

## The 1993 atomic mass evaluation

### (III) Separation and decay energies. Graphs of systematic trends

C. Borcea<sup>a,1</sup>, G. Audi<sup>a</sup>, A.H. Wapstra<sup>b</sup> and P. Favaron<sup>a</sup>

<sup>a</sup> *Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, CSNSM, IN2P3-CNRS,  
Laboratoire René Bernas, Bâtiment 108, F-91405 Orsay Campus, France*

<sup>b</sup> *National Institute of Nuclear Physics and High-Energy Physics, NIKHEF-K, P.O. Box 41882,  
1009 DB Amsterdam, The Netherlands*

Received 28 September 1993

**Abstract** This third paper in a series of four presents graphs of: two neutron separation energies and  $\alpha$ -decay energies as a function of neutron number, two proton separation energies as a function of proton number and double  $\beta$ -decay energies as a function of mass number which are considered as the most illustrative ones for the systematic trends.

#### 1. Introduction

All the information contained in the mass table (part I) and in the nuclear reaction and separation energy table (part II) can in principle be displayed in a plot of the binding energy or the mass versus  $Z$  and  $N$ . Such a plot, in which the binding energies vary rapidly, is complicated by the fact that there are four sheets, corresponding to the four possible combinations of parity for  $Z$  and  $N$ . These sheets are nearly parallel almost everywhere in this three dimensional space and have remarkably regular trends, as one may convince oneself by making various cuts (e.g.  $Z$  or  $N$  or  $A$  constant). Any derivative of the binding energies also defines four sheets. In the present context, *derivative* means a specified difference between the masses of two nearby nuclei. They are also smooth and have the advantage of displaying much smaller variations. For a derivative specified in such a way that differences are between nuclides in the same mass sheet, the near parallelism of these leads to an (almost) unique surface for the derivative, allowing thus a single display. Therefore, in order to illustrate the systematic trends of the masses, four derivatives of this last type were chosen:

- (i) the two neutron separation energies versus  $N$ , with lines connecting the isotopes of a given element (figs. 1–8);
- (ii) the two proton separation energies versus  $Z$ , with lines connecting the isotones (the same number of neutrons) (figs. 9–15);
- (iii) the  $\alpha$ -decay energies versus  $N$ , with lines connecting the isotopes of a given element (figs. 16–23);

<sup>1</sup> IN2P3-Visitor, on leave from the Institute for Atomic Physics, Bucharest.

(iv) the double  $\beta$ -decay energies versus  $A$ , with lines connecting the isotopes and the isotones (figs. 24–32).

These graphs of systematic trends supersede earlier graphs [1].

Various other representations are possible (e.g. separately for odd and even nuclei: one neutron separation energies versus  $N$ , one proton separation energy versus  $Z$ ,  $\beta$ -decay energy versus  $A$ , etc.); they can all be built starting from the values in papers I and II of the present series.

Clearly showing the systematic trends, these graphs can be quite useful for checking the quality of any interpolation or extrapolation (if not too far) and generally is an excellent testground for theoretical mass models. When some masses in a defined region deviate from the systematic trends, almost always there is a serious physical cause behind this, like a shell or subshell closure or onset of deformation. But, if only one mass presents a *pathological* situation, violating the systematic trends, then one may seriously question the correctness of the related data. As already mentioned in the preceding two papers, the new policy regarding the so called *systematics* is that those locally *irregular* masses which are derived from one, two or (in one case) three measurements of the same physical quantity are preserved in the tables as such. There are 56 such physical quantities that were selected partly in order to avoid too strongly oscillating plots. Taking into account the connections (see part I, figs. 1a–1h) has the consequence that 99 ground-state masses are concerned (and twice as many values in each type of plot). The recommended values for these masses are given in an additional table (table C in part I). It should be stressed that these are only the most striking cases and that not all irregularities have been removed here. In particular, as happened previously, the plots of  $\alpha$ -decay energies of light nuclei exhibit many overlaps and crossings that obscure the drawings; no attempt was made to locate possible origins of such irregularities. Work is in progress [2] for constructing an *idealized* surface of masses from the point of view of its regular character. Such a surface can be useful in order to single out the regions presenting an *anomaly*, in other words: a specific local physical effect. It can be very useful also for making extrapolations and it can help improving the existing models since the experimental *noise* will be much reduced.

In cases where the experimental mass values were replaced, the graphs connect with dashed lines the values of decay and separation energies given in part II. With solid lines are connected the *regularized* values and unreplaced ones.

The replaced values for data, masses and reaction and separation energies have been derived by observing the continuity property not only in the four representations given here but also several other possible representations, using a special graphics program [2] that also takes into account the consequences of a mass change due to its decay chains, and also consulting the predictions of all existing models. Therefore they are the best estimates such a procedure can yield.

### References

- [1] K. Bos, G. Audi and A.H. Wapstra, Nucl. Phys. A432 (1985) 140.  
[2] C. Borcea, G. Audi and J. Duflo, Proc. Conf. Nucl. Far From Stability/AMCO9, Bernkastel-Kues 1992, Inst. Phys. Conf. Series 132(1993)59; C. Borcea and G. Audi, Rev. Roum. Phys. 38 (1993) #45, to appear November 1993; CSNSM-9238 report, Orsay 1992.

### Figures

Figs. 1–8.  $2n$  separation energies.

Figs. 9–15.  $2p$  separation energies.

Figs. 16–23.  $\alpha$ -decay energies.

Figs. 24–32.  $\beta\beta$ -decay energies.

Mass numbers and element symbol are indicated only along the borders of the graphs; those for the intermediate points must be derived by enumeration. Open circles represent values estimated from systematic trends; points, experimental values. Lines connect points for isotopes ( $S_{2n}$ ,  $Q_\alpha$ ,  $Q_{\beta\beta}$ ) or isotones ( $S_{2p}$ ,  $Q_{\beta\beta}$ ). Nuclides for which the recommended value is different from the experimental one (see part I, section 4 and tables B and C there) are represented twice: with solid line and without symbol for the recommended value; with dotted line and with appropriate symbol for the experimental one. Where relevant, nuclidic name is given only beside the solid line. Other nuclides are connected with solid lines. In fig. 1, the  $S_{2n}$  ( ${}^5\text{He}$ ) point has been omitted for drawing purposes.

Fig. 1. Two neutrons separation energies  $N = 0$  to 25

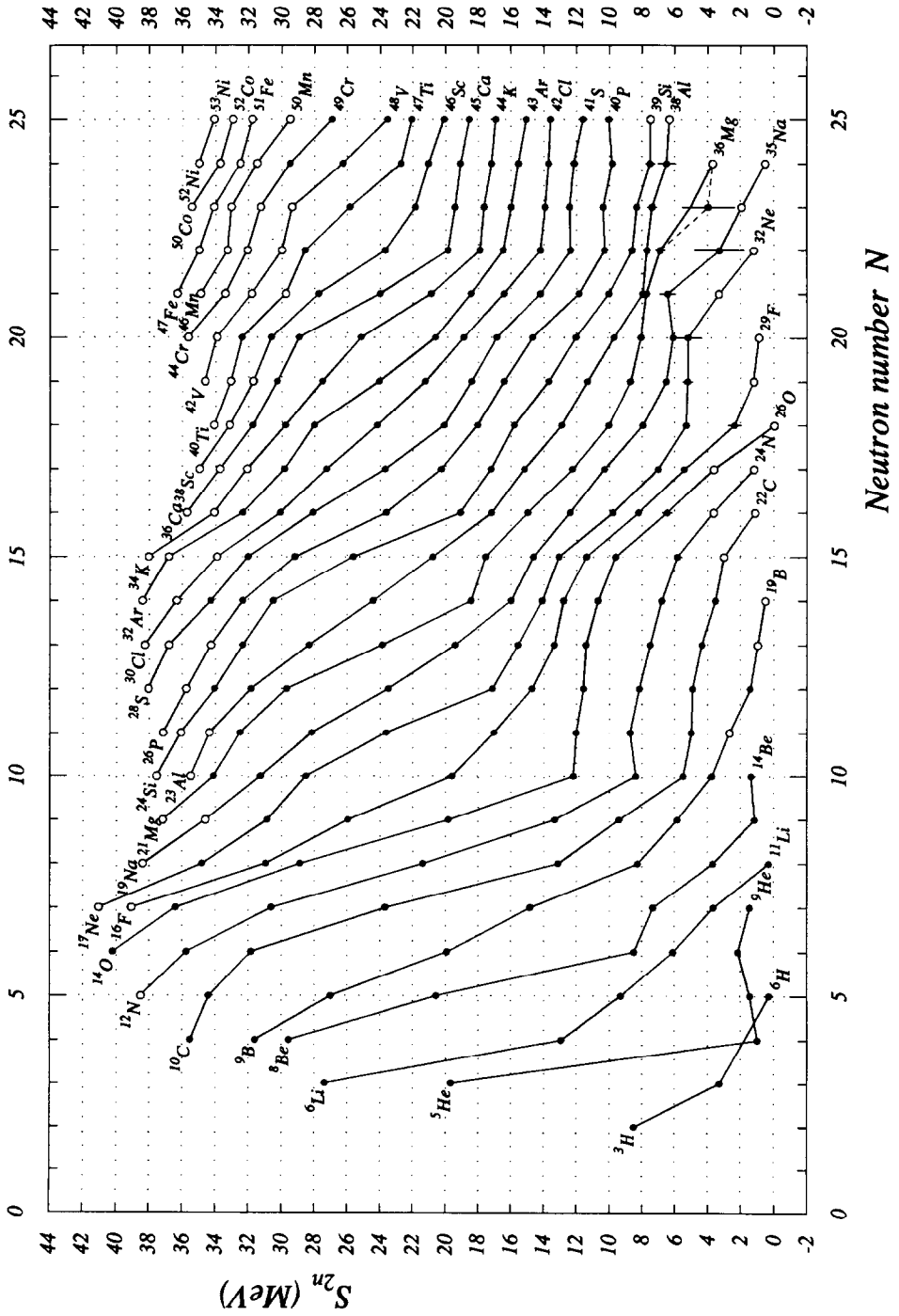


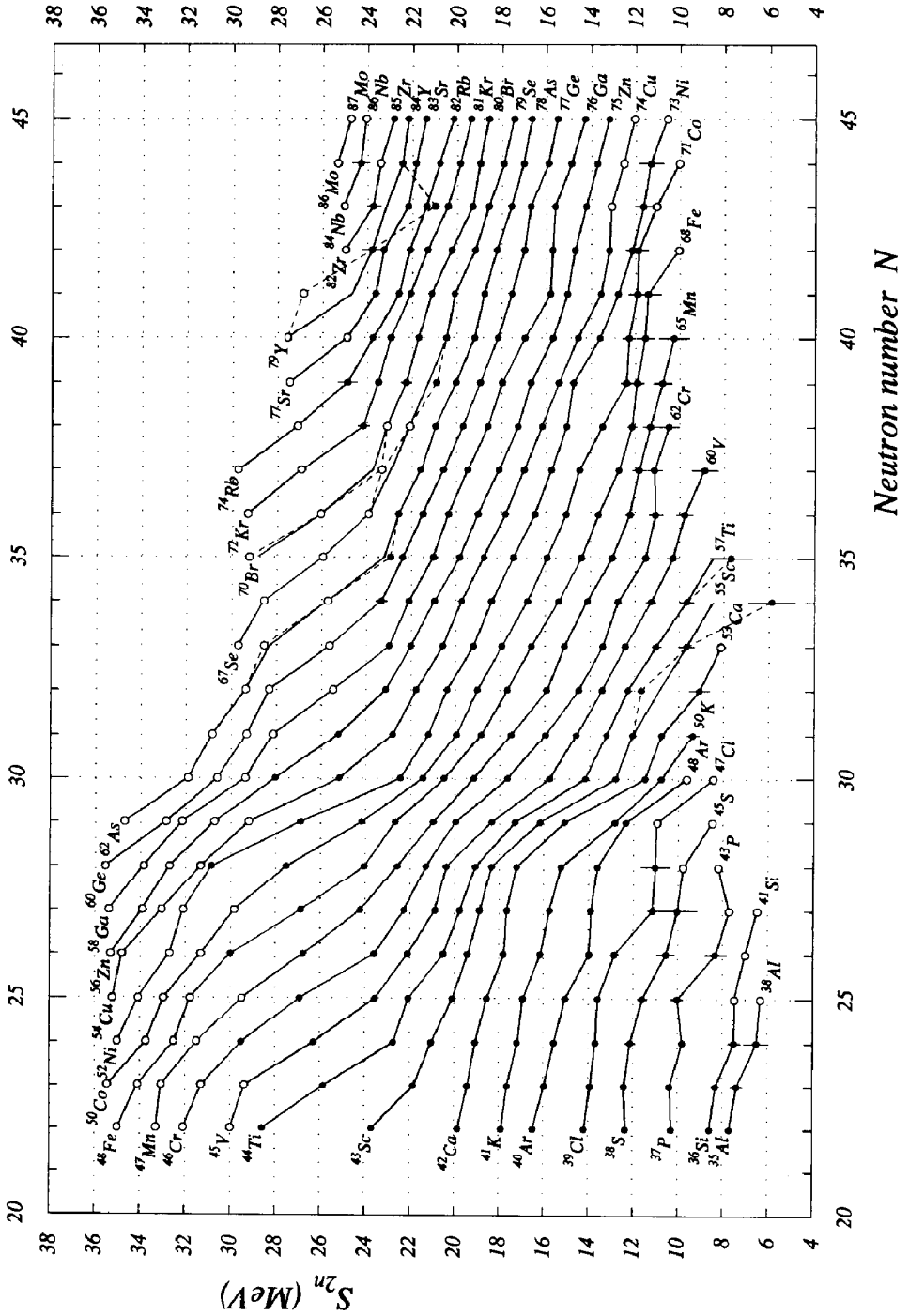
Fig. 2. Two neutrons separation energies  $N = 22$  to 45

