

Parity-Dependence in the Nuclear Level Density

D. Mocij^{a*}, T. Rauscher^a, K. Langanke^b, G. Martínez Pinedo^c, L. Pacearescu^d,
A. Fäßler^d, and F.-K. Thielemann^a

^aDepartment for Physics and Astronomy, University of Basel, Basel, Switzerland

^bInstitute for Physics and Astronomy, University of Aarhus, Aarhus, Denmark

^cInstitució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

^dInstitute of Theoretical Physics, University of Tübingen, Tübingen, Germany

Astrophysical reaction rates are sensitive to the parity distribution at low excitation energies. We combine a formula for the energy-dependent parity distribution with a microscopic-macroscopic nuclear level density. This approach describes well the transition from low excitation energies, where a single parity dominates, to high excitations where the two densities are equal.

1. Introduction

The nuclear level density is an important ingredient in the prediction of nuclear reaction rates in astrophysics. So far, most theoretical, global calculations of astrophysical rates assume an equal distribution of the state parities at all energies. It is obvious that this assumption is not valid at low excitation energies of a nucleus. However, a globally applicable recipe was lacking. For nuclei far from stability, where no experimental information on excited states is available, a large effect of the parity dependence on predicted cross sections can be expected.

2. Method

Single particle levels are divided into two groups, according to the individual parities. The group which has the smaller average occupation number is denoted by Π . Assuming that nucleons occupy the single-particle orbitals independently and randomly, the occupancy n of the Π -parity orbits is given [1] by a Poisson distribution,

$$P(n) = \frac{f^n}{n!} e^{-f} \quad (1)$$

where f is the average occupancy of orbits with parity Π . Then the ratio of the odd-parity to the even-parity probabilities is given by [1]

$$\frac{P_-}{P_+} = \frac{Z_-}{Z_+} = \tanh f. \quad (2)$$

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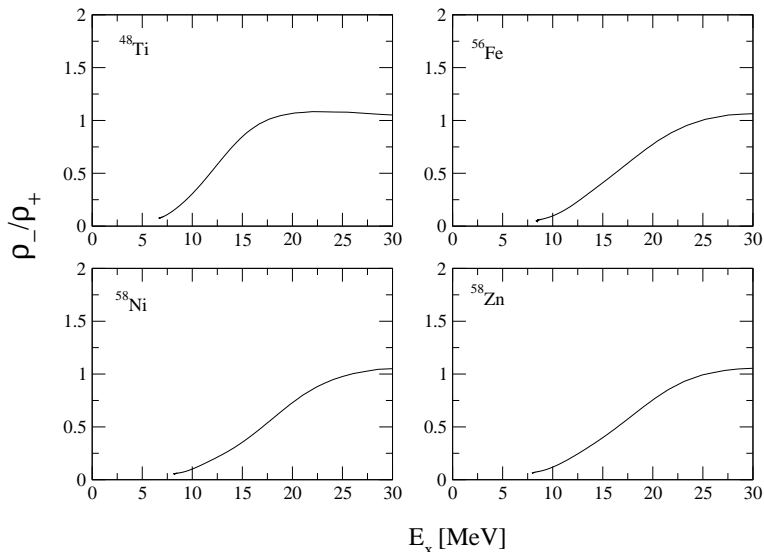


Figure 1. Odd- to even parity ratio calculated for ^{48}Ti , ^{56}Fe , ^{58}Ni and ^{58}Zn

In nuclei, f has to be replaced by the sum of individual contributions from neutrons and protons. To calculate the total partition function Z we use the macroscopic-microscopic nuclear level density of [2]. The average occupancy f is computed from BCS occupation numbers based on single particle levels from an axially symmetric deformed Saxon-Woods potential [3] with parameters from [4] which reproduce experimental data well [5,6]. All major shells up to $11\hbar\omega$ were included which allows to extend our calculations way beyond the previously studied $pf+g_{9/2}$ shell. Using $Z_+ + Z_- = Z$ and Eq. 2, we can thus determine Z_{\pm} and calculate the thermal energies for even- and odd parity states. Canonical entropies, heat capacities, and the parity projected level densities at a given excitation energy, are derived from standard thermodynamic relations.

3. Results and Discussion

Typical results for nuclei in the Fe-region are shown in Fig. 1. One can see that the assumption of equally distributed state parities is not fulfilled. Even at excitation energies of 10 - 15 MeV, the parity ratio is not yet equilibrated.

The evolution of the parity ratios within an isotopic chain is shown in Fig. 2. Starting with ^{54}Zn , where the pf -shell is filled in neutrons only to 20 %, and stopping with ^{74}Zn , where the next major shell has started to be populated, one can see that the ratio approaches unity for lower values of the excitation energy as one approaches the $N = 40$ shell closure. As the parity can only be changed by excitations from the pf to the sdg shell, the ratio will equilibrate faster with increasing neutron number as the gap between the last occupied orbit in the pf -shell and the sdg -shell will decrease. For ^{70}Zn , where the pf -shell is completely filled, a pronounced peak around 6 MeV shows up, which might be understood as follows: As the pf -shell is completely filled, the parity of the system will be changed by any neutron excitation, resulting in a dominance of negative parity states

