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Discussions of level densities and gamma-strength functions

From the fruitful discussions, a number of topics can be followed up quite directly, by doing calculations with already existing programs or measurements with present devices, while a number of topics should be kept in mind for future investigation. For some topics, the participants in the discussion promised a follow-up.

TOPICS:

A. Level density and strength functions at different shapes.
Co-existing nuclear shapes would result in slightly enhanced level-densities, building level densities more or less independently for the different shapes, providing the shapes are different enough. Especially fission isomeric decay is in principle a powerful tool.
-> Andreas will look into the possibility of such an experiment.

B. Angular momentum in statistical cascades as probed by the Oslo method.
The level density as probed directly by the Oslo method is not the total level density. The total level density is generated by scaling up the level density at the neutron separation energy by a factor sigma^2/Sum(2I+1) and making a suitable interpolation from the last measured level density point to the neutron separation energy. The normalization at low energy should not be a problem, since one here refers to resolved states. The notion of the total level density in formulas is confusing (Thomas), and it is not so clear what uncertainties and potential errors this may lead to.
-> Thomas will write a note containing the formulas for decay times, and a derivation of the changes in $\langle I \rangle$ and $\langle I^2 \rangle$ along the cascades. The conjecture is that the angular momentum distribution practically stays constant along the cascade.

C. The odd-even effect in mass number.
At low energy, for the pair of nuclei 161-162Dy, the Oslo data have a stronger odd-even effect than the combinatorial level density. This can either be expressed as an increase in entropy when going from even to odd: about $\Delta S \sim 1.9$ (factor of 7) (Oslo) and $\Delta S \sim 1.1$ (factor of 3) (comb), or an energy shift: (difference between even and odd backshifts) $\Delta E \sim 1.0$ MeV (Oslo) and $\Delta E \sim 0.6$ MeV (comb). For 161-162Dy, it seems that the combinatorial level density is in reasonable accordance with data with respect to the accumulated levels up to angular momentum I=6, and up to the excitation energy where the data are complete. But this may not be the general picture, which should arise from averaging over several nuclei.
-> Thomas will make a figure of Brookhaven compilation data for the start of the level density curves - averaged over 3 or 4 nuclei - for each group of odd-odd, odd-N, odd-Z and even-even. - together with the combinatorial model results. The limiting energy is about 2.1 MeV for even-even, 0.9 MeV for odd-A, and 0.7 MeV for odd-odd.

D. The constant temperature ansatz.
It seems that the constant temperature ansatz will result from a delicate balance between different physical quantities and parameters, and it seems strange that should be a general rule (Sven). When evaluating temperature for 10 rare-earth nuclei, using a smoothing procedure of the logarithm of the level density, one finds (Thomas): - the combinatorial level density predicts a gradually increasing microcanonical temperature for all nuclei. - the Oslo data indeed displays constant temperature for some nuclei, and gradually increasing temperatures in other cases; about half of each. Magne mentioned that these data are among the first ones applying the Oslo method, so they may lack some precision.
-> Thomas will rerun the calculations, checking out the (i) robustness of results to the parameterization of the extrapolation of the level density (ii) inclusion of the error bars in the Oslo results.

E. The strength function - especially the upbend.
The non-experts (Lund-Copenhagen) were impressed by the discovery and intense investigations of the upbend of the strength function and the check of the Brink-Axel hypothesis. Looking at the Shell Model M1 strength function, it would be interesting to see the dependence on initial energy of the strength function. For example, going from 6 MeV to 4 MeV, will one just see the higher energies (from 4 to 6 MeV) erased, while the rest of the curve stays up, or will the slope also change?
-> Magne: this could easily be done.

F. The "periodic table" of the upbend.
The question was raised: what is the pattern of the occurrence of the upbend. How does it relate to mass, charge and deformation? One may for example extract the following quantity: the strength function within the interval 1-2 MeV divided by the strength function within the interval 4-5 MeV, (or some other suitable interval) and plot it as dots as function of mass (or charge) number, in analogy to plots of the transition quadrupole moment of the lowest 2 -> 0 transition in even-even nuclei, or as a function of calculated deformation (Möller). Also, in this connection, it was discussed whether the use of special detectors, such as for example clover detectors can check the nature of the transitions, E1 or M1.

G. The canonical ensemble.
Two different views were expressed. First view (Magne and Sven): The canonical ensemble with constant temperature implies evaluating average values of quantities over a very wide energy range, whereby specific, energy dependent results must be smeared out. Such energy dependent quantities are more precisely investigated in the microcanonical ensemble. Second view (Thomas): Physical observables may come out quite the same, whether you make (i) averages over levels (for example for an energy interval between 4.5 and 5 MeV) or (ii) calculate the same observables with the grand-canonical ensemble with corresponding temperature and chemical potential. The probability for having a certain level occupied is given by the Fermi-function for the grand canonical ensemble, and one may guess that for the average over levels, the probability will not differ that much from a Fermi function

H. The even-odd effect in angular momentum - the "staggering".

Traditionally, the surplus of even angular momenta in level densities of even-even nuclei has loosely been referred to as "a pairing effect". However, as Sven showed at the meeting, and as has been published (Nucl. Phys. A941(2015)97), it is an effect of symmetries, the r-symmetry of the potential for deformed nuclei, and (more loosely) the Fermion exchange symmetry for open shell spherical or weekly deformed nuclei. So, in the future one should not refer to it as a pairing effect.

The staggering also affects the spin distribution function.

I. The parity distribution of level densities

Sven showed that the parity distribution of level densities displays specific structure depending on nucleus, deformation, and excitation energy. Also, it has the potential to become a fine probe of different theories. One may consider how the Oslo method in the future could be able to address this question.

J. Level densities at high excitation energy

The newly developed model (by J. Randrup) of the over-damped fission diffusion model was presented by Daniel. The application of the model would gain considerably if realistic level densities are applied. For the most heavy nuclei, the combinatorial model can be applied up to about 20 MeV. Above that, it simply takes too long time. So, the idea is to apply the combinatorial model up to about 5 MeV, and then apply the level density formula by Ignatyuk, with parameters fitted to the combinatorial level density within the interval 5-20 MeV. In the combinatorial level density, we have the effects of both pairing and of shell structure, and it is interesting to see how they affect the determined parameters. Thomas: one shuld have the proper prefactor for the Ignatyuk expression applied: $E^{-3/2}$, and it is not so clear whether this is with or without backshift.

General question: how long time would it take to calculate the combinatorial level density up to 5 MeV excitation energy for 5 million deformation grid points?

K. Which nuclei would be interesting to look at?

(i) Mo 100, since it is more deformed than the lighter Molybdenums.

-> Magne: Mo 100 will be done.

(ii) Some nuclei with shape coexistense, especially the above-mentioned fission isomers, but also other possibilities were discussed.