

Figure 2. The ground states of the 2,850 nuclides define a “cradle”

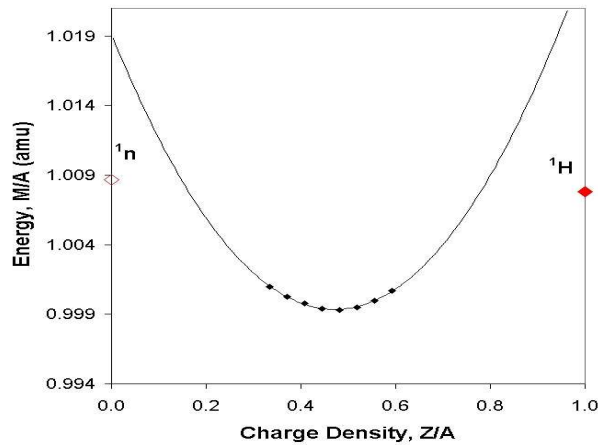


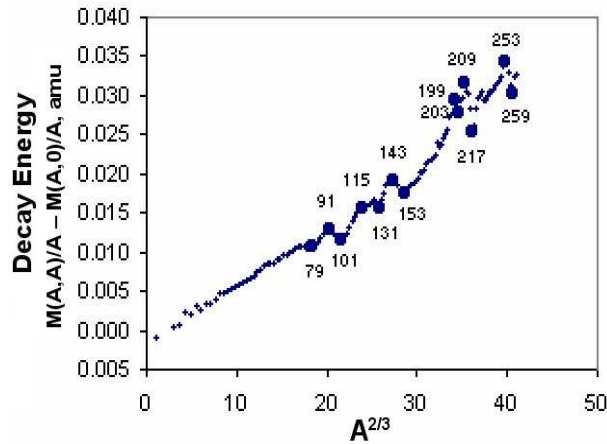
Figure 3. An illustrative cross section through Fig. 2 at  $A = 27$

by  $^{27}\text{F}$ ,  $^{27}\text{Ne}$ ,  $^{27}\text{Na}$ ,  $^{27}\text{Mg}$ ,  $^{27}\text{Al}$ ,  $^{27}\text{Si}$ ,  $^{27}\text{P}$ , and  $^{27}\text{S}$  yields much higher values of  $M/A$  for an assemblage of 27 neutrons at  $Z/A = 0$  or for an assemblage of 27 protons at  $Z/A = 1.0$ , respectively. Cross-sectional cuts through Fig. 2 at any other value of  $A > 1$  reveal an empirical mass parabola with values of  $M/A > M(^1\text{n})$  at  $Z/A = 0$  and values of  $M/A > M(^1\text{H})$  at  $Z/A = 1.0$ .

Typically the excess energy associated with these assemblages of pure neutrons or protons is  $\sim 10$  MeV per nucleon, plus the energy from Coulomb repulsion at  $Z/A = 1$ . Unlike the imagined dripping of neutrons near  $Z/A \approx 0$  [ref. 19, page 381], it thus appears that neutron emission may release significant amounts of energy from a neutron star.

Coulomb repulsion contributes to the high value of  $M/A$  for the assemblage of 27 protons on the right side of Fig. 3, but not to a nucleus of 27 neutrons on the left. In fact, Coulomb repulsion accounts for the difference between values of  $M/A$  at the intercepts where  $Z/A = 1.0$  and  $Z/A = 0$ , and this difference increases linearly with  $A^{2/3}$  over the mass range,  $A = 1 - 41$  [20]. The slope of this line is indistinguishable from that defined by the familiar  $\beta$ -decay of mirror nuclei close to the line of  $\beta$ -stability, e.g.,  $(^1\text{H}, ^1\text{n})$ ,  $(^3\text{He}, ^3\text{H})$ ,  $(^5\text{Li}, ^5\text{He})$ ,  $(^7\text{Be}, ^7\text{Li})$ , . . . ,  $(^{41}\text{Sc}, ^{41}\text{Ca})$  [20].

Thus, the values obtained for  $M/A$  from empirical mass parabolas at  $Z/A = 1.0$  and  $Z/A$



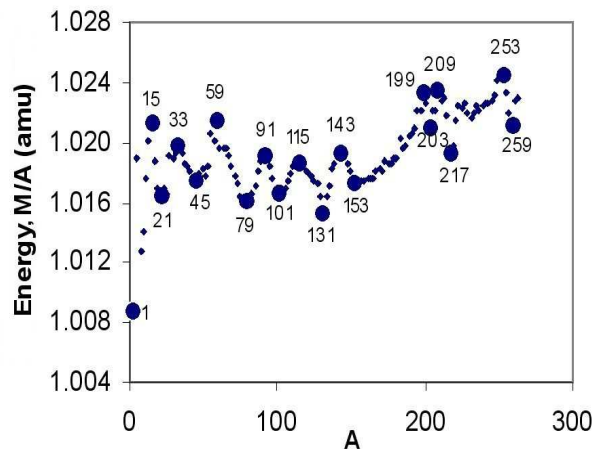
**Figure 4.** Decay energies of extreme nuclides, where the Coulomb energy drives ( $Z/A = 1$ )  $\rightarrow$  ( $Z/A = 0$ ), for all odd values of  $A$  from  $A = 1$  to  $263$

$= 0$  yield the same nuclear radius and the same coefficient for the Coulomb energy term as the mirror nuclei close to the line of  $\beta$ -stability for  $A = 1 - 41$  [20].