Fig. 3. Two neutrons separation energies  $N = 42$  to 65

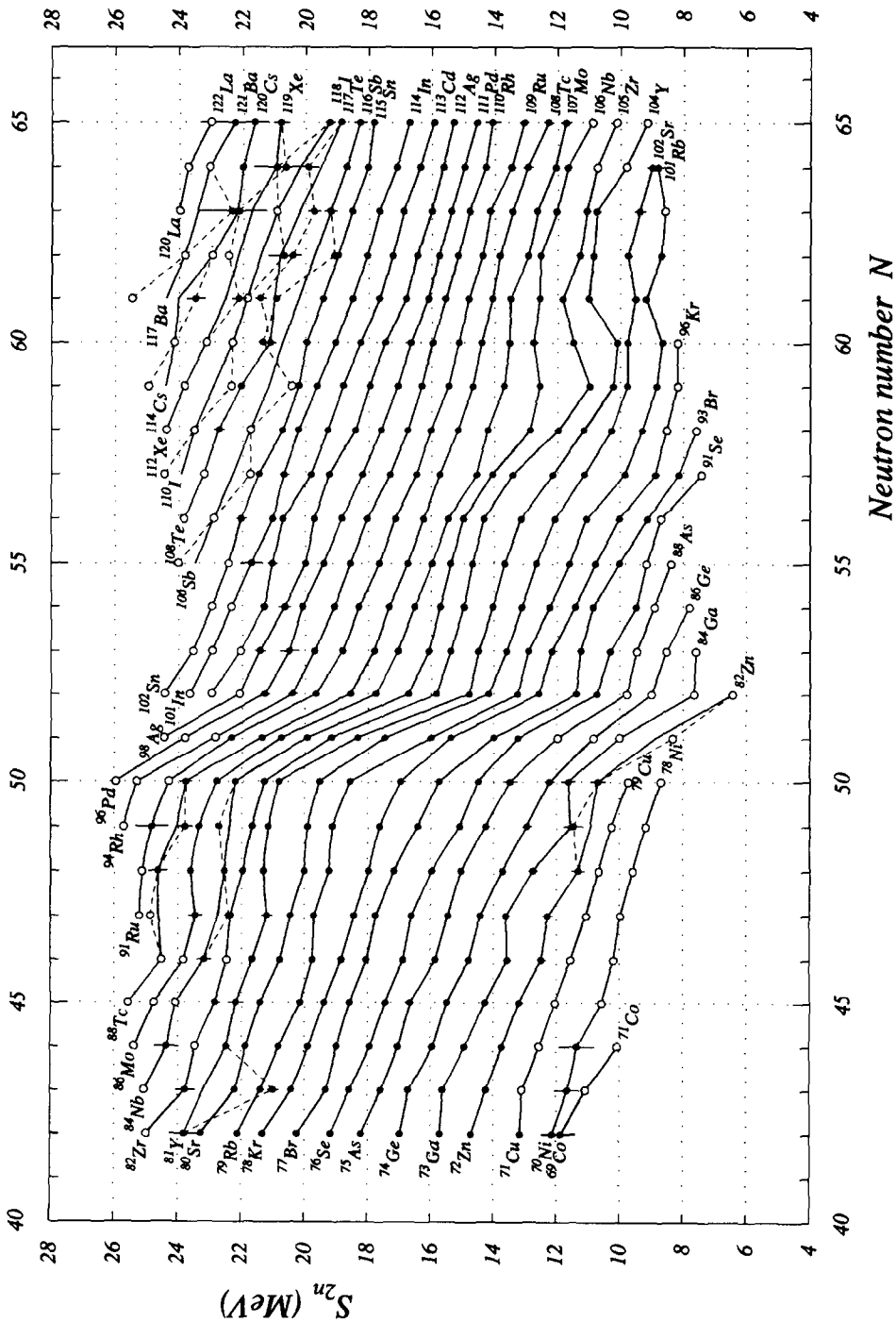


Fig. 4. Two neutrons separation energies  $N = 62$  to 85

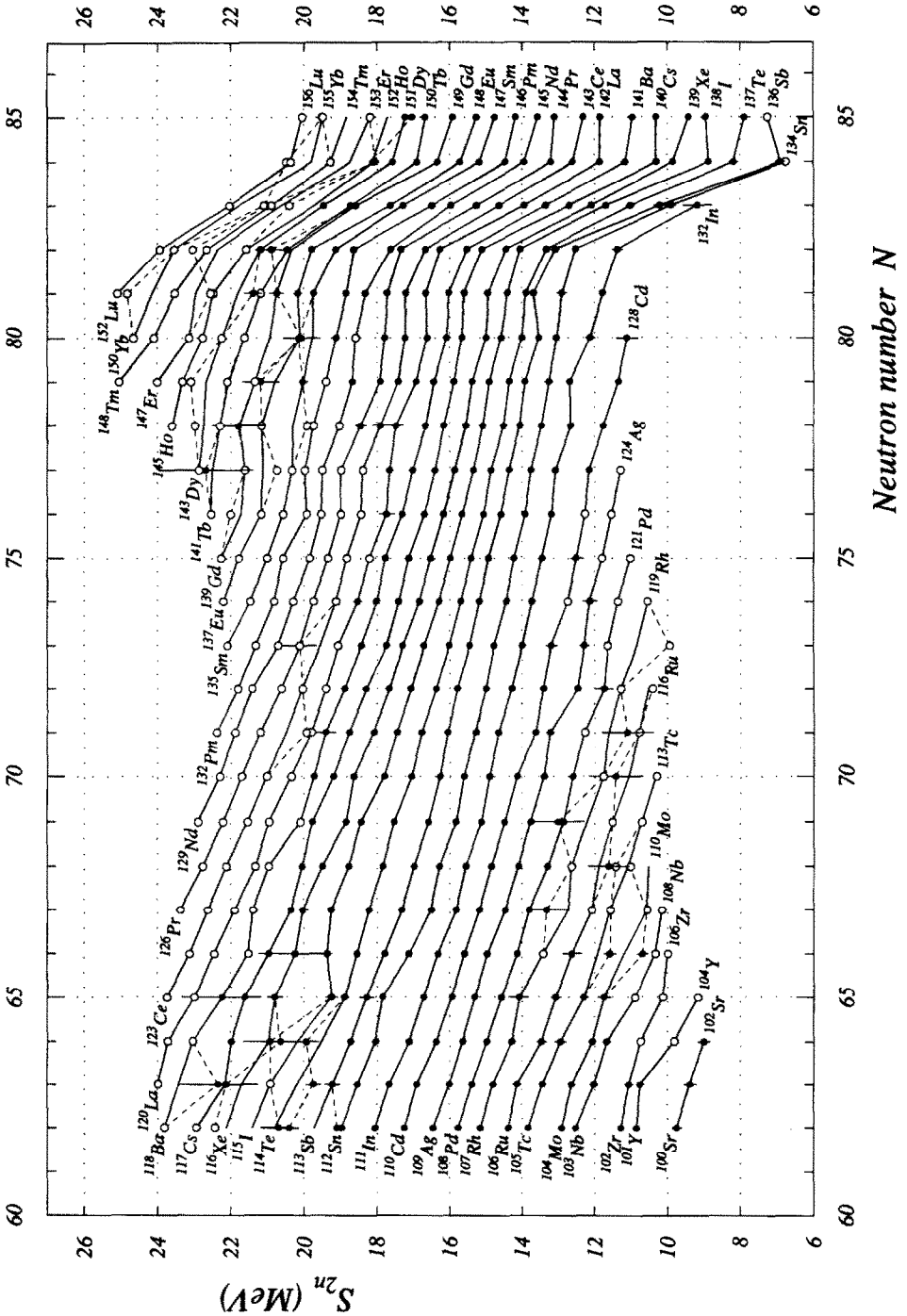


Fig. 5. Two neutrons separation energies  $N = 82$  to 105

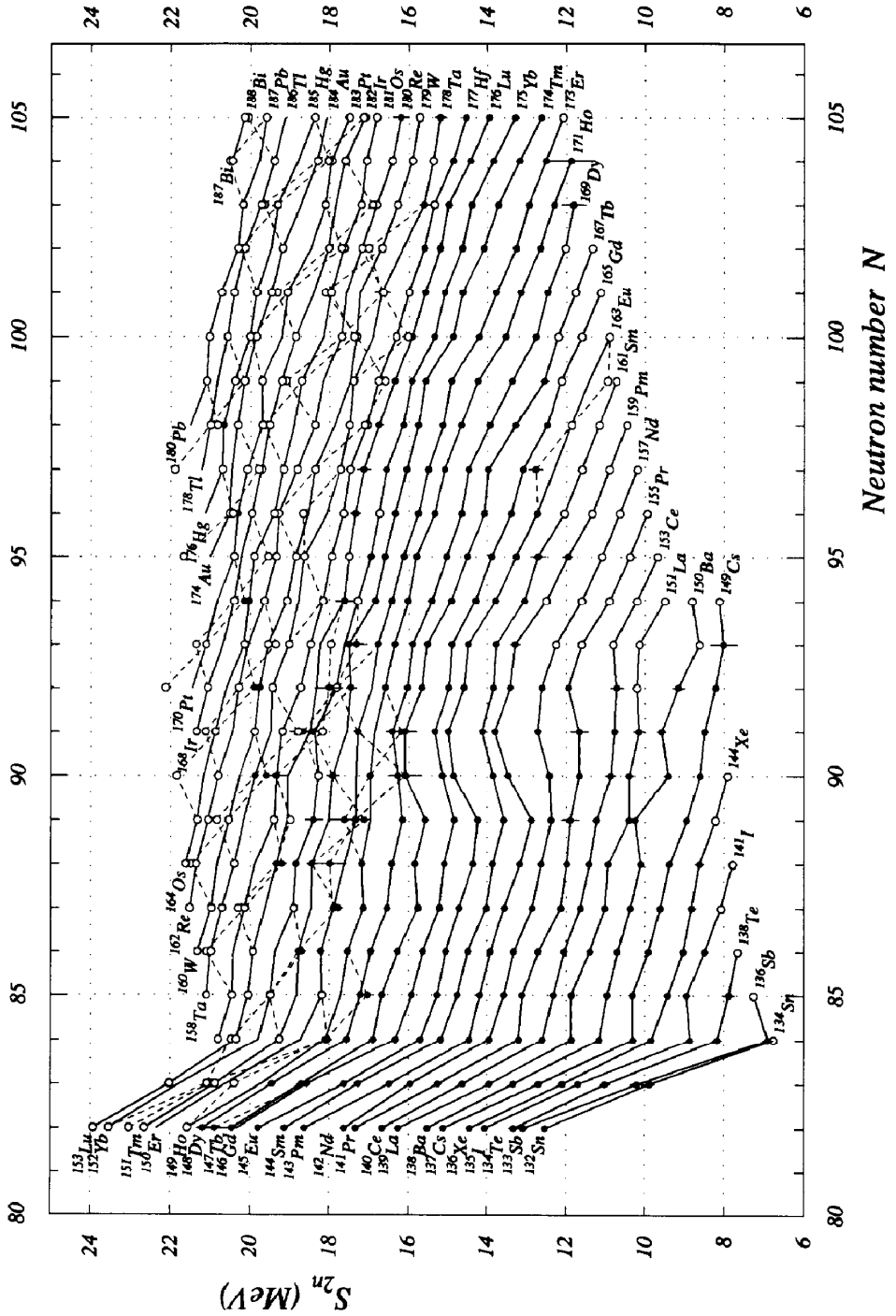




Fig. 6. Two neutrons separation energies  $N = 102$  to  $125$

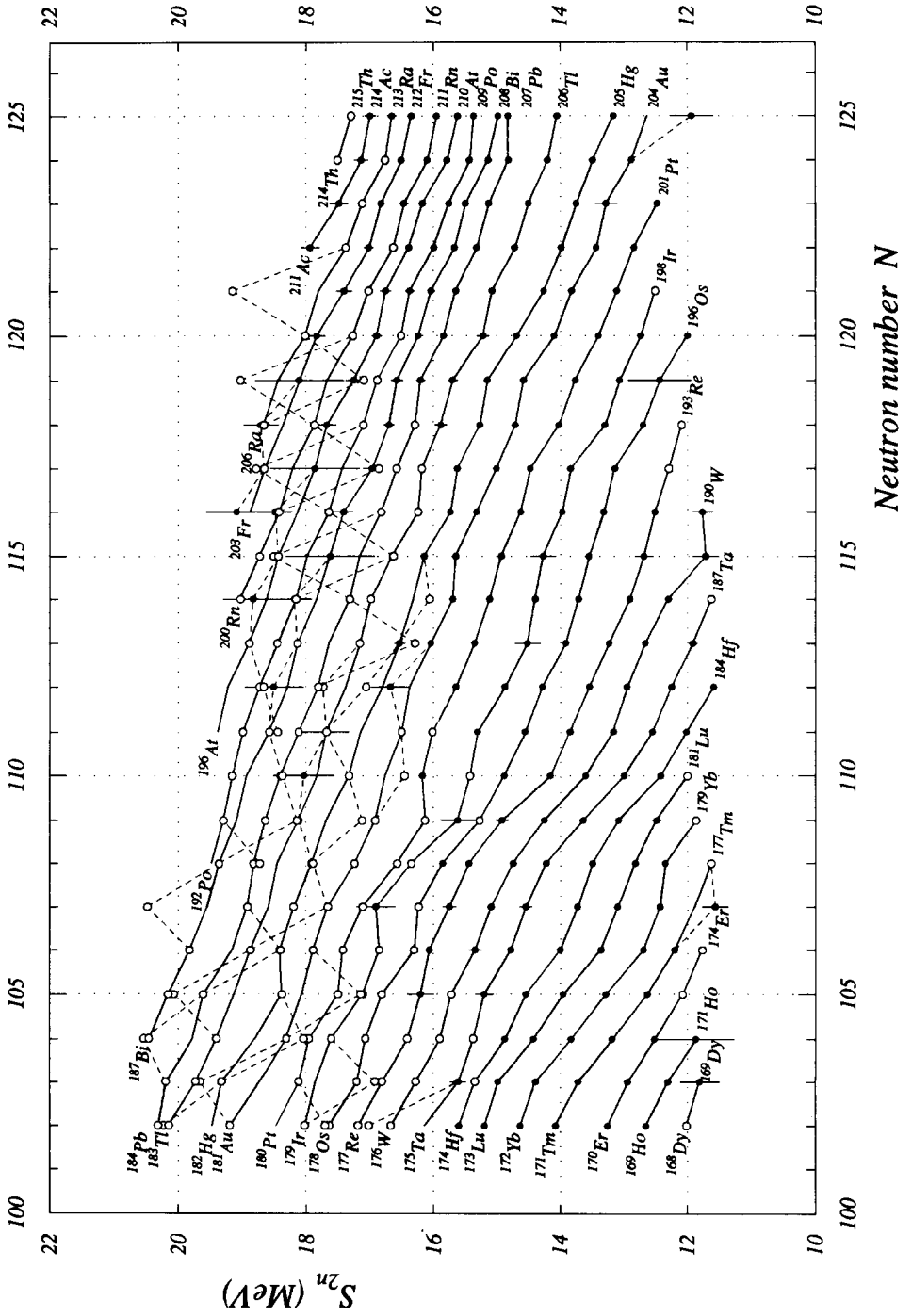


