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HYBRID MODEL FOR THE DECAY OF NUCLEAR GIANT RESONANCES

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HYBRID MODEL FOR THE DECAY OF NUCLEAR GIANT RESONANCES*

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ABSTRACT

The decay properties of nuclear giant multipole resonances are discussed within a hybrid model that incorporates, in a unitary consistent way, both the coherent and statistical features. It is suggested that the "direct" decay of the GR is described with continuum 1st RPA and the statistical decay calculated with a modified Hauser-Feshbach model. The two decay components are not independent owing to the presence of a mixing parameter that measures the degree of fragmentation of the GR. Application is made to the decay of the giant monopole resonance in ^{208}Pb. Suggestions are made concerning the calculation of the mixing parameter using the statistical properties of the shell model eigenstates at high excitation energies.

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I. INTRODUCTION

Nuclear giant resonances are collective states that sit in the 10-20 MeV excitation energy range. It has been established that the excitation energy of the GR goes like $A^{-1/3}$ and thus the heavier the nucleus, the lower this energy is. Nevertheless even in nuclei as heavy as ^{238}U, this excitation energy is high enough that one may consider the GR as embedded in a sea of two-particle two-hole states. Accordingly these highly collective nuclear states are fragmented into the background of more complicated and thus less collective states, owing to the coupling induced by the residual interaction.

Whereas the microscopic description of the structure of the GR is in a rather reasonable shape, the theoretical description of their decay into the open channels is rudimentary. In principle one may envisage a 2nd RPA in the continuum treatment, which would furnish both the escape width $\Gamma^{\uparrow}$ and the spreading width $\Gamma^{\downarrow}$. However, the procedure needed in order to actually calculate cross sections or branching ratios from such theories is not yet fully developed. What has been done so far in the literature is to assume either one of two modes, direct or statistical and asses then relative importance by calculating them separately and independentelly. This procedure invariably leads to several debated conclusions.

The purpose of this paper is to develop a hybrid theory of the decay of the GR in which both the direct and statistical decay processes are considered on the same footing. These two processes are not completely independent as both depend on the mixing parameter which is directly related to the spreading width. The theory is general enough to permit the inclusion of intermediate processes such as preequilibrium emission.

The plan of the paper is as follows. In Section II we review the direct vs. statistical description of the decay of the GR by presenting several cases. In Section III we develop our hybrid theory and apply it to the neutron decay of the giant monopole resonance in ^{208}Pb. In Section IV we discuss the calculational aspect of the mixing parameter. This entails describing the statistical properties of the nuclear shell model eigenstates at high excitation energies. Finally, in Section V we present our conclusions and indicate possible routes for further developments.

II. DIRECT vs. STATISTICAL DECAY MODES OF THE GR

Most of the recent work on GR decay has concentrated on answering the question of how direct or statistical it is. Invariably in the analysis of data, simplified versions of the "direct" and/or statistical decay models are used. To

give an example we show in Fig. 1, the neutron spectrum arising from the decay of the giant monopole resonance in ^{208}Pb (E_x = 13.5 MeV). According to the analysis of Ref. 1), the low energy part of the spectrum is purely statistical whereas at $E_n \gtrsim 4$ MeV, it is direct. However, this conclusion was reached via a statistical model calculation which employs a Fermi gas density of states in ^{207}Pb are used in the calculation, the statistical model explains the whole spectrum. It seems now that GR is in heavy nuclei decay almost entirely statistically[2].

Another case of interest to us here is the fission decay of actinide nuclei[3]. In particular it has been suggested that the giant quadrupole resonance in this mass region fissions predominantly directly. This is in contrast to the giant dipole resonance which seems to fission statistically. There are however several measurements based on electron scattering which were found to contradict the above conclusion concerning the GQR[4]. Again, we have here an example of using qualitative theory to reach quantitative conclusions. To make our point clear we show in Fig. 2, the calculation of the fission decay probability, $P_f(E\lambda)$ for the giant monopole, dipole and quadrupole resonances[5]. In the calculation, we have used realistic level densities and transition nucleus levels. The dotted curve shows the result for $P_f(E\lambda)$ obtained with the schematic model of Huizenga and Vandenbosch[6], which seems to be the one widely used in the analysis.