The decay energy, and hence the Coulomb energy of heavier nuclides,  $A > 41$ , can also be obtained from differences indicated by mass parabolas for values of  $M/A$  at  $Z/A = 1.0$  and  $Z/A = 0$ . Fig. 4 shows the results for all odd values of  $A$ , from  $A = 1$  to  $A = 263$ .

The decay energies of light nuclides in Fig. 4 vary linearly with  $A^{2/3}$ , but fine structure starts to appear near  $A \approx 80$ . Peak energies, at  $A = 91, 115, 143, 199, 209$  and  $253$ , likely arise from high Coulomb energy at  $Z/A = 1$  because of clustering of nucleons into tightly packed structures. Likewise, valleys at  $A = 79, 101, 131, 153, 203, 217$  and  $259$  likely mean low Coulomb energy at  $Z/A = 1$  because of more loosely packed nucleons.

There is no Coulomb energy associated with the other extreme form of nuclides, at  $Z/A = 0$ . These are the intercepts of mass parabolas at each value of  $A$  with the front plane in Fig. 2. However, these neutron-rich nuclides at  $Z/A = 0$  also reveal fine structure, as shown in Fig. 5 for all odd values of  $A$  from  $A = 1$  to  $263$ .



**Figure 5.** Values of  $M/A$  at  $Z/A = 0$  for all odd- $A$  parabolas,  $A = 1-263$

The data in Fig. 5 includes, for example,  $M/A = 1.019$  at  $A = 27$ , as shown earlier in Fig.

3. Note that all values of  $M/A$  for  $A > 1$  are higher than that of the free neutron at  $A = 1$ . This was first recognized as an indication of repulsive interactions between neutrons [17]. Neutron emission from these nuclides would typically generate about 10 MeV per nucleon, as shown by the example in Fig. 3 at  $A = 27$ .

The rhythmic distribution with  $A$  in values of  $M/A$  at  $Z/A = 0$  was not understood in 2000. However, the peaks and valleys in Fig. 5 occur at the same mass numbers as those in Fig. 4 for  $A \geq 79$ . Nuclear clustering into tightly packed structures produces peaks at  $A = 91, 115, 143, 199, 209$  and  $253$  in Fig. 4 from enhanced Coulomb repulsion. Nuclear clustering into tightly packed structures produce peaks at these same mass numbers in Fig. 5 from enhanced repulsion between neutrons. Loosely packed nucleons produce valleys at  $A = 79, 101, 131, 153, 203, 217$  and  $259$  in Fig. 4 from reduced Coulomb repulsion between loosely packed protons and in Fig. 5 from reduced repulsion between loosely packed neutrons.

The rhythmic scatter of data in Fig. 5 suggests that nuclear clustering also occurs below  $A = 79$ . However, the positive charge on light nuclei apparently maintains a spherical shape. Thus, the Coulomb energy is proportional to  $A^{2/3}$  at  $A < 79$  in Fig. 4, as well as in ordinary mirror nuclides [20].

#### 4. Theoretical and experimental studies needed

The structure of the solar core likely involves a central neutron star surrounded by iron-rich material. In order to see if neutron emission from the central neutron star might trigger a series of reactions that generate solar luminosity, neutrinos, and an outpouring of  $H^+$  ions from the solar surface [14], a better theoretical understanding is needed of:

- (a) repulsive interactions between neutrons
- (b) clustering of nucleons, and
- (c) neutron emission by penetration of a gravitational barrier.

Likewise, the proposed structure of the solar core can be tested by experimental measurements to look for evidence of:

- (d) low energy ( $E < 0.782$  MeV), anti-neutrinos coming from neutron decay near the solar core
- (e) another source for the neutral neutrino current detected by SNO experiment [21], and
- (f) a dense object (about 10 km) at the solar core.

The empirical basis for concluding the likely involvement of processes (a) – (c) in the operation of the Sun was presented above. However, a better theoretical basis for these processes is needed.

The presence of process (d) could be detected by measuring inverse  $\beta$ -decay induced by low energy anti-neutrinos coming from the Sun. For example, the  $^{35}\text{Cl} \rightarrow ^{35}\text{S}$  reaction might produce measurable levels of 87-day  $^{35}\text{S}$  in the Homestake Mine or in underground deposits of salt (NaCl).

Regarding item (e), the SNO experiment [21] on solar neutrinos shows that the charge current comes from the direction of the Sun, but new measurements are needed to determine the source of the much larger neutral current.

A recent paper [15] suggests that the 22-year cycle of solar magnetic storms may arise from the neutron star at the solar core and/or from the iron-rich super-conducting material that surrounds it. Measurements of gravity anomalies and of the Sun's quadrupole moment might also provide information on (f), a dense object at the solar core.

## 5. Acknowledgements

This study was supported by the University of Missouri-Rolla and the Foundation for Chemical Research, Inc., which kindly consented to our request to reproduce these figures from earlier reports to the Foundation for Chemical Research, Inc. This report was prepared for presentation at the Fourth, BEYOND 03 Conference, at Castle Ringberg, Germany on 9-14 June 2003. Parts were later presented as a plenary lecture at the 6th Workshop on “Quantum Field Theory Under the Influence of External Conditions” (QFEXT03) at the University of Oklahoma, Norman, 15-19 September 2003.

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