Fig. 7. Two neutrons separation energies  $N = 122$  to  $145$

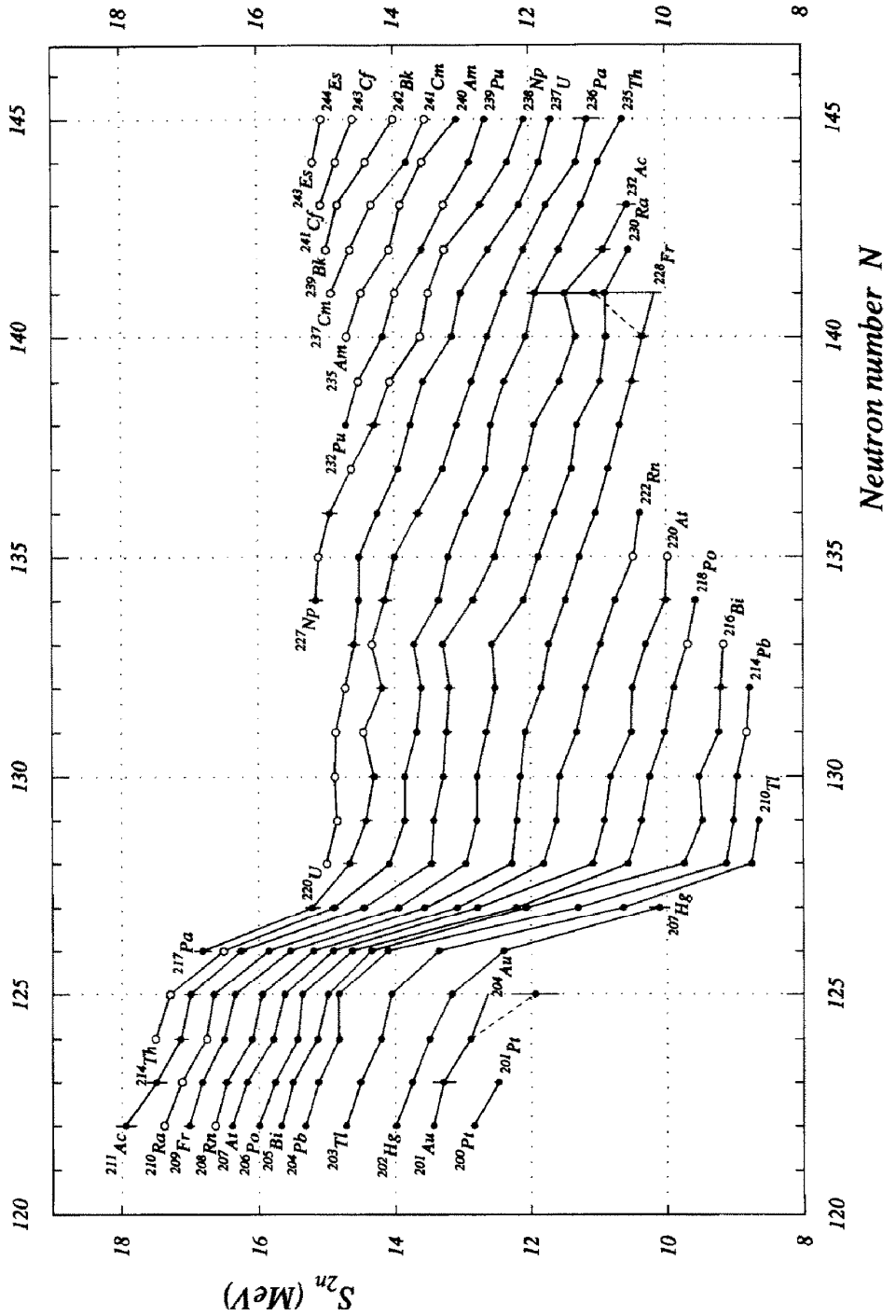


Fig. 8. Two neutrons separation energies  $N = 137$  to  $160$

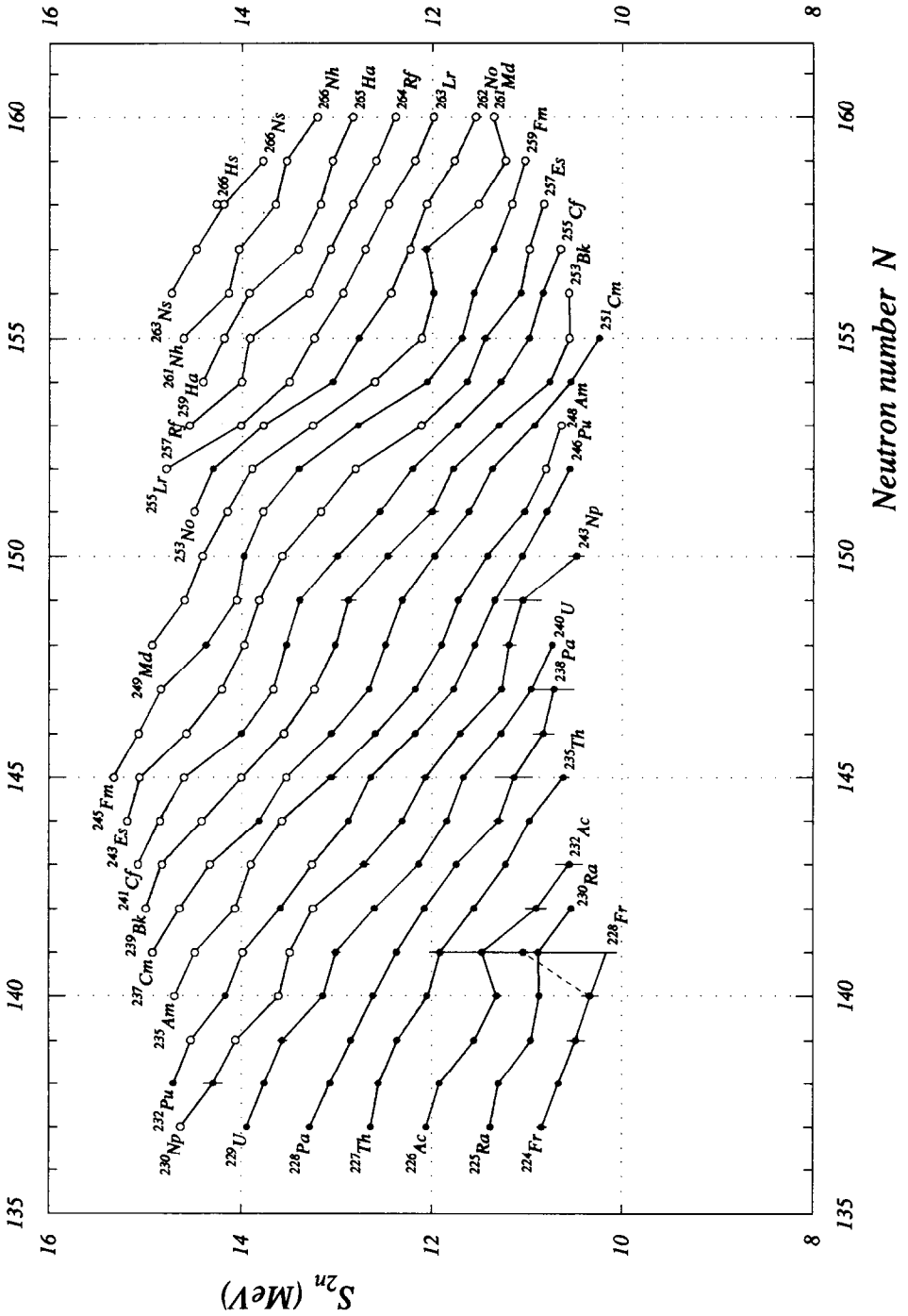


Fig. 9. Two protons separation energies  $Z = 0$  to 20

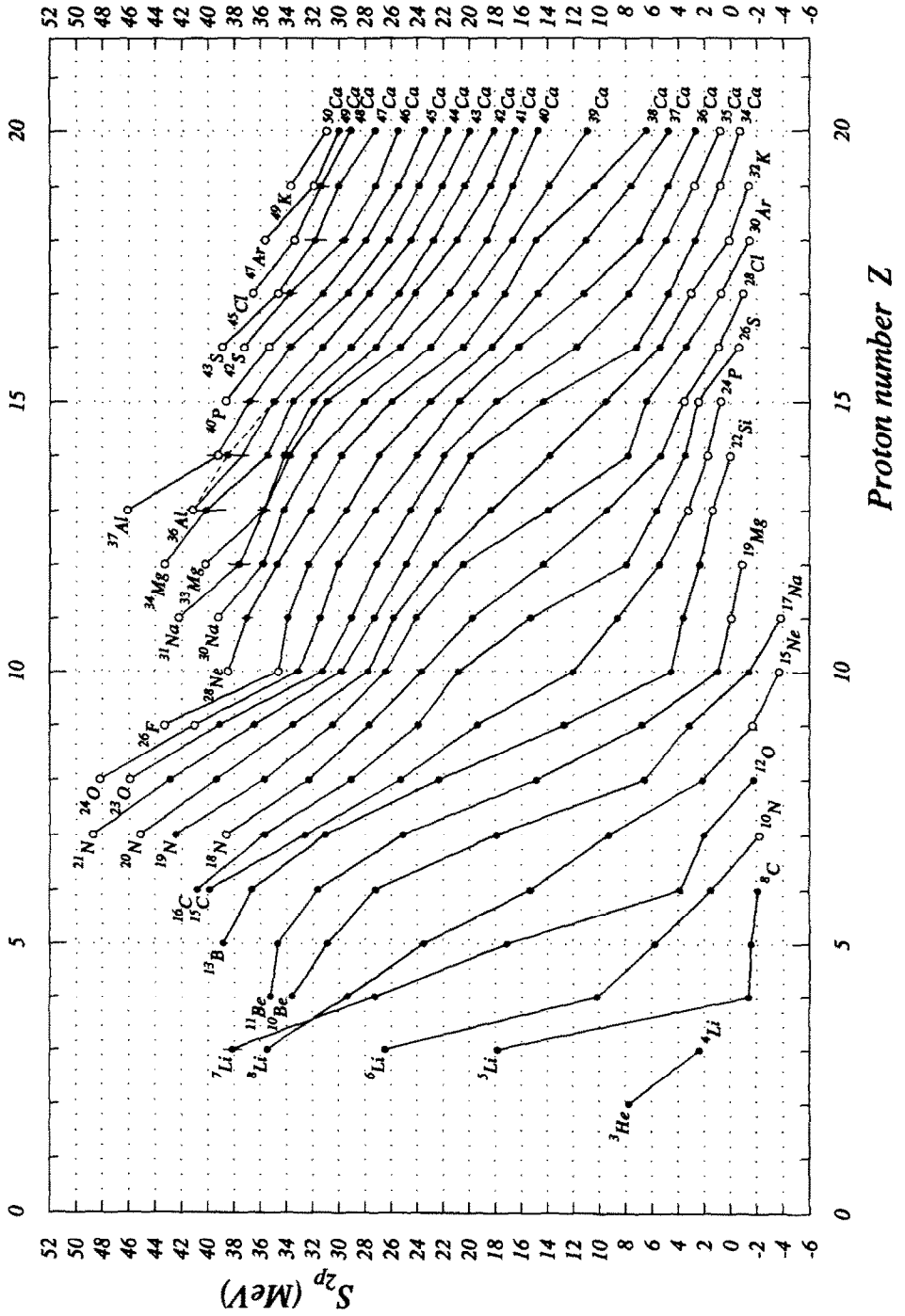


Fig. 10. Two protons separation energies  $Z = 17$  to 35

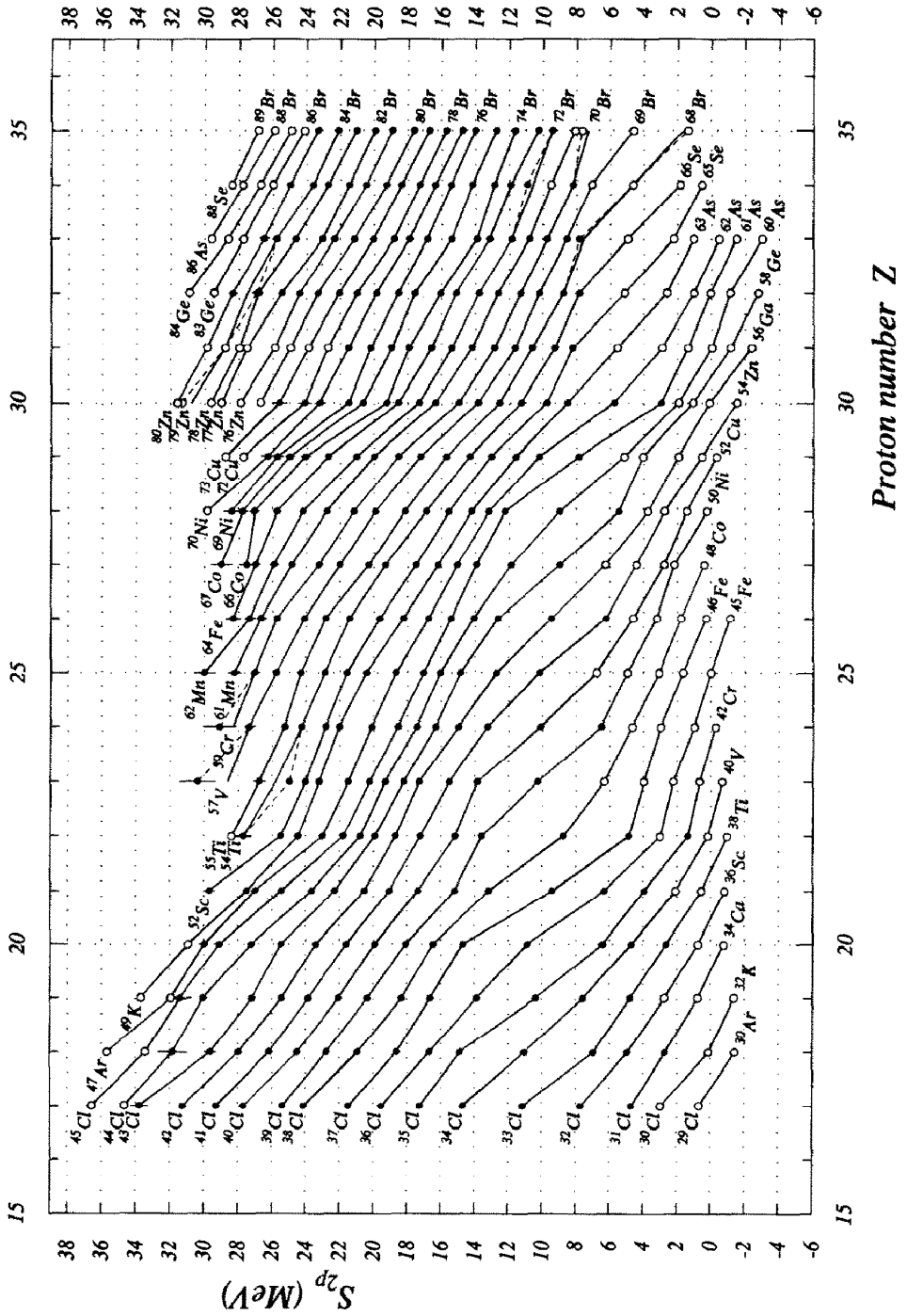


