{exp}^{(3)}$ which provide a good description of the low-lying vibrational quadrupole and octupole states and of the isoscalar $E2$- and $E3$-resonances in deformed nuclei[7] shows that the values of the constants $\kappa_{exp}^{(2)}$ and $\kappa_{exp}^{(3)}$ coincide with (3) up to a factor of 1.5 - 2. The calculations show that a considerable increase of the constant $\kappa_0^{(\lambda)}$ as compared to the value (3) would contradict the experimental data since there is no evidence for the existence of the low-lying collective vibrational states with $K^\pi = 4^+, 5^-, 6^+$ and 7^-. Therefore, in our calculations we have investigated the change of the results with decreasing $\kappa_0^{(\lambda)}$ as compared to the value (3).

Uncertainty in the value of the constant $\kappa_1^{(\lambda)}$ has been pointed out in papers /7/ where it was shown that for the quadrupole and octupole resonances the value (4) was overestimated in the absolute value. Therefore, we also compare the results obtained with (4) and with decreasing $\kappa_1^{(\lambda)}$.

To find the region of location of the giant multipole resonances we use the model-independent energy weighted sum rule (EWSR) in the following form:

$$\sum_i \omega_i B(E\lambda; 0^+ \to \lambda^\pi)_i = \frac{\lambda(2\lambda+1)^2}{4\pi} \frac{h^2}{2m} Ze^2 \langle r^{2\lambda-2} \rangle =$$

$$= 4{,}8\lambda(3+\lambda)^2 \frac{Z}{A^{2/3}} B(E\lambda)_{s.p.} \text{ MeV}. \quad (5)$$

Further results will be given in the single-particle units (spu) /17/:

$$B(E\lambda)_{s.p.} = \frac{2\lambda+1}{4\pi} \left(\frac{3}{3+\lambda}\right) R_0^{2\lambda} e^2 . \quad (6)$$

According to our calculations $\sum_i \omega_i B(E\lambda; 0^+ \to \lambda^\pi)_i$ exhaust 87%, 87%, 79% and 80% of the model-independent EWSR for $\lambda = 4, 5, 6$ and 7, respectively. This means that to describe correctly these multipole resonances we have chosen a sufficiently large number of single-particle levels of the Saxon-Woods potential. We have also used the model-dependent EWSR. Having calculated $\sum_i \omega_i B(E\lambda; 0^+ \to \lambda^\pi)_i$ throughout the whole available energy region and for all values of the projection K, we determine the contribution of separate energy regions and individual values of K to EWSR.

3. *HEXADECAPOLE RESONANCES* ($\lambda = 4$)

Now we study the behaviour of the strength function $b(E4; 0^+ \to 4^+)$ as a function of the excitation energy ω and determine the energy regions of the isoscalar and isovector E4-resonance. For ^{166}Er *Fig. 1* shows the functions $b(E4; 0^+ \to 4^+)$ calculated with $\kappa_1^{(\lambda)}$ given by (4) and with three values of $\kappa_0^{(4)}$. The solid curve is calculated with $\kappa_0^{(4)}$ given by (3). It is seen from this figure that with decreasing $\kappa_0^{(4)}$ by 17% the collectiveness of states with energy less than 15 *MeV* also decreases. If $\kappa_0^{(4)}$ will again be decreased by a factor of 9 then $b(E4; 0^+ \to 4^+)$ will only slightly be decreased. The question about the existence of strongly collectivized $\lambda = 4$ states with energy less than 10 *MeV* is still open. Therefore, it is desirable to study experimentally the E4-transitions.

