# Systematics of nuclear level density parameters

Till von Egidy[1] and Dorel Bucurescu[2]

[1] *Physik-Department,*

*Technische Universität München,*

*D-85748 Garching, Germany*

[2] *Horia Hulubei National Institute of Physics and Nuclear Engineering,*

*R-76900 Bucharest, Romania*

(Dated: June 28, 2005)

## Abstract

The level density parameters for the Back Shifted Fermi Gas (both without and with energy dependent level density parameter) and the Constant Temperature models have been determined for 310 nuclei between $^{18}$F and $^{251}$Cf by fitting the complete level schemes at low excitation energies *and* the s-wave neutron resonance spacings at the neutron binding energies. Simple formulas are proposed for the description of the two parameters of each of these models, which involve only quantities available from the mass tables. These formulas may constitute a reliable tool for extrapolating to nuclei far from stability, where nuclear level densities cannot be measured.

PACS numbers: PACS: 21.10.-k, 21.10.Ma

## I. INTRODUCTION

The nuclear level densities have a special importance in nuclear physics. Indeed, predicting the distribution of all the excited levels of a nucleus represents a great challenge of our understanding of this complicated quantum system. On the other hand, the level densities (LD) represent a very important ingredient in statistical model calculations of nuclear reaction cross sections, which are needed in many applications from astrophysical calculations (determining thermonuclear rates for nucleosynthesis) to fission or fusion reactor designs.

The direct, experimental determination of the level densities is limited both in the number of nuclear species and in the excitation energy range. Most of the existing experimental data are based on measuring the LD at an energy close to the neutron binding energy, by counting the number of neutron resonances observed in low-energy neutron capture. This kind of measurement is therefore limited to nuclei which are formed by adding one neutron to the stable species. In addition, one may determine the LD at lower excitation energies by directly counting the observed excited states, but this procedure is also limited by the accuracy and completeness of the available data. Nevertheless, we often need the level densities for many unstable nuclei, where they cannot be determined experimentally (e.g., in nucleosynthesis calculations). For such nuclei one has to rely on level densities either provided by some theoretical models, or extrapolated from nuclei for which experimental information is available. There have been considerable efforts in both these directions (see, e.g., [1, 2]), but the extrapolation to nuclei far from the stability line is still rather problematic.

The theoretical approaches at a microscopic level, such as to take into account shell effects, pairing correlations, and collective effects (see, e.g., the discussion in [1], and [2]), have made a remarkable progress, but their use in practical applications is rather complicated.

On the other hand, most calculations of the nuclear level densities are extensions and modifications of the Fermi gas model, to which the pairing and the shell effects are added semi-empirically, such as shown for the first time by Gilbert and Cameron [3]. However, the problem of the extrapolation of empirically determined parameters for such simple models to far away nuclei persists also in this case, since there is no consistent systematics of these parameters.

For excitation energies not much higher than the neutron separation energy, one can use for the level density simple models with only two parameters, such as the back-shifted Fermi

gas (BSFG) model [3, 4] or the constant temperature (CT) model [3]. As emphasized above, these simple models do not consider many details of the nuclear interactions, therefore the empirical parameters determined by fitting experimental data have complicated variations which implicitly reflect the shell effects, the pairing effects, etc. It is very important for the development of more reliable extrapolation methods to be able to recognize such dependencies and account for them in a simple way.

In this work we follow a heuristic approach to this problem. First, we determine a new set of empirical (phenomenological) LD parameters for such simple models as the BSFG and the CT model, by fitting the latest data on low-excitation energy levels *and* neutron resonance spacings at the neutron binding energies for 310 nuclei. Then, we study the variations of these phenomenological parameters for our set of nuclei, and observe how they correlate with those of other physical observables. We have considered such observables which are both experimentally known for a large number of nuclei (larger than that in our set) and more reliably calculated theoretically or extrapolated from the existing data. On the basis of the observed correlations, we determine simple formulas which describe the main features of our empirical LD data. These formulas are then proposed as reliable means for the extrapolation to unknown nuclei.

The next section of the article presents the details of the experimental data fitting procedure and the new phenomenological model parameters. The subsequent section presents the systematics of these parameters and the way we correlate them with different other physical quantitites, generally based on the mass tables. The final section presents the adopted formulas which describe the observed systematics and a discussion of their merits. These formulas can be recommended to calculate level densities up to, or slightly higher than, the neutron binding energies. A brief report with these results has recently been presented [5].

## II. EMPIRICAL LEVEL DENSITY PARAMETERS

### A. The models

For consistency, we give below the formulas of the phenomenological models used in the present study. The level density dependence on the excitation energy $U$ and spin $J$ is

assumed to have a separable form:

$$\rho(U, J, \pi) = \frac{1}{2}\rho(U)f(J) \tag{1}$$

where

$$f(J) = e^{J^2/2\sigma^2} - e^{(J+1)^2/2\sigma^2} \tag{2}$$

We have neglected the dependence of $\rho$ on the parity ($\pi$); although this is not true, especially in the case of the low excitation energies, this dependence is usually ignored.

### *1. The back-shifted Fermi gas model (BSFG)*

In this model ([3]) we have:

$$\rho(U) = \frac{\exp[2\sqrt{a(U-E_1)}]}{12\sqrt{2}\sigma a^{1/4}(U-E_1)^{5/4}} \tag{3}$$

The function $\exp(2\sqrt{ax})x^{-5/4}$ has a minimum at $x = (25/16)/a$. Therefore, $\rho$ was assumed to be constant below $(U - E_1) = (25/16)/a$. For the spin cutoff parameter $\sigma$ we have used the following expression proposed in Ref. [6], which is more adequate in the low energy region:

$$\sigma^2 = 0.0146A^{5/3}\frac{1+\sqrt{1+4a(U-E_1)}}{2a} \tag{4}$$

The level density parameter $a$ and the excitation energy shift $E_1$ ( the energy backshift) are considered to be free parameters in our approach, and were determined from a fit to the data of each nucleus from our set.

### *2. The BSFG model with energy dependence of "a"*

Microscopic calculations of LD's show that the shell effects are strongest at low excitation energies and are damped at high excitation energies. In the BSFG model the parameter $a$ has been taken independent of the energy, which means assuming that the shell effects continue to play a role at higher energies in the same way as at low energies. In order to include the damping of the shell effects, the following expression was proposed phenomenologically for the level density parameter [7, 8], which is inspired from microscopic treatments of the LD which show that $a$ must have an energy dependence:

$$a(U, Z, N) = \tilde{a}[1 + \frac{S(Z,N) - \Delta}{U - E_2}f(U - E_2)]; \tag{5}$$

where $\tilde{a}$ is the asymptotic value of the $a$ parameter (at high excitation energies). For the function $f$ the following form has been proposed [7, 9, 10]:

$$f(U - E_2) = 1 - e^{-\gamma(U-E_2)}; \tag{6}$$

$S(Z, N)$ is the so-called shell correction (or shell correction in the mass formula) defined as

$$S(Z, N) = M_{exp} - M_{LD} \tag{7}$$

where $M_{exp}$ is the experimental mass and $M_{LD}$ is the mass calculated with a macroscopic, liquid drop formula. The formula that we use for the liquid drop mass will be defined below. It does not include a pairing term. Therefore, the pairing $\Delta$ has to be subtracted, and this will be discussed later. Here we emphasize that in our present approach we use a formula for a spherical drop; this differs from other approaches which use liquid drop energies calculated for equilibrium shapes of nuclei [7, 8, 10]. We shall judge this choice from the point of view of the results we get and of a certain advantage for extrapolations to nuclei far from stability. In formula (5) we use $\gamma = 0.06$ MeV$^{-1}$, close to the values obtained, e.g., in Refs. [7, 8, 10]. In this approach the two free parameters that we determine from the fit to the data of each nucleus are $\tilde{a}$ and the corresponding backshift energy $E_2$.

*3. The constant temperature model*

The third model used is the constant temperature model (CT) [3], with

$$\rho(U) = \frac{1}{T} e^{(U-E_0)/T} \tag{8}$$

For the spin cut-off parameter $\sigma$, the formula $\sigma = 0.98A^{0.29}$ of Ref. [11] has been used in this case. The two free parameters of the model are the temperature $T$ and the backshift energy $E_0$. It was noted earlier that this simple model can give also good fits to data at both low energies and the neutron binding energy [11].

### B. The fit procedure and results

The set of data to which we fit the above level density formulas contains 310 nuclei between $^{19}$F and $^{251}$Cf. For these nuclei we have taken into consideration the current information on both the low-energy excited states [12] in a certain spin window and up to

a certain excitation energy, and on the level density at the neutron resonance energy [13]. The completeness of the low energy level scheme plays an important role. We checked it very carefully in the given energy and spin range. To judge the completeness we used our own experience, because we have been involved in level scheme construction since several decades. The level schemes are established by a large number of reactions and compared with theoretical expectations. The agreement between the predicted and measured level structure is frequently a good argument for the completeness. We assume that about 95% of the used levels are correctly placed. Table I lists all experimental quantities considered in the empirical fits. Additionally the three middle columns show the deuteron pairing, the shell correction and its derivative, all used for the interpretation of the level density parameters.

Each of the models considered above has two free parameters, which were fitted to the above mentioned data according to the procedure outlined in Ref. [11]. Namely, the calculated level spacings $D(U, J_1, J_2) = 1/\rho(U, J_1, J_2)$ in a spin window from $J_1$ to $J_2$ (where $\rho(U, J_1, J_2) = \sum_{J_1}^{J_2} \rho(U, J)$) are fitted to the experimental spacings $S_i = (U_{i+1} - U_i)$ including the average neutron resonance spacing $D_{res}$. For each nucleus, the following $\chi^2$ quantity has been minimized:

$$\chi^2 = \sum_i ((S_i - D_i)W_i)^2 + ((D_{res} - D(B_n, J_{res}))/\Delta D_{res})^2$$

The weight $W_i$ of the experimental spacings of adjacent levels is given by the spacing distribution, i.e., the fluctuation of level distances. The spacing of levels with different spins and parities follows a Poisson (exponential) distribution [11]

$$P(S/D) = e^{-S/D}$$

because the different quantum numbers prevent correlations between levels. The average value of an exponential function is 1 and the fluctuations correspond to the level spacing $D_i$. Consequently,

$$W_i = 1/D_i$$

However, $W_i$ is not varied in the fit procedure, because this would give a tendency towards too large $D_i$. Therefore, the fit procedure was repeated about four times and the weight was adjusted each time to the previously fitted $D_i$; this converged easily.

Usually the low energy level density is determined either by counting levels in arbitrary energy bins or by fitting the density function to the accumulated number of levels. Compared to these methods our fit to each individual level spacing has essential advantages, because we do not need arbitrary binning, the weight at very low energies where special nuclear structures play a role, is small, and we obtain automatically the correct errors of the level density parameters.

In general, for all the considered models, good fits have been obtained, with $\chi^2$ values close to 1, therefore all three models give a good description to both the low-energy level density and the average neutron resonance density.

Table II gives the model parameters obtained from the fit, which will be examined in the rest of the paper.

We emphasize here the main difference between our procedure and other approaches which also determined phenomenological parameters for the formulas outlined above. As said above, there are many sets of LD parameters based only on the neutron resonance level densities. In order to fit such data, very often one of the two model parameters has been eliminated (fixed to some values) leaving only one for the fit. Usually, it has been assumed that the energy shifts (or backshifts) $E_i$ were due only to the pairing, therefore they were related to the neutron and proton pairing energies $P_n$ and $P_p$, respectively. Thus, in many applications, the backshifts are kept fixed at values related to assumed pairing energies. A rough approximation is the simple functional dependence of the pairing gap $\delta = 12/\sqrt{A}$. Thus, in Ref. [10], the backshifts are chosen as $\chi\frac{12}{\sqrt{A}}$ with $\chi = 0, 1, 2$, for the odd-odd, odd-even, and even-even nuclei, respectively. Other descriptions are obtained by using pairing energies from the mass tables, like $1/2(P_p + P_n)$ (for even-even nuclei), - $1/2(P_p + P_n)$ (for odd-odd), and 0 (for odd-A) [9], or, as found empirically [14], -$1/3P_n(P_p)$ (for odd-Z(N) nuclei). By relating the backshifts to the nucleon pairing, implies putting all the shell effects in the second parameter of the model (e.g., $a$ in the case of the BSFG model). Nevertheless, it is not *a priori* obvious that the backshifts must depend only on the pairing. From this point of view, our procedure of leaving free in the fit both model parameters appears justified. Of course, the phenomenological values obtained in this way will have an increased usefulness if one succeeds to understand and systematize their behaviour.

## III. SYSTEMATICS OF THE LEVEL DENSITY PARAMETERS

### A. Results of the fits to the experimental level densities

Figure 1 shows, as an example, the quality of the BSFG and CT fits to the experimental cumulative number of levels of $^{26}$Al, one of the light nuclei with complete level scheme in the spin range 0-5$\hbar$, up to 8.2 MeV excitation. Figure 2 displays the results of the fits to the experimental data of Table I with the three two-parameter models: namely, the variation with the mass number of the parameters $a$ and $E_1$ of the BSFG model; $\tilde{a}$ and $E_2$ of the BSFG model with energy dependence (BSFG-ED); and $T$ and $E_0$ of the CT model.

These empirically determined parameters have, generally, a complicated behaviour. We note the following empirical observations. The parameters $a$, $\tilde{a}$, and $T$ do not show notable dependence on the type of nucleus (even-even, odd-A or odd-odd). $a$ shows a strong dependence on shell effects, having large variations at the shell closures, as observed in many other similar parameter sets (see, e.g., [1, 10]). Similarly, $T$ shows strong variations at the shell closures. The parameter $\tilde{a}$ is rather similar to that of other comparable evaluations [7, 10], although its absolute values correspond to our particular approach; the shell effects have almost disappeared in this parameter, due to the way they were incorporated in formula (5).

The back-shift energies $E_1, E_2$, and $E_0$ have an even more complicated behaviour, and in addition present a dependence on the type of the nucleus. In general, they are positive for the even-even nuclei, negative for the odd-odd nuclei, and smaller and negative for the odd-A nuclei, where they also show some notable oscillations. We note, however, that the behaviour of these parameters is very similar for all three models: $E_1$ and $E_2$ are almost identical, and there is a practically linear correlation between $E_0$ and $E_1$ (or $E_2$): Fig. 3 shows these correlations between $E_2$ and $E_1$, as well as between $E_0$ and $E_1$.

### B. Fits of the level density parameters as functions of various nuclear properties

It was tried to reproduce the deduced level density parameters by simple formulas using various values obtained from atomic masses and other tabulated experimental nuclear properties. For each level density parameter ($a$, $E_1$, $\tilde{a}$, $E_2$, $T$, $E_0$ ) a least squares program was written and a large variety of functions were fitted to the corresponding experimental

parameters of the 310 nuclides. Even-even, odd and odd-odd nuclei were frequently treated separately. Linear, quadratic, logarithmic, etc. dependencies were tried, but simple functions with few variables were preferred. In this way hundreds of $\chi^2$ values were produced and compared. The results of careful evaluations of all these calculations are presented in the following sections. Only the best results are given. The obtained normalized $\chi^2$ values lie between 2 and 4.

### C. Correlations of $a$, $\tilde{a}$ and $T$ with shell and pairing effects

As observed long time ago [3], and in many more recent publications, the level density parameter $a$ (Fig. 2) shows an almost linear dependence on A and a clear correlation with the shell correction $S$, eq. (7), having minima at the shell closures, where $S$ is negative. This allowed a description of this parameter in terms of a simple formula of the type $a/A = c_0 + c_1 S(Z,N)$ [3], with the two constants $c_0$ and $c_1$ suitably chosen. Indeed, the data shown in Fig. 2 can be described reasonably well by such a formula. The parameter $T$, which has an average dependence on mass as $A^{-2/3}$ [11], can be also well correlated with the shell correction. The dependence on $A^{-2/3}$ shows that the temperature $T$ decreases with increasing surface of the nucleus, because the surface nucleons are first excited. Bohr and Mottelson [15] define the temperature as $T \sim E/n_{ex}$, the average energy per excited nucleon, and $n_{ex}$ seems to be proportional to the surface. The parameter $\tilde{a}$ has an almost linear behaviour with mass, as proposed in Ref. [7].

We used the definition of the shell correction $S$ given by eq. (7). For the macroscopic, liquid drop mass calculation, we have chosen the recent Weizsäcker type formula proposed by Pearson [16], which gives a good description of nearly 2000 nuclear masses with just 5 parameters. This formula does not contain shell and pairing effects. With the definition of the nuclear binding energy as $E_b = NM_n + ZM_p - M(N,Z)c^2$, and $M(N,Z)$ the nuclear mass, this formula reads [16]

$$-\frac{E_b}{A} = a_{vol} + a_{sf}A^{-1/3} + \frac{3e^2}{5r_0}Z^2A^{-4/3} + (a_{sym} + a_{ss}A^{-1/3})(\frac{N-Z}{A})^2 \qquad (9)$$

with the parameter values (fitted to about 2000 mass values) being: $a_{vol} = -15.65$ MeV, $a_{sf} = 17.63$ MeV, $a_{sym} = 27.72$ MeV, $a_{ss} = -25.60$ MeV, and $r_0 = 1.233$fm. The shell correction $S(Z,N)$ (7), calculated from experimental masses [17] and this mass formula, is

given in Table I and also shown in the first panel of Fig. 4. As commented above, the LD parameters $a$ and $T$ (Fig. 1) are very well correlated with this quantity.

The $S$ values in Fig. 4 show slightly different curves for even-even, odd and odd-odd nuclei. Consequently a pairing correction has to be applied:

$$S' = S - \Delta \tag{10}$$

Various types of pairing corrections $\Delta$ were introduced in the fit procedures of $a$ and $T$. The best results were obtained with

$$\Delta = \begin{cases} 0.5P_d & \text{for even-even,} \\ 0 & \text{for odd-A,} \\ -0.5 & \text{for odd-odd nuclei} \end{cases} \tag{11}$$

The fitted factor in front of $P_d$ was always within the error bars close to 0.5 or 0.0; therefore we set it fixed to 0.5 or 0.0, respectively, because this is also reasonable from the physics point of view. $P_d$ is the so-called deuteron pairing [17, 18] calculated from mass tables in a similar way as $P_n$ and $P_p$:

$$P_d = \frac{1}{4}(-1)^{Z+1}[S_d(A+2, Z+1) - 2S_d(A, Z) + S_d(A-2, Z-1)],$$

where $S_d$ is the deuteron separation energy. The $P_d$ values are shown in Fig. 3. They are very similar for even-even and odd-odd nuclei and smaller, close to 0.0, for odd-mass nuclei.

### D. Correlations of $E_1$, $E_2$ and $E_0$

Inspection of Fig. 2 demonstrates that the back-shift curves are quite different for even-even, odd and odd-odd nuclei. The curves for the even-even nuclei are relatively smooth, while the odd-odd nuclei exhibit more fluctuations and odd nuclei have strong variations. Therefore a pairing correction has to be introduced. Again, comparison of various pairing corrections showed that $P_d$ is the best choice. Indeed, by comparing Figs. 2 and 4 one can realize that some fraction of $P_d$ describes already rather well the behaviour of $E_1, E_2, E_0$. In particular, $P_d$ appears to be a natural choice for the back-shifts of the odd-A nuclei, as it has smaller values than those for the even-even and odd-odd nuclei, and, moreover, it has a behaviour which correlates well with some of the variations observed in these back-shifts.

A closer look at these correlations showed that some structures in the back-shifts $E_i$ remain still unaccounted for - for example, the oscillation around mass 200, which is due to the 82 shell closure. This structure, as well as some other, smaller details, were found well correlated with the derivative of the shell correction $S(Z,N)$ of eq. (7) with respect to $A$. We calculate this numerically from the mass tables; it can be calculated in many ways, from differences of masses of two nearby nuclei, but, since we found that $P_d$ has some relevance for our problem, we calculate this as

$$\frac{dS(Z,N)}{dA} = [S(Z+1,N+1) - S(Z-1,N-1)]/4 \tag{12}$$

This derivative is also given in the $7^{th}$ column of Table I, and is shown in Fig. 4.

Other quantities which we have considered when looking for useful correlations were: (i) The energy of the first excited ($2_1^+$) state in the even-even nuclei (and averages of this value on the neighbouring nuclei in the case of the odd-A and odd-odd nuclei). This quantity is also shown in Fig. 4. As it is well known, its variations reflect the effects of the shell closures and collectivity. (ii) Alternatively, we have considered the quadrupole deformation parameter $\varepsilon_2$ as calculated by Möller and Nix [19]. One could find some good correlations between these quantities and the structures in our parameters, but not better than those with the other quantities in Fig. 4. In addition, when thinking about nuclei far from stability, relying on such quantities as $E(2_1^+)$ and/or $\varepsilon_2$, would have required the use of other extrapolation methods, or of some model.

