1 Atomic Masses and Deformations

Coordinator: M.B. Chadwick

Summary

This chapter discusses recommendations for nuclear masses, binding energies and ground-state deformations, for use in nuclear reaction model calculations. We recommend that the Möller *et al.* file **moller.dat** with data for nearly 9000 nuclides be used for these quantities. The whole region of masses is covered by **audi_95.dat**, which brings recommended masses for nearly 3000 nuclides based on experimental values. As a general rule, where experimental values exists, they should be used for calculations.

1.1 Calculated Masses and Deformations

1.1.1 Introduction

The file **moller.dat** contains tabulations of the atomic mass excesses and nuclear ground-state deformations of 8979 nuclei ranging from ^{16}O to $A = 339$. The calculations are based on the finite-range droplet macroscopic model and the folded-Yukawa single-particle microscopic model. Relative to the Möller *et. al.* 1981 mass table the current results are obtained with an improved macroscopic model, an improved pairing model with a new form for the effective-interaction pairing gap, and minimization of the ground-state energy with respect to additional shape degrees of freedom. The values of only nine constants are determined directly from a least-squares adjustment to the ground-state masses of 1654 nuclei ranging from ^{16}O to $[Z = 106, A = 263]$ and to 28 fission-barrier heights. The error of the mass model is 0.669 MeV for the entire region of nuclei considered, but is only 0.448 MeV for the region N greater than or equal to 65.

Within the Möller *et al.* table, results are given for ground-state deformations within two different nuclear shape parameterizations: the "ϵ parameterization" (Nilsson perturbed-spheroid parameterization); and the "β parameterization" (a spherical harmonic expansion). Möller *et al.* discuss the relation between these two parameterizations in Ref. [1.1], and note that their ϵ tabulations completely specify the nuclear shape, but the β tabulations do not since β_5 is not tabulated. For this reason, use of the "ϵ parameterization" is preferred.

The Möller *et al.* table also shows calculated ground-state microscopic energies (shell-corrections [2]), and calculated ground-state atomic mass excesses, for two different models: the finite-range liquid drop model (FRLDM); and the finite-range droplet model (FRDM). As discussed in Ref. [1.1], the more recent FRDM is preferred.

Figures 1.1 and 1.2 show the microscopic energy (shell-correction energy) and the ground state quadrupole deformation, from Möller *et al.*'s work [1.1].

[2] As discussed in Ref. [1.1], the microscopic energy includes the shell plus pairing correction, but it also includes the difference in macroscopic energy between the deformed and spherical nucleus. It is therefore defined to represent all additional effects over and above the *spherical* macroscopic energy.

