International Conference on Exotic Nuclei and Atomic Masses
Arles, 19-23 June 1995

Constrained Mass Extrapolations

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Abstract: The nuclear surface of masses posseses an overall continuity and has a shape that generaly resembles that of a paraboloid. This property allows to derive procedures for predicting masses of unknown nuclides based on the extrapolation of this surface. The continuity requirement constraints strongly the extrapolated values and allows for an error assignment.

There is a need, mainly in nuclear astrophysics, for mass predictions far from stability, sometimes close to the drip lines. Several models for nuclear masses make already predictions for nuclei far from stability. They have various degrees of sophistication: from local relations of Garvey-Kelson type to macroscopic-microscopic and purely microscopic calculations. The encountered difficulty is that of making a choice among the model predictions as they, in general, diverge substantially from one another (see e.g. ref. [1]).

The aim of the present work is not to derive another model, but to formulate for the first time a computer assisted procedure for extrapolating masses from the actually known ones. Moreover, it is desirable to estimate an error for these extrapolated masses.

The main physical fact used for the present purpose is the observed smoothness (or, equivalently, continuity) of the mass surface. This property can easily be inferred from the regular behavior of its derivatives (one and two nucleon separation energies and Q_α) over large domains in the (Z,N) plane (see e.g. fig. 1) - a well known fact for a long time. Moreover, these derivatives lie on almost straight lines suggesting a parabolic shape of the mass surface. On the same figure one can see the strong discontinuities appearing at proton and neutron shell closures. At a closer look, one observes a gradual decrease in the slope of the lines connecting the derivatives values with increasing neutron number.

The hypothesis on which the present extrapolation technique is based is therefore that the mass surface in between magic numbers has a shape of a paraboloid. In order to define the parameters of this paraboloid, one should rely only on those spherical nuclides having a regular behavior and that are placed inside a zone bordered by magic neutron and proton numbers. In a next step, a fitting procedure is applied to this restricted set of masses. The functional is a third degree polynomial in N and Z, therefore allowing for slight stiffnes variations of the paraboloid inside the given zone. Importantly, different free terms are taken so as to account for the four different parity combinations. That reflects the existence of the four foils into which the surface of mass splits due to parity. Once the coefficients are determined in this way, the extrapolations are readily obtained, yielding masses of spherical nuclides.

The selection of the set of nuclides on which the fitting is done requires some care. This

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selection should exclude all "structures": closed shell or subshell nuclei, zones of ground state deformation, any nucleus that has a nonregular behavior. That may leave a rather poor set in some regions. Therefore, a regularizing procedure has to be applied. This procedure is done by using a graphical interactive computer program that allows to simultaneously visualize four different derivatives as a function of A , Z , N or I, make changes in anyone of them and also compare with the predictions of all available mass models [1].

Once the extrapolations are obtained, using the same program, changes are made in the limits of acceptability imposed by continuity constraints in order to evaluate the errors. Not only the derivatives but also differences between model predictions on one side and measured or extrapolated mass values on the other side are examined during this procedure.

The known structures coming from ground state deformation are then reintroduced; following their trends, these structures are extended up to their completion in the domain of extrapolated masses.

The described extrapolation procedure has at least three important by-products that are: pairing energies, amplitude of the gain in energy due to deformation effects and extention of the deformation zones.

The method can provide reliable close extrapolations (5 to 10 masses away from the known ones). Venturing furher away is risky as the main hypothesis may be no longer valid: for large values of neutron deficit or excess, the stiffnes parameter of the paraboloid may change. This is reflected in the assigned errors.

In conclusion, a method has been presented for extrapolating nuclear masses based on the continuity properties of the mass surface. Not being a model, it will not predict possible new structures but rather show the general trend. It is reliable for close extrapolations for which the assigned errors are rather small.

1. C. Borcea and G. Audi, Roum.Rev.Phys.38(1993)455