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Neutron Repulsion Confirmed As Energy Source*

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Systematic properties of heavy nuclides reveal a fine structure in Coulomb energy that parallels variations in mass arising from n-n interactions between neutrons. These results confirm an earlier suggestion [1] that n-n interactions in the nucleus are repulsive. Neutron emission may release up to 1.1%-2.4% of the nuclear rest mass as energy. By comparison, 0.8% of the rest mass is converted to energy in hydrogen fusion and 0.1% is converted to energy in fission. Neutron emission in the core of the Sun may trigger a series of reactions that collectively produce the Sun's luminosity and an outpouring of protons and neutrinos from its surface.

KEY WORDS : Nucleon interactions; neutron-neutron repulsion; solar energy.

I. INTRODUCTION

This is a sequel to an earlier paper [1] on attractive and repulsive interactions between nucleons as possible sources of stellar energy. It was shown that, in addition to repulsive Coulomb interactions between positive nuclear charges, the n-n and p-p interactions in the nucleus are repulsive and symmetric while the n-p interactions are attractive. In that [1] and other papers [2-7] it was noted that the formation of the Sun on the collapsed core of a precursor super-nova may account for many observations of the Sun and its planetary system that are unexplained by the standard solar model.

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In the present study, the systematic properties of all 2,850 known nuclides [8] are re-examine to see how the potential energy from interactions between neutrons in the nucleus compares with that generated by the well-known repulsive interactions between positive charges in the nucleus.

II. NUCLEAR SYSTEMATICS

Fig. 1 shows a 3-dimensional plot of the potential energy per nucleon, M/A, versus charge density, Z/A, versus mass number, A, for all 2,850 known nuclides [8].

Repulsive interactions increase the potential energy (mass) and thus the vertical height of data points in Fig. 1. Attractive interactions have the opposite effect.

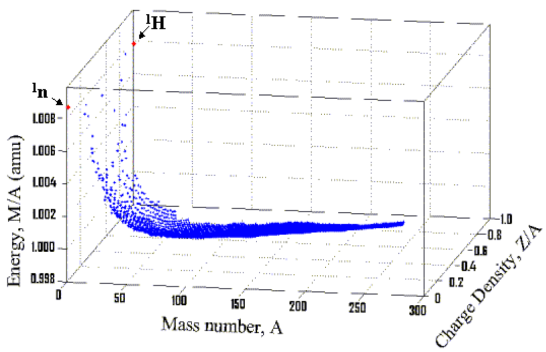

Fig. 1. This "cradle of the nuclides" [3] compares the potential energy per nucleon, M/A, charge density, Z/A, and mass number A for each of the 2,850 known nuclides [8].

Coulomb energy, the potential energy generated by repulsive interactions between positive charges, has long been recognized as one source of nuclear potential energy that detracts from nuclear stability [9] and increases the height of data points in Fig. 1.

A quantitative measure of Coulomb energy can be obtained from the decay of mirror nuclei, "*Any pair of nuclei which can be made from each other by interchanging all protons and neutrons…*" [10]. If n-n and p-p interactions are symmetric, then the energy released when a nucleus decays to its mirror is determined by the change in Coulomb energy. This Coulomb energy change is proportional to $A^{2/3}$ for the set of mirror nuclei where the parent nucleus has $A = 2Z - 1$ and the daughter has $A = 2Z + 1$ [9]. The electron-capture decay energies of these, $E_{EC} = M(A = 2Z\text{-}1) - M(A = 2Z\text{+}1)$, are shown in Fig. 2 for A = 1-41 amu.

The twenty-one pairs of mirror nuclides shown in Fig. 2 include (^{1}H, ^{1}n), (^{3}He, ^{3}H), (^{5}Li, ^{5}He), (^{7}Be, ^{7}Li), ….., (^{41}Sc, ^{41}Ca). The close fit of the decay energies to the line reaffirms symmetry of the n-n and p-p interactions. The slope of the least-squares line defined by the data yields a reasonable value of $a_C = 0.702$ MeV for the coefficient of the Coulomb energy term [10], where