### E. Fit with simple formulas

Finally, our procedure was to fit the LD parameters of Fig. 2 with simple formulas, in general linear (or at most quadratic) combinations of quantities from Fig. 4 with which we recognize useful correlations: $S(Z,N)$, $dS(Z,N)/dA$, $P_d$, and the mass number $A$. As mentioned above, we have studied a large number of such formulas with up to 10 parameters, and have selected those with a good $\chi^2$. Since these formulas were empirical, we have finally preferred those with less parameters, and with some symmetry. As emphasized above, for $a$ and $T$, the deuteron pairing $P_d$ was initially multiplied with an arbitrary coefficient, but after fitting the data, this was found to converge towards values close to either 1.0 or 0.5, which were subsequently kept in the final fit.

### 1. The BSFG model

There is a very clear correlation between the $a$ parameter and the shell correction $S(Z,N)$, which has been observed since the work of Ref. [3]. As explained above, we observed that the fit of $a/A$ is improved if one uses $S'$ of eq. (10) instead of $S$, and one adds a small $A$-dependence. So, the formula adopted for $a/A$ is the following:

$$a/A = p_1 + p_2 S'(Z,N) + p_3 A \qquad \text{for all nuclei} \tag{13}$$

with the $p_1,\ p_2,\ p_3$ constants given in Table III.

For the back-shift energy parameter, $E_1$ the adopted formula is

$$E_1 = \begin{cases} p_1 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA} & \text{even-even} \\ p_2 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA} & \text{odd-A} \\ p_3 + 0.5P_d + p_4 \frac{dS(Z,N)}{dA} & \text{odd-odd} \end{cases} \tag{14}$$

with the $p_1, ..., p_4$ values from Table III. One should note that we keep the same notation ($p_i$) for the parameters in the formulas (13) and (14) just for the compactness of Table III, but the $p_i$'s in (13) are completely independent from those in (14). The fits with the above formulas are shown in Fig. 5.

### 2. The BSFG-ED model

A similar approach to the BSFG model with energy dependence of the $a$ parameter, eqs. (5-7), led to the following formulas:

$$\tilde{a}/A = p_1 + p_3 A \qquad \text{all nuclei} \tag{15}$$

and

$$E_2 = \begin{cases} p_1 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA} & \text{even-even} \\ p_2 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA} & \text{odd-A} \\ p_3 + 0.5P_d + p_4 \frac{dS(Z,N)}{dA} & \text{odd-odd} \end{cases} \tag{16}$$

with the fitted $p_i$ parameter values shown in Table III, and the fits from Fig. 6. The use of eqs. (5-7) has practically eliminated the dependence on the shell correction, leaving $\tilde{a}/A$

with a practically linear dependence on mass $A$, as shown for the first time in [7]. It is very gratifying that the appropriate parameters in formulas (13) and (15) came out to have the same values (see Table III). Also, as remarked above, $E_1$ and $E_2$ are practically identical, so that formulas (14) and (16) are the same, with the same fit values of the parameters $p_i$. So, actually, the BSFG and BSFG-ED formulas are equivalent; the only difference between them is the way each of these models uses the shell correction term $S(Z,N)$.

*3. The CT model*

For the constant temperature model the fitted formulas are:

$$T \cdot A^{2/3} = p_1 + p_2 S' + p_3 S'^2 \tag{17}$$

and

$$E_0 = \begin{cases} p_1 - 0.5P_d + p_2 \frac{dS(Z,N)}{dA} & \text{even-even} \\ p_3 - \quad P_d + p_4 \frac{dS(Z,N)}{dA} & \text{odd-A} \\ p_1 + 0.5P_d + p_2 \frac{dS(Z,N)}{dA} & \text{odd-odd} \end{cases} \tag{18}$$

which is similar with (13), (15). The values of the fitted parameters, and the fits are shown in Table III and Fig. 7, respectively.

## IV. CONCLUSIONS

Fig. 8 shows a detailed comparison between the experimental neutron resonance density and the one calculated with the empirical formulas presented above (with the parameter values from Table III). It can be seen that for both the BSFG and BSFG-ED models the experimental data are reproduced within a factor of 2, for less than 10% of the data the agreement being worse. For the CT model the general agreement is somewhat weaker. In all three models there are still problems near $N = 50$ and $N = 82$, while in other regions a smooth behaviour and good agreement is observed.

The result of our investigation is a new set of nuclear level density parameters for 310 nuclei between $^{19}$F and $^{251}$Cf, for three two-parameter models (BSFG, BSFG-ED, and CT), by fitting the newest complete experimental data for both the low-energy excited states and the level density at the neutron binding energy. The empirical LD model parameters for all nuclei have been described by simple formulas with few parameters. Figures 5, 6,

and 7 show that the simple formulas proposed, (13) to (18), with the parameters given in Table III, describe reasonably well the whole set of empirical LD parameters (Table II). It is remarkable that these formulas describe also the main features of the back-shift energies $E_i$ which were determined from the data as free fit parameters.

The proposed formulas involve only the 'shell correction' (the difference between the experimental mass and the mass calculated with a macroscopic formula), its derivative with respect to the mass, and the deuteron pairing energy $P_d$. All these quantities can be taken or derived from the mass tables [17], so in essence our formulas calculate the level densities from nuclear masses. The formulas do not depend on any model; in extrapolating them to nuclei far from stability we only have to rely on the methods of extrapolation developed for the nuclear masses [20]. This means also that the coarse structure of the nuclei at higher excitations is mainly determined by the mass of the ground state.

Our formulas (13)-(18) (with parameter values from Table III) are completely empirical. Their derivation is based on the observation of the correlations between the phenomenological LD parameters and the (mass related) quantities entering these formulas. It remains a challenge for the theory to justify such empirical formulas. Since we did not guide ourselves on theoretical approaches to the level densities, it may be that we have not chosen the "most appropriate" functional forms. Nevertheless, this empirical study highlights a few points which need a deeper understanding. First, the finding that the deuteron pairing energy is more useful for the description of the LD parameters than the neutron and proton pairings (or their smooth description $\delta = 12/\sqrt{A}$), which were the only ones considered until now, is remarkable. Then, the finding that the inclusion of the derivative of the shell correction with respect to the mass helps to describe better the level densities, is equally interesting.

The present method of calculating level density parameters for nuclei for which there are no experimental data available, not from some local systematics and/or by some arbitrary extrapolation, but by using the formulas proposed above, seems to be a reasonable way of extrapolation to nuclei far from stability. The BSFG and CT models with parameters calculated with the formulas (13),(14), and (17), (18), respectively, may be safely used up to the neutron binding energy or slightly higher energies. The BSFG-ED model (BSFG with energy dependent level density parameter), formulas (15), (16), may be recommended up to higher energies ($\sim$15-20 MeV), since it contains the recommended damping of the shell

effects with increasing excitation energy.

We wish to thank G. Audi, T. Belgya, R. Capote Noy, R.F. Casten, M. Herman and F.-K. Thielemann for fruitful discussions and for providing data.

---

[1] A.V. Ignatyuk, IAEA-TECDOC-1034, IAEA, Vienna, 1998, p.65

[2] P. Demetriou and S. Goriely, Nucl. Phys. **A695**, 95 (2001)

[3] A. Gilbert and A.G.W. Cameron, Can. J. Phys. **43**, 1446 (1965); P.J. Brancazio and A.G.W. Cameron, Can. J. Phys. **47**, 1029 (1969)

[4] W. Dilg, W. Schantl, H. Vonach, and M. Uhl, Nucl. Phys. **217**, 269 (1973)

[5] D. Bucurescu and T. von Egidy, presented at the NUSTAR'05 Conference (Guidford, Jan. 5-8, 2005), and to be published in J. Phys. **G** (Nuclear Physics)

[6] Huang Zhongfu, He Ping, Su Zongdi, and Zhou Chunmei, Chin. J. Nucl. Phys. **13**, 147 (1991)

[7] A.V. Ignatyuk, G.N. Smirenkin, and A.S. Tishin, Sov. J. Nucl. Phys. **21**, 255 (1975)

[8] A.V. Ignatyuk, K.K. Istekov, and G.N. Smirenkin, Sov. J. Nucl. Phys. **29**, 450 (1979)

[9] T. Rauscher, F-K. Thielemann, and K-L. Kratz, Phys. Rev. **C56**, 1613 (1997)

[10] A.S. Iljinov, M.V. Mebel, N. Bianchi, E. De Sanctis, C. Guaraldo, V. Lucherini, V. Muccifora, E. Polli, A.R. Reolon, and P. Rossi, Nucl. Phys. **A543**, 450 (1979)

[11] T. von Egidy, H.H. Schmidt, and A.N. Behkami, Nucl. Phys. **A481**, 189 (1988)

[12] R.B. Firestone *et al.*, Table of Isotopes, John Wiley, New York, 1996; and the ENSDF database

[13] G. Reffo, IAEA-TECDOC-1034, IAEA, Vienna, 1998, p. 25; R. Capote Noy, personal communication (2004) and the RIPL-2 database, http://www-nds.iaea.org

[14] Po-lin Huang, S.M. Grimes, and T.N. Massey, Phys. Rev. **C62**, 024002 (2000)

[15] A. Bohr and B.R. Mottelson, Nuclear Structure, Vol. I, W.A. Benjamin, Inc. New York, Amsterdam 1969, p. 155

[16] J.M. Pearson, Hyp. Interactions **132**, 59 (2001)

[17] G. Audi, A.H. Wapstra, and C. Thibault, Nucl. Phys. **A729**, 337 (2003)

[18] The AME2003 files, retrieved from http://csnwww.in2p3.fr/amdc

[19] P. Möller and J.R. Nix, At. data Nucl. Data Tables **59**, 95 (1995)

[20] A.H. Wapstra, G. Audi, and C. Thibault, Nucl. Phys. **A729**, 129 (2003)

TABLE I: Experimental data used for the determination of level density parameters. The first columns give information concerning the lwo-energy, discrete levels, the last columns that concerning the level density at the neutron binding energies, while the three columns in the middle contain the deuteron pairing, the shell correction (calculated with eq. (7), (9)), and its derivative with respect to the mass (12).