A bump is clearly seen at energies of (12-18) *MeV*, which is shifted towards higher energies with decreasing

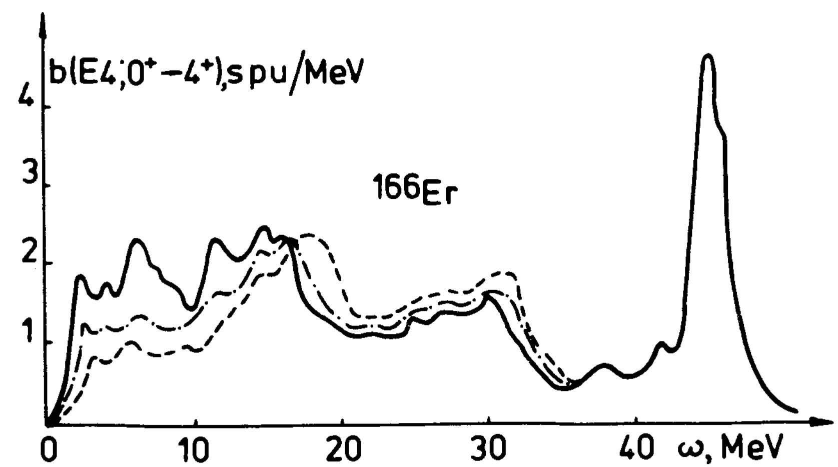

Fig. 1. The strength function $b(E4; 0^+ \to 4^+)$ *in* ^{166}Er *calculated with* $\kappa_1^{(4)} = -2.3 \cdot 10^{-6}$ *MeV·fermi*$^{-8}$ *and the following values of* $\kappa_0^{(4)}$: $4.2 \cdot 10^{-7}$ *MeV·fermi*$^{-8}$ *(solid curve),* $3.5 \cdot 10^{-7}$ *MeV·fermi*$^{-8}$ *(dot-dash curve) and* $4 \cdot 10^{-8}$ *MeV·fermi*$^{-8}$ *(dashed curve).*

$\kappa_0^{(4)}$. *Table 1* shows the contributions of different energy regions to the model-independent EWSR. The region

Table 1

The contributions of S to the model-independent EWSR from different energy intervals for the resonances with λ = 4, 5, 6 and 7 in ^{166}Er.

λ =4		λ =5		λ =6		λ =7	
Energy intervals, MeV	S,%	Energy Intervals, MeV	S,%	Energy Intervals, MeV	S,%	Energy Intervals, MeV	S,%
0–10	5	0–10	5	0–10	5	0–10	5
10–18	11	10–17	6	10–20	9	10–25	15
18–32	21	17–27	13	20–37	16	25–45	15
32–40	9	27–50	24	37–50	8	45–55	5
40–50	39	50–60	37	50–65	39	55–75	39
0 - 50	85	0–60	85	0–65	77	0–75	79

(10- 20) *MeV* gives 15% contribution to EWSR, which changes slightly with decreasing $\kappa_0^{(4)}$ by a factor of 10 (13%). So, one can state about the existence of an isoscalar (T=0) giant hexadecapole resonance at an energy of (14-18)*MeV*. It lies somewhat higher than the isoscalar quadrupole resonance and somewhat lower than the isoscalar octupole resonance and is not exhibited so strongly as these resonances. There is also a branch of the isoscalar resonance at an energy of about 30 *MeV*.

At an excitation energy of (40-50) *MeV* there lies the giant isovector hexadecapole resonance. This region gives a 39% contribution to EWSR. In the region (20-40)*MeV* the values of $b(E4; 0^+ \to 4^+)$ are considerably smaller. This resonance is seen rather clearly. With decreasing $\kappa_1^{(4)}$ the $\lambda = 4$, $T = 1$ resonance location is shifted towards low excitation energies. At $\kappa_1^{(4)\prime} = 1/3\,\kappa_1^{(4)}$ the giant isovector hexadecapole resonance lies at an energy of (30-40) *MeV*. If $|\kappa_1^{(4)}/\kappa_0^{(4)}| \sim 5$ and higher the isovector resonance is exhibited very strongly.

Table 2

The contributions of different K to the model EWSR for ^{166}Er.