In our calculation of $P_f(E\lambda)$, we have used the expression

$$P_f(E\lambda) = \frac{\Gamma_f(E\lambda)}{\Gamma_f(E\lambda) + \Gamma_n(E\lambda) + \Gamma_\gamma(E\lambda)} \qquad (1)$$

with Γ_n and Γ_γ representing the neutron and γ widths, respectively, and $\Gamma_f(E\lambda)$ evaluated within the incomplete damping model of Back et al.[7],which uses the following

$$\Gamma_f(E\lambda) = \frac{D}{2\pi}\left[N_D + N_{ABS.}\,\frac{N_B}{N_A + N_B}\right] \qquad (2)$$

In the above expression the first term accounts for the flux which passes directly throuhg the two fission barriers while the second accounts for the fraction of the flux which is trapped in the intermediate well before passing through the second barrier. For details of the calculation, see Ref. 5). When compared with the schematic model of H-V, our calculation represents a great improvement. In fact besides being insensitive to λ, the H-V expression requires a lowering of the fission barrier by as much as 50% in order to come close to our calculation.

The point we would like to make concerning the fission decay mode of the GR is that there is a clear room for both direct and statistical processes. In fact, if we take the data of Ref. 4) at value, one sees clearly that at

photon energies greaten than the fission barrier, the giant quadrupole resonance in ^{236}U, could accomodate up to about 40% direct decay. Several authors would contest this,especially in view of several recent hadron induced excitation measurement of the GR and GMR which seem to indicate about 90% direct fission decay . We shall not dwell here on the debate which is still going on concerning the fission mode. All the facts do seem to indicate that a consistent description of the fission decay of the GR in the actinide must involve both the direct and statistical decay modes.

Several other examples can be cited which show the need for a more general description of the decay of the GR. Quite recently the GQR neutron decay in ^{92}Zr was measured and was found, according to the analysis of Ref.[8], to exhibit about 20% direct decay probability. Once again, the statistical analysis made in Ref. 8) employed several rough approximations, which may render the above conclusion questionable.

The first attempt to analyse QR decay with both statistical and direct decay modes has been recently made by Beene et al.[9]. These authors discussed the γ-decay of the giant quadrupole resonance in ^{208}Pb with the following expression for the decay probability

$$P_\gamma(E2) = P_\gamma^D(E2) + P_\gamma^C(E2) \qquad (3)$$

where $P_\gamma^D(E2)$ is the direct γ-decay probability given by

$$P_\gamma^D = \frac{\Gamma_\gamma^\uparrow}{\Gamma_\gamma^D} \tag{4}$$

with $\Gamma_\gamma^\uparrow$ referring to the γ-partial escape width of the resonance and Γ its average total width. The statistical on compound decay probability, denoted by P_γ^c was calculated similarly as

$$P_\gamma^c = \frac{\Gamma_\gamma^c}{\Gamma^c} \tag{5}$$

The result of the calculation of Ref. 9) indicated that $P_\gamma^D \approx P_\gamma^c$. Similar conclusions were reached by Ref. 10) with a more refined calculation of P_γ^c. Thus, in this particular decay channel the statistical and direct decay modes contribute about equally.

Eq. (3), though reasonable from a qualitative point of view suffers from an inconsistancy, namely since the GR is fragmented into the compound nucleus background states, a remant of the former must appear in $P_\gamma^c(E2)$. This can be easily seen from simple unitarity argument. The missing ingredients in (3) is a mixing parameter which measures the degree of GR fragmentation. In the next section we derive an improved version of (3), consistent with the requirement of unitarity. Before actually doing this, we first discuss

briefly the microscopic description of the GR within the 2nd RPA. This discussion will serve in justifying our treatment of the GR decay through a combination of 1st RPA in the continuum, which supplies basically P^D, and the Hauser-Feshbach theory for P^c the mixing parameter alluded to earlier couples these two pieces.

III. HYBRID "DIRECT" + HAUSER-FESHBACH MODEL FOR THE DECAY OF THE NUCLEAR RPA

In this section we develop the hybrid model for the decay of the GR already anounced earlier. Before actually doing this we present first a brief discussion of the RPA description of the GR. Within this theory, the nuclear collective states are constructed as coherent superposition of 1p-1h configurations, coupled to both the continuum and the more complex 2p-2h subspace. The excitation operator that creates the GR by operating on the vacuum state is accordingly composed of both 1p-1h and 2p-2h pieces. In practice, it is advantageous to project out the 2p-2h subspace and work in the restricted 1p-1h space.

Employing the usual linearization procedure , on the equation of motion, one can show that the equation that determines the excitation amplitudes, have the following structure[11)]

$$\begin{pmatrix} A_{11}(\epsilon) & B_{11} \\ -B_{11}^{*} & -A_{11}^{*}(\epsilon) \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix} = \epsilon_N \begin{pmatrix} X \\ Y \end{pmatrix} \tag{6}$$

where X and Y are the RPA amplitudes that enter in the definition of the 1p-1h excitation operator. The RPA-looking matrix is different from the conventional one owing to the excitation energy-dependence of $A_{11}(E)$, which arises from the coupling to the 2p-2h subspace. In fact the explicit form of A demonstrates clearly this fact

$$A_{11}(\epsilon) = \mathring{A}_{11} + \sum_{2,2'} A_{12}^{*} \left(\epsilon_N - A_{22'}\right)^{-1} A_{2'1} \tag{7}$$

where $\mathring{A}_{11}$ is the usual 1p-1h submatrix.