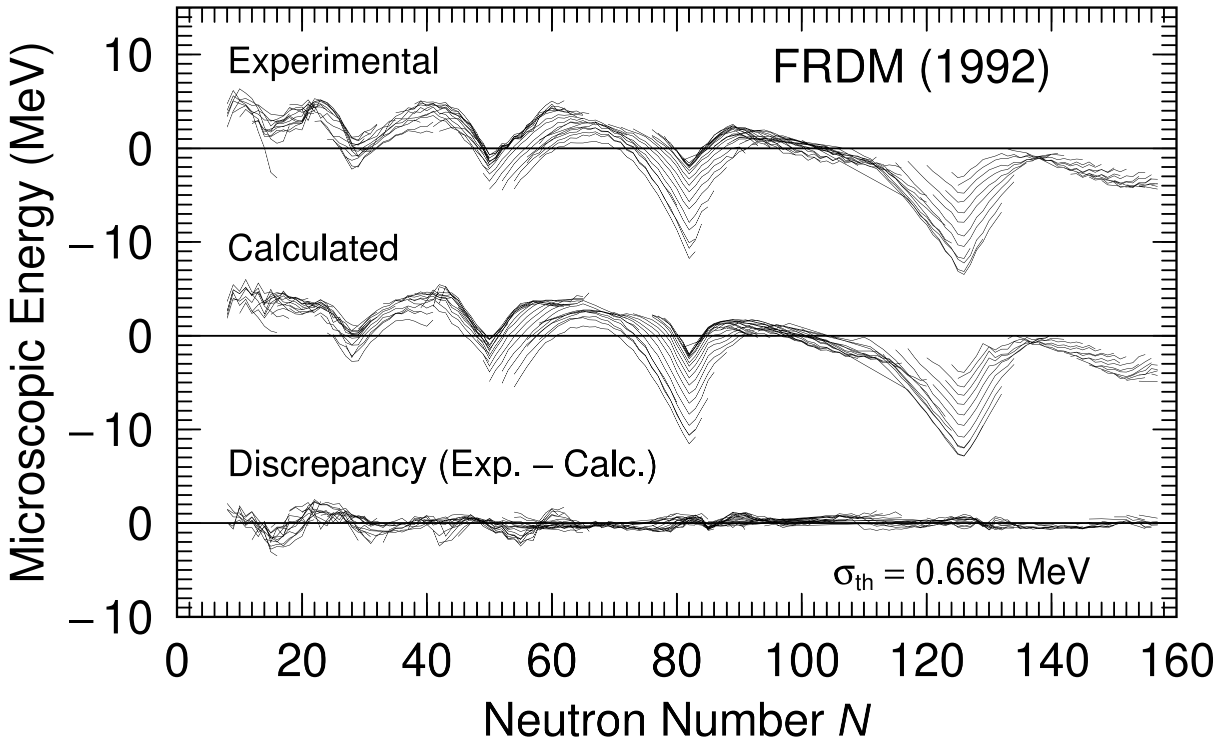

Figure 1.1: Comparison of experimental and calculated microscopic energies $E_{\rm mic}$ for 1654 nuclei, for Möller *et al.*'s FRDM model. The lines are drawn through isotopic chains. (Taken from Fig. 1 of Ref. [1.1]).

1.1.2 Format

EXPLANATION OF TABLE VARIABLES:

Z proton number. The mass table is ordered by increasing proton number. The corresponding chemical symbol of each named element is given in parentheses.

N neutron number.

A mass number.

ϵ_2 calculated ground-state quadrupole deformation in the Nilsson perturbed-spheroid parameterization.

ϵ_3 calculated ground-state octopole deformation in the Nilsson perturbed-spheroid parameterization.

ϵ_4 calculated ground-state hexadecapole deformation in the Nilsson perturbed-spheroid parameterization.

ϵ_6 calculated ground-state hexacontatetrapole deformation in the Nilsson perturbed-spheroid parameterization.

$\epsilon_6^{\rm sym}$ calculated ground-state hexacontatetrapole deformation in the Nilsson perturbed-spheroid parameterization for $\epsilon_3 = 0$.

β_2 calculated quadrupole deformation of the nuclear ground-state expressed in the spherical-harmonics expansion defined by Eq. (37) in Ref. [1.1].

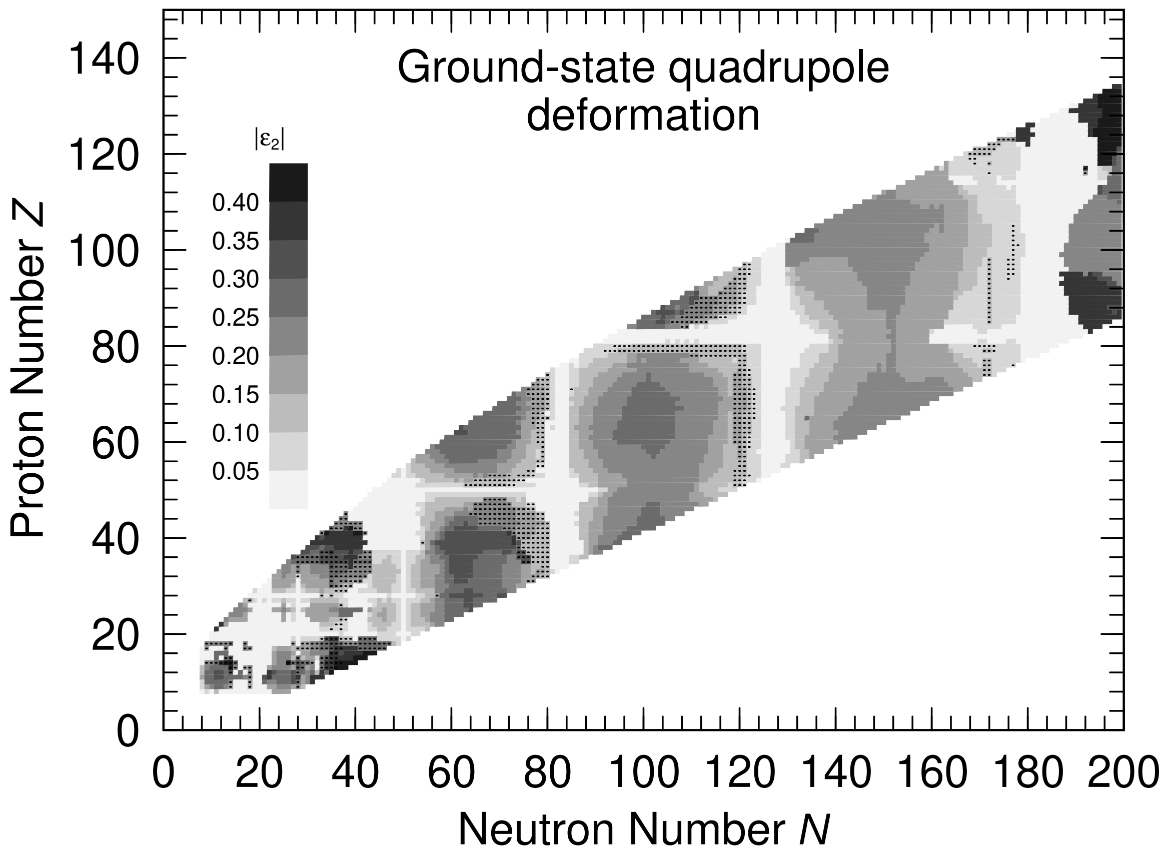

Figure 1.2: Calculated ground-state deformation values $|\epsilon_2|$ for 7969 nuclei using Möller *et al.*'s FRDM model. This figure is a grey-scale version of the color Fig. 9 in Ref. [1.1].