$\Sigma \omega_i\, B(E\lambda; 0^+ \to K^\pi)_i$

K	λ = 4		λ = 5		λ = 6		λ = 7	
	spu·MeV	%	spu·MeV	%	spu·MeV	%	spu·MeV	%
0	265	14	380	13	452	11	605	10
1	515	28	709	24	890	21	1181	20
2	460	25	675	22	842	20	1111	18
3	362	20	567	19	744	18	1007	17
4	243	13	416	14	590	14	845	14
5	-	-	254	8	397	10	619	10
6	-	-	-	-	249	6	430	7
7	-	-	-	-	-	-	255	4
	1845	100%	3001	100%	4164	100%	6053	100%

The $\lambda = 4$ states are contributed by the components with K=0,1,2,3 and 4, their contributions to EWSR being different. This is seen from *Table 2*. For the functions $b(E4; 0^+ \to 4^+3)$ and $b(E4; 0^+ \to 4^+4)$ the maxima lie at the same energies as for the total function $b(E4; 0^+ \to 4^+)$, but are exhibited not so strongly. On the whole, in contrast with the giant isoscalar quadrupole and octupole resonances localized in rather narrow energy intervals, the isoscalar E4 -resonance lies in the energy region (10-30)*MeV*. The broadening of the E4 -resonance is due to the contribution of a large number of projections K and oscillator shells, since it is also contributed by the matrix elements with $\Delta N = 0,2,4$. The above regions of high collectivity at energies of about 5 *MeV*, ~ 15 *MeV* and ~30 *MeV* are due to a certain concentration of states corresponding to the poles of the secular equation with energy inside the oscillator shell ω_0 and energies about $2\omega_0$ and $4\omega_0$.

4. *GIANT RESONANCES WITH* $\lambda=5$

Now we study the dependence of the strength function $b(E5; 0^+ \to 5^-)$ on the excitation energy and determine the regions of location of the resonances with $\lambda = 5$, $T=0$ and $T=1$. It is seen from *Fig. 2,* which is similar to *Fig. 1* for $\lambda=4$, that at the values of $\kappa_0^{(5)}$ one given by (3) and the other by 22% less, the collective states are clearly seen at an energy of ~ 7 ***MeV***. They disappear if $\kappa_0^{(5)}$ decreases by a factor of 50. Thus, the existence of the low energy $\lambda = 5$ resonance seems to be probable. Therefore, the experiments on $E5$-excitations are necessary.

The function $b(E5; 0^+ \to 5^-)$ increases in the region (17-27) ***MeV*** which is close to $3\omega_0 \simeq 22$ ***MeV***. The contribution of this region to EWSR is 13%. With decreasing $\kappa_0^{(5)}$ the resonance with $T=0$ is seen more clearly and becomes narrower. However, only at an energy of (5-30) ***MeV*** we can speak more definitely about a wide

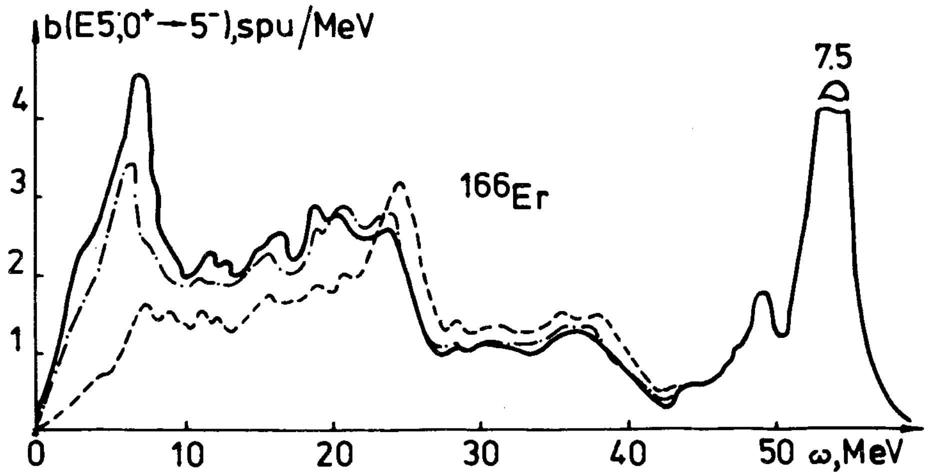

Fig. 2. The strength function $b(E5; 0^+ \to 5^-)$ *in* ^{166}Er *calculated with* $\kappa_1^{(5)} = -6.3 \cdot 10^{-8}$ *MeV·fermi* $^{-10}$ *and the following values of* $\kappa_0^{(5)}$: $9.6 \cdot 10^{-9}$ *MeV·fermi* $^{-10}$ *(solid curve),* $7.5 \cdot 10^{-9}$ *MeV·fermi* $^{-10}$ *(dot-dash curve) and* $2 \cdot 10^{-10}$*MeV·fermi*$^{-10}$ *(dashed curve).*