Clearly $A_{11}(E)$ contains poles at $E_N = A_{22}$, which represent the fragmentation of the GR strength over the 2p-2h background. One usually averages out these singularities by inserting an appropriate constant imaginary term in the denominator of the second term. This results in a smooth strength distribution whose width, when the coupling to open channels is switched off, is just the damping width of the GR.

In realistic calculations, the solution of Eq. (6) poses severe problems, owing to the very large density of states of the 2p-2h configurations, especially in heavy nuclei. To give an example we show in Fig. 3, the

calculated 2p-2h density of 2^+ states in ^{92}Zr, in the energy region around the GQR ($E^* \sim 14$ MeV). Clearly ρ_{2^+} could reach a million. This aspect naturally calls for a statistical treatment of the 2p-2h subspace, as is done in statistical nuclear reactions involving the compound nucleus.

The statistical treatment alluded to above is based on the theoretical developement of multistep compound processes discussed by Friedman et al.[12)]. In this approach, the non-direct reaction leading from channel c to c' is determined by summing the individual probabilities for all processes which begin with c and end with c' where a succesion of compound classe is visited along the way as the system evolves along various routes. In the case discussed here,we take c to the giante resonance and c' any open final channel. It might sound a bit peculiar to call the CR the entrance channel, but considering the time delay aspect of the problem, namely order of magnitudes longer time required for the formation and decay of the 2p-2h, 3p-3h, stages than that for the formation and eventual "direct" decay of the GR, we believe our procedure is quite reasonably, closely related to the time delay is the density of states involved (see earlier discussion of the density of states of 2p-2h configurations).

Our ideas above can be summarized in Fig. 4. The GR considered as a "direct" channel feeds flux to the 2p-2h subspace which is coupled both to the exit channels, through the transmission coefficients $\tau_{1,c'}$ and the 3p-3h space. The 3p-3h subspace itself is coupled to the exit channels (through $\tau_{2,c'}$) and to the next complicated configuration, and so on. The flux fed from the GR therefore percolate through the different stages, allowing always couplings in both directions, (up and down, as exemplified by the thick arrows) notwithstanding the ratios $\frac{\rho_{i+1}}{\rho_i}$ being always very large (i refers to no particles and holes) and accordingly favoring the down coupling.

What is shown in Fig. 4 can be translated into mathematics using classical statistical arguments as was shown in Refs. 12) and 13).

To proceed, it is convenient to introduce a set of generalized transmission coefficients, $T_{n,c}$, which represent the probability for getting from channel c to the subspace of np-nh. This includes both direct coupling c $\longleftrightarrow$ np-nh as well as indirect coupling through (n-1)p-(n-1)h, (n-2)-p(n-2)h etc. subspaces. Let us also define downward branching ratios μ_{nm} (n < m) which measure the internal coupling between mp-mh and np-nh both directly through the other subspaces. From μ_{nm} we can also define the inclusive downward mixing parametes of the np-nh subspace

$$\mu_{n\downarrow} = \sum_{m(>n)} \mu_{nm} \tag{8}$$

The flux which arrives at the np-nh subspace and stops there is then given by $T_{n,c} - T_{n,c}\,\mu_{n\downarrow}$. The second factor is just the depletion of the flux at n due to the coupling downward to more complex stages.

The cross-section which describes the transition from the GR to the find channel c', can then be written down in a generalized Hauser-Feshbach form

$$\sigma_{GR,c'} = \sum_{n} (1-\eta_{n\downarrow}) \frac{T_{n,GR}\, T_{n,c'}}{\sum_{c''} T_{n,c''}} \tag{9}$$

The factor $(1-\eta_{n\downarrow})$ indicate how much of the flux which entered the np-nh subspace from the c "survives" the downward leakage. At this point we must remember that we have treated the GR, so far, as the entrance channel. Of course the GR has to be populated from the real entrance channel (γ, α, etc.). Thus we have to give a special interpretation for the transmission coefficient $T_{n,GR}$. To reach the GR from the entrance channel, one uses an average transmission coefficient $\tau_{c,GR}$ given by $2\pi\, \Gamma^{c}_{GR}\, \rho_{GR}$ with Γ^{c}_{GR} denoting the partial width of GR and ρ_{GR} is of the order of 1 MeV^{-1}. The structure of $T_{n,c'}$ is constructed as follows. We introduce transmission coefficients, $\tau_{n,c'}$ which describe direct coupling of c' and np-nh subspace. Then