| | Energy range [MeV] | Spin window [$\hbar$] | Number of levels | Deuteron pairing [a]) [MeV] | Shell energy [b]) [MeV] | $\Delta$ Shell energy [c]) [MeV] | n binding energy [MeV] | Spin [$\hbar$] | Density per MeV |
|---|---|---|---|---|---|---|---|---|---|
| $^{18}$F | 6.88 | 0 - 4 | 47 | -6.763 | 1.586 | 0.900 | 9.149 | | |
| $^{19}$F | 8.32 | 1/2 -11/2 | 60 | -1.783 | 1.792 | 0.383 | 10.432 | | |
| $^{20}$F | 4.60 | 0 - 3 | 26 | -4.386 | 4.131 | 0.005 | 6.601 | 0 - 1 | 6( 2) |
| $^{20}$Ne | 13.97 | 0 - 6 | 103 | -4.886 | -3.358 | -0.028 | 16.865 | | |
| $^{23}$Na | 8.98 | 1/2 - 7/2 | 77 | 0.068 | 0.174 | -0.278 | 12.419 | | |
| $^{24}$Na | 4.57 | 0 - 4 | 30 | -3.702 | 2.854 | -0.307 | 6.960 | 1 - 2 | 11( 3) |
| $^{24}$Mg | 12.00 | 0 - 4 | 66 | -5.237 | -4.325 | -0.292 | 16.531 | | |
| $^{25}$Mg | 7.97 | 1/2 - 9/2 | 58 | 0.170 | -0.339 | -0.357 | 7.331 | 1/2 | 2( 1) |
| $^{26}$Mg | 8.58 | 0 - 4 | 51 | -3.580 | -1.503 | -0.412 | 11.093 | 2 - 3 | 23( 9) |
| $^{27}$Mg | 5.93 | 1/2 - 7/2 | 31 | -0.800 | 0.726 | -0.348 | 6.443 | 1/2 | 4( 1) |
| $^{26}$Al | 8.19 | 0 - 5 | 160 | -5.503 | 0.305 | -0.451 | 11.366 | | |
| $^{27}$Al | 8.00 | 1/2 -11/2 | 65 | -0.347 | -1.256 | -0.651 | 13.058 | | |
| $^{28}$Al | 5.01 | 1 - 4 | 33 | -3.473 | 1.206 | -0.407 | 7.725 | 2 - 3 | 22( 7) |
| $^{28}$Si | 11.59 | 0 - 6 | 62 | -5.287 | -6.129 | -0.591 | 17.180 | | |
| $^{29}$Si | 9.00 | 1/2 - 9/2 | 68 | -1.076 | -2.943 | -0.327 | 8.474 | 1/2 | 5( 2) |
| $^{30}$Si | 9.97 | 0 - 4 | 77 | -3.855 | -3.133 | -0.269 | 10.609 | 0 - 1 | 3( 1) |
| $^{30}$P | 8.02 | 0 - 5 | 107 | -3.554 | -2.060 | 0.237 | 11.319 | | |
| $^{31}$P | 7.15 | 1/2 - 9/2 | 45 | 0.200 | -2.564 | 0.266 | 12.312 | | |
| $^{32}$P | 4.88 | 0 - 4 | 35 | -2.877 | 0.132 | 0.166 | 7.936 | 0 - 1 | 13( 4) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{32}$S | 8.87 | 0 - 4 | 44 | -3.696 | -5.181 | 0.265 | 15.042 | | |
| $^{33}$S | 4.95 | 1/2 -11/2 | 22 | 0.141 | -1.877 | 0.247 | 8.642 | 1/2 | 7( 2) |
| $^{34}$S | 6.49 | 0 - 4 | 25 | -3.018 | -2.470 | 0.179 | 11.417 | 1 - 2 | 37( 14) |
| $^{35}$S | 4.11 | 1/2 - 7/2 | 17 | 0.203 | 0.332 | 0.242 | 6.986 | 1/2 | 5( 2) |
| $^{36}$Cl | 3.97 | 1 - 3 | 19 | -2.801 | 0.848 | 0.228 | 8.580 | 1 - 2 | 44( 11) |
| $^{38}$Cl | 1.99 | 0 - 3 | 8 | -3.054 | 3.523 | 0.560 | 6.108 | 1 - 2 | 67( 18) |
| $^{38}$Ar | 8.00 | 0 - 6 | 80 | -3.186 | -1.557 | 0.360 | 11.838 | | |
| $^{40}$Ar | 5.98 | 0 - 6 | 58 | -2.630 | 1.510 | 0.270 | 9.869 | | |
| $^{41}$Ar | 2.41 | 1/2 - 5/2 | 9 | 0.129 | 3.901 | 0.006 | 6.099 | 1/2 | 14( 4) |
| $^{40}$K | 3.49 | 1 - 3 | 28 | -3.096 | 2.287 | 0.343 | 7.800 | 1 - 2 | 67( 22) |
| $^{41}$K | 5.03 | 5/2 - 9/2 | 50 | -0.266 | 2.594 | 0.100 | 10.095 | 7/2 - 9/2 | 400( 43) |
| $^{42}$K | 1.26 | 0 - 6 | 12 | -3.233 | 4.603 | -0.109 | 7.534 | 1 - 2 | 67( 22) |
| $^{40}$Ca | 8.49 | 0 - 4 | 57 | -4.385 | -4.209 | 0.288 | 15.643 | | |
| $^{41}$Ca | 4.10 | 1/2 -11/2 | 26 | -0.140 | -0.168 | 0.573 | 8.363 | 1/2 | 31( 4) |
| $^{43}$Ca | 2.28 | 1/2 - 7/2 | 13 | -0.095 | 2.459 | -0.055 | 7.933 | 1/2 | 50( 13) |
| $^{44}$Ca | 3.72 | 0 - 4 | 13 | -3.079 | 1.076 | -0.262 | 11.131 | 3 - 4 | 556( 93) |
| $^{45}$Ca | 2.85 | 1/2 - 7/2 | 15 | -0.349 | 2.628 | -0.402 | 7.415 | 1/2 | 41( 6) |
| $^{46}$Sc | 1.93 | 2 - 5 | 27 | -3.221 | 3.554 | -0.409 | 8.761 | 3 - 4 | 769( 59) |
| $^{47}$Ti | 2.53 | 1/2 - 5/2 | 12 | -0.420 | 0.945 | -0.540 | 8.880 | 1/2 | 40( 7) |
| $^{48}$Ti | 4.08 | 0 - 4 | 20 | -2.998 | -0.562 | -0.597 | 11.627 | 2 - 3 | 570( 80) |
| $^{49}$Ti | 2.67 | 1/2 - 7/2 | 11 | -0.292 | 0.680 | -0.600 | 8.142 | 1/2 | 55( 9) |
| $^{50}$Ti | 4.95 | 0 - 4 | 14 | -3.458 | -1.570 | -0.261 | 10.939 | 3 - 4 | 250( 50) |
| $^{51}$Ti | 3.24 | 1/2 - 7/2 | 12 | -0.527 | 0.088 | 0.266 | 6.372 | 1/2 | 8( 4) |
| $^{51}$V | 3.39 | 1/2 - 9/2 | 17 | 0.280 | -0.309 | -0.395 | 11.051 | 1/2 | 430( 110) |
| $^{52}$V | 2.11 | 1 - 5 | 15 | -2.738 | 1.277 | 0.011 | 7.311 | 3 - 4 | 240( 40) |
| $^{51}$Cr | 3.01 | 1/2 - 9/2 | 20 | -0.126 | -1.124 | -0.642 | 9.261 | 1/2 | 75( 7) |
| $^{53}$Cr | 3.00 | 1/2 - 7/2 | 14 | -0.329 | -0.902 | -0.172 | 7.939 | 1/2 | 23( 2) |
| $^{54}$Cr | 3.93 | 0 - 4 | 16 | -2.757 | -1.527 | -0.066 | 9.719 | 1 - 2 | 130( 13) |
| $^{55}$Cr | 2.60 | 1/2 - 9/2 | 16 | -0.440 | 0.694 | -0.005 | 6.246 | 1/2 | 16( 2) |
| $^{56}$Mn | 2.11 | 1 - 3 | 31 | -2.633 | 1.013 | -0.089 | 7.270 | 2 - 3 | 430( 80) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{55}$Fe | 2.58 | 1/2 - 7/2 | 11 | -0.463 | -3.274 | -0.265 | 9.298 | 1/2 | 56( 7) |
| $^{57}$Fe | 3.00 | 1/2 - 9/2 | 36 | -0.211 | -1.293 | -0.083 | 7.646 | 1/2 | 39( 4) |
| $^{58}$Fe | 3.76 | 0 - 4 | 17 | -2.874 | -1.882 | -0.052 | 10.045 | 0 - 1 | 154( 24) |
| $^{59}$Fe | 2.17 | 1/2 - 7/2 | 15 | -0.471 | 0.395 | -0.128 | 6.581 | 1/2 | 39( 8) |
| $^{60}$Co | 2.32 | 2 - 5 | 37 | -2.801 | 0.805 | -0.098 | 7.492 | 3 - 4 | 800( 96) |
| $^{59}$Ni | 2.49 | 1/2 - 7/2 | 13 | -0.492 | -3.637 | 0.097 | 8.999 | 1/2 | 75( 5) |
| $^{60}$Ni | 3.60 | 0 - 3 | 12 | -3.150 | -4.020 | 0.082 | 11.388 | 1 - 2 | 500( 180) |
| $^{61}$Ni | 2.70 | 1/2 - 9/2 | 25 | -0.317 | -1.460 | 0.053 | 7.820 | 1/2 | 73( 5) |
| $^{62}$Ni | 3.47 | 0 - 4 | 14 | -3.209 | -2.274 | 0.025 | 10.597 | 1 - 2 | 480( 34) |
| $^{63}$Ni | 1.46 | 1/2 - 7/2 | 9 | -0.432 | 0.098 | -0.039 | 6.838 | 1/2 | 63( 12) |
| $^{65}$Ni | 1.93 | 1/2 - 7/2 | 11 | -0.546 | 1.143 | -0.133 | 6.098 | 1/2 | 51( 8) |
| $^{64}$Cu | 1.51 | 0 - 3 | 22 | -2.399 | 0.903 | 0.349 | 7.916 | 1 - 2 | 1050( 100) |
| $^{66}$Cu | 1.98 | 0 - 3 | 28 | -2.295 | 2.138 | 0.326 | 7.066 | 1 - 2 | 770( 70) |
| $^{65}$Zn | 1.95 | 1/2 - 5/2 | 14 | 0.318 | 0.103 | 0.412 | 7.979 | 1/2 | 280( 13) |
| $^{67}$Zn | 1.69 | 1/2 - 7/2 | 18 | 0.415 | 1.601 | 0.368 | 7.052 | 1/2 | 216( 26) |
| $^{68}$Zn | 3.41 | 0 - 4 | 16 | -2.423 | 0.407 | 0.303 | 10.198 | 2 - 3 | 2500( 380) |
| $^{69}$Zn | 2.09 | 1/2 - 5/2 | 18 | 0.312 | 2.425 | 0.347 | 6.482 | 1/2 | 180( 14) |
| $^{71}$Zn | 1.80 | 1/2 - 5/2 | 10 | 0.391 | 2.936 | 0.247 | 5.834 | 1/2 | 140( 15) |
| $^{70}$Ga | 1.27 | 0 - 4 | 16 | -2.386 | 3.349 | 0.235 | 7.654 | 0 - 1 | 2860( 490) |
| $^{72}$Ga | 1.04 | 0 - 4 | 20 | -2.904 | 4.389 | 0.085 | 6.520 | 1 - 2 | 2630( 420) |
| $^{71}$Ge | 1.61 | 1/2 - 7/2 | 29 | 0.234 | 2.778 | 0.312 | 7.416 | 1/2 | 1120( 300) |
| $^{73}$Ge | 1.16 | 1/2 - 9/2 | 21 | 0.289 | 3.395 | 0.151 | 6.783 | 1/2 | 667( 130) |
| $^{74}$Ge | 2.98 | 0 - 4 | 24 | -2.983 | 1.562 | 0.032 | 10.196 | 4 - 5 | 16100( 3900) |
| $^{75}$Ge | 1.43 | 1/2 - 9/2 | 24 | -0.048 | 2.967 | -0.010 | 6.505 | 1/2 | 330( 110) |
| $^{77}$Ge | 1.05 | 1/2 - 9/2 | 14 | -0.163 | 1.999 | -0.064 | 6.072 | 1/2 | 220( 70) |
| $^{76}$As | 0.81 | 0 - 4 | 37 | -2.935 | 4.518 | -0.034 | 7.328 | 1 - 2 | 13000( 1350) |
| $^{75}$Se | 1.21 | 1/2 - 7/2 | 26 | -0.073 | 3.070 | -0.011 | 8.028 | 1/2 | 2940( 690) |
| $^{77}$Se | 1.01 | 1/2 - 7/2 | 16 | -0.049 | 3.240 | -0.058 | 7.419 | 1/2 | 1540( 240) |
| $^{78}$Se | 2.91 | 0 - 6 | 28 | -2.937 | 1.425 | -0.122 | 10.498 | 0 - 1 | 9100( 2500) |
| $^{79}$Se | 1.50 | 1/2 - 9/2 | 28 | 0.028 | 2.709 | -0.156 | 6.963 | 1/2 | 500( 125) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{81}$Se | 1.84 | 1/2 - 9/2 | 19 | -0.067 | 1.334 | -0.314 | 6.701 | 1/2 | 500( 200) |
| $^{83}$Se | 1.72 | 1/2 - 5/2 | 15 | 0.231 | -0.099 | -0.310 | 5.818 | 1/2 | 200( 100) |
| $^{80}$Br | 0.78 | 0 - 5 | 36 | -2.918 | 4.029 | -0.201 | 7.892 | 1 - 2 | 21300( 2300) |
| $^{82}$Br | 1.00 | 0 - 5 | 22 | -2.599 | 2.672 | -0.319 | 7.593 | 1 - 2 | 9500( 1400) |
| $^{79}$Kr | 1.14 | 1/2 -11/2 | 30 | -0.098 | 2.712 | -0.155 | 8.334 | 1/2 | 4000( 1300) |
| $^{81}$Kr | 1.40 | 1/2 - 7/2 | 21 | -0.122 | 2.608 | -0.220 | 7.873 | 1/2 | 3570( 770) |
| $^{84}$Kr | 3.23 | 0 - 5 | 16 | -2.309 | -0.659 | -0.557 | 10.521 | 4 - 5 | 5000( 2500) |
| $^{85}$Kr | 2.75 | 1/2 - 9/2 | 30 | 0.323 | -0.030 | -0.561 | 7.121 | 1/2 | 1000( 100) |
| $^{86}$Rb | 1.83 | 0 - 5 | 24 | -2.429 | 0.445 | -0.707 | 8.651 | 2 - 3 | 5900( 1000) |
| $^{88}$Rb | 1.92 | 0 - 4 | 21 | -1.995 | -0.123 | 0.154 | 6.082 | 1 - 2 | 560( 90) |
| $^{85}$Sr | 1.99 | 1/2 - 9/2 | 27 | -0.056 | 0.996 | -0.619 | 8.530 | 1/2 | 3100( 1200) |
| $^{87}$Sr | 3.24 | 1/2 - 3/2 | 17 | 0.054 | -0.823 | -0.880 | 8.428 | 1/2 | 385( 118) |
| $^{88}$Sr | 4.31 | 0 - 5 | 17 | -3.305 | -3.489 | -0.359 | 11.113 | 4 - 5 | 3400( 1000) |
| $^{89}$Sr | 3.14 | 1/2 - 9/2 | 18 | -0.738 | -1.787 | 0.214 | 6.359 | 1/2 | 42( 5) |
| $^{90}$Y | 2.19 | 0 - 3 | 16 | -1.700 | -0.992 | 0.354 | 6.857 | 0 - 1 | 270( 30) |
| $^{91}$Zr | 2.94 | 1/2 - 9/2 | 25 | -0.435 | -2.163 | 0.456 | 7.195 | 1/2 | 167( 39) |
| $^{92}$Zr | 3.20 | 0 - 5 | 19 | -2.028 | -2.071 | 0.431 | 8.635 | 2 - 3 | 1820( 330) |
| $^{93}$Zr | 2.19 | 1/2 - 5/2 | 12 | -0.554 | -0.454 | 0.362 | 6.734 | 1/2 | 286( 65) |
| $^{94}$Zr | 2.37 | 0 - 4 | 9 | -2.058 | -0.689 | 0.346 | 8.221 | 2 - 3 | 6250( 590) |
| $^{95}$Zr | 2.38 | 1/2 - 5/2 | 11 | -0.743 | 0.482 | 0.273 | 6.462 | 1/2 | 310( 80) |
| $^{97}$Zr | 2.27 | 1/2 - 9/2 | 10 | -1.180 | 1.293 | 0.494 | 5.575 | 1/2 | 77( 18) |
| $^{94}$Nb | 1.01 | 2 - 5 | 23 | -2.258 | 0.733 | 0.231 | 7.228 | 4 - 5 | 12500( 1600) |
| $^{93}$Mo | 2.55 | 1/2 - 9/2 | 19 | -0.479 | -3.057 | 0.201 | 8.070 | 1/2 | 370( 70) |
| $^{95}$Mo | 1.43 | 1/2 - 7/2 | 11 | -0.493 | -0.984 | 0.163 | 7.369 | 1/2 | 758( 103) |
| $^{96}$Mo | 2.60 | 0 - 4 | 17 | -2.394 | -1.149 | 0.214 | 9.154 | 2 - 3 | 9520( 910) |
| $^{97}$Mo | 1.57 | 1/2 - 7/2 | 25 | -0.488 | 0.653 | 0.160 | 6.821 | 1/2 | 950( 180) |
| $^{98}$Mo | 2.58 | 0 - 6 | 28 | -2.302 | 0.279 | 0.261 | 8.643 | 2 - 3 | 13300( 3600) |
| $^{99}$Mo | 1.26 | 1/2 - 9/2 | 23 | 0.005 | 2.276 | 0.252 | 5.925 | 1/2 | 1000( 200) |
| $^{101}$Mo | 0.99 | 1/2 - 9/2 | 34 | -0.049 | 3.433 | 0.013 | 5.398 | 1/2 | 1250( 230) |
| $^{100}$Tc | 0.72 | 2 - 5 | 27 | -2.589 | 3.014 | 0.029 | 6.764 | 4 - 5 | 83300( 9000) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{100}$Ru | 2.50 | 0 - 6 | 23 | -2.618 | -0.994 | -0.024 | 9.673 | 2 - 3 | 40000( 6400) |
| $^{102}$Ru | 2.05 | 0 - 4 | 13 | -2.615 | 0.397 | -0.044 | 9.220 | 2 - 3 | 55600( 9300) |
| $^{103}$Ru | 0.88 | 1/2 -11/2 | 27 | -0.168 | 2.360 | -0.122 | 6.232 | 1/2 | 1820( 500) |
| $^{105}$Ru | 0.89 | 1/2 - 5/2 | 23 | -0.197 | 2.962 | -0.173 | 5.910 | 1/2 | 3330( 830) |
| $^{104}$Rh | 0.74 | 1 - 3 | 40 | -2.550 | 2.837 | -0.098 | 6.999 | 0 - 1 | 31300( 3900) |
| $^{105}$Pd | 1.11 | 1/2 - 9/2 | 23 | -0.201 | 0.785 | -0.137 | 7.094 | 1/2 | 4170( 520) |
| $^{106}$Pd | 2.41 | 0 - 4 | 21 | -2.627 | 0.006 | -0.144 | 9.561 | 2 - 3 | 97100( 4700) |
| $^{107}$Pd | 0.79 | 1/2 -11/2 | 15 | -0.083 | 1.922 | -0.138 | 6.536 | 1/2 | 3700( 1200) |
| $^{108}$Pd | 2.43 | 0 - 6 | 20 | -2.613 | 0.826 | -0.129 | 9.228 | 2 - 3 | 90900( 7400) |
| $^{109}$Pd | 0.68 | 1/2 - 7/2 | 20 | -0.065 | 2.490 | -0.128 | 6.154 | 1/2 | 5490( 1000) |
| $^{111}$Pd | 0.67 | 1/2 - 9/2 | 16 | 0.018 | 2.678 | -0.157 | 5.726 | 1/2 | 6700( 2200) |
| $^{108}$Ag | 0.69 | 0 - 4 | 26 | -2.526 | 2.260 | -0.178 | 7.271 | 0 - 1 | 45500( 8300) |
| $^{110}$Ag | 0.71 | 1 - 3 | 45 | -2.592 | 3.093 | -0.206 | 6.809 | 0 - 1 | 66200( 6100) |
| $^{107}$Cd | 1.60 | 1/2 - 7/2 | 26 | -0.206 | -1.177 | -0.169 | 7.924 | 1/2 | 7410( 1920) |
| $^{109}$Cd | 1.48 | 1/2 - 7/2 | 23 | -0.110 | 0.193 | -0.204 | 7.327 | 1/2 | 8300( 2100) |
| $^{111}$Cd | 1.56 | 1/2 - 7/2 | 36 | -0.211 | 1.016 | -0.251 | 6.976 | 1/2 | 6450( 830) |
| $^{112}$Cd | 2.16 | 0 - 4 | 13 | -2.564 | 0.003 | -0.306 | 9.394 | 0 - 1 | 50000( 10000) |
| $^{113}$Cd | 1.41 | 1/2 - 7/2 | 42 | -0.171 | 1.538 | -0.294 | 6.540 | 1/2 | 5260( 690) |
| $^{114}$Cd | 2.81 | 0 - 3 | 30 | -2.584 | 0.271 | -0.308 | 9.043 | 0 - 1 | 40300( 4200) |
| $^{115}$Cd | 1.37 | 1/2 - 7/2 | 27 | -0.102 | 1.614 | -0.314 | 6.141 | 1/2 | 4260( 630) |
| $^{117}$Cd | 1.36 | 1/2 - 7/2 | 19 | -0.080 | 1.256 | -0.380 | 5.777 | 1/2 | 2560( 590) |
| $^{114}$In | 0.84 | 2 - 5 | 12 | -2.482 | 1.870 | -0.350 | 7.274 | 4 - 5 | 76900( 17700) |
| $^{116}$In | 0.90 | 3 - 4 | 20 | -2.588 | 2.150 | -0.399 | 6.785 | 4 - 5 | 105300( 5500) |
| $^{113}$Sn | 1.87 | 1/2 - 7/2 | 24 | -0.633 | -0.775 | -0.018 | 7.743 | 1/2 | 6370( 2110) |
| $^{115}$Sn | 1.86 | 1/2 - 7/2 | 11 | -1.029 | -0.453 | -0.074 | 7.546 | 1/2 | 3500( 1300) |
| $^{116}$Sn | 3.98 | 0 - 4 | 65 | -3.242 | -1.397 | -0.054 | 9.563 | 0 - 1 | 21700( 6600) |
| $^{117}$Sn | 2.09 | 1/2 - 7/2 | 25 | -0.893 | -0.022 | -0.123 | 6.943 | 1/2 | 2630( 900) |
| $^{118}$Sn | 2.50 | 0 - 4 | 13 | -3.319 | -1.324 | -0.121 | 9.327 | 0 - 1 | 18200( 1700) |
| $^{119}$Sn | 1.99 | 1/2 - 7/2 | 29 | -0.798 | -0.068 | -0.178 | 6.484 | 1/2 | 2080( 390) |
| $^{120}$Sn | 2.47 | 0 - 4 | 13 | -3.325 | -1.717 | -0.227 | 9.108 | 0 - 1 | 11100( 2500) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{121}$Sn | 1.50 | 1/2 - 7/2 | 18 | -0.740 | -0.702 | -0.267 | 6.170 | 1/2 | 610( 74) |
| $^{123}$Sn | 1.50 | 1/2 - 7/2 | 16 | -0.772 | -1.885 | -0.358 | 5.946 | 1/2 | 600( 180) |
| $^{125}$Sn | 1.90 | 1/2 - 7/2 | 15 | -0.835 | -3.551 | -0.436 | 5.733 | 1/2 | 200( 48) |
| $^{122}$Sb | 0.65 | 1 - 4 | 19 | -2.485 | 1.065 | 0.104 | 6.806 | 2 - 3 | 76900( 11800) |
| $^{124}$Sb | 0.76 | 2 - 5 | 25 | -2.385 | -0.006 | 0.057 | 6.467 | 3 - 4 | 41700( 5200) |
| $^{123}$Te | 1.89 | 1/2 - 7/2 | 45 | 0.044 | 0.416 | 0.000 | 6.929 | 1/2 | 7580( 860) |
| $^{124}$Te | 3.00 | 0 - 4 | 44 | -2.404 | -1.301 | -0.024 | 9.424 | 0 - 1 | 58800( 10400) |
| $^{125}$Te | 2.19 | 1/2 - 7/2 | 71 | 0.081 | -0.432 | -0.008 | 6.569 | 1/2 | 5260( 550) |
| $^{126}$Te | 2.85 | 0 - 6 | 46 | -2.385 | -2.370 | -0.034 | 9.114 | 0 - 1 | 26300( 3500) |
| $^{127}$Te | 2.20 | 1/2 - 7/2 | 71 | 0.098 | -1.739 | -0.003 | 6.288 | 1/2 | 1820( 330) |
| $^{129}$Te | 2.20 | 1/2 - 7/2 | 50 | 0.069 | -3.516 | 0.003 | 6.082 | 1/2 | 1350( 270) |
| $^{131}$Te | 2.40 | 1/2 - 7/2 | 36 | 0.048 | -5.739 | 0.008 | 5.929 | 1/2 | 670( 220) |
| $^{128}$I | 0.43 | 1 - 5 | 23 | -2.235 | -0.144 | -0.050 | 6.826 | 2 - 3 | 66700( 13300) |
| $^{130}$I | 0.39 | 2 - 5 | 21 | -2.204 | -1.641 | -0.042 | 6.500 | 3 - 4 | 33300( 3300) |
| $^{129}$Xe | 1.00 | 1/2 - 9/2 | 20 | -0.176 | -0.733 | -0.013 | 6.909 | 1/2 | 4000( 1600) |
| $^{130}$Xe | 2.39 | 0 - 6 | 23 | -2.435 | -2.568 | -0.039 | 9.256 | 0 - 1 | 26300( 3500) |
| $^{131}$Xe | 1.04 | 1/2 - 7/2 | 14 | -0.128 | -2.005 | -0.015 | 6.605 | 1/2 | 4350( 1130) |
| $^{132}$Xe | 3.08 | 2 - 5 | 30 | -2.369 | -4.021 | -0.051 | 8.937 | 1 - 2 | 20400( 6300) |
| $^{133}$Xe | 1.36 | 1/2 - 7/2 | 13 | -0.130 | -3.778 | -0.033 | 6.434 | 1/2 | 1330( 420) |
| $^{135}$Xe | 2.49 | 1/2 - 9/2 | 27 | -0.201 | -6.046 | -0.036 | 6.364 | 1/2 | 625( 230) |