Fig. 11. Two protons separation energies  $Z = 32$  to 50

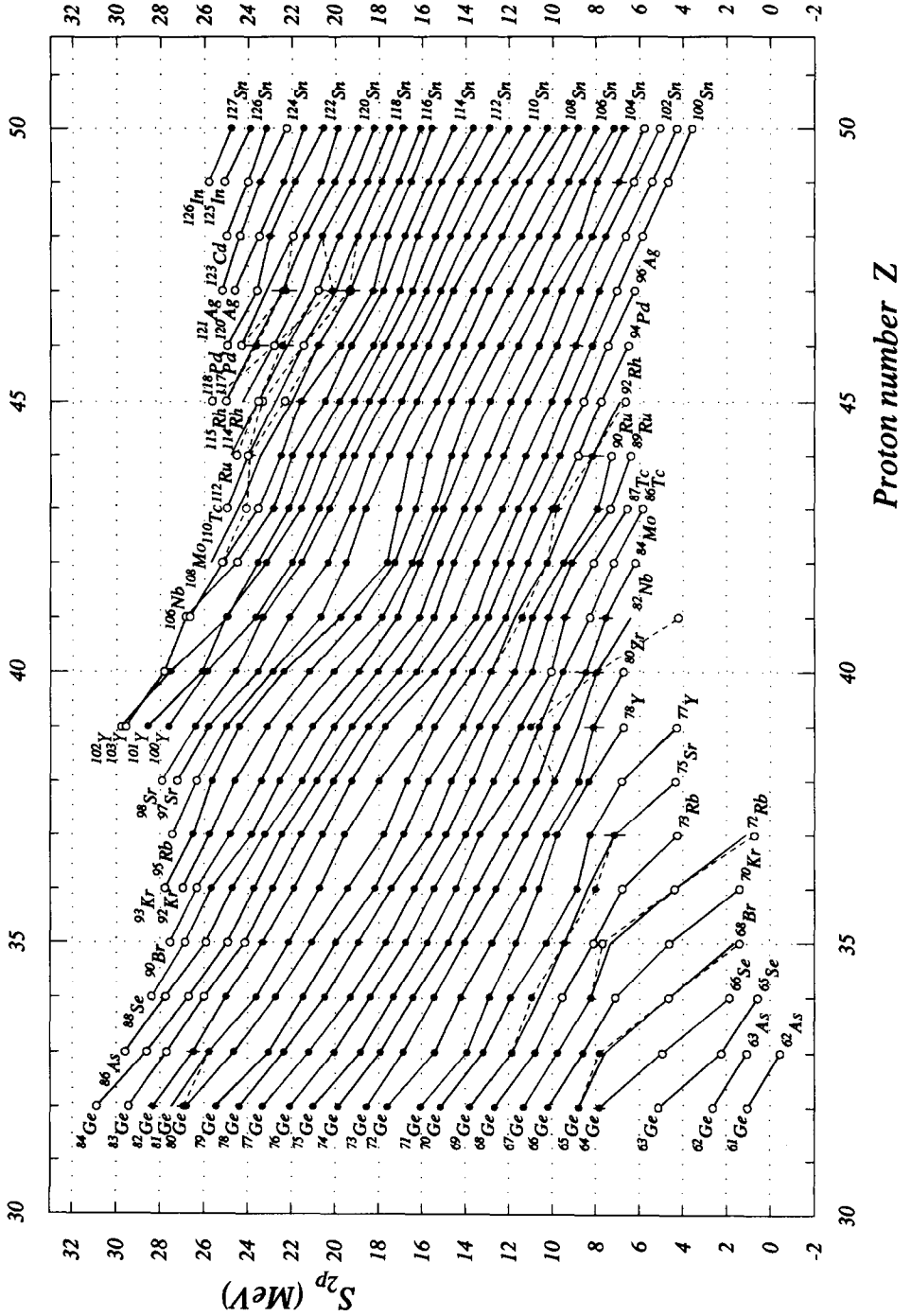


Fig. 12. Two protons separation energies  $Z = 47$  to 65

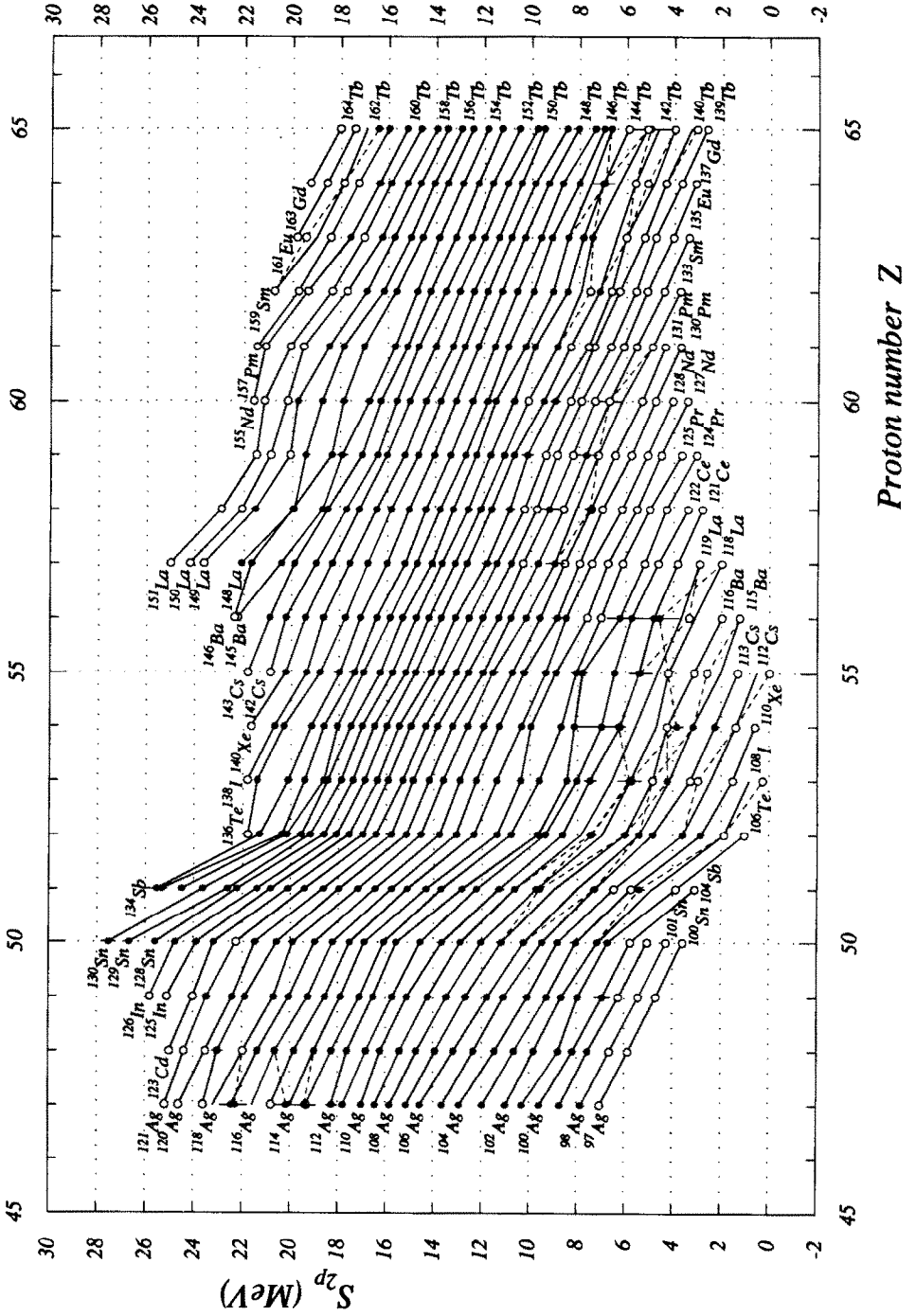


Fig. 13. Two protons separation energies  $Z = 62$  to  $80$

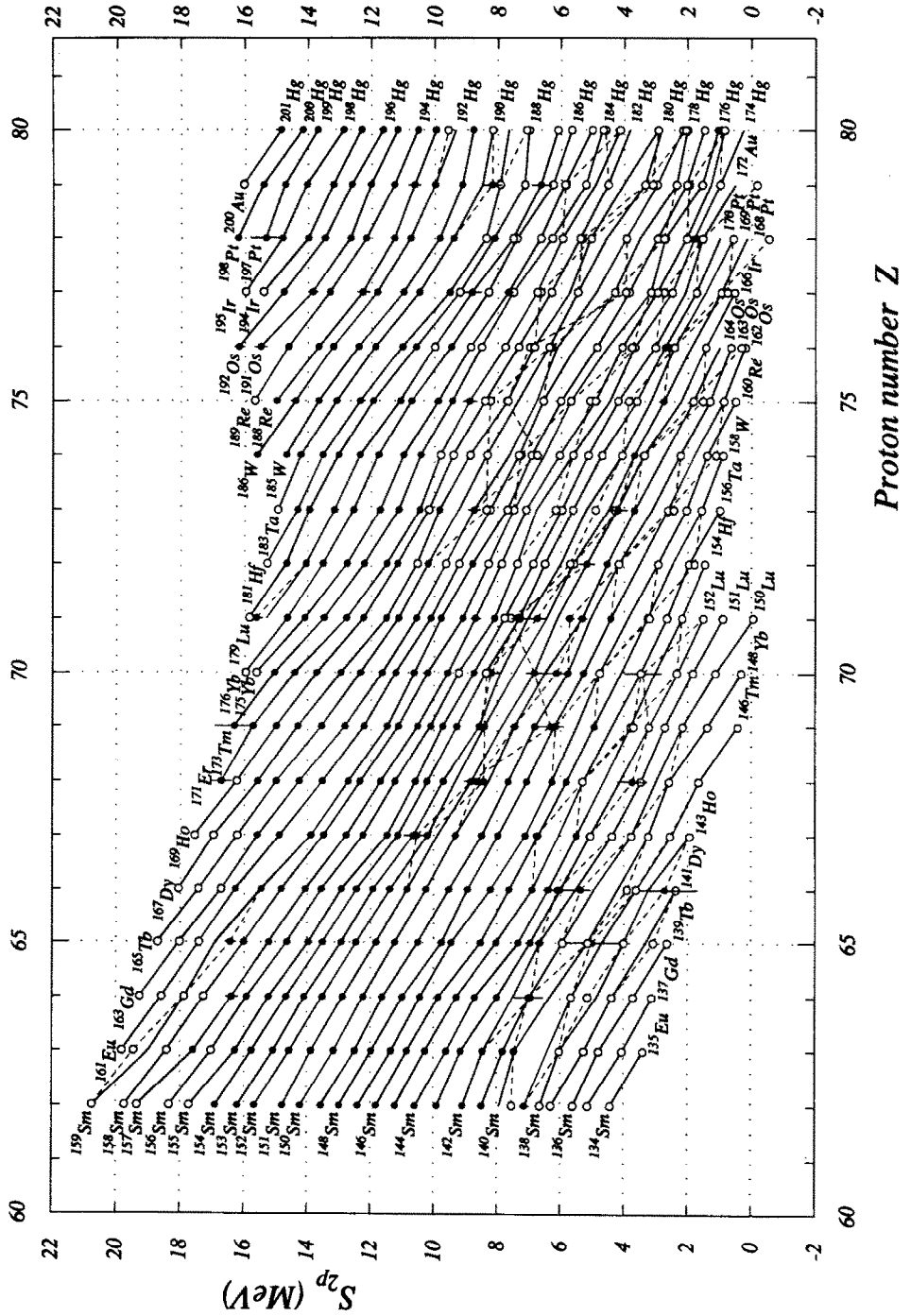




Fig. 14. Two protons separation energies  $Z = 77$  to 95

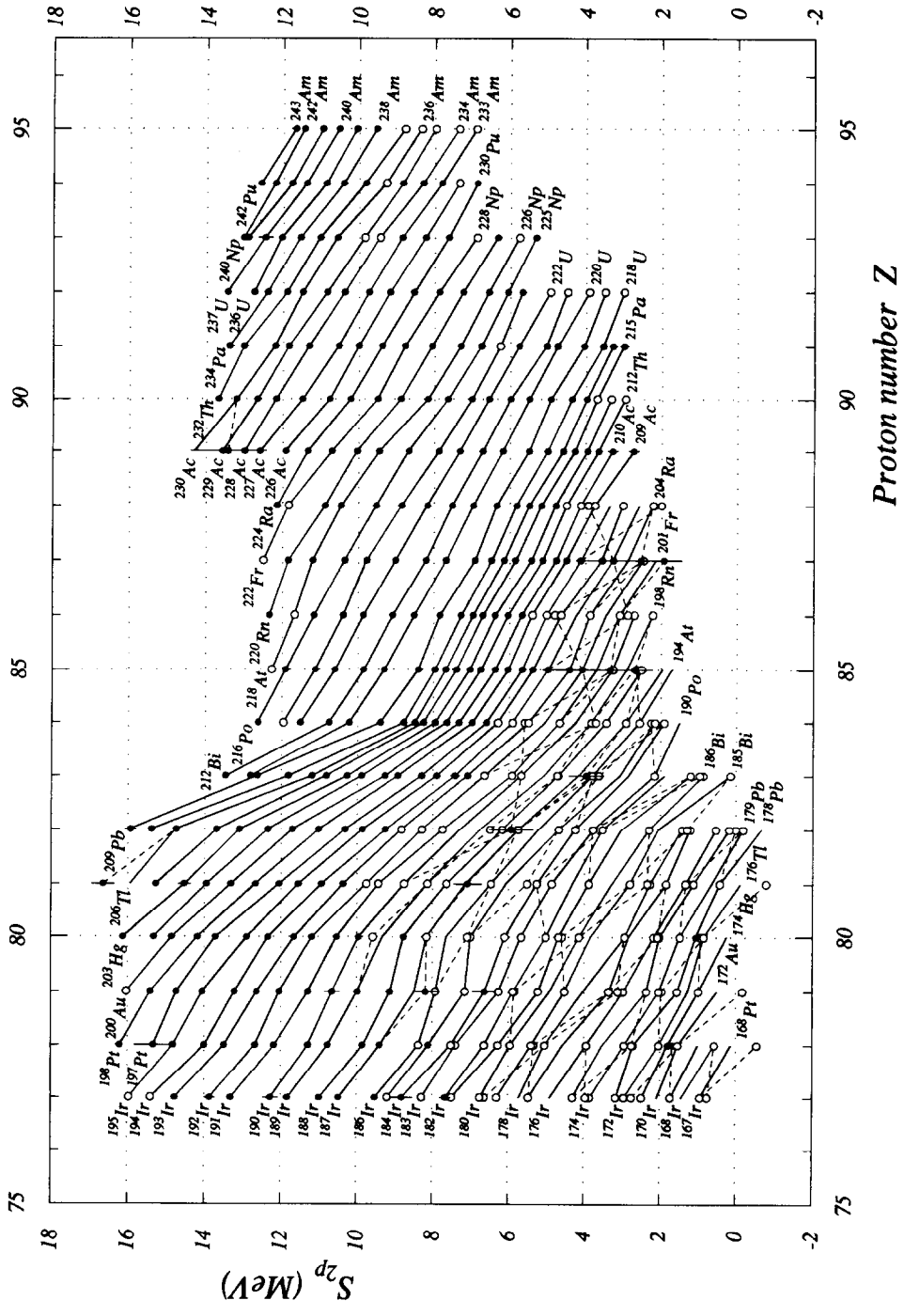