$$T_{n,c'} = \tau_{n,c'} + \sum_{m=1}^{n-1} T_{m,c'}\, \mu_{mn} \tag{10}$$

The second factor, $\sum_m T_{m,c'}\, \mu_{mn}$ describes the indirect couplings between c' and n through the (n-1)p-(n-1)h, (n-2)p-(n-1)h etc. and though the GR. For simplicity, we take only the 2p-2h subspace. Then

$$T_{1,c'} = \tau_{1,c'} + \mu\, \tau_{GR,c'} \tag{11}$$

As far as $T_{1,c}$ is concerned, owing to the fact that c couples directly only to the GR, we have

$$T_{1,c} = \mu\, \tau_{GR,c} \tag{12}$$

If we ignore all other subspaces, the factor $(1-\mu_{n+})$ is then absent and we have for the 2p-2h contributions to the $c \to c'$ cross section

$$\sigma_{cc'}^{(2p-2h)} = \frac{\mu\, \tau_{GR,c}\, (\tau_{1,c'} + \mu\, \tau_{GR,c'})}{\sum_{c''} (\tau_{1,c''} + \mu\, \tau_{GR,c''})} \tag{13}$$

Besides the above cross section there is the "direct" GR cross section which from Eq.(9), can be written as

$$\sigma_{cc'}^{(GR)} = (1-\mu)\, \frac{\tau_{GR,c}\, \tau_{GR,c'}}{\sum_{c''} \tau_{GR,c''}} \tag{14}$$

The generalization of the above equations to include (3p-3h), (4p-4h) subspaces, is straight-forward and can be easily accomplished with a repeated use of Eq.(9). We

should mention here that the sum of Eqs. (13) and (14) satisfies the general unitarity requirement as long as the entrance channel transmission coefficient in Eq.(13) resembles exactly the exit channel one, in the sense that

$$\sum_{c'} \sigma_{cc'} = (\tau_{GR,c} + \tau_{1,c}) \tag{15}$$

The sum of Eqs.(13) and (14) is the principal result of this section. The resulting equation expresses the cross section as a sum of a "direct" term and a compound term. So far analysis of data have performed assuming for $\sigma_{cc'}$, either one of the two terms, depending on the part of the spectrum studied. A more consistent approach, however, should start with our Eqs. (13) and (14) with the aim of extracting the value of μ. This procedure has been followed previously in connection with isospin mixing in nuclear compound reactions, namely the case of analog resonances coupled to the lower-isospin background[14]. The parameter μ extracted in this case measures the degree of nonconservation of isospin due to Coulomb mixing of the upper and lower isospin states.

In the case studied here, μ should measure the degree of GR fragmentation into the more complex compound nucleus configurations. The unambiguous extraction of μ, however is directly tied to the a priori knowledge of τ_c^D and τ_c^C. The former can be calculated using a suitable RPA description of the coherent 1p-1h excitation in the region of high excitation energies (continuum RPA). The compound transmission coefficients can be evaluated using the optical model. We should stress that the Hauser-Feshbach evaluation of the second term in Eq. (2) **is not valid** owing to the presence of the unknown parameter μ. If such a calculation were to be performed, one ends up evaluating $\tau^C + \mu\tau^D$, whose interpretations in terms of optical potentials is, to say the least, ambiguous.

IV. APPLICATIONS

In order to demonstrate the usefulness of our theory we present in Fig. 1 a calculation of the decay probability, of the monopole giant resonance in ^{208}Pb, excited through the (α,α') reaction[15]. This probability is nothing but $\sigma_{cc'}/\tau_\gamma$, from our Eqs. (13) and (14). Two values of μ were considered, $\mu=1$ and $\mu=0.5$. The direct piece of the decay was estimated using the result of F.T. Kuchnir et al.[16,17] and de Haro et al.[18], whereas the statistical piece was calculated, in accordance with Eq. (13) using for the $\tau^C_{c'}$, the Hauser-Feshbach model as recently employed by Dias et al.[2] Clearly for the $\mu=1$ case a renormalization of the statistical calculation of Ref. 2) has to be made in order to account for the "indirect" CN decay exemplified by $(\mu=1)$ $\tau^D_{c'}$, whose value was taken to be $2\pi\,\Gamma^D_c\,\rho_D$ with $\rho_D \cong 1\,\text{MeV}^{-1}$.

It is obvious from the figure that the GMR in ^{208}Pb does not accomodate appreciable direct piece since the mixing parameter seems to be close to 1, in complete agreement with the conclusions of Refs. 5,6). The example described above should convey the principal message of our work: by comparing to a less prejudiced expression for the decay probability of the GR (neither entirely direct nor entirely compound) one should be able to extract the important mixing parameter μ.