| $^{137}$Xe | 2.29 | 1/2 - 9/2 | 42 | -0.134 | -6.414 | 1.032 | 4.026 | 1/2 | 77( 36) |
| $^{134}$Cs | 0.63 | 2 - 5 | 26 | -2.193 | -1.847 | -0.054 | 6.892 | 3 - 4 | 47600( 4500) |
| $^{135}$Cs | 1.07 | 5/2 - 7/2 | 6 | -0.101 | -3.807 | -0.110 | 8.762 | 7/2 - 9/2 | 62500( 11700) |
| $^{131}$Ba | 1.32 | 1/2 - 5/2 | 19 | -0.186 | 0.023 | -0.026 | 7.494 | 1/2 | 17240( 3000) |
| $^{133}$Ba | 1.36 | 1/2 - 5/2 | 19 | -0.198 | -0.912 | -0.064 | 7.190 | 1/2 | 9090( 2900) |
| $^{135}$Ba | 1.01 | 1/2 - 5/2 | 8 | -0.265 | -2.292 | -0.059 | 6.972 | 1/2 | 2700( 260) |
| $^{136}$Ba | 2.44 | 0 - 5 | 18 | -2.179 | -4.237 | -0.150 | 9.108 | 1 - 2 | 25000( 3800) |
| $^{137}$Ba | 2.41 | 1/2 - 7/2 | 18 | -0.315 | -4.220 | -0.094 | 6.906 | 1/2 | 826( 81) |
| $^{138}$Ba | 3.25 | 0 - 4 | 18 | -2.932 | -6.142 | 0.383 | 8.612 | 1 - 2 | 3850( 740) |
| $^{139}$Ba | 2.58 | 1/2 - 5/2 | 20 | -0.172 | -4.406 | 0.842 | 4.723 | 1/2 | 53( 8) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{139}$La | 1.77 | 1/2 - 9/2 | 15 | 0.651 | -4.184 | 0.299 | 8.778 | 9/2 -11/2 | 31250( 5860) |
| $^{140}$La | 0.80 | 1 - 5 | 20 | -2.079 | -2.536 | 0.719 | 5.161 | 3 - 4 | 4500( 800) |
| $^{137}$Ce | 1.48 | 1/2 - 7/2 | 17 | -0.142 | -1.243 | -0.129 | 7.482 | 1/2 | 20000( 8000) |
| $^{141}$Ce | 2.21 | 1/2 - 9/2 | 20 | -0.288 | -3.026 | 0.679 | 5.428 | 1/2 | 320( 50) |
| $^{142}$Ce | 2.81 | 0 - 3 | 24 | -2.000 | -3.268 | 0.589 | 7.170 | 3 - 4 | 15400( 4700) |
| $^{143}$Ce | 1.23 | 1/2 - 9/2 | 16 | -0.327 | -1.712 | 0.583 | 5.145 | 1/2 | 910( 410) |
| $^{142}$Pr | 0.75 | 1 - 4 | 12 | -2.125 | -1.389 | 0.578 | 5.843 | 2 - 3 | 9100( 1600) |
| $^{143}$Nd | 2.41 | 1/2 - 5/2 | 22 | -0.360 | -2.243 | 0.542 | 6.124 | 1/2 | 1160( 110) |
| $^{144}$Nd | 2.70 | 0 - 5 | 29 | -2.127 | -2.445 | 0.493 | 7.817 | 3 - 4 | 28600( 4100) |
| $^{145}$Nd | 2.06 | 1/2 - 7/2 | 35 | -0.376 | -0.816 | 0.471 | 5.755 | 1/2 | 2220( 250) |
| $^{146}$Nd | 2.29 | 0 - 4 | 30 | -2.117 | -1.225 | 0.492 | 7.565 | 3 - 4 | 58800( 10400) |
| $^{147}$Nd | 1.05 | 1/2 - 5/2 | 15 | -0.300 | 0.416 | 0.468 | 5.292 | 1/2 | 3450( 590) |
| $^{148}$Nd | 1.87 | 0 - 3 | 14 | -2.255 | -0.203 | 0.413 | 7.333 | 2 - 3 | 286000(139000) |
| $^{149}$Nd | 0.99 | 1/2 - 7/2 | 31 | 0.044 | 1.257 | 0.208 | 5.039 | 1/2 | 6450( 830) |
| $^{151}$Nd | 0.74 | 1/2 - 7/2 | 20 | -0.082 | 0.912 | -0.095 | 5.335 | 1/2 | 6060( 550) |
| $^{148}$Pm | 0.40 | 1 - 2 | 12 | -2.122 | 1.788 | 0.402 | 5.895 | 3 - 4 | 192000( 44000) |
| $^{145}$Sm | 2.20 | 1/2 -11/2 | 26 | -0.400 | -2.024 | 0.441 | 6.757 | 1/2 | 1490( 130) |
| $^{148}$Sm | 2.40 | 0 - 5 | 36 | -2.214 | -0.734 | 0.407 | 8.141 | 3 - 4 | 196000( 19000) |
| $^{149}$Sm | 1.06 | 1/2 -11/2 | 27 | -0.288 | 0.995 | 0.391 | 5.871 | 1/2 | 10000( 2000) |
| $^{150}$Sm | 2.05 | 0 - 6 | 37 | -2.174 | 0.384 | 0.342 | 7.987 | 3 - 4 | 476000( 68000) |
| $^{151}$Sm | 0.96 | 1/2 - 3/2 | 22 | 0.140 | 1.943 | 0.077 | 5.596 | 1/2 | 21700( 3800) |
| $^{152}$Sm | 1.59 | 0 - 6 | 19 | -2.095 | 0.625 | -0.078 | 8.258 | 3 - 4 | 962000(139000) |
| $^{153}$Sm | 0.49 | 1/2 - 9/2 | 21 | 0.044 | 1.484 | -0.094 | 5.868 | 1/2 | 20800( 2200) |
| $^{155}$Sm | 0.99 | 1/2 - 5/2 | 19 | -0.121 | 0.543 | -0.068 | 5.807 | 1/2 | 8770( 1150) |
| $^{152}$Eu | 0.35 | 1 - 4 | 63 | -2.491 | 3.157 | 0.099 | 6.307 | 2 - 3 | 1370000(131000) |
| $^{153}$Eu | 0.74 | 1/2 - 9/2 | 22 | 0.044 | 1.870 | -0.057 | 8.550 | 5/2 - 7/2 | 1790000(320000) |
| $^{154}$Eu | 0.49 | 1 - 5 | 74 | -1.911 | 2.477 | -0.073 | 6.442 | 2 - 3 | 910000(165000) |
| $^{155}$Eu | 1.11 | 1/2 - 7/2 | 25 | 0.126 | 1.164 | -0.141 | 8.151 | 5/2 - 7/2 | 1087000(142000) |
| $^{156}$Eu | 0.39 | 0 - 5 | 27 | -1.486 | 1.455 | -0.078 | 6.340 | 2 - 3 | 232600( 81100) |
| $^{153}$Gd | 0.80 | 1/2 - 9/2 | 49 | 0.067 | 2.087 | -0.022 | 6.247 | 1/2 | 71400( 15000) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{155}$Gd | 1.09 | 1/2 - 5/2 | 32 | -0.005 | 1.713 | -0.118 | 6.435 | 1/2 | 69400( 7200) |
| $^{156}$Gd | 1.97 | 0 - 4 | 35 | -1.931 | 0.333 | -0.149 | 8.536 | 1 - 2 | 588000( 69000) |
| $^{157}$Gd | 0.93 | 1/2 - 7/2 | 26 | -0.149 | 0.920 | -0.091 | 6.360 | 1/2 | 33300( 6700) |
| $^{158}$Gd | 2.08 | 0 - 4 | 45 | -1.729 | -0.276 | -0.045 | 7.937 | 1 - 2 | 204000( 21000) |
| $^{159}$Gd | 1.30 | 1/2 - 5/2 | 34 | -0.101 | 0.319 | -0.053 | 5.943 | 1/2 | 12200( 900) |
| $^{161}$Gd | 0.91 | 1/2 -11/2 | 21 | -0.185 | -0.282 | -0.078 | 5.635 | 1/2 | 5000( 500) |
| $^{160}$Tb | 0.39 | 0 - 5 | 27 | -1.599 | 1.274 | -0.068 | 6.375 | 1 - 2 | 238000( 17000) |
| $^{157}$Dy | 0.53 | 1/2 - 7/2 | 20 | -0.133 | 1.725 | -0.058 | 6.969 | 1/2 | 208000( 70000) |
| $^{159}$Dy | 0.59 | 1/2 - 9/2 | 16 | -0.187 | 1.202 | -0.045 | 6.833 | 1/2 | 45500( 23000) |
| $^{161}$Dy | 0.87 | 1/2 - 5/2 | 20 | -0.100 | 0.695 | -0.045 | 6.454 | 1/2 | 37000( 6900) |
| $^{162}$Dy | 1.90 | 0 - 5 | 37 | -1.772 | -0.547 | -0.068 | 8.197 | 2 - 3 | 417000( 35000) |
| $^{163}$Dy | 0.96 | 1/2 - 7/2 | 26 | -0.200 | -0.062 | -0.088 | 6.271 | 1/2 | 16100( 1300) |
| $^{164}$Dy | 2.01 | 0 - 5 | 35 | -1.594 | -1.161 | -0.024 | 7.658 | 2 - 3 | 147000( 13000) |
| $^{165}$Dy | 0.74 | 1/2 - 9/2 | 22 | -0.174 | -0.512 | -0.042 | 5.716 | 1/2 | 6700( 500) |
| $^{166}$Ho | 0.64 | 0 - 7 | 43 | -1.408 | 0.297 | -0.018 | 6.244 | 3 - 4 | 238000( 28000) |
| $^{163}$Er | 0.71 | 1/2 - 7/2 | 21 | -0.105 | 1.121 | -0.036 | 6.903 | 1/2 | 125000( 31000) |
| $^{165}$Er | 1.01 | 1/2 - 9/2 | 41 | -0.062 | 0.553 | -0.044 | 6.650 | 1/2 | 47600( 9100) |
| $^{167}$Er | 0.90 | 1/2 -11/2 | 30 | -0.204 | -0.233 | 0.005 | 6.436 | 1/2 | 26300( 2100) |
| $^{168}$Er | 2.10 | 0 - 6 | 65 | -1.558 | -1.234 | -0.030 | 7.771 | 3 - 4 | 238000( 17000) |
| $^{169}$Er | 0.86 | 1/2 -11/2 | 23 | -0.178 | -0.659 | -0.029 | 6.003 | 1/2 | 10000( 1000) |
| $^{171}$Er | 0.71 | 1/2 - 9/2 | 13 | -0.194 | -1.001 | -0.054 | 5.682 | 1/2 | 6800( 930) |
| $^{170}$Tm | 0.48 | 0 - 6 | 26 | -1.328 | 0.177 | -0.001 | 6.592 | 0 - 1 | 118000( 10000) |
| $^{171}$Tm | 1.29 | 1/2 - 7/2 | 16 | -0.027 | -0.626 | -0.040 | 7.486 | 1/2 - 3/2 | 256000( 66000) |
| $^{169}$Yb | 0.84 | 1/2 -11/2 | 26 | -0.179 | 0.367 | 0.010 | 6.867 | 1/2 | 125000( 47000) |
| $^{170}$Yb | 2.44 | 0 - 2 | 30 | -1.739 | -0.742 | 0.025 | 8.470 | 3 - 4 | 625000( 16000) |
| $^{171}$Yb | 1.03 | 1/2 -13/2 | 30 | -0.229 | -0.191 | 0.029 | 6.615 | 1/2 | 30300( 5500) |
| $^{172}$Yb | 1.76 | 0 - 6 | 33 | -1.572 | -1.237 | 0.037 | 8.019 | 0 - 1 | 173000( 14000) |
| $^{173}$Yb | 1.13 | 1/2 - 9/2 | 16 | -0.363 | -0.820 | 0.042 | 6.367 | 1/2 | 14200( 530) |
| $^{174}$Yb | 1.64 | 0 - 4 | 11 | -1.566 | -1.686 | 0.080 | 7.465 | 2 - 3 | 128000( 15000) |
| $^{175}$Yb | 1.13 | 1/2 - 9/2 | 21 | -0.377 | -1.092 | 0.101 | 5.822 | 1/2 | 6200( 700) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{177}$Yb | 1.00 | 1/2 - 9/2 | 20 | -0.299 | -1.229 | 0.051 | 5.566 | 1/2 | 5400( 560) |
| $^{176}$Lu | 0.85 | 0 - 7 | 50 | -1.310 | -0.046 | 0.122 | 6.288 | 3 - 4 | 333000( 45000) |
| $^{177}$Lu | 0.96 | 1/2 - 9/2 | 15 | -0.197 | -0.601 | 0.104 | 7.073 | 13/2 -15/2 | 364000(112000) |
| $^{175}$Hf | 0.81 | 1/2 -13/2 | 23 | -0.179 | 0.025 | 0.055 | 6.708 | 1/2 | 55600( 15400) |
| $^{177}$Hf | 0.88 | 1/2 - 9/2 | 19 | -0.121 | -0.370 | 0.063 | 6.383 | 1/2 | 33300( 7800) |
| $^{178}$Hf | 1.90 | 2 - 5 | 39 | -1.282 | -1.196 | 0.024 | 7.626 | 3 - 4 | 417000( 52000) |
| $^{179}$Hf | 1.29 | 1/2 - 9/2 | 36 | -0.057 | -0.676 | -0.052 | 6.099 | 1/2 | 17500( 1800) |
| $^{180}$Hf | 1.83 | 0 - 4 | 38 | -1.400 | -1.623 | -0.011 | 7.388 | 4 - 5 | 217000( 14000) |
| $^{181}$Hf | 1.19 | 1/2 - 9/2 | 22 | -0.232 | -1.053 | 0.004 | 5.695 | 1/2 | 10600( 1700) |
| $^{181}$Ta | 0.63 | 1/2 -11/2 | 8 | 0.022 | -0.809 | -0.098 | 7.577 | 1/2 - 3/2 | 833000(139000) |
| $^{182}$Ta | 0.79 | 2 - 5 | 39 | -1.315 | -0.332 | -0.054 | 6.063 | 3 - 4 | 238000( 17000) |
| $^{183}$Ta | 0.98 | 5/2 - 7/2 | 14 | -0.105 | -0.900 | -0.019 | 6.934 | 9/2 -11/2 | 286000( 57000) |
| $^{181}$W | 0.96 | 1/2 - 7/2 | 15 | -0.165 | -0.621 | -0.166 | 6.681 | 1/2 | 50000( 17500) |
| $^{183}$W | 1.24 | 1/2 - 9/2 | 23 | -0.235 | -1.067 | -0.053 | 6.191 | 1/2 | 16700( 1700) |
| $^{184}$W | 1.44 | 0 - 4 | 16 | -1.526 | -1.840 | -0.034 | 7.412 | 0 - 1 | 83300( 6900) |
| $^{185}$W | 1.25 | 1/2 - 9/2 | 46 | -0.135 | -1.129 | -0.090 | 5.754 | 1/2 | 14300( 1400) |
| $^{187}$W | 1.00 | 1/2 - 5/2 | 23 | -0.218 | -1.368 | -0.156 | 5.467 | 1/2 | 11800( 1100) |
| $^{186}$Re | 0.61 | 1 - 5 | 27 | -1.492 | -0.466 | -0.101 | 6.179 | 2 - 3 | 323000( 31000) |
| $^{188}$Re | 0.56 | 1 - 5 | 30 | -1.592 | -0.740 | -0.196 | 5.872 | 2 - 3 | 244000( 18000) |
| $^{187}$Os | 0.67 | 1/2 -11/2 | 22 | -0.081 | -1.085 | -0.032 | 6.290 | 1/2 | 34500( 3600) |
| $^{188}$Os | 2.11 | 0 - 2 | 23 | -1.796 | -2.244 | -0.032 | 7.990 | 0 - 1 | 250000( 38000) |
| $^{189}$Os | 0.61 | 1/2 - 7/2 | 17 | -0.024 | -1.506 | -0.152 | 5.920 | 1/2 | 21300( 2700) |
| $^{190}$Os | 1.48 | 0 - 6 | 17 | -1.782 | -2.809 | -0.186 | 7.792 | 1 - 2 | 294000( 35000) |
| $^{191}$Os | 0.64 | 1/2 - 9/2 | 25 | -0.138 | -2.245 | -0.322 | 5.759 | 1/2 | 14300( 2000) |
| $^{193}$Os | 0.55 | 1/2 - 7/2 | 11 | -0.373 | -3.234 | -0.420 | 5.583 | 1/2 | 8700( 800) |
| $^{192}$Ir | 0.46 | 0 - 3 | 32 | -1.902 | -1.483 | -0.330 | 6.198 | 1 - 2 | 400000( 80000) |
| $^{193}$Ir | 1.09 | 1/2 - 7/2 | 28 | -0.061 | -2.837 | -0.368 | 7.772 | 1/2 | 1429000(408000) |
| $^{194}$Ir | 0.55 | 0 - 3 | 35 | -1.735 | -2.649 | -0.411 | 6.067 | 1 - 2 | 142900( 40800) |
| $^{193}$Pt | 0.54 | 1/2 - 7/2 | 15 | 0.161 | -2.449 | -0.411 | 6.255 | 1/2 | 45500( 17000) |
| $^{195}$Pt | 0.70 | 1/2 - 7/2 | 20 | 0.041 | -3.719 | -0.504 | 6.105 | 1/2 | 5000( 2000) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{196}$Pt | 2.01 | 0 - 6 | 32 | -1.592 | -5.292 | -0.568 | 7.922 | 0 - 1 | 55600( 9300) |
| $^{197}$Pt | 0.60 | 1/2 - 7/2 | 14 | -0.030 | -4.949 | -0.608 | 5.846 | 1/2 | 2860( 820) |
| $^{199}$Pt | 0.65 | 1/2 - 7/2 | 12 | -0.058 | -6.157 | -0.694 | 5.556 | 1/2 | 2940( 780) |
| $^{198}$Au | 0.68 | 0 - 3 | 26 | -1.494 | -4.920 | -0.603 | 6.512 | 1 - 2 | 60600( 3300) |
| $^{199}$Hg | 0.76 | 1/2 - 5/2 | 10 | -0.385 | -6.211 | -0.528 | 6.664 | 1/2 | 9500( 3200) |
| $^{200}$Hg | 2.20 | 0 - 2 | 21 | -1.721 | -7.703 | -0.572 | 8.028 | 0 - 1 | 12500( 4700) |
| $^{201}$Hg | 0.65 | 1/2 - 7/2 | 11 | -0.235 | -7.556 | -0.592 | 6.230 | 1/2 | 1540( 360) |
| $^{202}$Hg | 1.87 | 0 - 4 | 24 | -1.538 | -9.090 | -0.648 | 7.754 | 1 - 2 | 11100( 3700) |
| $^{204}$Tl | 0.69 | 0 - 4 | 15 | -1.220 | -8.932 | -0.573 | 6.656 | 0 - 1 | 3600( 640) |
| $^{206}$Tl | 2.00 | 0 - 6 | 24 | -0.966 | -10.818 | -0.634 | 6.504 | 0 - 1 | 182( 50) |
| $^{205}$Pb | 2.26 | 1/2 - 9/2 | 29 | -0.862 | -9.699 | -0.165 | 6.732 | 1/2 | 500( 125) |
| $^{207}$Pb | 2.74 | 1/2 - 9/2 | 8 | -1.412 | -11.869 | -0.110 | 6.738 | 1/2 | 31( 6) |
| $^{208}$Pb | 4.37 | 0 - 8 | 24 | -3.226 | -13.137 | 0.411 | 7.368 | 0 - 1 | 26( 6) |
| $^{209}$Pb | 3.69 | 1/2 -15/2 | 40 | -1.168 | -11.126 | 0.886 | 3.937 | 1/2 | 3( 1) |
| $^{210}$Bi | 1.48 | 2 - 7 | 19 | -1.267 | -9.173 | 1.307 | 4.605 | 4 - 5 | 250( 44) |
| $^{227}$Ra | 0.53 | 1/2 - 5/2 | 16 | -0.105 | 1.271 | 0.093 | 4.561 | 1/2 | 32300( 6300) |
| $^{229}$Th | 0.49 | 1/2 - 7/2 | 20 | -0.052 | 1.147 | -0.001 | 5.257 | 1/2 | 200000(120000) |
| $^{230}$Th | 1.20 | 0 - 5 | 24 | -1.558 | 0.306 | -0.089 | 6.794 | 2 - 3 | 1613000(312000) |
| $^{231}$Th | 0.99 | 1/2 - 5/2 | 30 | -0.305 | 1.006 | -0.125 | 5.118 | 1/2 | 104000( 16000) |
| $^{233}$Th | 0.79 | 1/2 - 5/2 | 24 | -0.391 | 1.019 | -0.118 | 4.786 | 1/2 | 60200( 2200) |
| $^{233}$Pa | 0.48 | 1/2 -11/2 | 30 | -0.121 | 0.979 | -0.115 | 6.529 | 3/2 - 5/2 | 1330000(270000) |
| $^{234}$Pa | 0.20 | 0 - 4 | 8 | -1.394 | 1.530 | -0.099 | 5.220 | 1 - 2 | 1670000(280000) |
| $^{233}$U | 0.63 | 1/2 - 9/2 | 20 | -0.315 | 0.575 | -0.152 | 5.762 | 1/2 | 217000( 33000) |
| $^{234}$U | 1.50 | 0 - 6 | 39 | -1.517 | -0.147 | -0.157 | 6.845 | 2 - 3 | 1818000(165000) |
| $^{235}$U | 0.90 | 1/2 - 5/2 | 22 | -0.261 | 0.545 | -0.127 | 5.297 | 1/2 | 83300( 5600) |
| $^{236}$U | 1.17 | 0 - 6 | 26 | -1.452 | -0.144 | -0.152 | 6.545 | 3 - 4 | 2326000(108000) |
| $^{237}$U | 0.77 | 1/2 - 5/2 | 12 | -0.430 | 0.456 | -0.143 | 5.126 | 1/2 | 66700( 4500) |
| $^{238}$U | 1.27 | 0 - 4 | 25 | -1.522 | -0.100 | -0.103 | 6.154 | 0 - 1 | 286000( 65000) |
| $^{239}$U | 0.97 | 1/2 - 5/2 | 20 | -0.378 | 0.562 | -0.147 | 4.806 | 1/2 | 48100( 700) |
| $^{237}$Np | 0.87 | 1/2 -11/2 | 35 | -0.118 | 0.470 | -0.137 | 6.580 | 1/2 - 3/2 | 1670000(170000) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{238}$Np | 0.40 | 1 - 5 | 29 | -1.170 | 0.923 | -0.092 | 5.488 | 2 - 3 | 1754000( 92000) |
| $^{239}$Np | 0.53 | 1/2 -11/2 | 23 | -0.138 | 0.519 | -0.079 | 6.215 | 3/2 - 5/2 | 2440000(600000) |
| $^{239}$Pu | 0.91 | 1/2 - 9/2 | 24 | -0.315 | -0.001 | -0.119 | 5.646 | 1/2 | 111000( 12000) |
| $^{240}$Pu | 1.25 | 0 - 5 | 24 | -1.336 | -0.512 | -0.090 | 6.534 | 0 - 1 | 455000( 10000) |
| $^{241}$Pu | 0.85 | 1/2 - 9/2 | 24 | -0.287 | 0.141 | -0.086 | 5.242 | 1/2 | 80600( 4600) |
| $^{242}$Pu | 1.19 | 0 - 4 | 14 | -1.379 | -0.402 | -0.118 | 6.310 | 0 - 1 | 1370000(150000) |
| $^{243}$Pu | 0.91 | 1/2 - 9/2 | 25 | -0.325 | 0.202 | -0.058 | 5.034 | 1/2 | 74000( 8200) |
| $^{245}$Pu | 0.58 | 1/2 - 9/2 | 8 | -0.409 | 0.314 | -0.123 | 4.771 | 1/2 | 52600( 8300) |
| $^{242}$Am | 0.46 | 0 - 6 | 35 | -1.179 | 0.565 | -0.092 | 5.538 | 2 - 3 | 1724000(119000) |
| $^{243}$Am | 0.54 | 1/2 -13/2 | 18 | -0.195 | 0.176 | -0.120 | 6.365 | 1/2 - 3/2 | 2500000(500000) |
| $^{244}$Am | 0.59 | 0 - 4 | 42 | -1.213 | 0.659 | -0.116 | 5.366 | 2 - 3 | 1370000(113000) |
| $^{243}$Cm | 0.98 | 1/2 - 9/2 | 21 | -0.192 | -0.265 | -0.074 | 5.693 | 1/2 | 71400( 15300) |
| $^{244}$Cm | 1.19 | 0 - 3 | 8 | -1.265 | -0.878 | -0.129 | 6.801 | 2 - 3 | 1333000(267000) |
| $^{245}$Cm | 0.80 | 1/2 -11/2 | 26 | -0.329 | -0.340 | -0.134 | 5.520 | 1/2 | 84700( 8600) |
| $^{246}$Cm | 1.72 | 0 - 3 | 32 | -1.362 | -0.867 | -0.134 | 6.458 | 0 - 1 | 769000(118000) |
| $^{247}$Cm | 0.56 | 1/2 - 9/2 | 14 | -0.341 | -0.217 | -0.143 | 5.156 | 1/2 | 33300( 5600) |
| $^{248}$Cm | 1.31 | 0 - 4 | 12 | -1.581 | -0.750 | -0.100 | 6.213 | 4 - 5 | 714000(150000) |
| $^{249}$Cm | 0.59 | 1/2 - 9/2 | 18 | -0.441 | 0.094 | -0.001 | 4.713 | 1/2 | 35700( 6400) |
| $^{250}$Bk | 0.24 | 1 - 6 | 20 | -1.238 | 0.549 | -0.010 | 4.970 | 3 - 4 | 909000( 83000) |
| $^{250}$Cf | 1.30 | 0 - 5 | 19 | -1.515 | -1.321 | -0.016 | 6.625 | 4 - 5 | 1429000(204000) |
| $^{251}$Cf | 0.70 | 1/2 -11/2 | 25 | -0.297 | -0.462 | -0.001 | 5.108 | 1/2 | 83300( 14000) |