β_3 calculated octopole deformation of the nuclear ground-state expressed in the spherical-harmonics expansion defined by Eq. (37) in Ref. [1.1].

β_4 calculated hexadecapole deformation of the nuclear ground-state expressed in the spherical-harmonics expansion defined by Eq. (37) in Ref. [1.1].

β_6 calculated hexacontatetrapole deformation of the nuclear ground-state expressed in the spherical-harmonics expansion defined by Eq. (37) in Ref. [1.1].

$E_{\rm mic}$ calculated ground-state microscopic energy, given by the difference between the calculated ground-state atomic mass excess and the spherical macroscopic energy calculated from Eq. (40), in the preferred Möller *et al.* model, the FRDM (see Ref. [1.1]). Since this microscopic energy represents the difference compared to the spherical energy, and not the macroscopic energy at equilibrium nuclear deformation, it should not be used for the shell corrections needed in the level density formulation, described in Chapter 5.

$M_{\rm th}$ calculated ground-state atomic mass excess, in the preferred Möller *et al.* model, the FRDM.

$M_{\rm exp}$ experimental ground-state atomic mass excess in the 1989 midstream evaluation of Audi with 4 revisions [1.2].

$\sigma_{\rm exp}$ experimental error associated with the ground-state atomic mass excess in the 1989 midstream evaluation of Audi with 4 revisions [1.2].

$E_{\rm mic}^{\rm FL}$ calculated ground-state microscopic energy, given by the difference between the calculated ground-state atomic mass excess and the spherical macroscopic energy calculated from Eq. (62) of Ref. [1.1], in the FRLDM model [1.1]. Since this microscopic energy represents the difference compared to the spherical energy, and not the macroscopic energy at equilibrium nuclear deformation, it should not be used for the shell corrections needed in the level density formulation, described in Chapter 5.

$M_{\rm mic}^{\rm FL}$ calculated ground-state atomic mass excess, in the FRLDM model [1.1].

1.2 Experimental Masses

File **audi_95.dat** brings recent compilation of masses, binding energies, β-decay energies (not needed within RIPL) and atomic masses for 2931 nuclides ranging from the neutron and the proton up to $A = 273$ [1.3]. The values given there are not purely experimental data, but recommended values based on the experimental ones. These values are very close to the experimental values of Möller *et al.* [1.1]; the differences can be neglected for most nuclear reaction calculation applications.

The file contains just the energies mentioned above together of the error or uncertainity derived from the adjusted masses and the correlation matrix. Nuclei denoted by # in the file give values and error estimated from systematic trends. The file is organized using 124 character long lines, what may cause some inconvenience to a not sufficiently careful user at 80-columns wide display and/or narrow printout.

1.3 Other Files

For completeness, we also include two other electronic files: *beijing.dat* and *jaeri_deform.dat*, these are described below.

The *beijing.dat* file contains a compilation of experimental masses, calculated masses by Möller *et al.*, as well as ground state spins and parities, and abundances and half-lives.

The *jaeri_deform.dat* is a compilation of deformation parameters of excited states for calculating DWBA direct reactions involving the excitation of various multipolarities, from the Japan Atomic Energy Research Institute.

1.4 Conclusions and Recommendations

The files to be used for obtaining nuclear masses, binding energies, Q-values and ground-state deformations are **moller.dat**, which brings all quantities quoted above for nearly 9000 nuclei, and **audi_95.dat**, restricted to recommended masses based on experimental values. Where experimental values exists, they should be used.

When Q-values are calculated, it is necessary to make use of the masses of a number of different nuclei. We note the importance of using the same source of information for all masses in such calculations. This is particularly important for nuclei far from stability, where experimental masses may only exist for certain of the nuclides involved. In such cases, one should make use of calculated masses for all the nuclei involved in the reaction, for consistency purposes.

References

[1.1] P. Möller, J.R. Nix, W.D. Myers and W.J. Swiatecki, Atomic Data Nucl. Data Tbl. **59**, 185 (1995). This publication can also be accessed at the WWW address: http://t2.lanl.gov/publications/publications.html.

[1.2] G. Audi, Midstream Atomic Mass Evaluation, private communication to P. Möller (1989), with 4 revisions.

[1.3] G. Audi and A.H. Wapstra, Nuclear Physics **A595**, 409 (1995). RIPL file **audi_95.dat** is the original file 'mass_rmd.mas95' of Audi and Wapstra. The other files of these authors do not enter RIPL.