At this point, we make an attempt at a generalization of Eq. (13) to incorporate the contribution arising from pre-equilibrium emission. This is easily accomplished using the nested doorway approach of Ref. 10). The important new features are that the cross section is now composed of three distinct pieces, and the mixing parameter μ is divided into three terms. Namely

$$\sigma_{cc'} = \sigma^{(GR)}_{cc'} + (1-\mu_2)\mu_1\tau^D_\gamma \frac{\tau^P_{c'} + \mu_1\tau^D_{c'}}{\sum\limits_{c''}(\tau^P_{c''} + \mu_1\tau^D_{c''})} + (\mu_1\mu_2+\mu')\tau^D_\gamma \frac{\tau^C_{c'} + \mu_2\tau^P_{c'} + (\mu_1\mu_2+\mu')\tau^D_{c'}}{\sum\limits_{c''}[\tau^C_{c''} + \mu_2\tau^P_{c''} + (\mu_1\mu_2+\mu')\tau^D_{c''}]} \tag{16}$$

with

$$\sigma^{(GR)}_{cc'} = (1-\mu_1-\mu')\tau^D_\gamma \frac{\tau^D_{c'}}{\sum\limits_{c''}\tau^D_{c''}} \tag{17}$$

In the above μ_1 measures the mixing of GR with the 2p-2h states, μ_2 refers to the mixing of the 2p-2h with the compound nuclear states and μ' refers to the mixing of the GR directly with the compound states, which may be set equal to zero for all practical purposes. The transmission coefficient related to the GR (1p-1h), the pre-equilibrium stage (2p-2h) and the compound stage are called τ^D, τ^P and τ^C, respectively. It is important to note here that unitarity is still preserved both in Eq. (9) in the sense that by summing over the final channels c', we obtain

$$\sum_{c'} \overline{\sigma}_{cc'} = \tau_{\gamma}^{D} \tag{18}$$

irrespective of the detailed nature of the decay.

Very precise and detailed measurements are required to test the above generalization of our theory. However before testing the generalization, a more thorough test of the simple, two-term expression is required in order to extract the mixing parameter μ. If this parameter is found strongly dependent on energy, then intermediate, pre-equilibrium processes, must be taken into account through our generalized expression, Eq. (16). Work is presently in progress to test the above ideas. In the next section we discuss the calculational aspect of μ with the aid of the statistical features of the nuclear shell model at high excitation energy.

V. THE GIANT RESONANCE MIXING PARAMETER AND THE STATISTICAL PROPERTIES OF THE NUCLEAR SHELL MODEL

The GR mixing parameter, μ, introduced earlier, can be expressed as

$$\mu = \frac{\Gamma^{\downarrow}}{\Gamma^{\downarrow} + \Gamma^{\uparrow}} \tag{19}$$

where $\Gamma^{\downarrow}$ is the damping width of the GR arising from the coupling between the 1p-1h and 2p-2h subspace, and $\Gamma^{\uparrow}$ is the escape width to the open channels. Since $\Gamma^{\uparrow}$ can be calculated from continuum RPA (namely P_D), we need here to discuss the evaluation of $\Gamma^{\downarrow}$ which is connected with statistics.

The simplest possible expression for $\Gamma^{\downarrow}$ is Fermi's Golden Rule's,

$$\Gamma^{\downarrow} = 2\pi \sum_i |\langle GR | V | (2p-2h)_i \rangle|^2 \tag{20}$$

$$\approx 2\pi \overline{|\langle GR | V | (2p-2h) \rangle|^2}\, \rho_{2p-2h} \tag{21}$$

In writing the second expression for $\Gamma^{\downarrow}$ above we have assumed that a representative average matrix element squared is a reasonable approximation for the ratio of the i-sum in the first expression over the density of the 2p-2h states. The calculation of (20) or (21) can be greatly simplified if statistical treatment is found applicable in the sense that the amplitudes $a_{j,i}$ associated with the basis vector $|j\rangle$ which is used to construct the nuclear state $|2p\text{-}2h\rangle_i$ are random. Namely the ensemble average

$$\overline{a_{j,i}\, a_{j',i}} = \overline{|a_{j,i}|^2}\, \delta_{jj'} \tag{22}$$

The average square matrix element of Eq. (21) then becomes

$$\overline{|\langle GR|V|2p\text{-}2h\rangle|^2} = \sum_j \overline{|a_{j,i}|^2}\, |\langle GR|V|j\rangle|^2 \tag{23}$$

Thus it is important to verify the probability distribution of the amplitudes $a_{j,i}$. Within the theory of random matrices, this distribution is gaussian (Porter-Thomas), namely

$$P(|a_{j,i}|) = \sqrt{\frac{2N}{\pi}}\, \exp\left[-N\, |a_{j,i}|^2\right] \tag{24}$$

where $\sum_j |a_{j,i}|^2 = 1$, and N is the dimension of the basis.