region of the $E5$-resonance. The regions with higher collectivity lie at energies of about 5 ***MeV***, ~ 20 ***MeV*** and ~ 35 ***MeV*** what corresponds to the concentration of poles of the secular equation with matrix elements for which $\Delta N = 1, 3, 5$.

At an excitation energy of about 55 ***MeV*** there is the $\lambda=5$, $T=1$ resonance. Its contribution to EWSR is 37%. The resonance $\lambda=5$, $T=1$ is more clearly seen as compared to the $\lambda=5$, $T=0$ resonance. With decreasing $\kappa_1^{(5)}$ by a factor of 3 as compared to the estimate (4) the region of the isovector resonance is shifted towards an energy of about 45 ***MeV***, and it is mixed with the isoscalar resonance more strongly.

The resonance $\lambda=5$, $T=1$ is clearly exhibited in the functions $b(E5; 0^+ \to 5^- 4)$ and $b(E5; 0^+ \to 5^- 5)$ whereas other maxima are not. It is seen from *Fig. 2* that the model-dependent EWSR is contributed by the transitions with different values of K, the greatest contribution being related to the transitions to the states with $K=1, 2$ and 3.

5. *THE* 6^+ *AND* 7^- *EXCITED STATES*

The broadening of the energy region of the isoscalar resonances with $\lambda=4,5$ with increasing λ is even more clearly seen for the resonances with $\lambda=6$ and 7. ***Figures 3*** and ***4*** show the functions $b(E\lambda; 0^+ \to \lambda^\pi)$ for ^{166}Er with $\lambda=6$ and 7. The constants $\kappa_0^{(\lambda)}$ and $\kappa_1^{(\lambda)}$ are calculated by formulae (3) and (4). These figures also give the functions $b(E\lambda; 0^+ \to \lambda^\pi)$ calculated with the decreased values of $\kappa_0^{(\lambda)}$. It is seen from the figures that the giant isoscalar resonances with $\lambda=6$ and 7 have a wide energy region. For the given multipolarities the branches of a resonance satisfying different ΔN are not so clearly seen. One can observe their overlapping. The exclusion makes some splitting of regions with higher collectivity at an energy of about 42 ***MeV*** for $\lambda=6$ and about 50 ***MeV*** for $\lambda=7$ corresponding to $\Delta N=6$ and 7. Of great interest is the energy region (3-15) ***MeV***. The structure of states in this region is very sensitive to the value of the constant $\kappa_0^{(\lambda)}$. The experimental study of $E6$- and