Fig. 15. Two protons separation energies  $Z = 92$  to  $110$

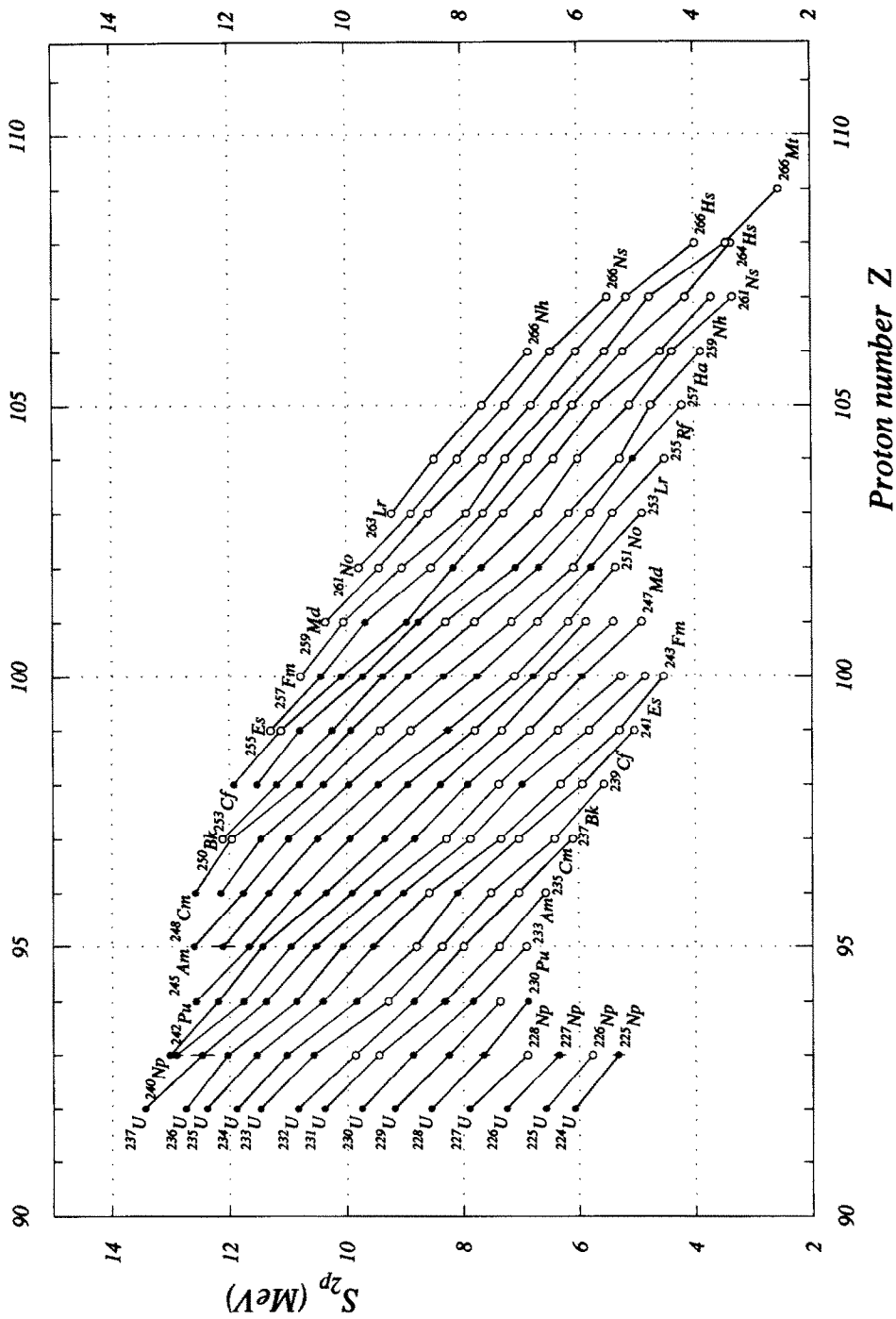


Fig. 16.  $\alpha$ -decay energies  $N = 0$  to 25

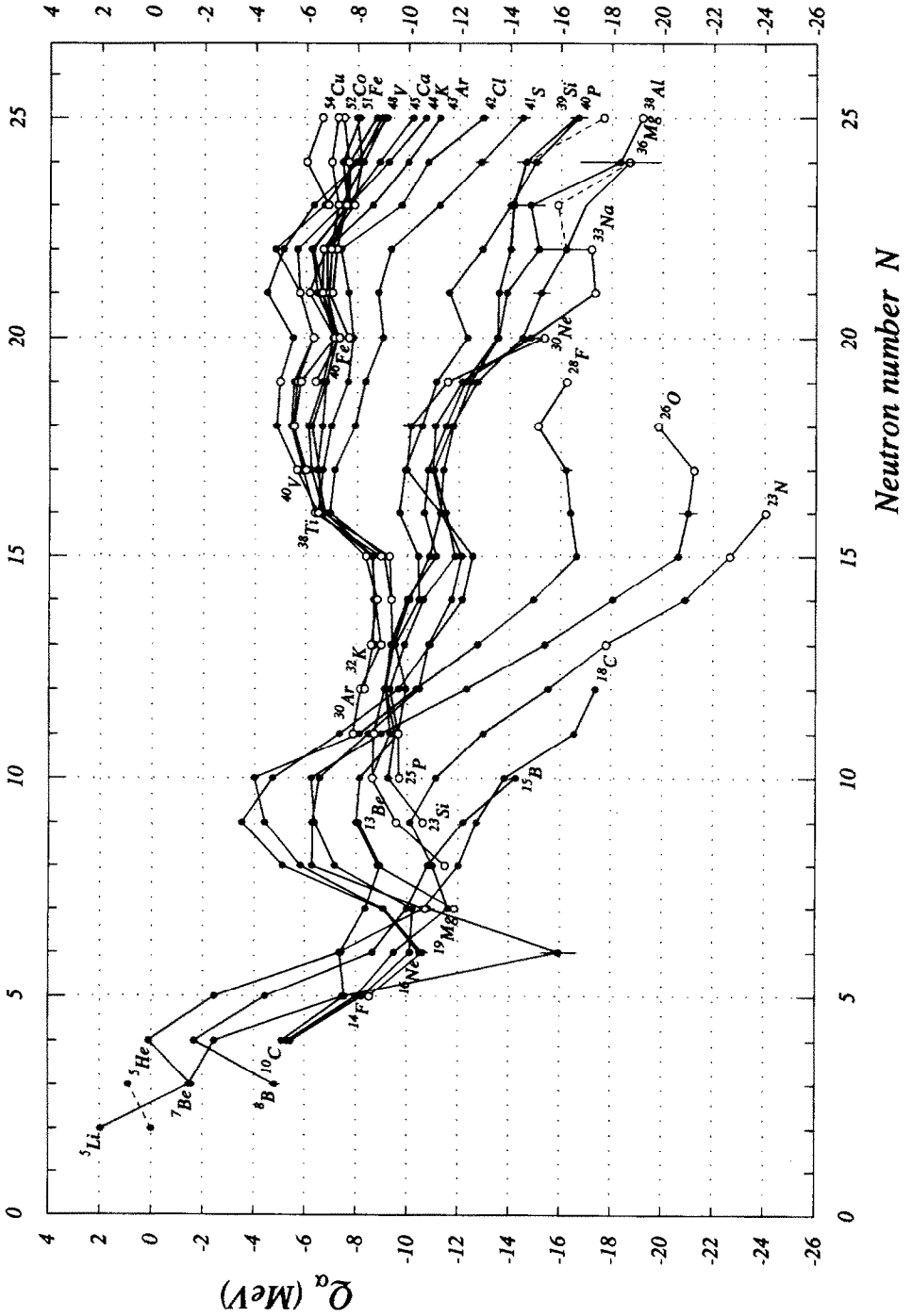


Fig. 17.  $\alpha$ -decay energies  $N = 22$  to 45

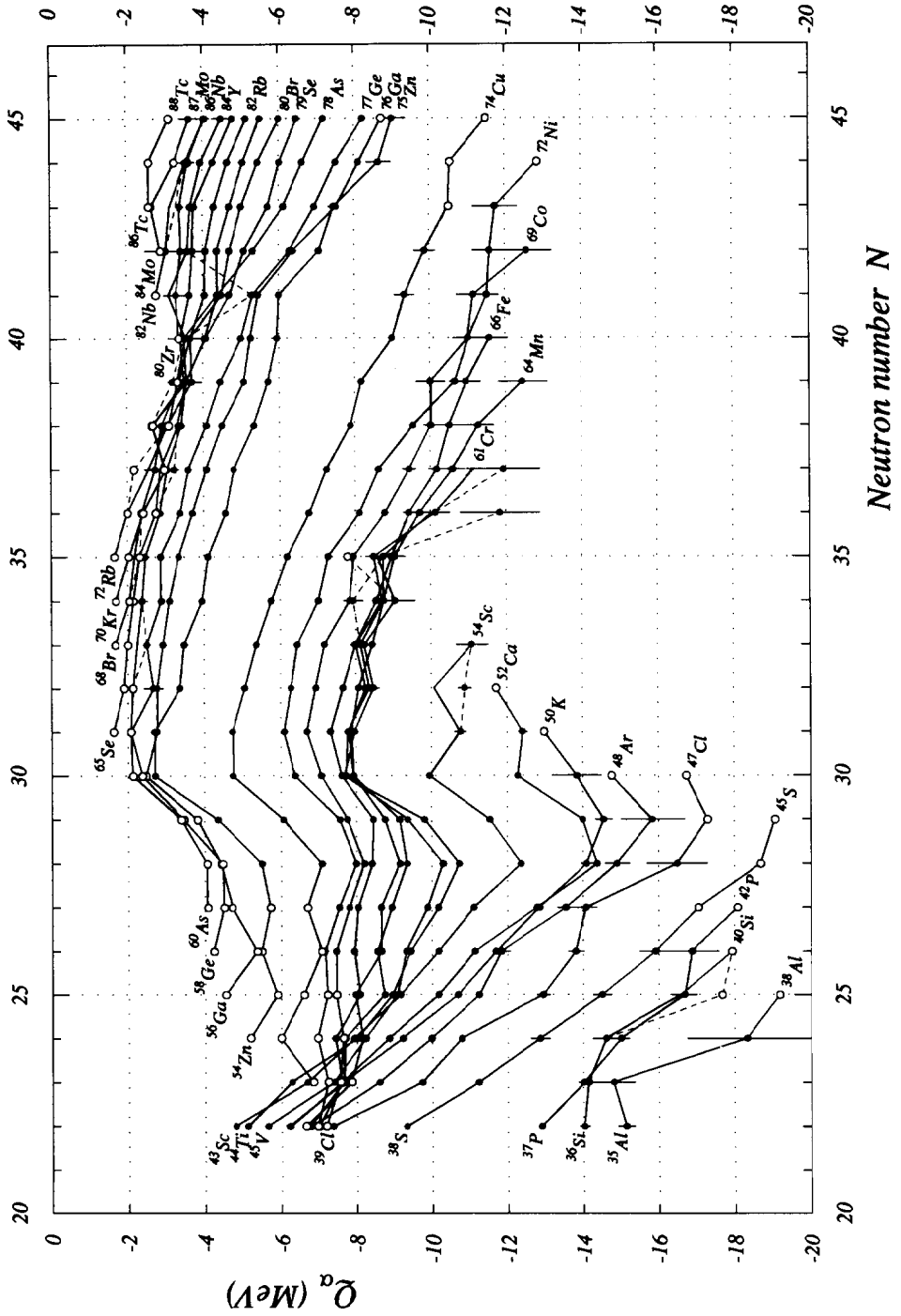


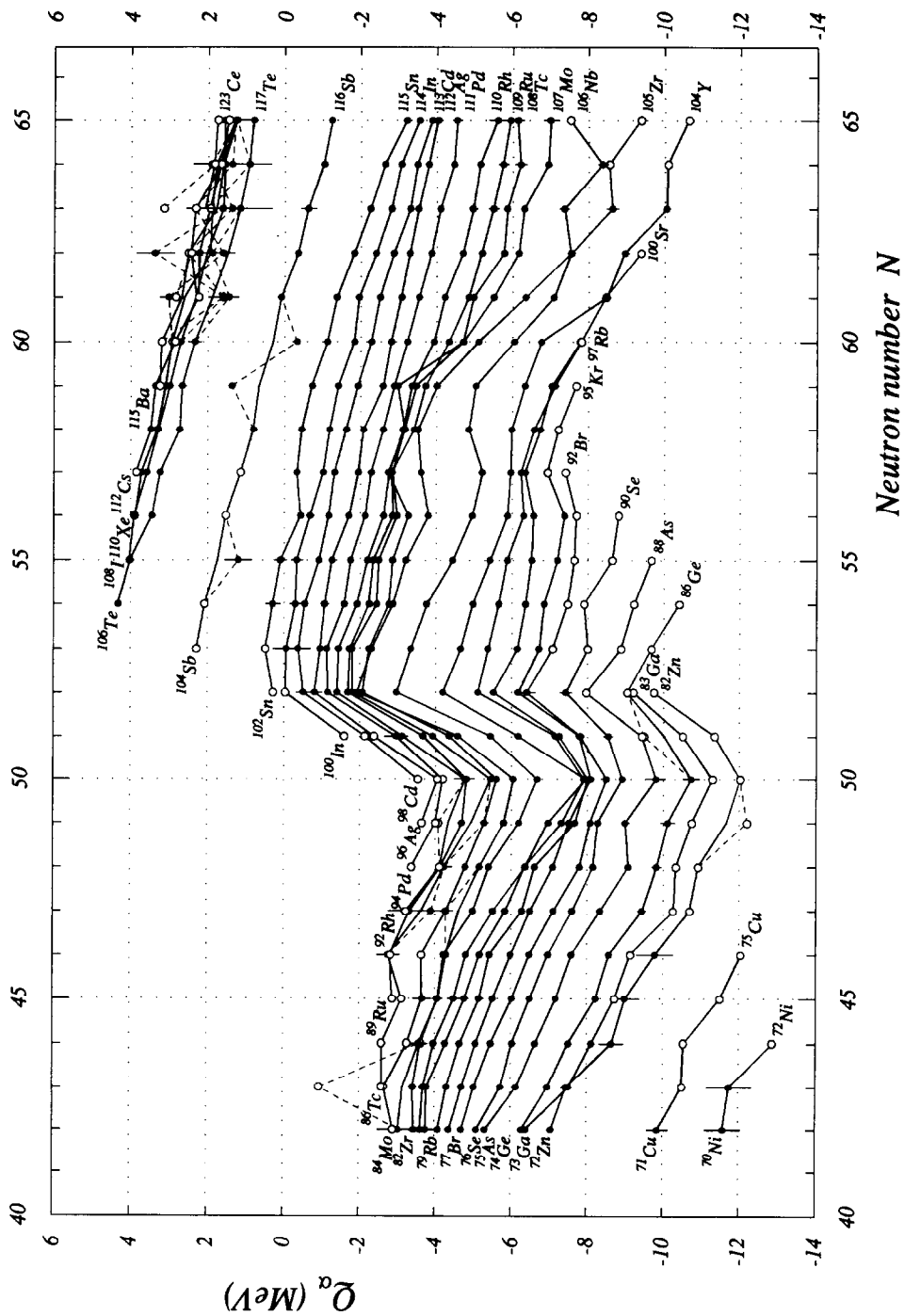
Fig. 18.  $\alpha$ -decay energies  $N = 42$  to 65