In a preliminary study[19], we have checked the above by performing a realistic shell model calculation in s-d nuclei. We have taken $(sd)^7({}^{23}Na)$ with a baseis size N = 517. The result of our calculation for $j\pi = 1/2^+$ with the Wildenthal interaction do not follow Eq. (24). This however does not exclude the possibility of constructing an empirical

distribution for the $a_{j,i}$. This is being carried out for several nuclei for the purpose of establishing systematics. With this, the calculation of $\Gamma^{\uparrow}$ and μ, the mixing parameter, can be done easily.

VI. CONCLUSIONS

In this paper the decay properties of nuclear giant resonances are discussed within a hybrid model that combines both the direct component and the statistical, compound, component in a unitarity consistent way. The mixing parameter which measures the degree of fragmentation of the GR with the background configurations appears as a natural link between the direct piece and compound piece of the decay probability. It is suggested that the analysis of the data is made in conjunction with an RPA - type calculation of the direct piece and a modified Hauser-Feshbach calculation of the statistical piece, with the final aim being the extraction of the mixing parameter.

Finally it is suggested that the theoretical calculation of the mixing parameter is simplified greatly with the use of the statistical properties of the nuclear shell model eigenstates at high excitation energy.

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FIGURE CAPTIONS

Figure 1. The histogram is the measured neutron decay spectrum from the E0 giant resonance in ^{208}Pb (ref.7). The two curves shown by the full line (μ=1) and dashed line (μ=0.5) are the predicted spectrum using equation 6 taking into account the resolution of the experiment (500 keV). Each of the 141 neutron groups is represented by a Gaussian with FWHM = 500 keV (see Ref. 5), 6) for more details). Both spectra (μ=1 and μ=0.5) are normalized to the number of neutrons in the interval between 3-4 MeV. The excitation energy of the residual nucleus ^{207}Pb, is depicted by E_x (upper abscissa). See text for more details.

Figure 2. Calculated fission probabilities of the GMR (dashed dotted curve), GDR (dashed curve) and GQR (full curve). See text for details. Also shown is the experimental data for the GDR fission decay. The dotted curve represents the results of $P_f(E\lambda)$ (equal for all λ's) obtained from the approximate Vandenbosch-Huizenga expression. From Ref. 5).

Figure 3. Calculated level density of 2^+ states in ^{92}Zr within the single particle shell model.

Figure 4. A schematic diagram showing the reaction coupling scheme.