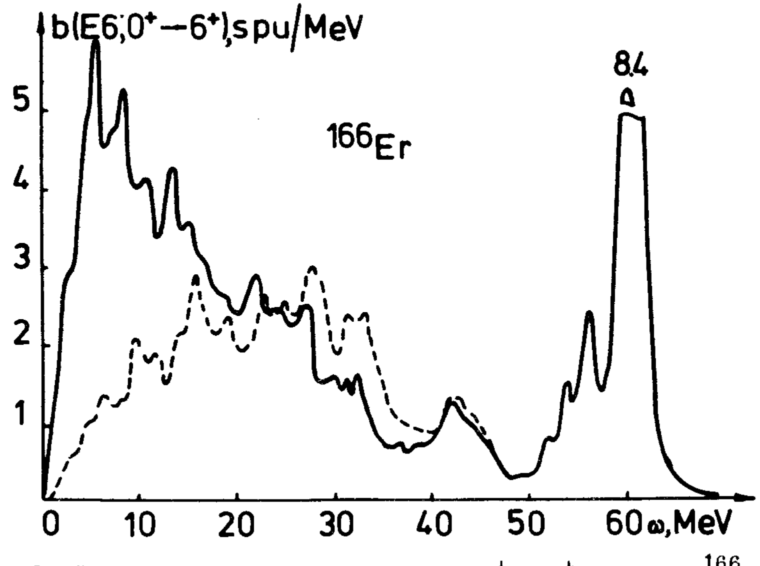

Fig. 3. The strength functions $b(E6; 0^+ \to 6^+)$ *in* ^{166}Er *calculated with* $\kappa_1^{(6)} = -1.7 \cdot 10^{-9}$ *MeV·fermi*$^{-12}$ *and the following values of* $\kappa_0^{(6)}$: $2.2 \cdot 10^{-10}$ *MeV·fermi*$^{-12}$ *(solid curve),* $2 \cdot 10^{-11}$ *MeV·fermi*$^{-12}$ *(dashed curve).*

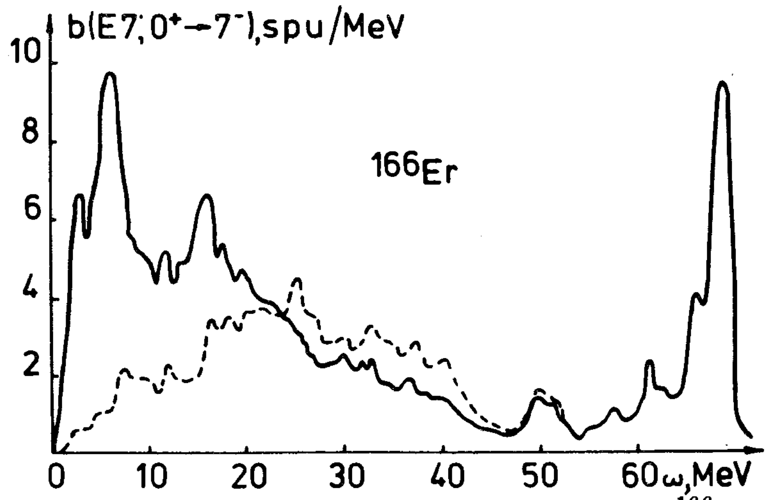

Fig. 4. The strength function $b(E7; 0^+ \to 7^-)$ *in* ^{166}Er *calculated with* $\kappa_1^{(7)} = -4.3 \cdot 10^{-11}$ *MeV·fermi*$^{-14}$ *and the following values of* $\kappa_0^{(7)}$: $5 \cdot 10^{-12}$ *MeV·fermi*$^{-14}$ *(solid curve),* $5 \cdot 10^{-13}$ *MeV·fermi*$^{-14}$ *(dashed curve).*

E7 -excitations testifies more definitely to the existence of the low-lying collective resonances with $\lambda = 6$ and 7.

At excitation energies of about 60 *MeV* for $\lambda = 6$ and about 70 *MeV* for $\lambda = 7$ there are resonances with $T = 1$. Their contribution to EWSR is about 40%. With decreasing $\kappa_1^{(\lambda)}$ by a factor of three the energy of the resonance $\lambda = 6$, $T = 1$ decreases up to about 50 *MeV*, and the isovector resonance for $\lambda = 7$ splits into two branches with an energy of about 45 and 55 *MeV*, the isoscalar and isovector resonances being noticeably mixed. The contributions of different K to EWSR are given in *Table 2*.

By the example of ^{166}Er *Table 1* shows the contributions to the model-independent EWSR for $\lambda = 4, 5, 6$ and 7 in different energy intervals. It is also seen from the *Table* that the calculated value of the energy weighted sum for different multipolarities exhausts (77-85)% of the model-independent EWSR. This means that in our calculations we have used a sufficiently wide configurational space. A more precise consideration of the continuum will obviously influence the description of the location and width of isovector giant resonances.