Fig. 19.  $\alpha$ -decay energies  $N = 62$  to 85

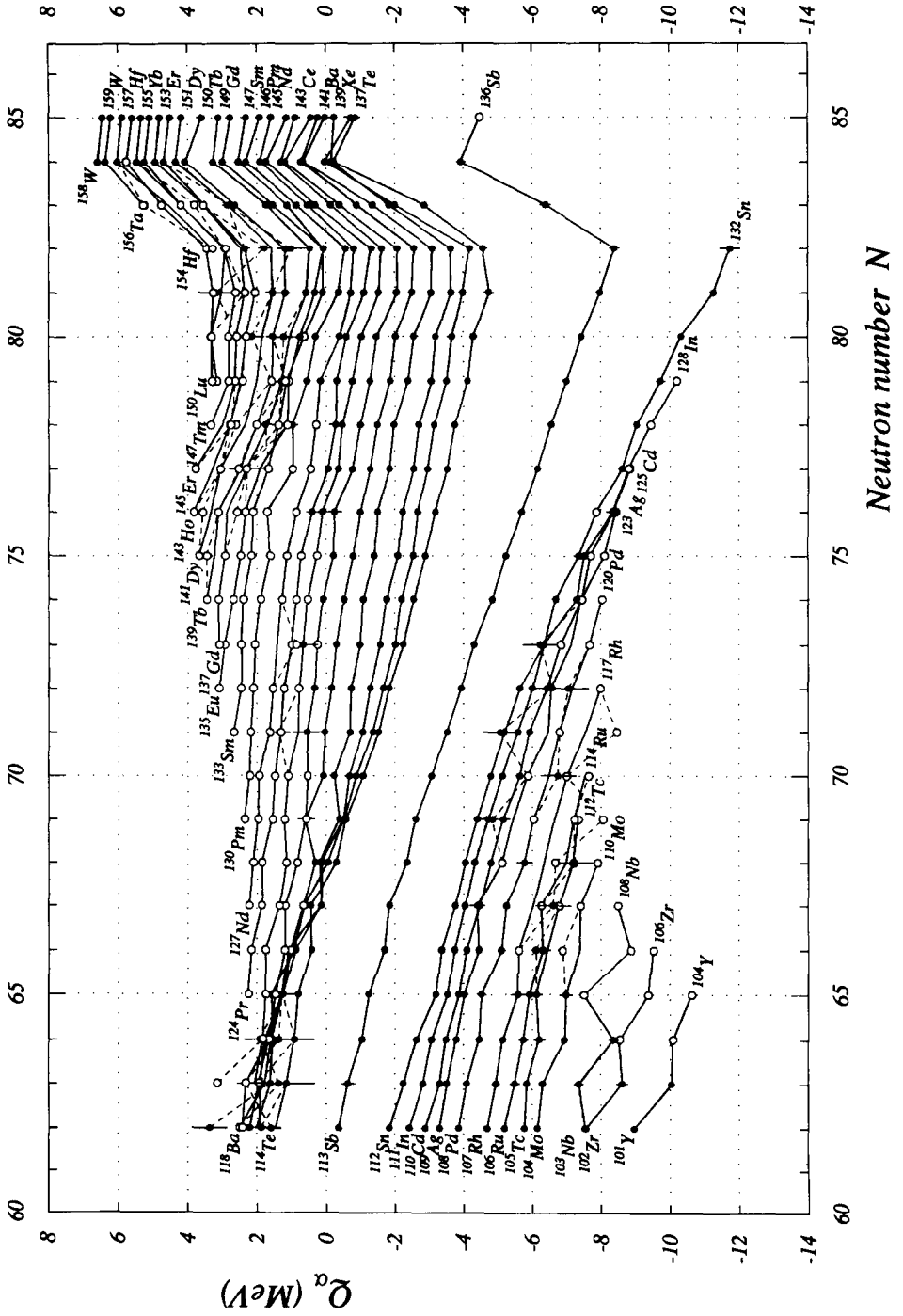


Fig. 20.  $\alpha$ -decay energies  $N = 82$  to 105

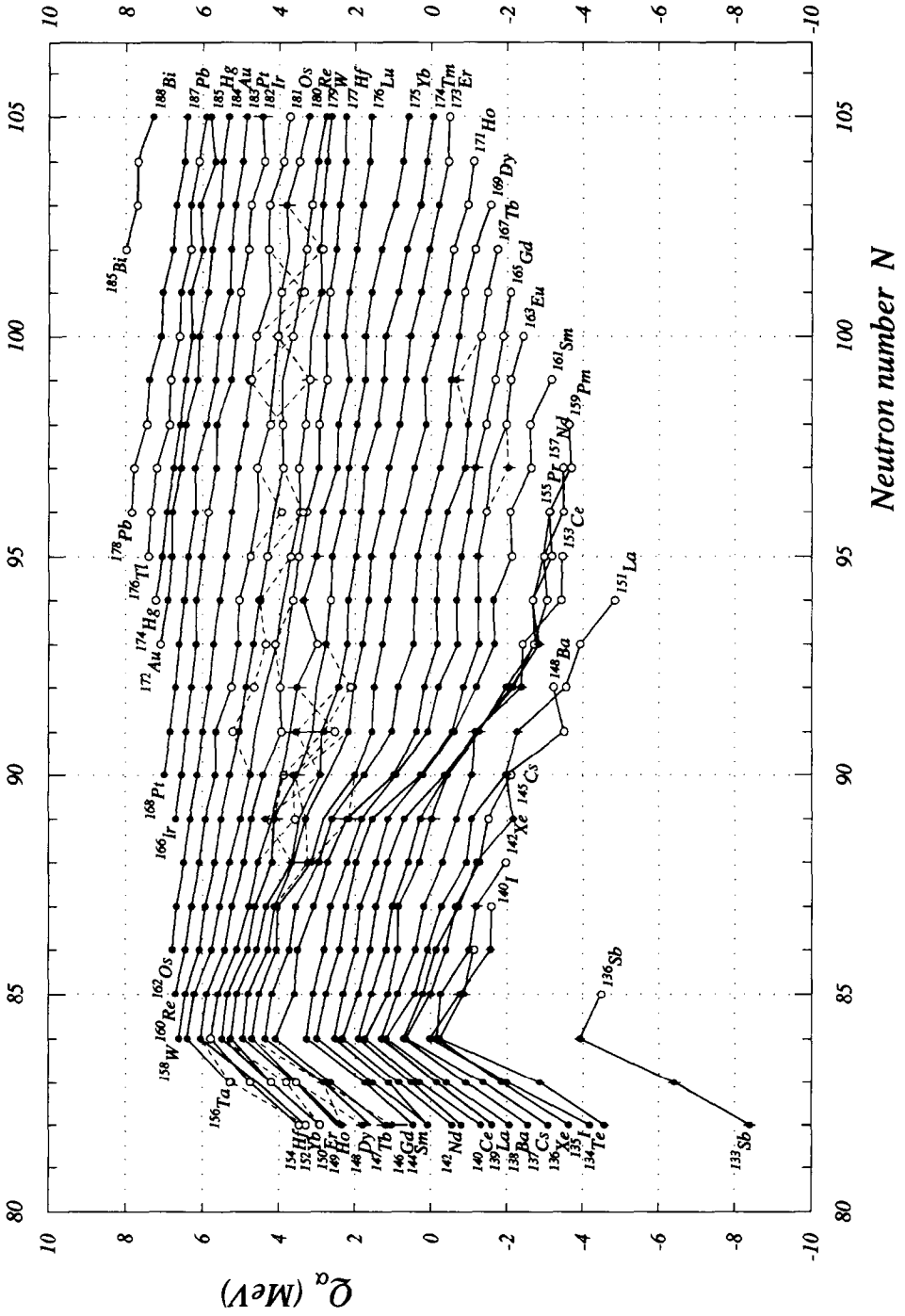


Fig. 21.  $\alpha$ -decay energies  $N = 102$  to 125

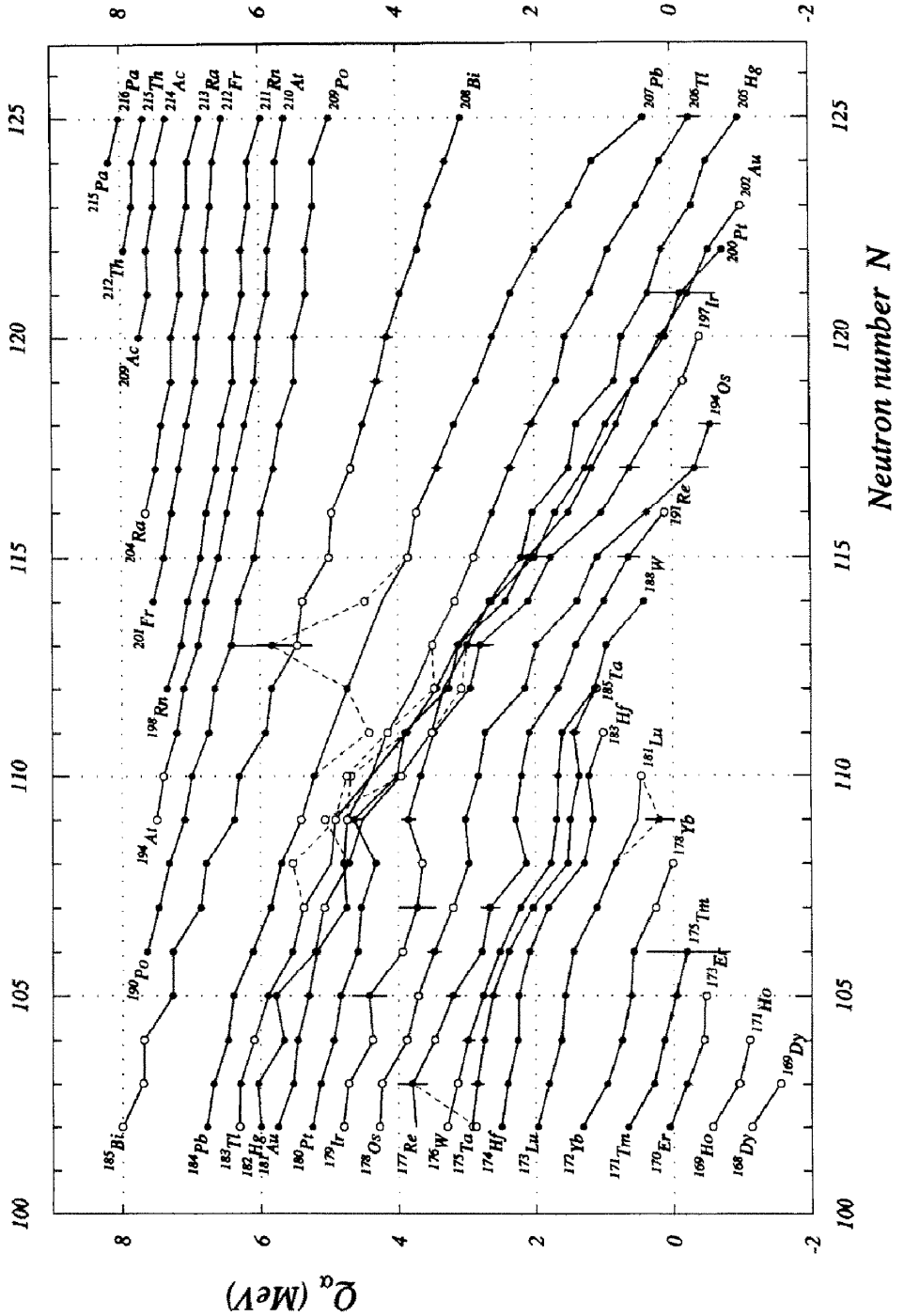




Fig. 22.  $\alpha$ -decay energies  $N = 122$  to 145

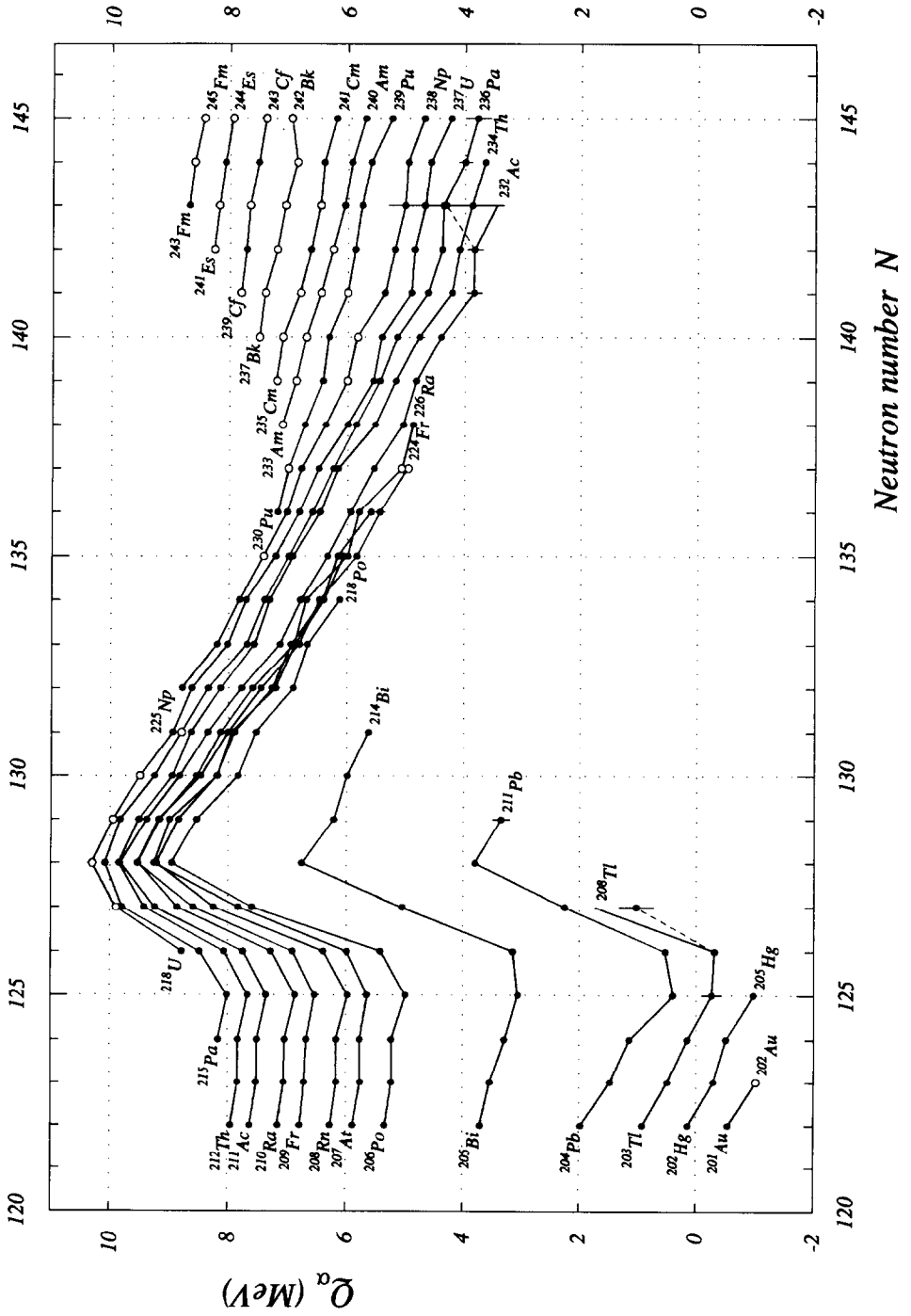


Fig. 23.  $\alpha$ -decay energies  $N = 137$  to  $160$