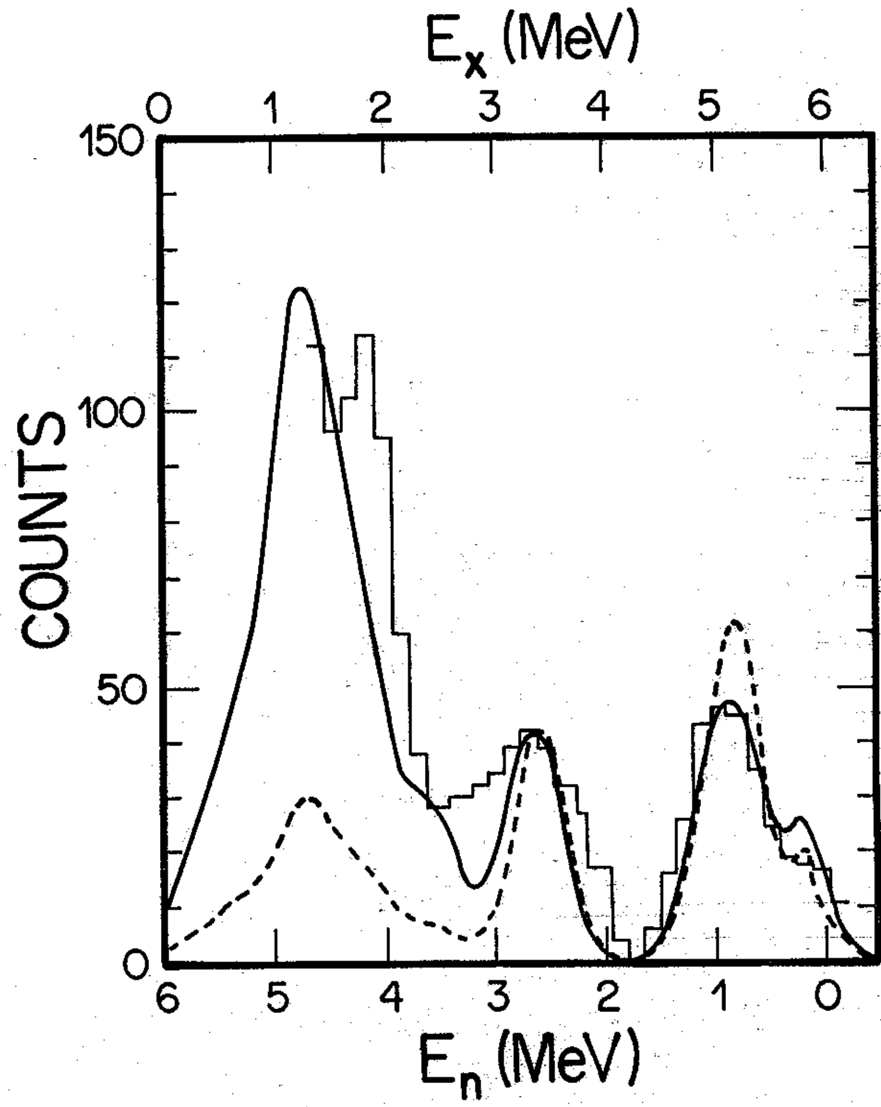

Fig. 1

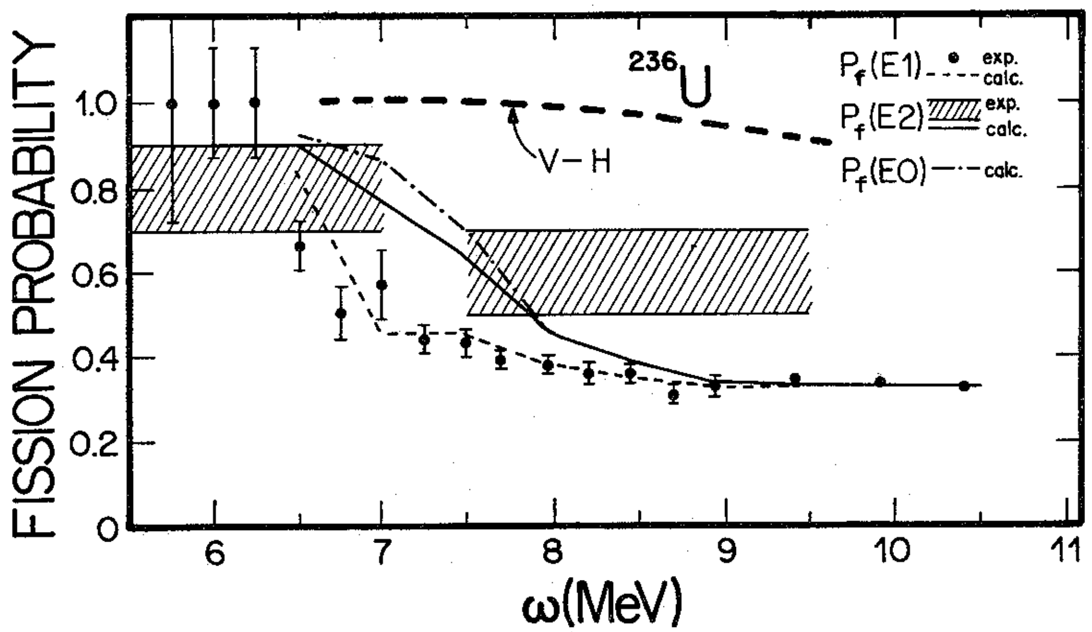
FISSION PROBABILITY
ω(MeV)
^{236}U
$P_f(E1)$ exp. calc.
$P_f(E2)$ exp. calc.
$P_f(E0)$ calc.
V−H