6. CONCLUSION

The strength functions $b(E\lambda; 0^+ \to \lambda^\pi)$ as a function of the excitation energy for the states with λ from 1 to 7 in ^{238}U is shown in *Fig. 5*. For $\lambda = 1, 2$ and 3 the calculations are performed with the constants from refs. /7,19/ and for $\lambda = 4, 5, 6$ and 7 with those given by (3) and (4). The broadening of resonances with increasing λ and shift of maxima in the region of high excitation energies are clearly seen. There may exist the low-energy resonances with $\lambda = 5, 6$ and 7 if $\kappa_0^{(\lambda)}$ will not be much less than the value (3).

Wide isoscalar resonances should exist at energies of (10-17) *MeV* for $\lambda = 4$, (10-25) *MeV* for $\lambda = 5$, (15-30) *MeV* for $\lambda = 6$ and (10-40) *MeV* for $\lambda = 7$. The collectivity may increase for $\lambda = 4$ at energies of about 25 *MeV*, for $\lambda = 5$ about 35 *MeV*, *for* $\lambda = 6$ about *40 MeV*

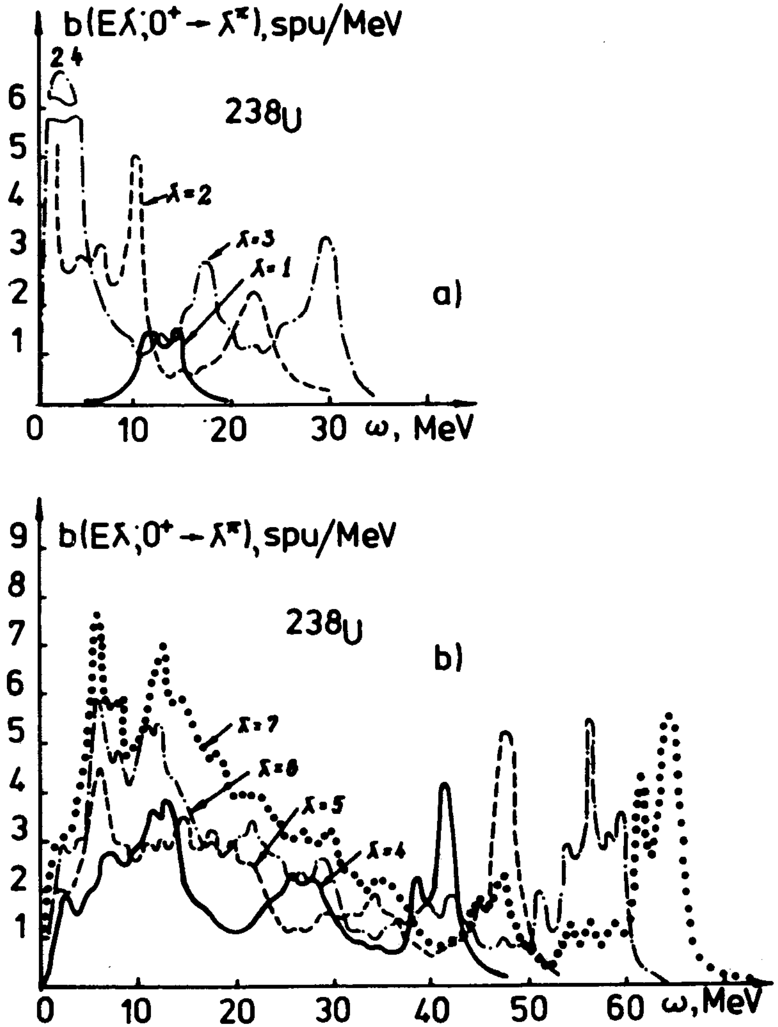

Fig. 5. The strength functions $b(E\lambda;\, 0^+ \to \lambda^\pi)$ *in* ^{238}U. *The constants* $\kappa_0^{(\lambda)}$ *and* $\kappa_1^{(\lambda)}$ *for* $\lambda=1,2,3$ *are taken from papers* /7,19/, *and for* $\lambda=4,5,6,7$ *are calculated by formulae (3) and (4).*

and for $\lambda=7$ about 47 *MeV*. The isovector resonances with $\lambda=4,5,6$ and 7 are rather clearly seen.