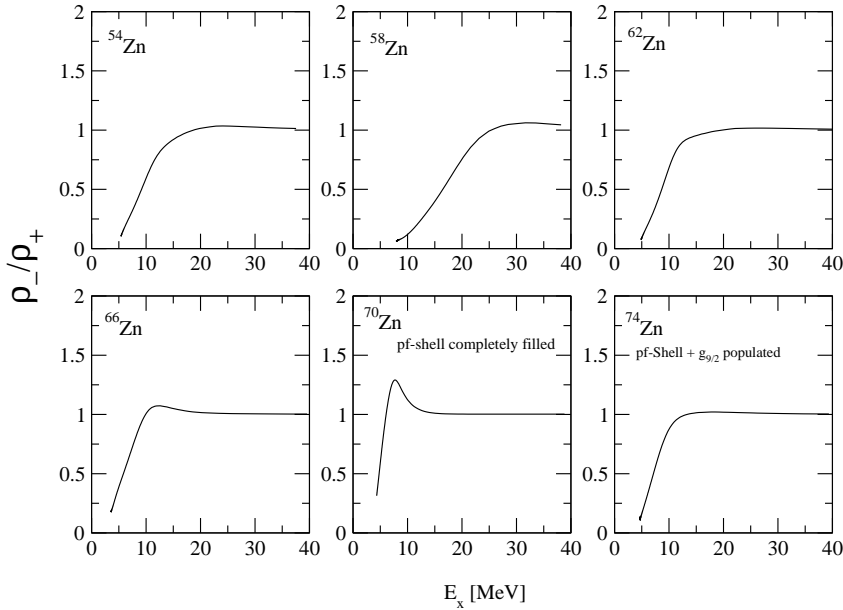


Figure 2. Evolution of the odd- to even-parity ratio within the Zn-chain.

at the energies for which the peak appears. However, as shown below, this effect strongly depends on the inputs and has to be interpreted with caution.

There are two essential inputs to our calculations: the total level density ρ_{tot} which is used to calculate the total partition function utilized in Eq.(2) and the single particle levels from the deformed Saxon-Woods potential needed to compute the average occupancy f . Both inputs are prone to possible uncertainties. We explored the sensitivity to these uncertainties by simulating the combined effects of uncertainties in both inputs by variation of only the total level density ρ_{tot} and keeping the Saxon-Woods parameters unchanged. Fig. 3 shows the impact of varying the level density parameter a in the range of $8 \leq a \leq 12 \text{ MeV}^{-1}$. This corresponds to a $\pm 20\%$ variation of the standard parameter a and implies a change in ρ_{tot} of up to a factor of 5 at an excitation energy of 6 MeV. It has to be emphasized once more that this large variation of the level density is not due to the uncertainty of ρ_{tot} alone but rather is supposed to contain the combined uncertainties in ρ_{tot} and the single particle levels. Fig. 3 clearly shows the need for improved consistency within the inputs, especially at shell closures.

4. Conclusion and Outlook

We have shown that the assumption of equally distributed state parities is only justified for high excitation energies. For lower energies, even still at particle separation energies which are in the order of several MeV, this assumption is clearly not fulfilled. Further investigations are needed to arrive at an understanding of the peak-strengths found at shell closures. Work is in progress to calculate the parity distribution for a large number of nuclei far from stability on the proton as well as neutron rich side. Influences on nucleosynthesis calculations will be studied.

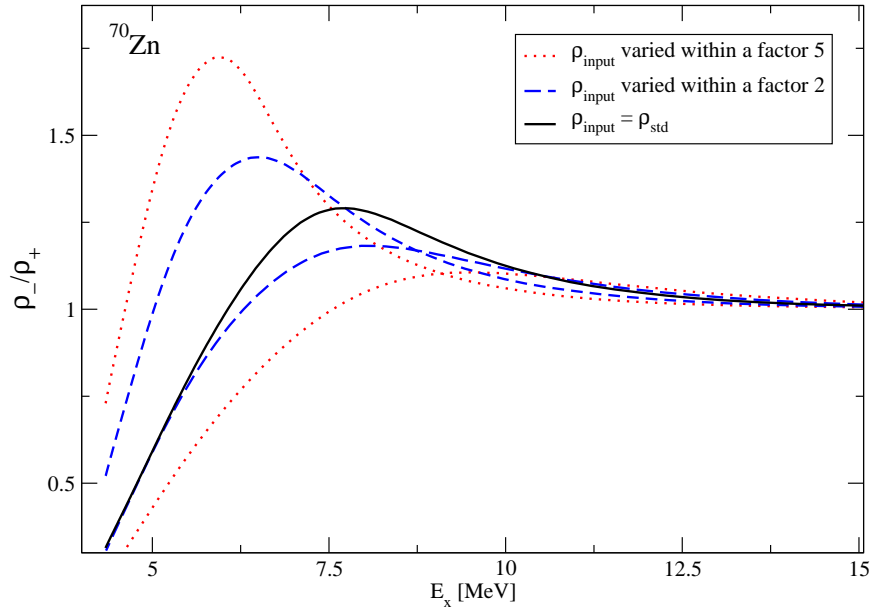


Figure 3. Influence of the input level-density parameter a on the peak strength in ^{70}Zn . The black curve is obtained by using the standard level-density parameter [2]. The dashed (dotted) curve corresponds to a variation of the level-density parameter a which translates to a variation of the input level density by a factor of 2 or 5, respectively.

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