[a]) - the deuteron pairing energy, from mass table;

[b]) - shell correction, eqs. (7), (9);

[c]) - the derivative of $S(Z, N)$ with respect to the mass, calculated with eq. (12).

TABLE II: Level density parameters for the three models determined from fits to the data specified by Table I.

| | BSFG | | BSFG with ED | | CT | |
|---|---|---|---|---|---|---|
| Nucleus | a($\delta$a) | $E_1$($\delta E_1$) | $\tilde{a}$($\delta\tilde{a}$) | $E_2$($\delta E_2$) | T($\delta$T) | $E_0$($\delta E_0$) |
| | [MeV$^{-1}$] | [MeV] | [MeV$^{-1}$] | [MeV] | [MeV] | [MeV] |
| $^{18}$F | 2.68(47) | -1.28(174) | 2.88(53) | -1.49(182) | 2.33(43) | -2.37(186) |
| $^{19}$F | 2.26(36) | -2.52(199) | 2.13(32) | -2.25(189) | 2.84(50) | -3.57(223) |
| $^{20}$F | 2.86(34) | -2.16(133) | 2.65(30) | -1.98(128) | 2.23(45) | -3.49(206) |
| $^{20}$Ne | 2.24(26) | 1.46(165) | 2.31(28) | 1.32(167) | 2.94(33) | 0.29(158) |
| $^{23}$Na | 3.11(40) | 0.46(130) | 3.09(39) | 0.47(129) | 2.19(28) | -1.03(135) |
| $^{24}$Na | 2.99(31) | -2.41(110) | 2.88(29) | -2.30(108) | 2.20(62) | -3.40(277) |
| $^{24}$Mg | 3.04(47) | 3.71(151) | 3.35(51) | 3.80(140) | 2.37(30) | 1.75(134) |
| $^{25}$Mg | 3.23(37) | 0.39(108) | 3.28(37) | 0.37(108) | 2.24(32) | -1.47(145) |
| $^{26}$Mg | 3.32(39) | 1.37(103) | 3.28(38) | 1.40(103) | 2.05(28) | 0.20(129) |
| $^{27}$Mg | 4.58(45) | 1.61(68) | 4.42(43) | 1.63(68) | 1.46(21) | 0.33(94) |
| $^{26}$Al | 2.90(28) | -2.91(120) | 3.16(34) | -3.34(131) | 2.43(23) | -4.38(133) |
| $^{27}$Al | 3.02(44) | -0.57(144) | 3.16(46) | -0.75(147) | 2.19(33) | -1.29(148) |
| $^{28}$Al | 3.60(22) | -1.31(70) | 3.67(22) | -1.37(71) | 1.98(19) | -2.69(108) |
| $^{28}$Si | 3.43(55) | 4.38(115) | 4.14(69) | 4.30(124) | 2.04(24) | 3.12(105) |
| $^{29}$Si | 3.87(46) | 2.30(87) | 4.37(58) | 1.97(100) | 2.16(27) | -0.48(131) |
| $^{30}$Si | 2.73(29) | -0.62(152) | 2.87(31) | -0.71(148) | 2.49(34) | -1.05(167) |
| $^{30}$P | 3.21(32) | -1.31(110) | 3.74(43) | -1.86(126) | 2.14(25) | -2.17(124) |
| $^{31}$P | 3.58(66) | 0.47(149) | 4.01(76) | 0.24(155) | 1.84(33) | -0.12(139) |
| $^{32}$P | 3.75(29) | -1.21(74) | 3.95(31) | -1.34(76) | 2.00(35) | -2.79(167) |
| $^{32}$S | 3.39(63) | 1.65(17) | 3.95(80) | 1.34(183) | 1.97(34) | 1.06(142) |
| $^{33}$S | 4.01(26) | 0.25(62) | 4.36(29) | 0.11(64) | 1.75(24) | -0.56(112) |
| $^{34}$S | 3.94(32) | 1.32(73) | 4.09(34) | 1.22(75) | 1.84(25) | 0.30(114) |
| $^{35}$S | 4.50(55) | 0.12(93) | 4.43(54) | 0.14(93) | 1.50(25) | -0.52(114) |
| $^{36}$Cl | 4.19(30) | -1.06(74) | 4.28(31) | -1.11(75) | 1.85(29) | -2.61(151) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{38}$Cl | 6.14(57) | -0.09(70) | 5.61(52) | -0.04(69) | 1.17(15) | -1.01(87) |
| $^{38}$Ar | 4.21(59) | 1.36(107) | 4.21(59) | 1.35(107) | 1.51(18) | 1.30(80) |
| $^{40}$Ar | 4.72(81) | 0.54(110) | 4.18(69) | 0.65(104) | 1.35(22) | 0.43(92) |
| $^{41}$Ar | 5.78(53) | -0.27(75) | 4.95(44) | -0.02(72) | 1.32(18) | -1.54(102) |
| $^{40}$K | 4.73(23) | -1.54(58) | 4.60(22) | -1.47(57) | 1.66(22) | -2.93(131) |
| $^{41}$K | 5.61(11) | -0.13(26) | 5.10(9) | 0.05(24) | 1.43(8) | -1.64(60) |
| $^{42}$K | 4.40(37) | -3.03(85) | 3.94(31) | -2.79(79) | 1.85(26) | -4.58(147) |
| $^{40}$Ca | 5.27(74) | 3.61(87) | 5.29(88) | 2.88(112) | 1.45(20) | 2.28(89) |
| $^{41}$Ca | 5.65(20) | 0.50(35) | 5.69(20) | 0.49(35) | 1.30(10) | -0.20(62) |
| $^{43}$Ca | 5.77(35) | -0.69(53) | 5.23(30) | -0.56(50) | 1.38(13) | -1.96(80) |
| $^{44}$Ca | 5.93(27) | 1.06(49) | 5.36(23) | 1.18(47) | 1.34(8) | -0.03(61) |
| $^{45}$Ca | 6.38(30) | 0.13(44) | 5.70(26) | 0.22(43) | 1.23(9) | -1.02(63) |
| $^{46}$Sc | 5.82(14) | -2.22(34) | 5.41(13) | -2.08(32) | 1.44(10) | -3.77(76) |
| $^{47}$Ti | 5.14(30) | -1.35(74) | 4.96(28) | -1.26(72) | 1.65(16) | -2.94(110) |
| $^{48}$Ti | 5.67(20) | 0.59(42) | 5.47(19) | 0.66(41) | 1.47(8) | -0.73(60) |
| $^{49}$Ti | 6.36(31) | 0.07(49) | 6.18(30) | 0.10(49) | 1.25(10) | -0.89(70) |
| $^{50}$Ti | 6.06(33) | 2.13(50) | 6.02(33) | 2.14(50) | 1.30(8) | 1.19(58) |
| $^{51}$Ti | 5.74(85) | 0.11(87) | 5.72(84) | 0.11(87) | 1.29(24) | -0.55(100) |
| $^{51}$V | 7.06(29) | 0.93(35) | 7.15(30) | 0.92(35) | 1.23(7) | -0.37(50) |
| $^{52}$V | 6.34(29) | -0.94(39) | 6.36(29) | -0.94(39) | 1.23(8) | -1.76(57) |
| $^{51}$Cr | 5.91(18) | -0.41(38) | 6.20(20) | -0.49(39) | 1.42(8) | -1.68(61) |
| $^{53}$Cr | 5.66(26) | -0.46(55) | 5.88(27) | -0.53(56) | 1.46(12) | -1.60(80) |
| $^{54}$Cr | 5.73(24) | 0.60(51) | 5.77(24) | 0.59(51) | 1.44(9) | -0.48(68) |
| $^{55}$Cr | 6.30(27) | -0.49(41) | 6.11(26) | -0.45(41) | 1.27(14) | -1.45(78) |
| $^{56}$Mn | 6.28(30) | -2.31(45) | 6.35(31) | -2.33(46) | 1.39(10) | -3.94(69) |
| $^{55}$Fe | 5.73(22) | -0.62(54) | 6.56(29) | -0.94(59) | 1.49(14) | -1.84(94) |
| $^{57}$Fe | 5.92(19) | -1.34(36) | 6.25(21) | -1.45(37) | 1.47(9) | -2.83(61) |
| $^{58}$Fe | 6.26(24) | 0.55(42) | 6.37(25) | 0.52(42) | 1.37(8) | -0.62(60) |
| $^{59}$Fe | 6.75(37) | -0.91(45) | 6.64(36) | -0.89(44) | 1.24(11) | -2.00(68) |
| $^{60}$Co | 7.23(19) | -1.37(25) | 7.41(20) | -1.40(25) | 1.1(8) | -2.61(55) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{59}$Ni | 6.10(21) | -0.84(47) | 7.11(28) | -1.19(53) | 1.43(9) | -2.10(72) |
| $^{60}$Ni | 6.05(40) | 0.28(61) | 6.69(46) | 0.08(65) | 1.44(12) | -0.85(77) |
| $^{61}$Ni | 6.79(16) | -0.69(29) | 7.23(18) | -0.79(30) | 1.28(8) | -1.96(60) |
| $^{62}$Ni | 6.52(21) | 0.54(43) | 6.70(22) | 0.50(44) | 1.33(7) | -0.48(60) |
| $^{63}$Ni | 7.08(38) | -1.08(51) | 7.05(38) | -1.07(51) | 1.20(11) | -2.11(77) |
| $^{65}$Ni | 8.31(40) | -0.03(38) | 7.85(41) | -0.04(43) | 1.03(8) | -1.20(58) |
| $^{64}$Cu | 7.26(22) | -1.99(36) | 7.35(22) | -2.02(37) | 1.27(7) | -3.64(58) |
| $^{66}$Cu | 8.01(23) | -1.28(29) | 7.69(21) | -1.22(28) | 1.12(5) | -2.70(45) |
| $^{65}$Zn | 7.86(23) | -0.91(36) | 7.83(23) | -0.91(36) | 1.16(6) | -2.32(56) |
| $^{67}$Zn | 8.30(24) | -0.95(29) | 7.76(22) | -0.88(29) | 1.07(8) | -2.16(60) |
| $^{68}$Zn | 8.42(26) | 1.14(30) | 7.88(24) | 1.21(30) | 1.05(5) | 0.13(41) |
| $^{69}$Zn | 9.03(29) | -0.50(31) | 8.15(25) | -0.41(29) | 0.98(6) | -1.67(47) |
| $^{71}$Zn | 10.14(49) | 0.09(38) | 8.96(42) | 0.22(38) | 0.87(7) | -1.03(49) |
| $^{70}$Ga | 10.09(37) | -0.66(25) | 9.22(33) | -0.59(24) | 0.91(5) | -1.81(41) |
| $^{72}$Ga | 9.91(31) | -1.23(23) | 8.77(26) | -1.13(22) | 0.92(5) | -2.44(39) |
| $^{71}$Ge | 9.82(40) | -0.91(23) | 8.76(35) | -0.80(22) | 0.95(5) | -2.29(38) |
| $^{73}$Ge | 9.67(33) | -1.15(23) | 8.40(27) | -1.04(22) | 0.95(5) | -2.35(40) |
| $^{74}$Ge | 9.96(34) | 0.77(21) | 8.82(30) | 0.88(20) | 0.91(4) | -0.29(30) |
| $^{75}$Ge | 9.14(55) | -1.16(29) | 8.06(48) | -1.06(28) | 0.98(8) | -2.28(47) |
| $^{77}$Ge | 9.29(53) | -1.15(33) | 8.52(48) | -1.09(32) | 0.96(8) | -2.14(53) |
| $^{76}$As | 10.39(20) | -1.89(18) | 9.21(17) | -1.75(17) | 0.96(3) | -3.59(32) |
| $^{75}$Se | 10.12(30) | -1.25(21) | 8.95(25) | -1.12(20) | 0.96(6) | -2.77(49) |
| $^{77}$Se | 10.10(26) | -1.18(25) | 8.86(22) | -1.06(23) | 0.94(6) | -2.50(53) |
| $^{78}$Se | 10.25(34) | 0.75(18) | 9.13(30) | 0.84(17) | 0.93(4) | -0.32(29) |
| $^{79}$Se | 9.41(39) | -1.15(24) | 8.41(34) | -1.04(23) | 0.99(6) | -2.37(41) |
| $^{81}$Se | 10.83(35) | -0.06(21) | 10.22(33) | -0.01(21) | 0.83(4) | -1.00(32) |
| $^{83}$Se | 10.09(42) | -0.71(31) | 10.12(42) | -0.71(31) | 0.90(6) | -1.76(47) |
| $^{80}$Br | 10.65(19) | -1.74(17) | 9.62(17) | -1.62(16) | 0.94(3) | -3.37(30) |
| $^{82}$Br | 10.70(26) | -1.12(20) | 10.10(24) | -1.07(19) | 0.90(4) | -2.34(34) |
| $^{79}$Kr | 10.29(41) | -1.22(20) | 9.22(36) | -1.12(19) | 0.95(5) | -2.62(35) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{81}$Kr | 11.17(34) | -0.66(20) | 10.03(30) | -0.57(19) | 0.87(4) | -1.91(34) |
| $^{84}$Kr | 8.93(32) | 0.97(28) | 8.74(31) | 0.99(28) | 0.98(4) | 0.25(37) |
| $^{85}$Kr | 12.47(37) | 0.87(15) | 12.48(38) | 0.87(50) | 0.73(3) | -0.02(22) |
| $^{86}$Rb | 9.53(26) | -0.64(22) | 9.85(27) | -0.67(22) | 0.99(4) | -1.71(35) |
| $^{88}$Rb | 9.81(36) | -0.54(25) | 10.34(39) | -0.59(25) | 0.91(5) | -1.39(37) |
| $^{85}$Sr | 10.93(54) | -0.18(21) | 10.48(52) | -0.14(20) | 0.88(5) | -1.30(33) |
| $^{87}$Sr | 9.11(44) | -0.10(38) | 9.43(46) | -0.16(38) | 1.04(11) | 1.28(74) |
| $^{88}$Sr | 8.95(41) | 1.97(30) | 9.71(45) | 1.88(31) | 0.97(5) | 1.31(37) |
| $^{89}$Sr | 9.63(39) | 0.87(28) | 10.51(44) | 0.80(29) | 0.88(6) | 0.25(39) |
| $^{90}$Y | 9.03(32) | -0.57(33) | 9.81(36) | -0.67(34) | 1.01(6) | -1.48(48) |
| $^{91}$Zr | 10.03(44) | 0.52(25) | 11.05(50) | 0.39(26) | 0.89(5) | -0.23(36) |
| $^{92}$Zr | 9.99(34) | 1.07(25) | 10.47(36) | 1.03(25) | 0.90(4) | 0.29(33) |
| $^{93}$Zr | 10.72(52) | 0.10(33) | 10.95(53) | 0.08(33) | 0.86(6) | -0.85(45) |
| $^{94}$Zr | 12.02(46) | 1.13(31) | 11.86(45) | 1.16(31) | 0.76(4) | 0.35(36) |
| $^{95}$Zr | 11.89(63) | 0.59(31) | 11.63(61) | 0.60(31) | 0.76(5) | -0.19(40) |
| $^{97}$Zr | 11.77(66) | 0.81(30) | 11.06(61) | 0.83(29) | 0.71(5) | 0.38(37) |
| $^{94}$Nb | 10.88(26) | -1.37(20) | 11.07(27) | -1.39(21) | 0.86(3) | -2.44(33) |
| $^{93}$Mo | 9.78(34) | 0.21(26) | 11.31(41) | 0.08(27) | 0.94(5) | -0.60(38) |
| $^{95}$Mo | 10.56(29) | -0.52(28) | 11.04(31) | -0.56(29) | 0.89(6) | -1.41(51) |
| $^{96}$Mo | 10.90(21) | 0.59(21) | 10.88(21) | 0.60(21) | 0.87(4) | -0.29(35) |
| $^{97}$Mo | 11.14(36) | -0.81(21) | 10.83(35) | -0.78(21) | 0.87(4) | -1.91(34) |
| $^{98}$Mo | 12.02(41) | 0.68(16) | 11.29(38) | 0.72(16) | 0.79(3) | -0.18(25) |
| $^{99}$Mo | 12.57(41) | -0.64(17) | 11.37(36) | -0.58(17) | 0.75(4) | -1.53(29) |
| $^{101}$Mo | 13.00(40) | -1.11(16) | 11.21(33) | -1.02(15) | 0.74(3) | -2.17(27) |
| $^{100}$Tc | 13.93(31) | -1.26(15) | 12.95(29) | -1.21(14) | 0.71(3) | -2.44(25) |
| $^{100}$Ru | 12.15(26) | 0.70(15) | 12.00(25) | 0.72(16) | 0.80(2) | -0.16(25) |
| $^{102}$Ru | 12.94(27) | 0.57(19) | 12.04(25) | 0.62(19) | 0.76(3) | -0.30(32) |
| $^{103}$Ru | 12.30(48) | -1.18(18) | 11.11(43) | -1.12(18) | 0.80(4) | -2.27(32) |
| $^{105}$Ru | 13.39(51) | -1.31(21) | 11.81(44) | -1.21(20) | 0.75(4) | -2.55(34) |
| $^{104}$Rh | 13.33(22) | -1.75(15) | 12.50(20) | -1.68(14) | 0.81(4) | -3.38(39) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{105}$Pd | 12.79(26) | -0.81(16) | 12.35(25) | -0.79(16) | 0.78(3) | -1.88(28) |
| $^{106}$Pd | 13.42(16) | 0.68(14) | 12.71(15) | 0.73(14) | 0.75(2) | -0.29(26) |
| $^{107}$Pd | 13.46(56) | -0.77(19) | 12.37(51) | -0.73(18) | 0.72(4) | -1.63(32) |
| $^{108}$Pd | 14.34(22) | 1.07(14) | 13.09(19) | 1.13(14) | 0.70(2) | 0.18(21) |
| $^{109}$Pd | 14.02(34) | -1.19(18) | 12.60(30) | -1.11(17) | 0.72(5) | -2.34(40) |
| $^{111}$Pd | 15.84(66) | -0.71(16) | 14.05(57) | -0.66(16) | 0.62(4) | -1.56(28) |
| $^{108}$Ag | 14.27(29) | -1.18(14) | 13.68(27) | -1.15(14) | 0.74(4) | -2.47(34) |
| $^{110}$Ag | 14.93(19) | -1.55(12) | 13.85(17) | -1.48(11) | 0.73(3) | -3.10(32) |
| $^{107}$Cd | 12.84(42) | -0.51(17) | 13.54(45) | -0.55(17) | 0.79(3) | -1.63(28) |
| $^{109}$Cd | 14.04(45) | -0.33(16) | 13.92(45) | -0.33(16) | 0.72(3) | -1.36(26) |
| $^{111}$Cd | 14.04(27) | -0.52(13) | 13.43(26) | -0.49(13) | 0.72(2) | -1.64(22) |
| $^{112}$Cd | 14.25(30) | 0.77(18) | 13.50(29) | 0.81(17) | 0.71(3) | -0.06(30) |
| $^{113}$Cd | 14.17(29) | -0.74(13) | 13.25(26) | -0.69(12) | 0.72(2) | -1.90(22) |
| $^{114}$Cd | 14.73(20) | 0.92(12) | 13.81(18) | 0.99(12) | 0.71(2) | -0.23(23) |
| $^{115}$Cd | 15.06(35) | -0.43(13) | 14.01(32) | -0.39(13) | 0.66(2) | -1.37(22) |
| $^{117}$Cd | 15.27(53) | -0.25(15) | 14.41(49) | -0.22(15) | 0.63(3) | -1.04(24) |
| $^{114}$In | 14.23(38) | -0.68(19) | 13.84(37) | -0.67(19) | 0.69(4) | -1.52(38) |
| $^{116}$In | 14.76(23) | -1.12(16) | 14.22(21) | -1.09(16) | 0.69(4) | -2.26(36) |
| $^{113}$Sn | 13.67(56) | -0.03(18) | 14.16(59) | -0.06(18) | 0.74(4) | -1.06(27) |
| $^{115}$Sn | 14.07(68) | 0.52(25) | 14.37(70) | 0.51(25) | 0.70(4) | -0.33(33) |
| $^{116}$Sn | 14.13(40) | 1.66(11) | 13.99(40) | 1.67(11) | 0.73(2) | 0.52(17) |
| $^{117}$Sn | 14.15(66) | 0.21(18) | 14.16(66) | 0.21(18) | 0.69(4) | -0.68(27) |
| $^{118}$Sn | 13.53(27) | 0.96(20) | 13.33(26) | 0.97(20) | 0.74(3) | 0.21(30) |
| $^{119}$Sn | 14.38(42) | 0.05(15) | 14.42(42) | 0.04(15) | 0.68(3) | -0.85(23) |
| $^{120}$Sn | 13.14(40) | 0.85(22) | 13.17(40) | 0.85(22) | 0.76(3) | 0.12(32) |
| $^{121}$Sn | 12.23(35) | -0.66(22) | 12.63(37) | -0.69(23) | 0.79(4) | -1.47(34) |
| $^{123}$Sn | 12.84(62) | -0.47(24) | 14.07(70) | -0.54(25) | 0.74(5) | -1.20(36) |
| $^{125}$Sn | 12.10(58) | -0.20(27) | 14.44(73) | -0.36(28) | 0.77(5) | -0.83(37) |
| $^{122}$Sb | 14.78(29) | -1.13(16) | 14.90(30) | -1.14(16) | 0.70(4) | -2.21(35) |
| $^{124}$Sb | 14.14(25) | -1.22(14) | 14.94(27) | -1.26(15) | 0.71(3) | -2.25(32) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{123}$Te | 15.12(26) | -0.21(11) | 14.84(25) | -0.20(11) | 0.68(2) | -1.27(18) |