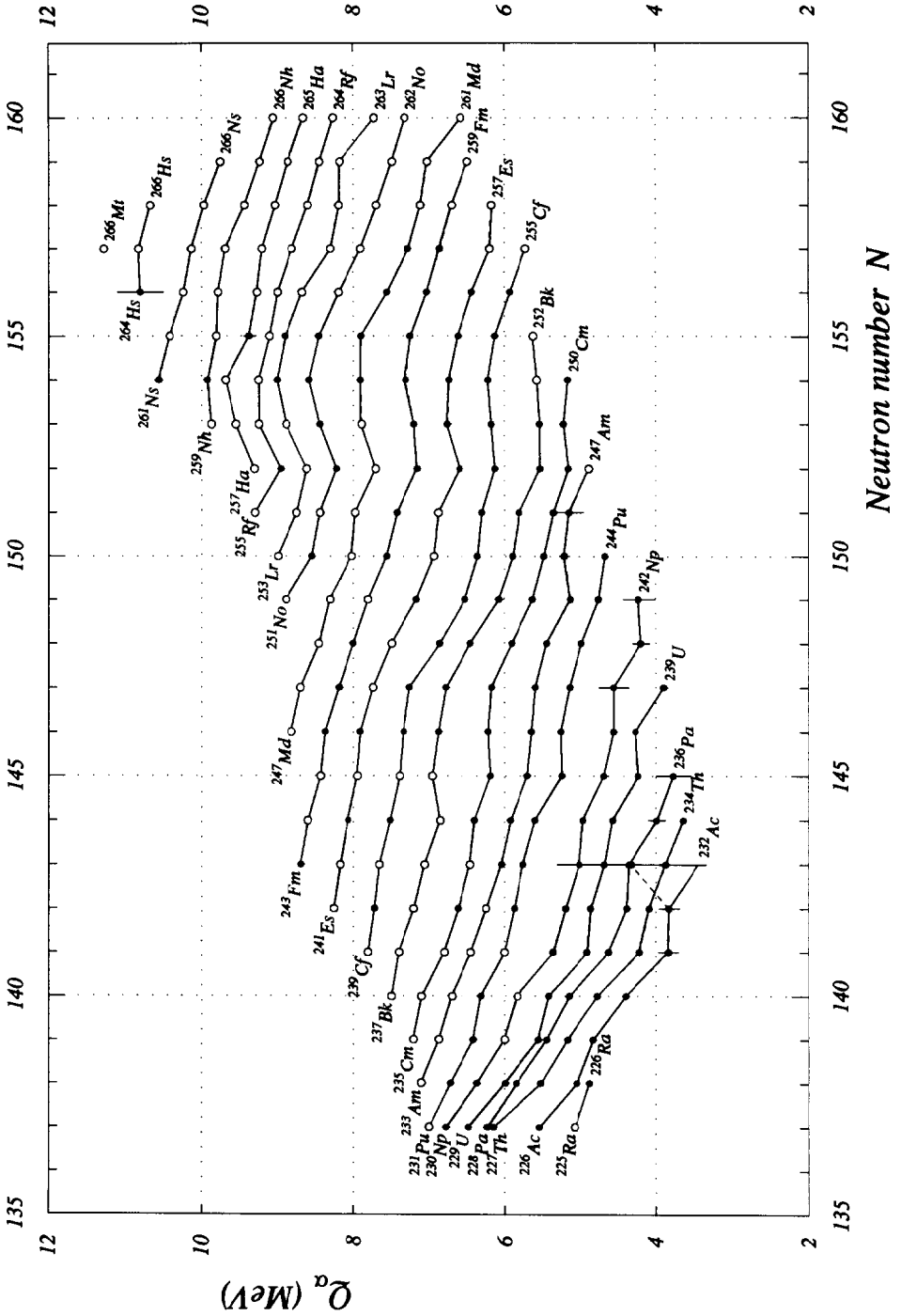


Fig. 24. Double  $\beta$ -decay energies  $A = 0$  to 35

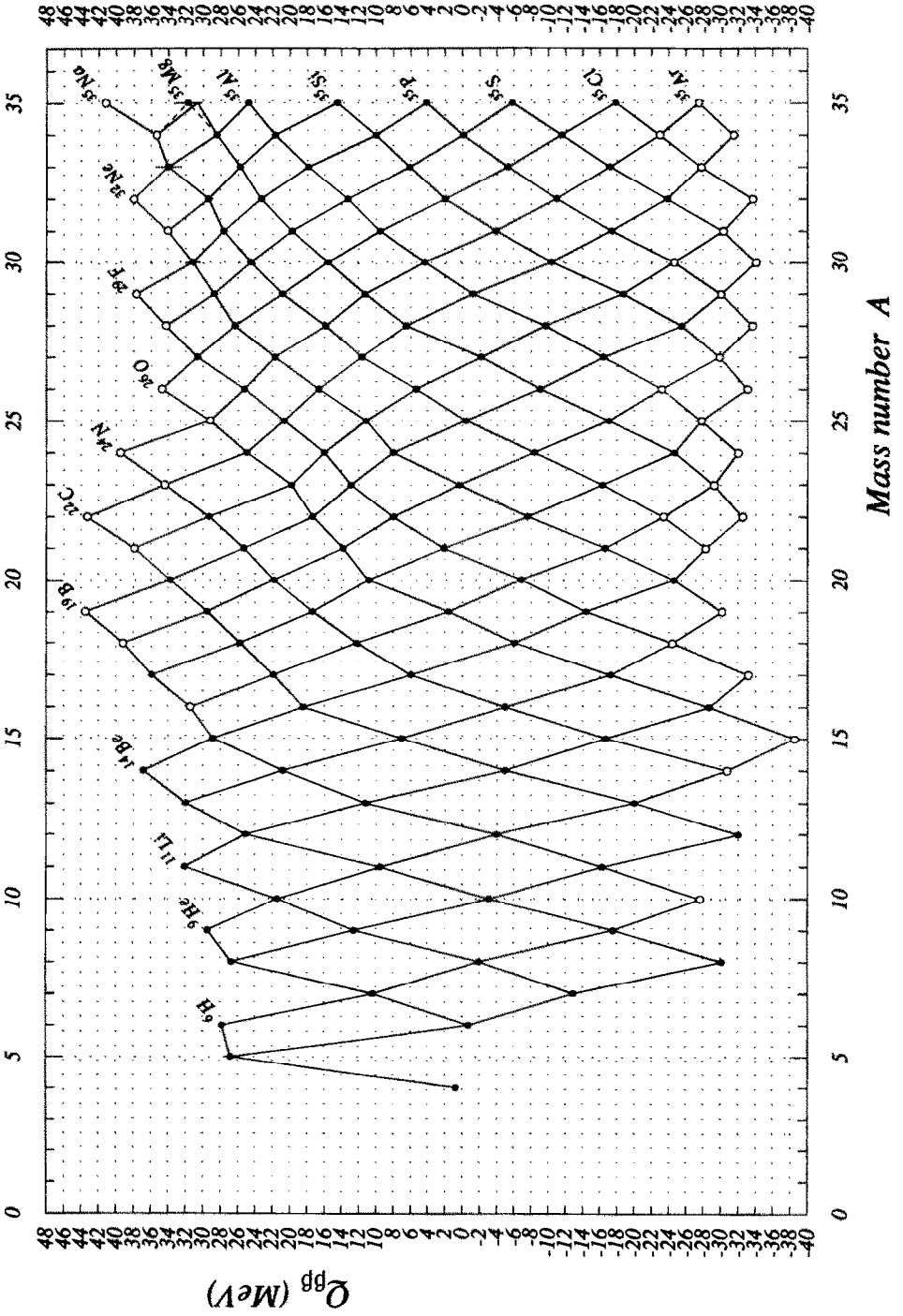


Fig. 25. Double  $\beta$ -decay energies  $A = 32$  to  $65$

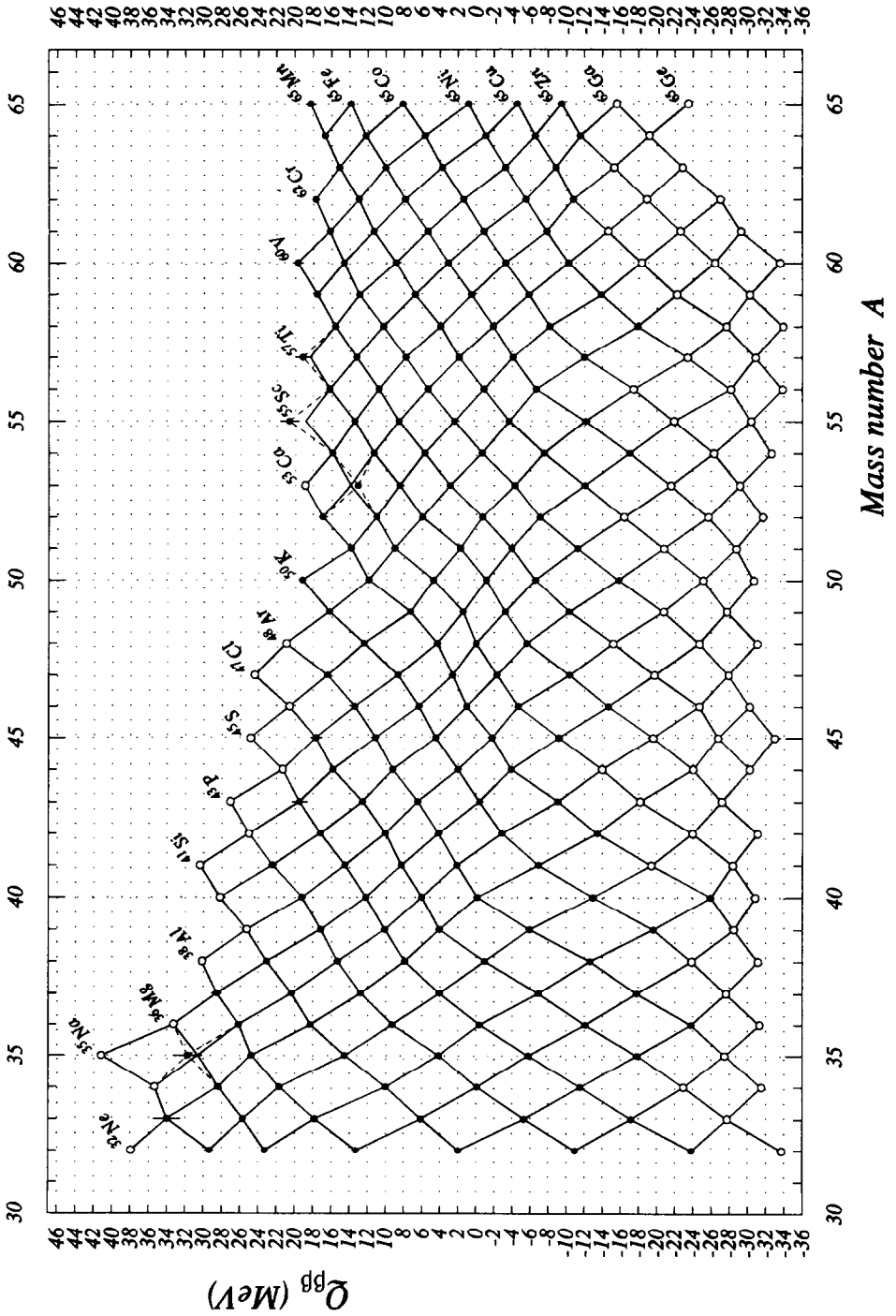


Fig. 26. Double  $\beta$ -decay energies  $A = 62$  to 95

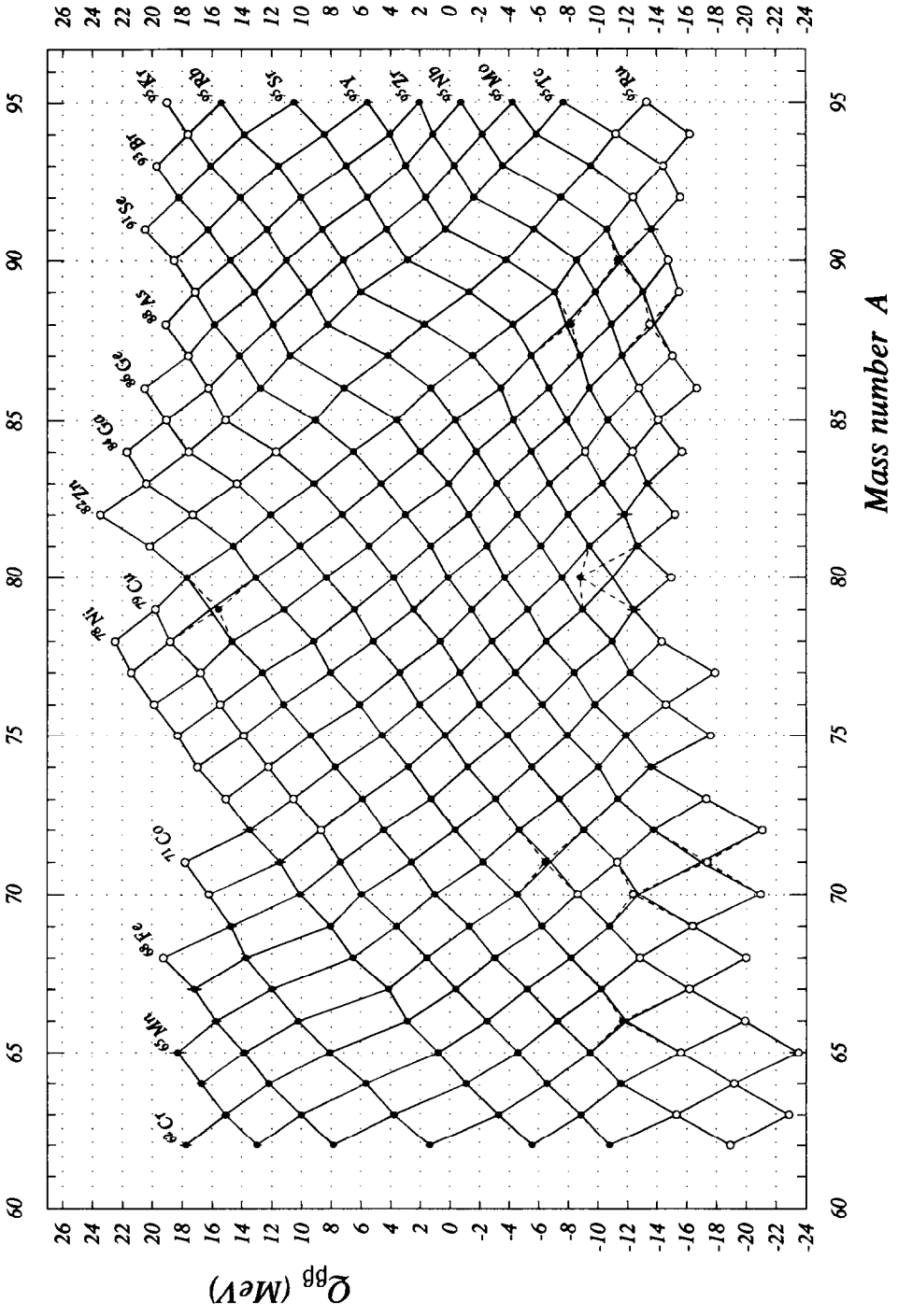


Fig. 27. Double  $\beta$ -decay energies  $A = 92$  to  $125$

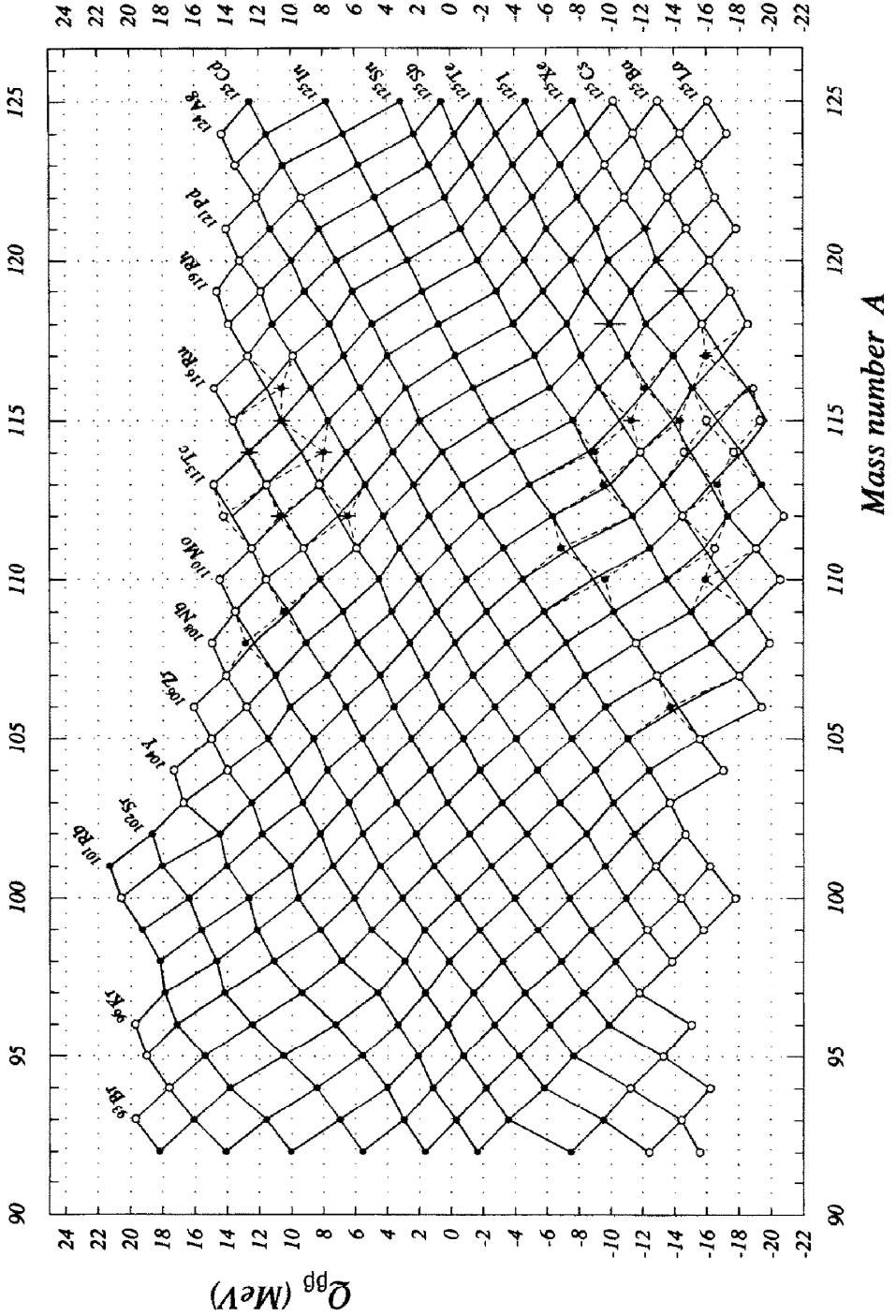