When describing the one-phonon states with $\lambda \geq 4$, used in the two-phonon components of the wave functions within the quasi-particle-phonon nuclear model, the isoscalar constants $\kappa_0^{(\lambda)}$ should be taken somewhat less than the values given by (3) whereas the isovector constants $\kappa_1^{(\lambda)}$ can be calculated by (4).

REFERENCES

1. *Hanna S.S. Proc. Int. Conf. on Selected Topics in Nuclear Structure, v. II, p.195; JINR, D-9920, Dubna, 1976.*
2. *Moss J.M., Youngblood D.H., Rozsa C.M. et al. Phys.Rev.Lett., 1976, 37, p.816; Dietrich F.S. et al. Phys. Rev.Lett., 1977, 38, p.156.*
3. *Савицкий Г.А., Немашкало А.А,. Хвастунов В.М. Препринт ХФТИ, 76-16, Харьков, 1976.*
4. *Satchler G.R. Phys.Rep., 1974, 14C, p.97. Bes D.R., Broglia R.A., Nilsson B.S. Phys.Rep., 1975, 16C, p.1.*
5. *Faessler A. Proc. Int. Conf. on Selected Topics in Nuclear Structure, v.II, p.242; JINR, D-9920, Dubna, 1976.*
6. *Liu K.F., Brown G.E. Nucl.Phys., 1976, A265, p.385.*
7. *Malov L.A., Nesterenko V.O., Soloviev V.G. Phys. Lett., 1976, 64B, p.247; J.Phys.G: Nucl.Phys., 1977, 3, L219;*
   Кырчев Г. и др. ЯФ, 1977, 25, с.951.
8. *Soloviev V.G., Stoyanov Ch., Vdovin A.I. Nucl.Phys., 1977, A288, p.376.*
9. *Борзов И.Н., Камерджиев С.П. Изв. АН СССР /сер. физ./, 1977, 41, с.4.*
10. *Martorell J. et al. Phys.Lett., 1976, 60B, p.313.*
11. *Geramb H.V., Amos K. Lett.Nuovo Cim., 1975, 14, p.526.*
12. *Немашкало А.А. и др. Письма в ЖЭТФ, 1977, 26, с.569.*
13. *Hicks R.S. et al. Nucl.Phys., 1977, A278, p.261.*
14. *Gosman A., Lin L. Phys.Lett., 1972, 42B, p.310. Bagnell R.D. et al. Phys.Lett., 1977, 66B, p.129.*
15. *Horikawa Y., Hoshino T., Arima A. Phys.Lett., 1976, 63B, p.134; Семенко С.Ф. Изв. АН СССР /сер. физ./, 1976, 40, с. 836.*
   Knüpfer W., Knauss K., Huber M.G. Phys.Lett., 1977, 66B, p.305; Dehesa J.S. et al. Phys.Rev., 1977, C15,

p.1858; Grecksch E., Knüpfer W. and Huber M.G. Lett. Nuovo Cim., 1975, 14, p.505; Hamamoto I. Nucl.Phys., 1972, A196, p.101.
16. *Soloviev V.G. JINR, E4-11012, Dubna, 1977.*
17. *Соловьев В.Г. Теория сложных ядер, "Наука", М., 1971 /перевод Pergamon Press, Oxford, 1976).*
18. *Малов Л.А., Нестеренко В.О., Соловьев В.Г. ТМФ, 1977, 32, с.134.*
19. *Akulinichev S.V., Malov L.A. J.Phys.G:Nucl.Phys., 1977, 3, p.625.*
20. *Гареев Ф.А. и др. ЭЧАЯ, 1973, 4, с.357; Иванова С.П. и др. ЭЧАЯ, 1976, 7, с.450; Gareev F.A. et al. Nucl.Phys., 1971, A171, p.134; Григорьев Е.П., Соловьев В.Г. Структура четных деформированных ядер, "Наука", М., 1974.*
21. *Bohr A., Mottelson B.R. Nuclear Structure, v.2, Benjamin, New York, 1975.*
22. *Натан О., Нильссон С.К. В сб.: Альфа-, бета-, гамма-спектроскопия. Атомиздат, М., 1969.*

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