| $^{124}$Te | 15.04(30) | 1.00(11) | 15.10(31) | 1.00(11) | 0.71(2) | -0.10(18) |
| $^{125}$Te | 15.51(25) | -0.07(9) | 15.80(26) | -0.10(9) | 0.67(2) | -1.19(15) |
| $^{126}$Te | 14.36(24) | 0.88(10) | 15.17(26) | 0.85(11) | 0.72(2) | -0.08(17) |
| $^{127}$Te | 13.89(40) | -0.44(13) | 15.08(44) | -0.51(14) | 0.73(3) | -1.50(21) |
| $^{129}$Te | 14.21(47) | -0.18(14) | 16.96(59) | -0.33(15) | 0.69(3) | -1.09(22) |
| $^{131}$Te | 14.18(43) | 0.17(15) | 19.36(65) | -0.08(17) | 0.68(3) | -0.63(22) |
| $^{128}$I | 14.01(33) | -1.64(17) | 14.81(36) | -1.70(18) | 0.76(5) | -2.89(41) |
| $^{130}$I | 12.87(25) | -2.07(21) | 14.52(31) | -2.23(22) | 0.81(5) | -3.34(50) |
| $^{129}$Xe | 13.39(68) | -0.94(21) | 13.84(71) | -0.97(21) | 0.76(5) | -1.88(34) |
| $^{130}$Xe | 14.05(25) | 0.73(14) | 14.94(27) | 0.68(14) | 0.73(2) | -0.08(22) |
| $^{131}$Xe | 14.41(51) | -0.66(20) | 15.85(58) | -0.73(21) | 0.70(4) | -1.50(32) |
| $^{132}$Xe | 13.50(55) | 0.95(16) | 15.49(63) | 0.84(17) | 0.75(3) | 0.08(24) |
| $^{133}$Xe | 13.37(62) | -0.48(24) | 16.15(80) | -0.63(26) | 0.73(5) | -1.18(36) |
| $^{135}$Xe | 14.15(81) | 0.58(20) | 19.86(119 | 0.36(22) | 0.68(5) | -0.12(26) |
| $^{137}$Xe | 15.71(44) | 0.38(25) | 23.37(225 | 0.23(27) | 0.54(6) | -0.03(29) |
| $^{134}$Cs | 13.37(22) | -1.65(16) | 15.28(27) | -1.81(18) | 0.78(4) | -2.82(37) |
| $^{135}$Cs | 12.50(40) | -0.77(33) | 14.86(54) | -0.97(36) | 0.80(4) | -1.50(51) |
| $^{131}$Ba | 14.90(36) | -0.65(17) | 14.89(35) | -0.65(17) | 0.71(3) | -1.72(27) |
| $^{133}$Ba | 14.44(59) | -0.72(20) | 15.04(62) | -0.75(20) | 0.72(4) | -1.73(31) |
| $^{135}$Ba | 13.11(40) | -0.86(30) | 14.58(47) | -0.96(32) | 0.77(4) | -1.66(46) |
| $^{136}$Ba | 13.49(30) | 0.69(17) | 15.65(37) | 0.57(19) | 0.75(3) | -0.03(27) |
| $^{137}$Ba | 13.58(34) | 0.45(20) | 16.85(47) | 0.29(21) | 0.72(3) | -0.25(28) |
| $^{138}$Ba | 12.39(39) | 1.12(22) | 15.60(54) | 0.88(24) | 0.79(3) | 0.48(30) |
| $^{139}$Ba | 12.69(65) | 0.04(29) | 16.05(90) | -0.14(32) | 0.72(6) | -0.48(41) |
| $^{139}$La | 12.27(34) | -0.22(23) | 14.87(45) | -0.47(25) | 0.79(3) | -0.83(32) |
| $^{140}$La | 13.52(40) | -1.20(19) | 16.17(51) | -1.35(21) | 0.71(5) | -1.91(38) |
| $^{137}$Ce | 16.30(67) | -0.01(15) | 17.18(76) | -0.08(17) | 0.65(3) | -0.91(26) |
| $^{141}$Ce | 15.39(51) | 0.62(17) | 18.08(63) | 0.55(18) | 0.60(3) | 0.11(24) |
| $^{142}$Ce | 15.48(58) | 0.90(16) | 17.34(66) | 0.83(17) | 0.62(4) | 0.22(26) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{143}$Ce | 15.83(99) | -0.25(20) | 17.21(111 | -0.30(21) | 0.61(7) | -0.84(41) |
| $^{142}$Pr | 13.97(69) | -1.05(38) | 15.73(82) | -1.14(40) | 0.71(9) | -1.78(73) |
| $^{143}$Nd | 15.54(38) | 0.40(17) | 17.37(44) | 0.33(17) | 0.64(3) | -0.36(26) |
| $^{144}$Nd | 15.40(28) | 0.95(12) | 16.44(30) | 0.91(12) | 0.64(2) | 0.29(20) |
| $^{145}$Nd | 17.08(35) | 0.25(11) | 17.78(37) | 0.23(12) | 0.59(2) | -0.55(17) |
| $^{146}$Nd | 16.12(38) | 0.51(13) | 16.25(38) | 0.51(13) | 0.63(2) | -0.25(19) |
| $^{147}$Nd | 16.96(50) | -0.62(17) | 16.63(49) | -0.61(17) | 0.60(3) | -1.39(28) |
| $^{148}$Nd | 19.70(103) | 0.70(16) | 18.90(98) | 0.72(16) | 0.53(3) | -0.07(22) |
| $^{149}$Nd | 18.57(38) | -0.65(11) | 17.51(35) | -0.62(11) | 0.55(2) | -1.48(18) |
| $^{151}$Nd | 17.26(34) | -0.91(14) | 16.55(32) | -0.89(14) | 0.60(2) | -1.76(24) |
| $^{148}$Pm | 17.33(59) | -1.48(22) | 16.79(56) | -1.45(22) | 0.62(3) | -2.57(36) |
| $^{145}$Sm | 14.82(28) | 0.43(14) | 16.38(32) | 0.37(14) | 0.66(2) | -0.19(21) |
| $^{148}$Sm | 17.34(23) | 0.77(9) | 17.05(23) | 0.78(9) | 0.60(1) | -0.01(15) |
| $^{149}$Sm | 17.95(44) | -0.39(11) | 17.14(42) | -0.37(10) | 0.57(2) | -1.12(18) |
| $^{150}$Sm | 18.77(29) | 0.64(8) | 17.57(27) | 0.66(8) | 0.56(1) | -0.15(14) |
| $^{151}$Sm | 18.55(41) | -0.98(14) | 17.02(37) | -0.93(14) | 0.59(4) | -2.08(34) |
| $^{152}$Sm | 18.96(26) | 0.45(10) | 17.61(24) | 0.48(10) | 0.56(2) | -0.25(18) |
| $^{153}$Sm | 17.76(28) | -1.08(13) | 16.62(25) | -1.05(12) | 0.61(3) | -2.06(29) |
| $^{155}$Sm | 17.19(35) | -0.80(15) | 16.77(33) | -0.79(15) | 0.61(3) | -1.68(32) |
| $^{152}$Eu | 19.62(20) | -1.60(8) | 18.09(18) | -1.54(8) | 0.60(2) | -3.03(22) |
| $^{153}$Eu | 17.27(27) | -0.83(12) | 15.98(24) | -0.78(11) | 0.65(3) | -1.88(26) |
| $^{154}$Eu | 19.13(31) | -1.43(8) | 17.92(29) | -1.38(8) | 0.60(3) | -2.77(22) |
| $^{155}$Eu | 17.73(27) | -0.54(11) | 16.87(26) | -0.51(11) | 0.63(2) | -1.54(28) |
| $^{156}$Eu | 17.51(66) | -1.34(15) | 16.97(64) | -1.32(15) | 0.63(3) | -2.44(25) |
| $^{153}$Gd | 19.29(38) | -0.87(8) | 17.59(34) | -0.82(8) | 0.58(3) | -1.94(21) |
| $^{155}$Gd | 19.35(34) | -0.67(13) | 17.94(31) | -0.62(13) | 0.58(2) | -1.74(22) |
| $^{156}$Gd | 18.45(21) | 0.36(9) | 17.43(20) | 0.39(8) | 0.60(2) | -0.61(17) |
| $^{157}$Gd | 18.36(44) | -0.70(12) | 17.61(42) | -0.68(12) | 0.59(2) | -1.63(20) |
| $^{158}$Gd | 17.91(13) | 0.28(8) | 17.45(13) | 0.29(8) | 0.61(1) | -0.69(16) |
| $^{159}$Gd | 17.71(27) | -0.71(12) | 17.45(27) | -0.70(11) | 0.61(2) | -1.68(19) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{161}$Gd | 17.29(32) | -0.57(12) | 17.53(32) | -0.57(12) | 0.59(2) | -1.25(21) |
| $^{160}$Tb | 18.20(24) | -1.28(11) | 17.82(23) | -1.26(11) | 0.61(2) | -2.39(20) |
| $^{157}$Dy | 19.46(63) | -0.94(13) | 18.06(58) | -0.90(13) | 0.58(2) | -2.02(24) |
| $^{159}$Dy | 17.62(91) | -0.86(17) | 16.71(86) | -0.83(17) | 0.62(4) | -1.75(29) |
| $^{161}$Dy | 18.06(37) | -0.88(14) | 17.51(36) | -0.86(14) | 0.61(3) | -1.87(31) |
| $^{162}$Dy | 18.08(21) | 0.30(9) | 17.81(20) | 0.31(9) | 0.60(1) | -0.58(15) |
| $^{163}$Dy | 17.31(27) | -0.84(13) | 17.36(27) | -0.84(13) | 0.62(2) | -1.76(21) |
| $^{164}$Dy | 17.75(23) | 0.38(10) | 18.06(24) | 0.37(10) | 0.60(1) | -0.42(15) |
| $^{165}$Dy | 16.90(29) | -0.94(14) | 17.32(30) | -0.96(14) | 0.62(2) | -1.77(23) |
| $^{166}$Ho | 18.29(27) | -1.00(9) | 18.63(28) | -1.01(9) | 0.59(1) | -1.94(16) |
| $^{163}$Er | 19.20(50) | -0.80(12) | 18.27(47) | -0.77(12) | 0.58(2) | -1.78(21) |
| $^{165}$Er | 18.34(40) | -0.74(10) | 17.89(39) | -0.73(9) | 0.60(2) | -1.72(17) |
| $^{167}$Er | 18.19(24) | -0.65(10) | 18.38(24) | -0.65(10) | 0.60(1) | -1.50(17) |
| $^{168}$Er | 17.79(15) | 0.26(7) | 18.17(16) | 0.25(7) | 0.60(1) | -0.62(14) |
| $^{169}$Er | 17.57(25) | -0.67(11) | 18.13(26) | -0.69(11) | 0.60(2) | -1.43(24) |
| $^{171}$Er | 17.67(41) | -0.68(16) | 18.55(44) | -0.70(16) | 0.59(2) | -1.33(26) |
| $^{170}$Tm | 18.38(25) | -1.05(11) | 18.79(26) | -1.07(11) | 0.61(2) | -2.05(20) |
| $^{171}$Tm | 19.39(49) | 0.05(13) | 19.83(54) | -0.02(14) | 0.58(2) | -0.89(21) |
| $^{169}$Yb | 19.90(65) | -0.50(10) | 19.57(64) | -0.49(10) | 0.55(3) | -1.33(23) |
| $^{170}$Yb | 18.16(19) | 0.38(11) | 18.06(19) | 0.38(11) | 0.61(1) | -0.61(17) |
| $^{171}$Yb | 18.47(37) | -0.45(9) | 18.63(38) | -0.45(9) | 0.58(2) | -1.21(17) |
| $^{172}$Yb | 18.88(18) | 0.32(8) | 19.29(18) | 0.31(8) | 0.59(2) | -0.50(16) |
| $^{173}$Yb | 18.34(38) | -0.25(18) | 19.07(40) | -0.27(18) | 0.57(2) | -0.89(30) |
| $^{174}$Yb | 18.29(35) | 0.45(17) | 19.11(37) | 0.43(17) | 0.57(2) | -0.17(26) |
| $^{175}$Yb | 17.91(35) | -0.41(13) | 18.88(37) | -0.43(13) | 0.58(2) | -1.06(21) |
| $^{177}$Yb | 18.06(35) | -0.52(13) | 19.18(38) | -0.54(13) | 0.57(2) | -1.16(21) |
| $^{176}$Lu | 19.55(30) | -0.71(8) | 20.20(32) | -0.73(8) | 0.56(1) | -1.57(13) |
| $^{177}$Lu | 18.22(61) | -0.42(15) | 18.74(64) | -0.43(15) | 0.55(2) | -0.94(21) |
| $^{175}$Hf | 19.08(55) | -0.53(10) | 19.06(55) | -0.53(10) | 0.57(2) | -1.28(19) |
| $^{177}$Hf | 19.21(50) | -0.50(12) | 19.55(52) | -0.51(12) | 0.56(2) | -1.23(21) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{178}$Hf | 19.07(24) | 0.23(8) | 19.57(25) | 0.21(8) | 0.57(2) | -0.58(24) |
| $^{179}$Hf | 19.18(25) | -0.35(9) | 19.81(26) | -0.37(9) | 0.56(2) | -1.13(18) |
| $^{180}$Hf | 17.86(22) | -0.03(10) | 18.67(23) | -0.04(10) | 0.59(2) | -0.80(22) |
| $^{181}$Hf | 19.68(43) | -0.21(11) | 20.72(46) | -0.24(11) | 0.53(2) | -0.85(18) |
| $^{181}$Ta | 20.52(49) | -0.29(15) | 21.31(51) | -0.30(15) | 0.54(2) | -0.87(26) |
| $^{182}$Ta | 19.06(23) | -0.96(9) | 19.96(25) | -0.99(9) | 0.57(1) | -1.87(16) |
| $^{183}$Ta | 17.70(46) | -0.76(17) | 18.44(49) | -0.79(17) | 0.60(2) | -1.51(26) |
| $^{181}$W | 19.07(75) | -0.55(15) | 19.64(77) | -0.56(16) | 0.58(3) | -1.38(26) |
| $^{183}$W | 19.22(30) | -0.24(10) | 20.24(33) | -0.27(11) | 0.55(2) | -0.92(17) |
| $^{184}$W | 18.76(30) | 0.08(14) | 19.72(33) | 0.04(14) | 0.58(2) | -0.64(21) |
| $^{185}$W | 19.45(28) | -0.50(8) | 20.54(30) | -0.52(8) | 0.56(1) | -1.30(14) |
| $^{187}$W | 19.14(36) | -0.81(13) | 20.44(40) | -0.85(14) | 0.57(2) | -1.63(22) |
| $^{186}$Re | 19.87(28) | -0.90(10) | 21.05(31) | -0.93(10) | 0.56(1) | -1.76(18) |
| $^{188}$Re | 19.93(26) | -1.00(10) | 21.45(29) | -1.04(10) | 0.55(1) | -1.88(17) |
| $^{187}$Os | 19.07(29) | -0.78(11) | 20.08(32) | -0.81(11) | 0.58(2) | -1.57(19) |
| $^{188}$Os | 19.88(37) | 0.34(12) | 21.23(37) | 0.32(11) | 0.58(2) | -0.63(19) |
| $^{189}$Os | 18.60(38) | -1.04(15) | 19.97(42) | -1.08(15) | 0.59(2) | -1.87(25) |
| $^{190}$Os | 19.44(26) | 0.29(11) | 21.32(29) | 0.24(12) | 0.56(2) | -0.33(20) |
| $^{191}$Os | 18.29(37) | -1.07(13) | 20.39(43) | -1.14(13) | 0.60(2) | -1.91(21) |
| $^{193}$Os | 18.06(42) | -1.00(19) | 21.24(54) | -1.11(20) | 0.59(3) | -1.69(30) |
| $^{192}$Ir | 19.45(45) | -1.55(13) | 21.77(53) | -1.65(13) | 0.60(2) | -2.74(22) |
| $^{193}$Ir | 22.77(58) | -0.30(9) | 26.11(67) | -0.38(9) | 0.52(2) | -1.21(15) |
| $^{194}$Ir | 17.98(61) | -1.66(15) | 21.23(75) | -1.84(17) | 0.64(3) | -2.78(25) |
| $^{193}$Pt | 19.15(78) | -1.02(17) | 21.55(90) | -1.10(18) | 0.58(3) | -1.87(27) |
| $^{195}$Pt | 15.30(79) | -1.57(24) | 18.25(99) | -1.77(26) | 0.72(5) | -2.43(36) |
| $^{196}$Pt | 17.97(29) | 0.38(10) | 22.53(38) | 0.21(10) | 0.61(2) | -0.33(18) |
| $^{197}$Pt | 14.91(63) | -1.61(25) | 18.99(89) | -1.90(29) | 0.72(4) | -2.38(39) |
| $^{199}$Pt | 16.06(64) | -1.25(23) | 22.16(101 | -1.57(27) | 0.66(4) | -1.90(35) |
| $^{198}$Au | 16.00(22) | -1.72(16) | 20.98(36) | -2.12(18) | 0.71(3) | -2.74(35) |
| $^{199}$Hg | 15.82(69) | -1.27(26) | 21.56(107 | -1.66(31) | 0.69(4) | -2.02(40) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{200}$Hg | 14.29(26) | -0.62(19) | 19.79(45) | -1.22(23) | 0.77(4) | -1.40(37) |
| $^{201}$Hg | 13.39(54) | -1.78(31) | 19.45(98) | -2.46(40) | 0.80(5) | -2.46(46) |
| $^{202}$Hg | 13.79(56) | -0.61(22) | 20.93(102 | -1.38(29) | 0.77(4) | -1.23(31) |
| $^{204}$Tl | 12.90(41) | -1.96(28) | 20.45(94) | -3.21(40) | 0.84(4) | -2.72(42) |
| $^{206}$Tl | 10.41(54) | -1.25(32) | 18.33(136 | -3.13(53) | 0.98(7) | -1.62(44) |
| $^{205}$Pb | 12.71(56) | -0.61(22) | 21.47(114 | -1.60(31) | 0.81(4) | -1.08(30) |
| $^{207}$Pb | 11.08(54) | 0.60(42) | 19.85(158 | -1.73(67) | 0.91(9) | 0.23(57) |
| $^{208}$Pb | 10.01(60) | 1.17(39) | 18.41(168 | -0.67(64) | 1.06(11) | 0.52(67) |
| $^{209}$Pb | 11.22(58) | 0.61(55) | 27.12(355 | 0.31(51) | 0.77(12) | 0.69(49) |
| $^{210}$Bi | 11.40(49) | -1.24(29) | 19.73(118 | -2.21(42) | 0.82(8) | -1.43(53) |
| $^{227}$Ra | 24.33(65) | -0.86(12) | 22.91(60) | -0.84(12) | 0.46(2) | -1.56(20) |
| $^{229}$Th | 25.35(88) | -0.77(15) | 24.01(179 | -0.76(15) | 0.45(3) | -1.49(22) |
| $^{230}$Th | 24.33(46) | 0.05(9) | 23.13(43) | 0.06(8) | 0.47(1) | -0.59(14) |
| $^{231}$Th | 26.41(41) | -0.42(8) | 25.17(39) | -0.40(7) | 0.43(2) | -1.16(17) |
| $^{233}$Th | 25.98(34) | -0.58(9) | 24.75(32) | -0.57(9) | 0.43(1) | -1.29(15) |
| $^{233}$Pa | 22.27(44) | -0.98(9) | 21.32(42) | -0.96(9) | 0.53(2) | -1.87(16) |
| $^{234}$Pa | 28.01(62) | -0.70(13) | 26.92(59) | -0.69(13) | 0.41(2) | -1.37(23) |
| $^{233}$U | 25.37(43) | -0.51(9) | 24.69(42) | -0.50(9) | 0.45(1) | -1.17(16) |
| $^{234}$U | 25.24(22) | 0.30(6) | 24.52(21) | 0.30(6) | 0.45(1) | -0.38(11) |
| $^{235}$U | 25.08(30) | -0.51(9) | 24.44(29) | -0.50(9) | 0.45(2) | -1.22(20) |
| $^{236}$U | 25.76(21) | 0.14(7) | 25.07(20) | 0.15(7) | 0.44(1) | -0.46(13) |
| $^{237}$U | 25.60(39) | -0.43(12) | 25.04(38) | -0.42(12) | 0.43(2) | -1.02(23) |
| $^{238}$U | 25.26(35) | 0.06(8) | 24.48(34) | 0.07(8) | 0.45(1) | -0.59(14) |
| $^{239}$U | 26.67(31) | -0.31(9) | 25.95(30) | -0.30(9) | 0.42(2) | -0.92(18) |
| $^{237}$Np | 25.01(27) | -0.40(6) | 24.47(26) | -0.39(6) | 0.47(1) | -1.14(12) |
| $^{238}$Np | 25.96(33) | -0.84(11) | 25.55(32) | -0.84(11) | 0.45(2) | -1.64(24) |
| $^{239}$Np | 25.26(58) | -0.63(8) | 24.65(55) | -0.62(8) | 0.46(1) | -1.34(15) |
| $^{239}$Pu | 25.23(49) | -0.30(11) | 25.22(49) | -0.30(11) | 0.45(1) | -0.91(14) |
| $^{240}$Pu | 25.16(20) | 0.12(8) | 24.97(20) | 0.13(8) | 0.46(1) | -0.50(15) |
| $^{241}$Pu | 26.03(29) | -0.32(7) | 25.86(29) | -0.32(7) | 0.42(1) | -0.90(13) |