Fig. 28. Double  $\beta$ -decay energies  $A = 122$  to  $155$

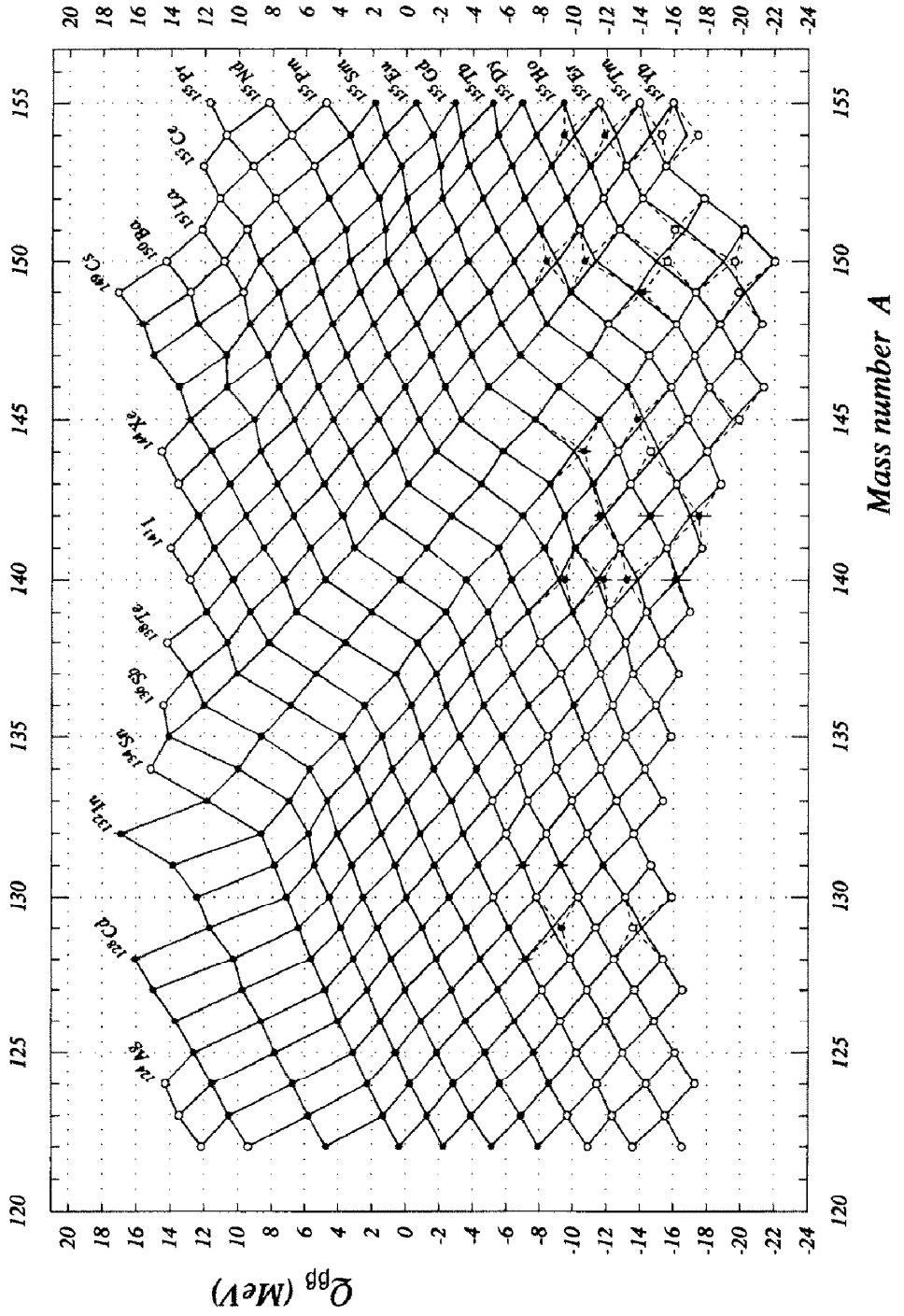


Fig. 29. Double  $\beta$ -decay energies  $A = 152$  to  $185$

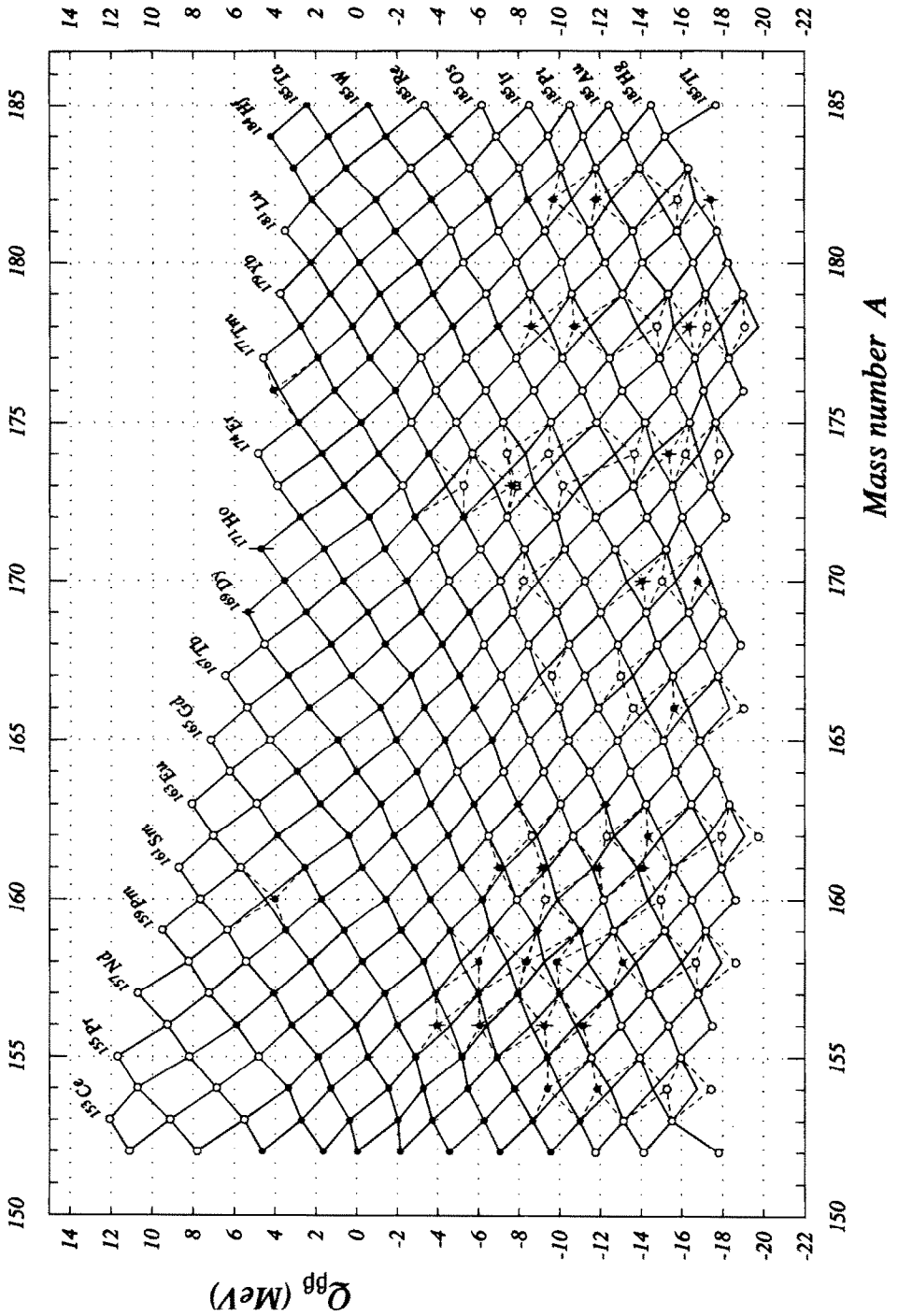




Fig. 30. Double  $\beta$ -decay energies  $A = 182$  to  $215$

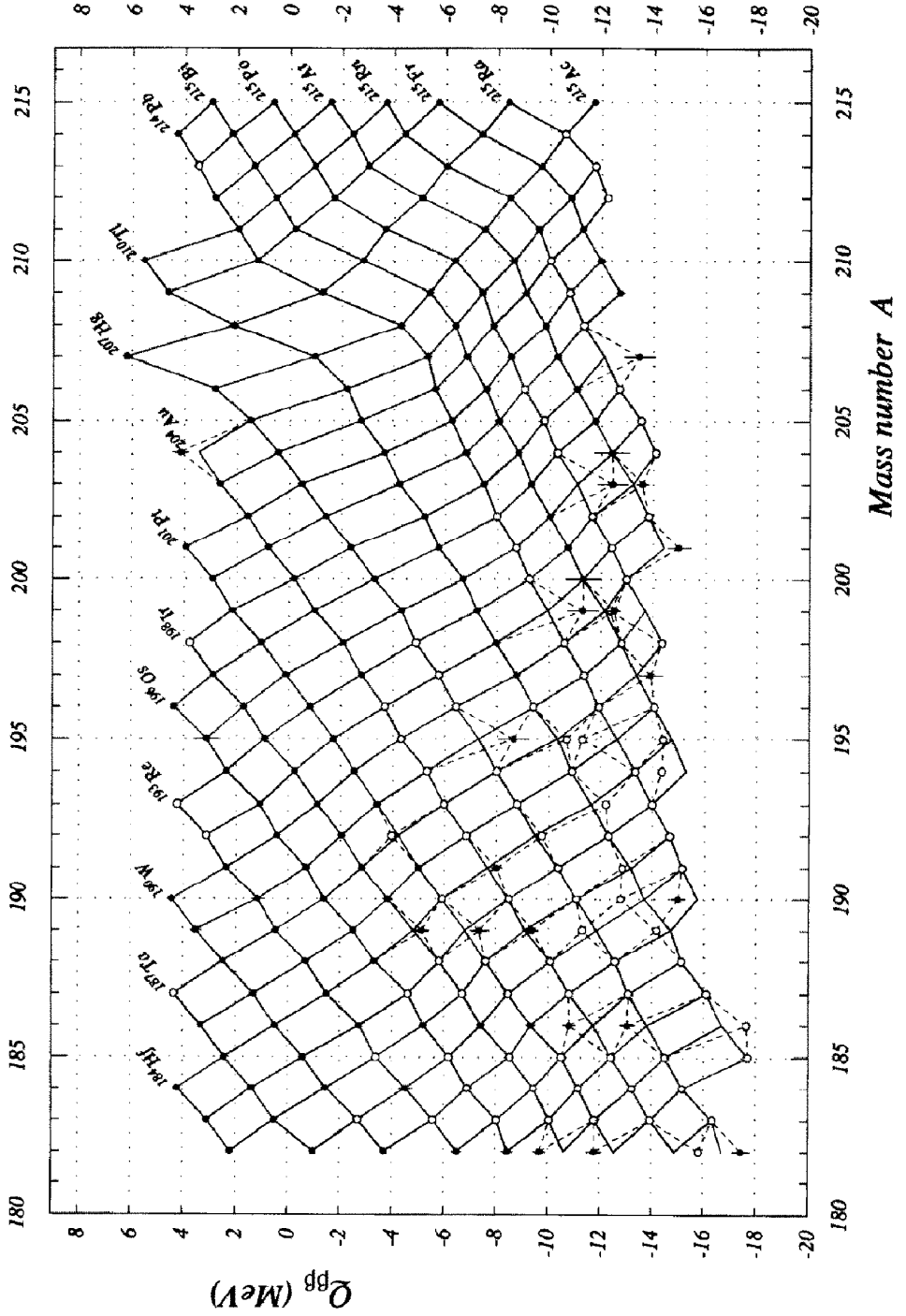


Fig. 31. Double  $\beta$ -decay energies  $A = 212$  to 245

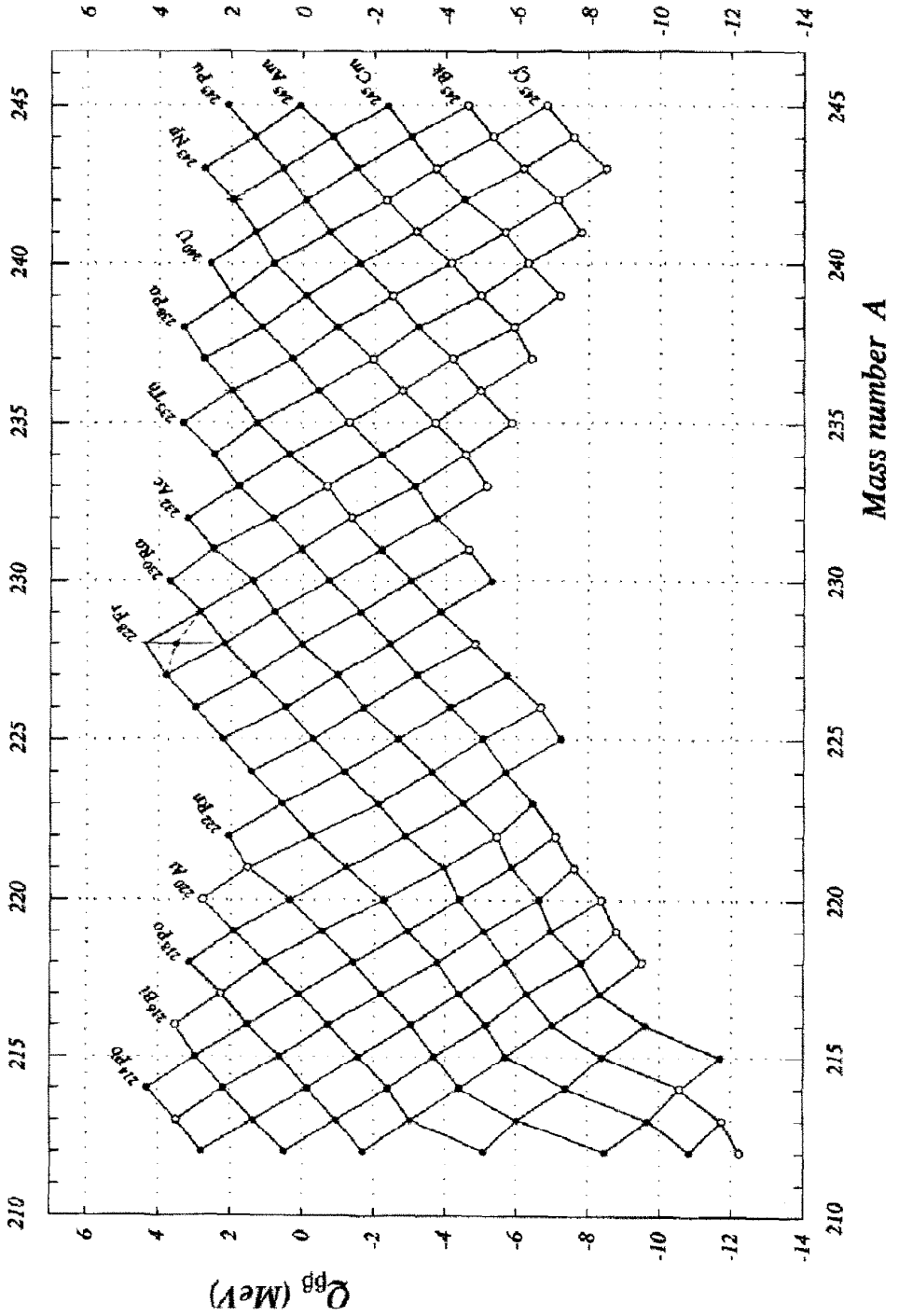


Fig. 32. Double  $\beta$ -decay energies  $A = 237$  to  $270$