Fig. 2

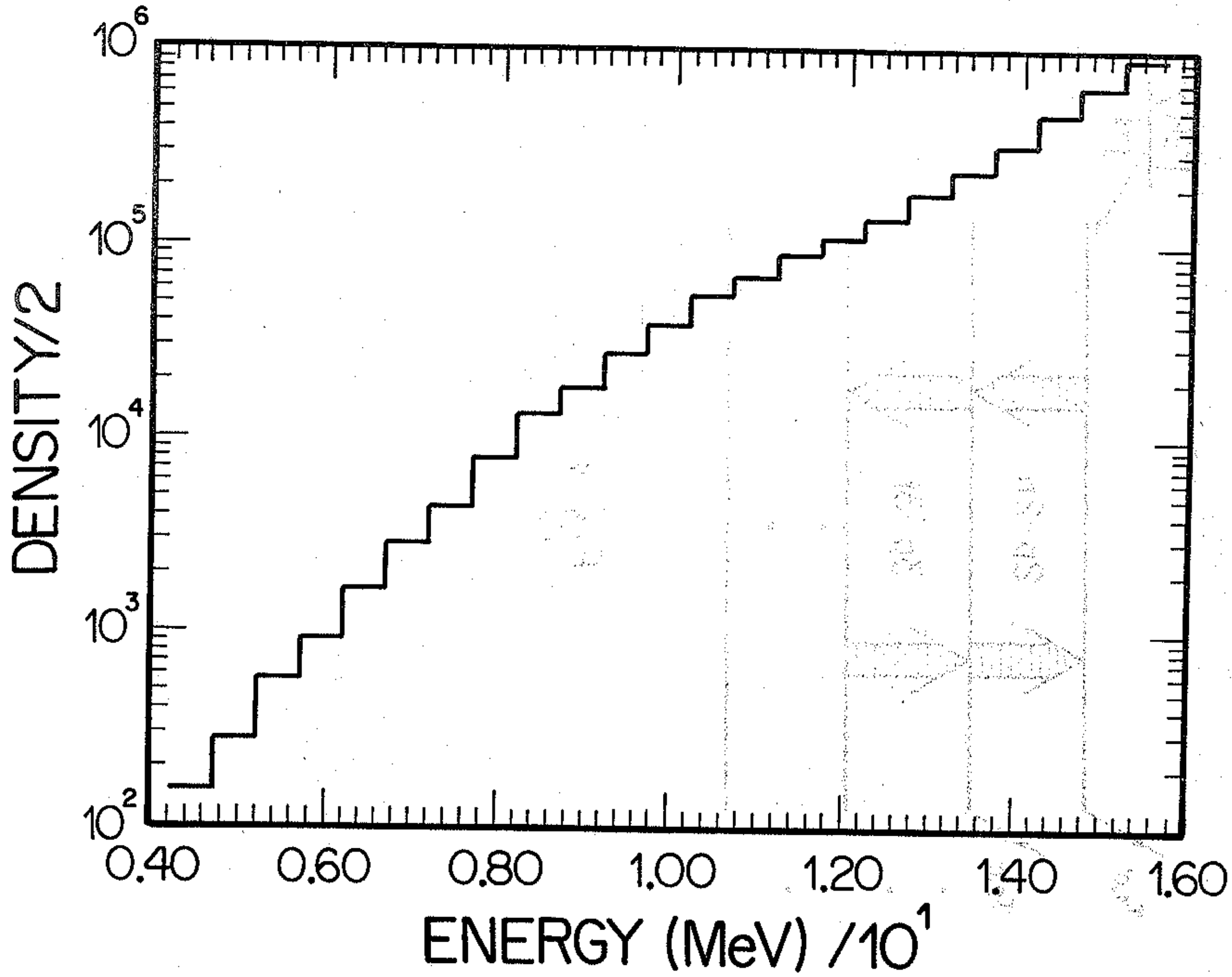
DENSITY/2
ENERGY (MeV) /10^1

Fig. 3

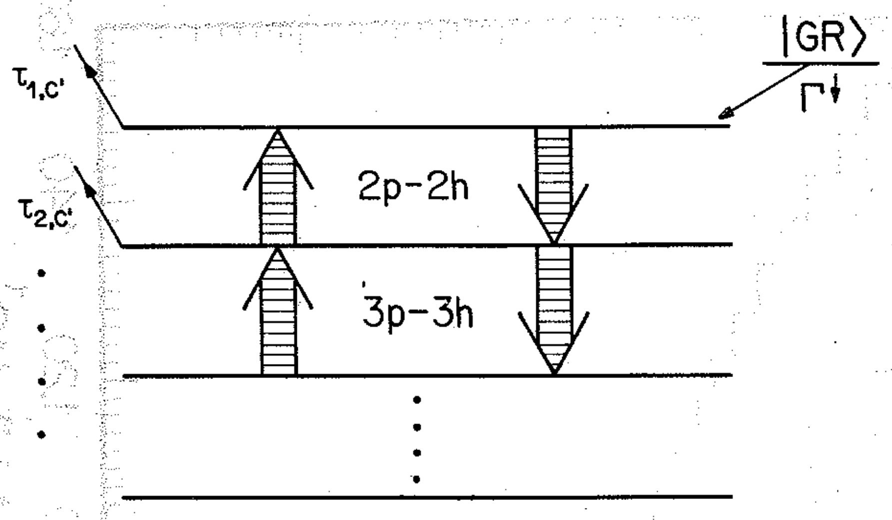

Fig. 4