| | | | | | | |
|---|---|---|---|---|---|---|
| $^{242}$Pu | 28.97(51) | 0.34(10) | 28.57(50) | 0.34(10) | 0.40(1) | -0.22(15) |
| $^{243}$Pu | 27.20(40) | -0.19(7) | 26.93(39) | -0.19(7) | 0.41(1) | -0.74(12) |
| $^{245}$Pu | 27.63(64) | -0.19(12) | 27.20(62) | -0.19(12) | 0.39(2) | -0.57(20) |
| $^{242}$Am | 26.19(23) | -0.74(7) | 26.22(23) | -0.74(7) | 0.44(1) | -1.49(15) |
| $^{243}$Am | 26.42(48) | -0.43(8) | 26.20(47) | -0.43(8) | 0.44(1) | -1.05(15) |
| $^{244}$Am | 26.02(29) | -0.84(7) | 25.96(29) | -0.84(7) | 0.45(1) | -1.67(12) |
| $^{243}$Cm | 24.39(43) | -0.26(9) | 24.70(44) | -0.26(9) | 0.46(1) | -0.82(15) |
| $^{244}$Cm | 24.63(61) | 0.17(16) | 24.92(62) | 0.17(16) | 0.46(2) | -0.34(23) |
| $^{245}$Cm | 24.96(33) | -0.39(8) | 25.38(34) | -0.40(8) | 0.45(1) | -0.99(13) |
| $^{246}$Cm | 27.56(44) | 0.42(7) | 27.81(45) | 0.42(7) | 0.42(1) | -0.29(12) |
| $^{247}$Cm | 23.64(54) | -0.62(12) | 23.89(54) | -0.62(12) | 0.47(2) | -1.17(20) |
| $^{248}$Cm | 25.03(62) | 0.29(13) | 24.99(62) | 0.30(13) | 0.43(2) | -0.18(25) |
| $^{249}$Cm | 25.53(57) | -0.57(10) | 25.42(57) | -0.56(10) | 0.43(2) | -1.11(16) |
| $^{250}$Bk | 25.86(38) | -0.94(9) | 25.95(38) | -0.95(9) | 0.44(1) | -1.66(16) |
| $^{250}$Cf | 24.74(35) | 0.20(9) | 25.42(36) | 0.19(9) | 0.45(1) | -0.31(16) |
| $^{251}$Cf | 26.34(49) | -0.43(7) | 26.96(50) | -0.43(7) | 0.42(1) | -0.99(13) |

TABLE III: Resume of the formulas (13)-(18) proposed for the description of the phenomenological model parameters (Fig. 2). The quantities $P_d$, $S'(Z,N)$, and $dS(Z,N)/dA$ are given in MeV (Table I), therefore the dimensions of the different $p_i$ constants in the formulas are such that $a$, $\tilde{a}$ are in MeV$^{-1}$, and $T$, $E_i$ are in MeV, respectively. Also, note that for the compactness of the table we use the same notation, $p_i$, for the fitted parameters in the different formulas, but, for example in the case of the BSFG, the $p_i$ constants in the formula of $a$ and of $E_1$, respectively, have differemt meanings (they are factors for different quantities and have completely different values).

| Model | Formula | Parameters in the formula | | | | Type of |
|---|---|---|---|---|---|---|
| | | $p_1$ | $p_2$ | $p_3$ | $p_4$ | nuclei |
| | $\mathbf{a/A} = p_1 + p_2 S'(Z,N) + p_3 A$ | 0.127(1) | 4.98(13)$\times 10^{-3}$ | -8.95(53)$\times 10^{-5}$ | | all |
| **BSFG** | | | | | | |
| | $\mathbf{E_1} = p_1 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA}$ | -0.468(30) | -0.565(23) | -0.231(39) | 0.438(83) | e-e |
| | $= p_2 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA}$ | | | | | o-e,e-o |
| | $= p_3 + 0.5P_d + p_4 \frac{dS(Z,N)}{dA}$ | | | | | o-o |
| | $\mathbf{\tilde{a}/A} = p_1 + p_3 A$ | 0.127(1) | | -9.05(53)$\times 10^{-5}$ | | all |
| **BSFG-ED** | | | | | | |
| | $\mathbf{E_2} = p_1 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA}$ | -0.477(31) | -0.577(23) | -0.231(40) | 0.442(87) | e-e |
| | $= p_2 - 0.5P_d + p_4 \frac{dS(Z,N)}{dA}$ | | | | | o-e,e-o |
| | $= p_3 + 0.5P_d + p_4 \frac{dS(Z,N)}{dA}$ | | | | | o-o |
| | $\mathbf{T.A^{2/3}} = p_1 + p_2 S'(Z,N) + p_3 S'(Z,N)^2$ | 17.45(6) | -0.51(4) | 0.051(10) | | all |
| **CT** | | | | | | |
| | $\mathbf{E_0} = p_1 - 0.5P_d + p_2 \frac{dS(Z,N)}{dA}$ | -1.23(3) | 0.32(14) | -1.42(3) | 0.84(14) | e-e |
| | $= p_3 - P_d + p_4 \frac{dS(Z,N)}{dA}$ | | | | | o-e,e-o |
| | $= p_1 + 0.5P_d + p_2 \frac{dS(Z,N)}{dA}$ | | | | | o-o |

$S(Z,N) = M_{exp} - M_{LD}$, cf. eqs. (7) and (9); $S'(Z,N)$ cf. eqs. (10) and (11);

$P_d = \frac{1}{4}(-1)^{Z+1}[S_d(A+2,Z+1) - 2S_d(A,Z) + S_d(A-2,Z-1)]$; ($S_d$ - deuteron separation energy) [17, 18].

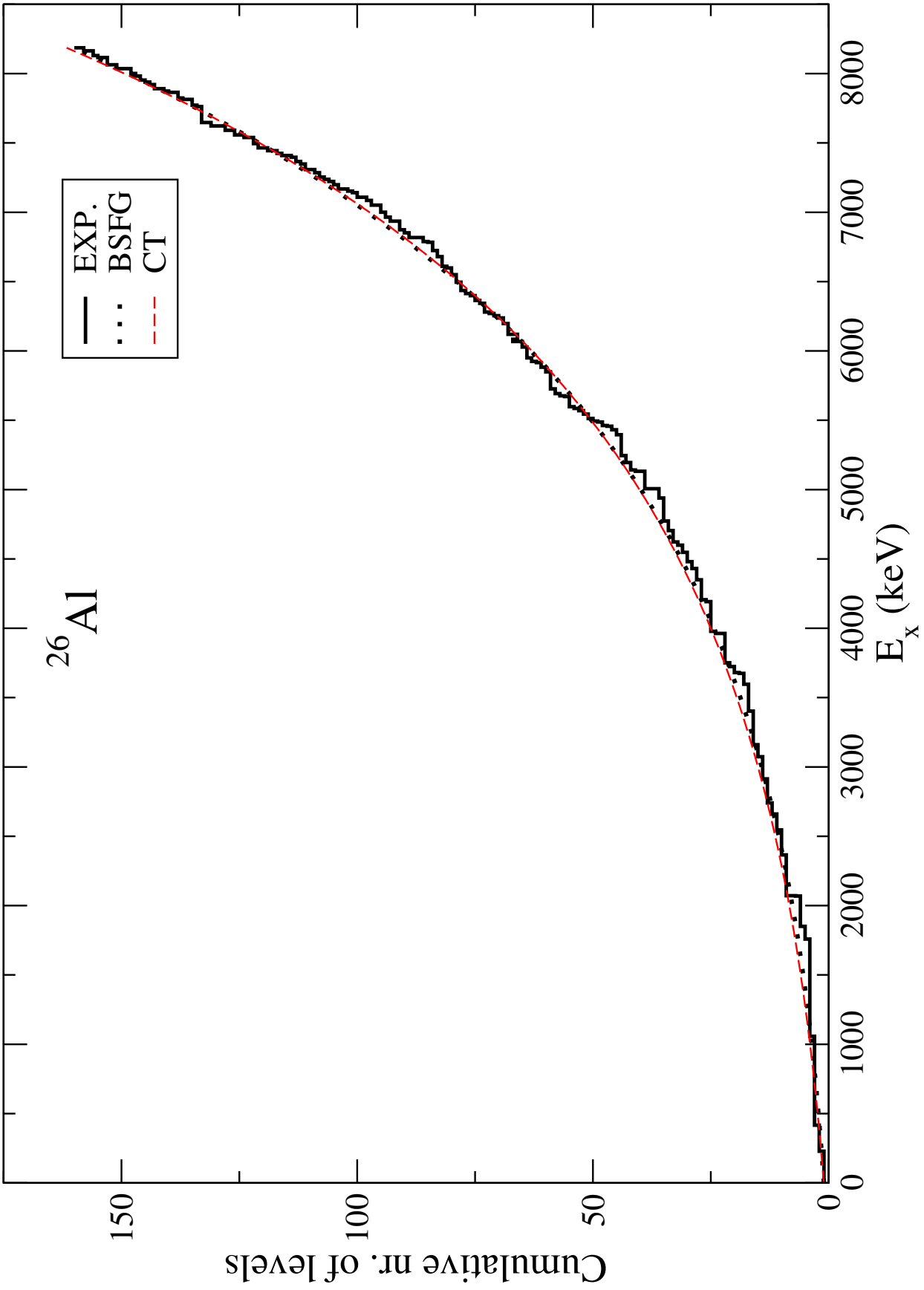


FIG. 1: (Color online) Fits of the experimental cumulative number of levels of $^{26}$Al with spin 0-5$\hbar$ with the BSFG and CT model formulas.

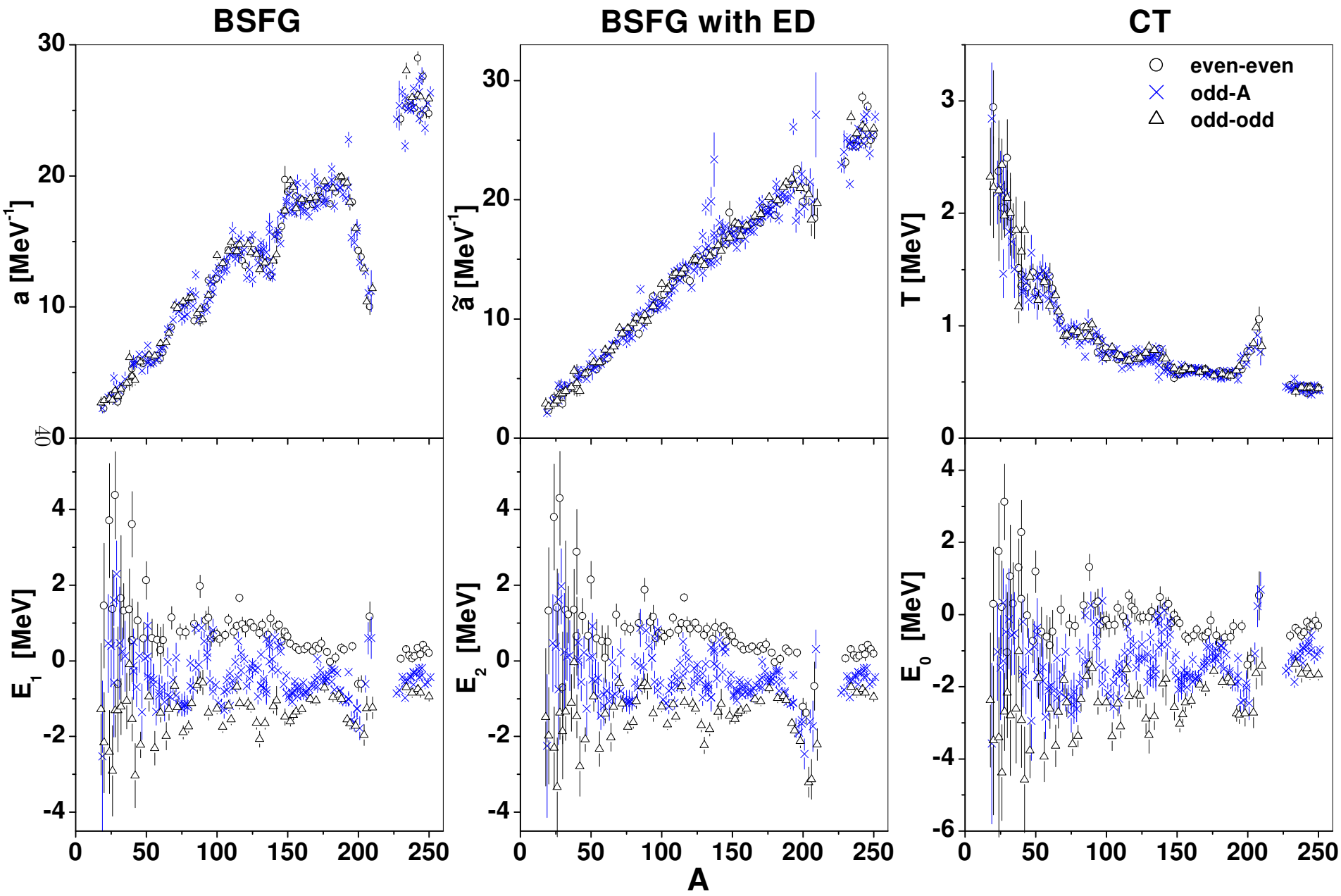


FIG. 2: (Color online) Phenomenological level density parameters for the three models considered in this work (see text for details).

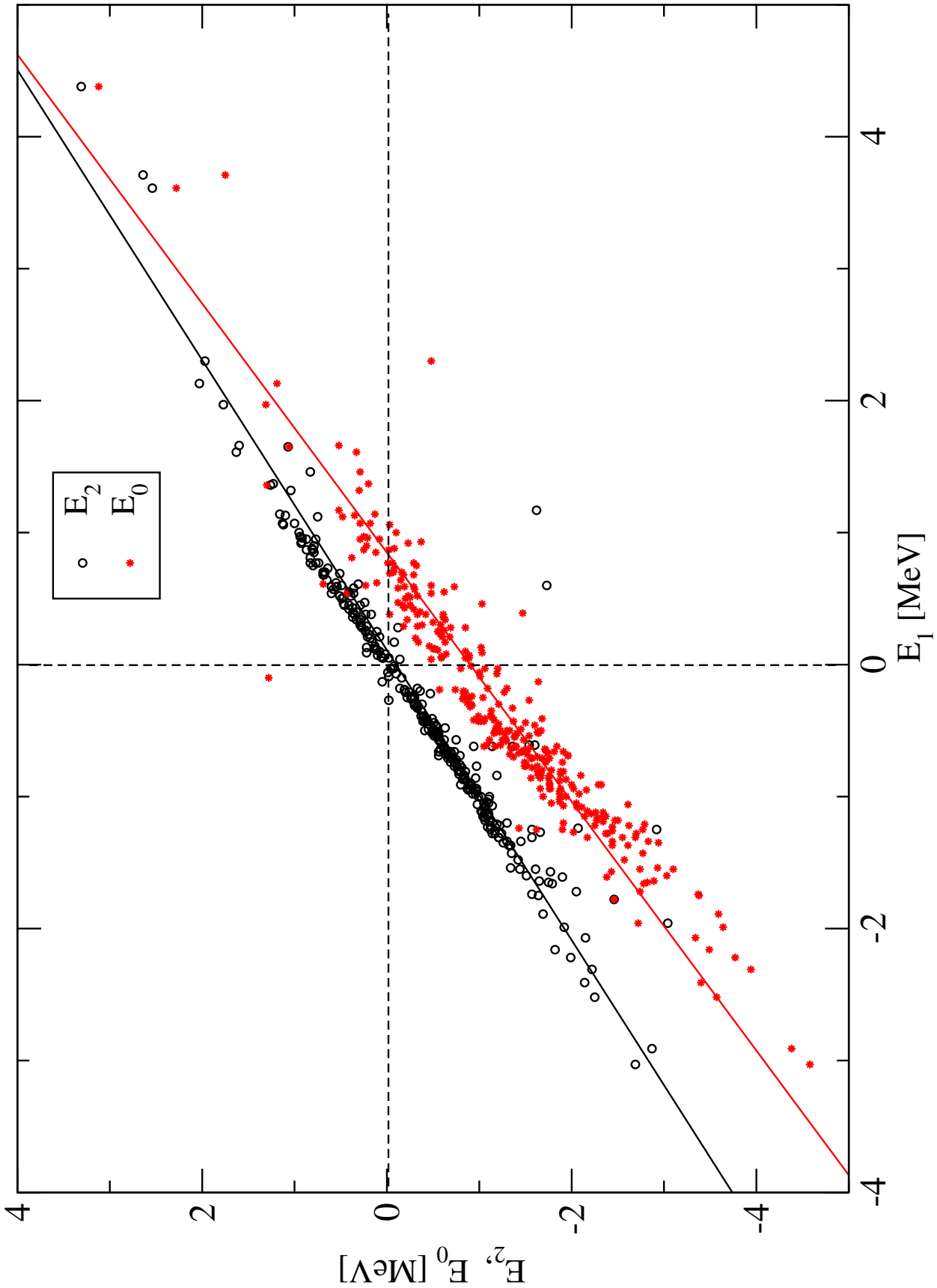


FIG. 3: (Color online) The linear correlations between the backshift energies of the three models. The straight line fitted to the $E_2$ versus $E_1$ correlation passes through the origin and has slope close to 1.

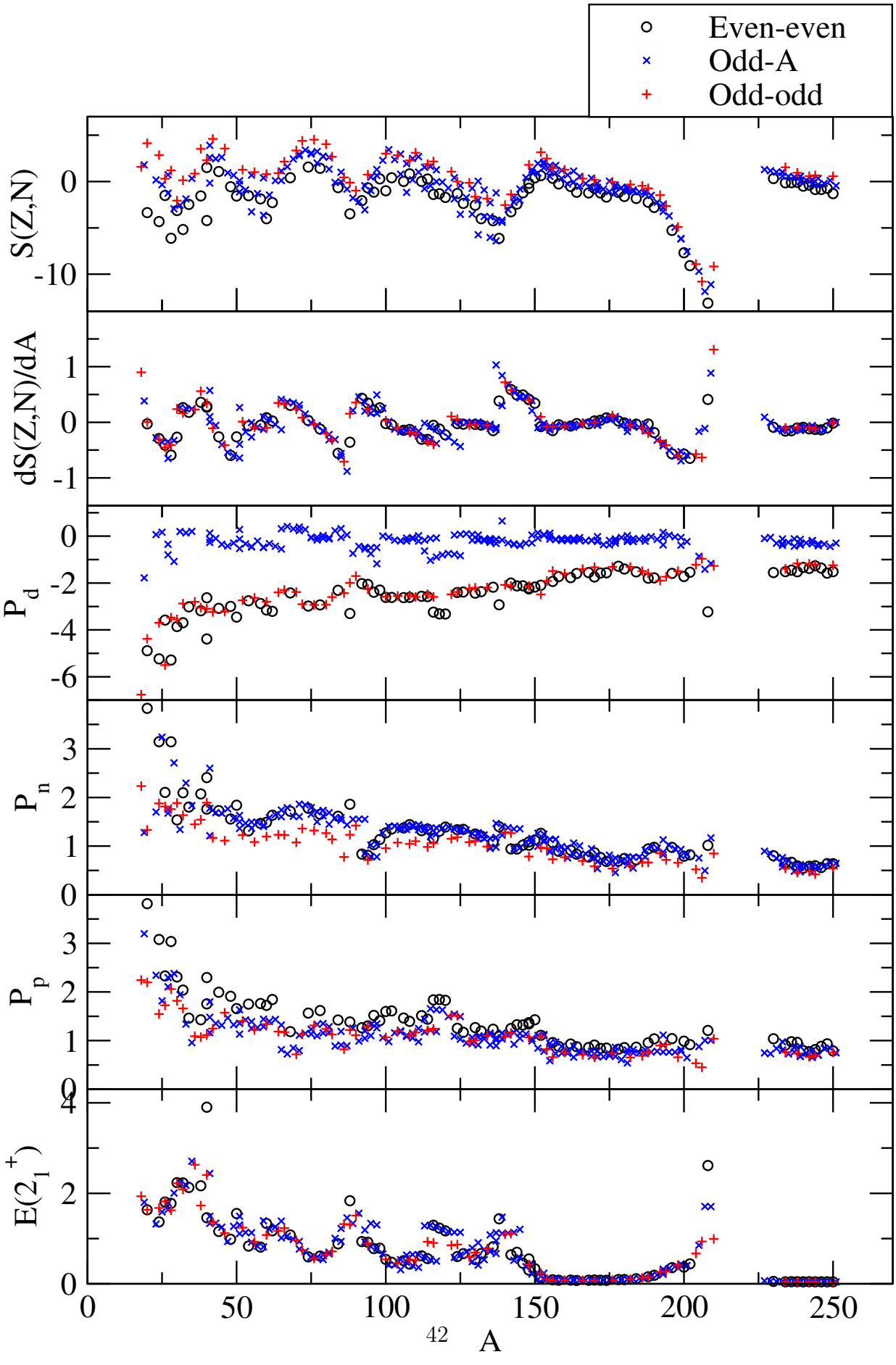




FIG. 4: (Color online) Different physical quantities used to find correlations with the LD phenomenological parameters (all in MeV). $S$ is the shell correction, eqs. (7), (9), $dS/dA$ - its derivative, eq. (12), $P_d$ - the deuteron pairing energy. See text for more details.

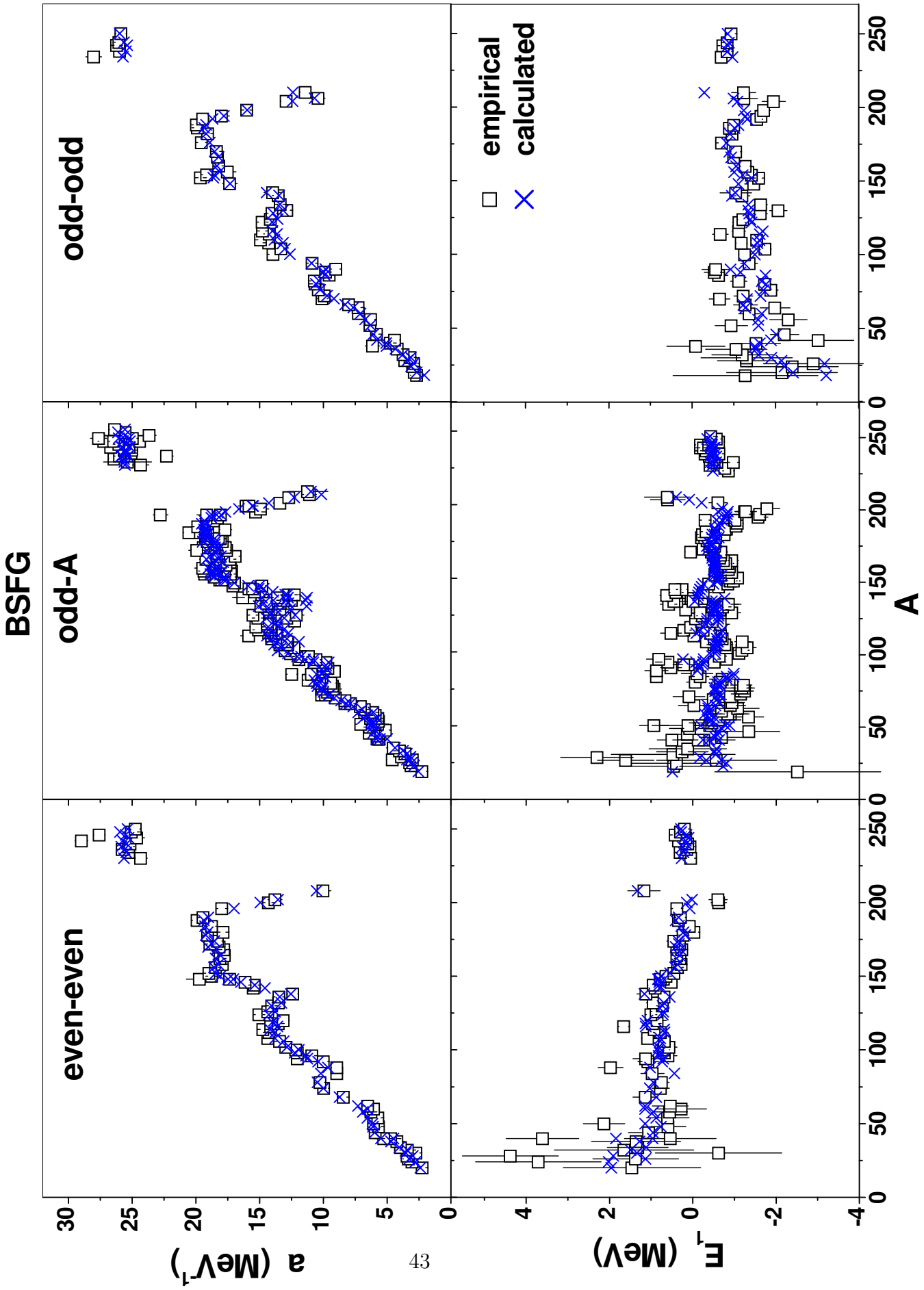


FIG. 5: (Color online) Fits to the BSFG model parameters (Fig. 1) with the empirical formulas (13) and (14) and $p_i$ values from Table III.

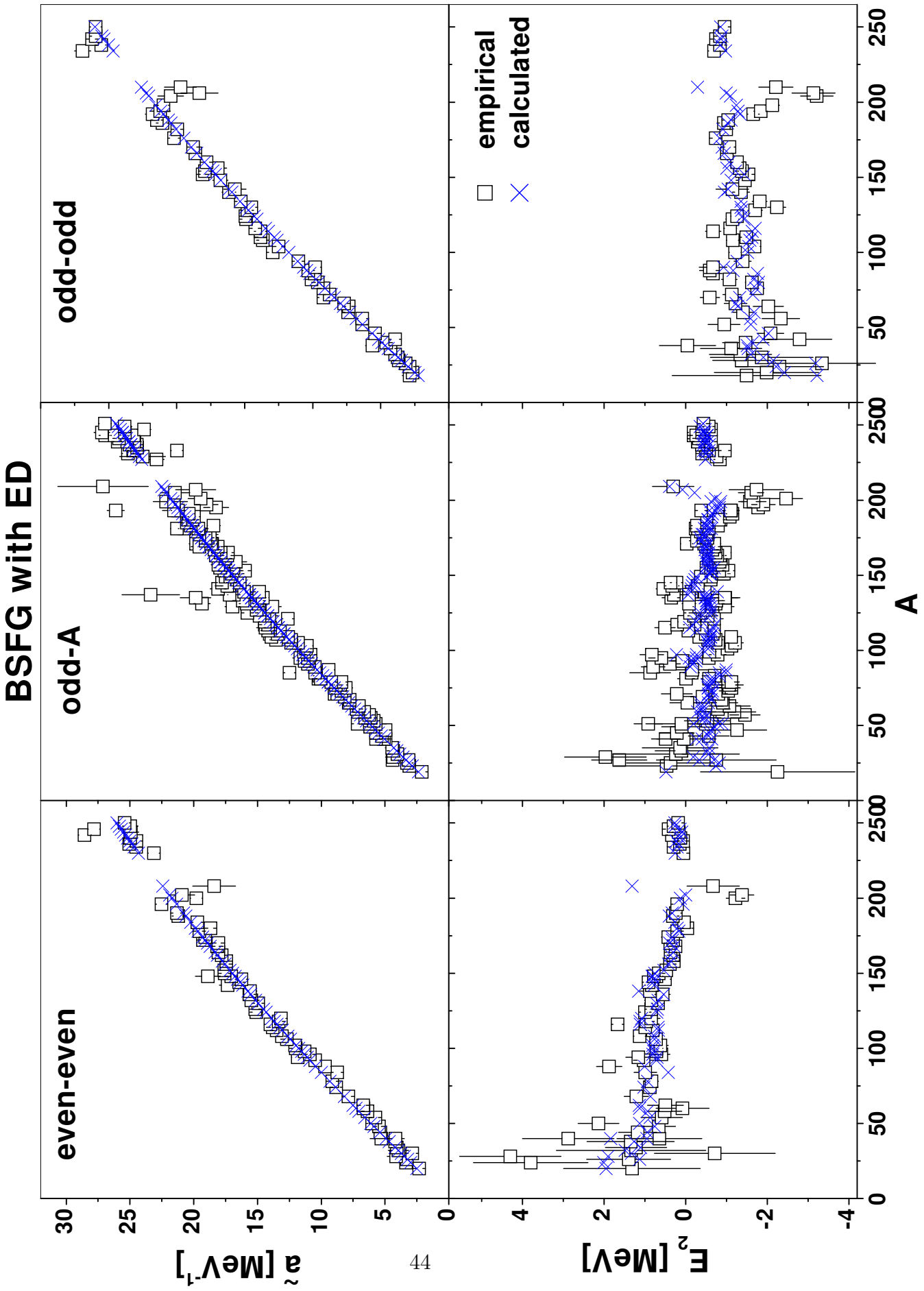




FIG. 6: (Color online) Same as Fig. 5, but for the BSFG model with energy dependence, formulas (15) and (16). Note that the $p_i$ parameters found from fit (Table III) are identical with those of

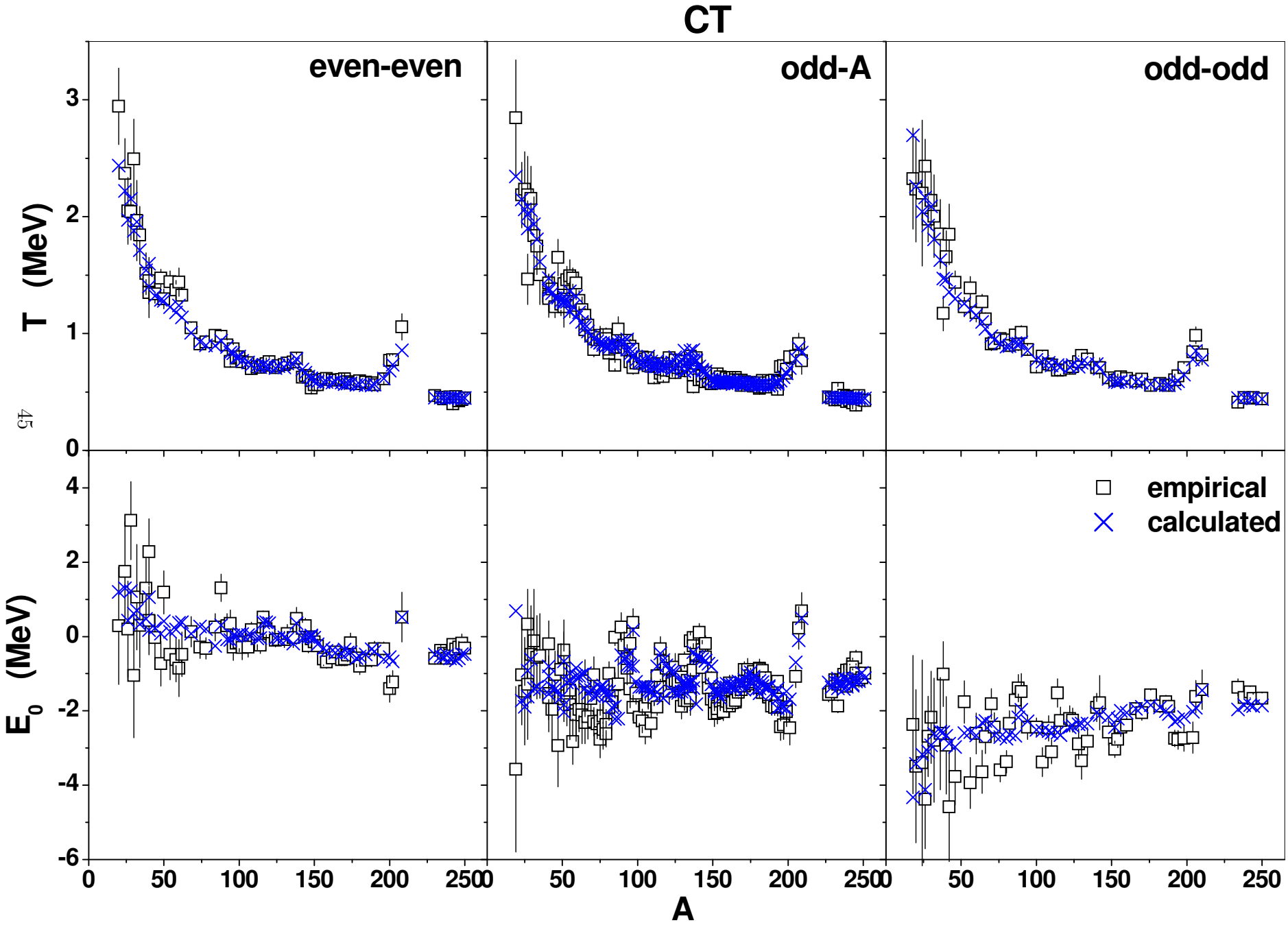


FIG. 7: (Color online) Same as Fig. 5 but for the CT model, formulas (17) and (18).

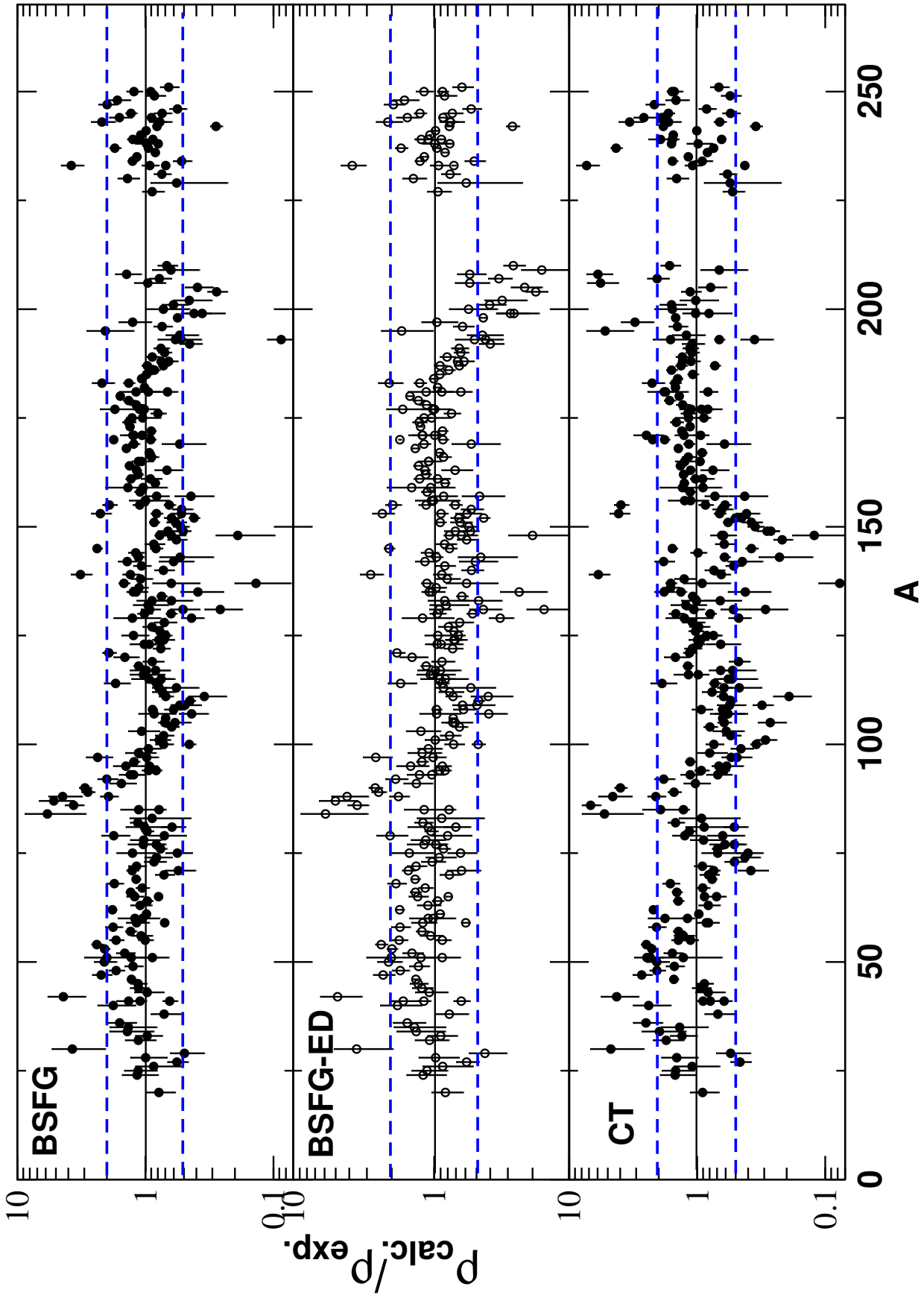


FIG. 8: (Color online) Test of the formulas proposed in this work for the level density at the neutron resonance energy. The dashed lines mark a difference by a factor of 2 between the experimental and calculated values.