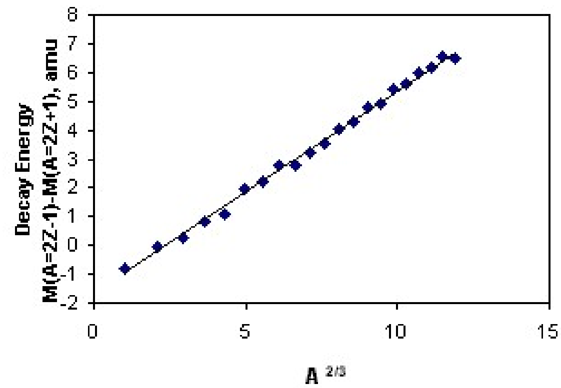

Fig. 2. Electron-capture decay energies *vs.* $A^{2/3}$ for mirror nuclides (A = 1-41 amu).

$$\text{Coulomb energy} = a_C\, Z^2/A^{1/3} \qquad (1)$$

The energy generated by interactions between neutrons, rather than the Coulomb energy generated by interactions between positive charges, can be obtained by fitting isobaric mass parabolas to the data points in Fig. 1 at each value of A. These isobaric mass parabolas are shown in Fig. 3.

Extrapolations of these mass parabola to the point where Z/A = 0, i.e., to the front plane in Fig. 3, yields the mass per nucleon for nuclides composed only of neutrons. Fig. 4 shows the mass per nucleon at these intercepts for odd-A nuclides when Z/A = 0.

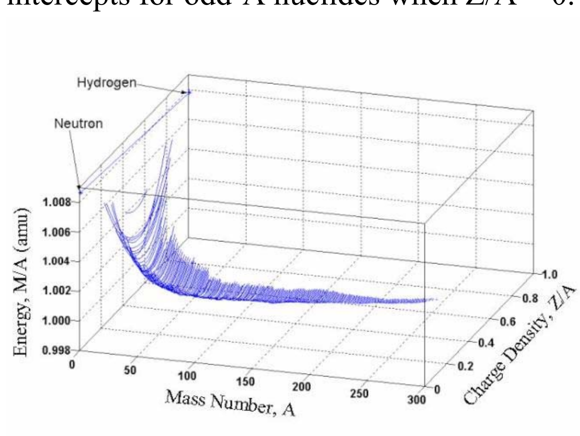

Fig. 3. Isobaric mass parabolas defined by nuclear mass data [8] for all sets of odd-A nuclides (A = 1-263 amu).

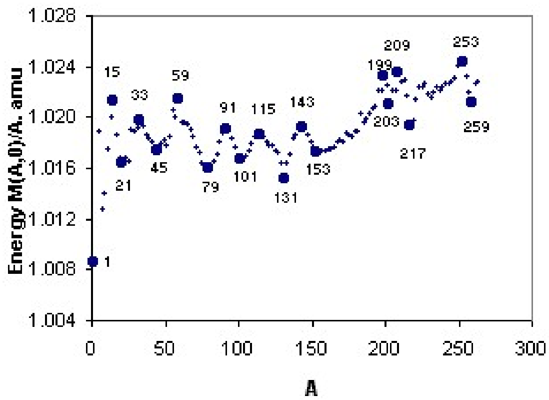

Fig. 4. The mass per nucleon for odd-A nuclides at Z/A = 0. These odd-A nuclides consist only of neutrons (A = 1-263 amu).

Two features in Fig. 4 are noteworthy for nuclides composed entirely of neutrons:

- The hypothetical nuclides at Z/A = 0 (A>1 amu) all have higher potential energy per nucleon than does the real nuclide, the neutron, at A = 1 amu [8].
- There is a rhythmic scatter in values of mass per nucleon. Mass numbers are identified at peaks and valleys.

The first feature was one of the points cited earlier as evidence for repulsive n-n interactions[1,11]. These make the mass per nucleon higher in assemblages of neutrons than in the free neutron.

The second feature, the rhythmic scatter of data points in Fig. 4, is also informative. This feature is mirrored at the other extreme when isobaric mass parabolas are extrapolated to the point where Z/A = 1, i.e., to the back plane of Fig. 3 where the nuclei are composed entirely of protons.

Coherence in the waves of values for M/A (mass per nucleon) at Z/A = 1 and Z/A = 0 can be seen by looking at the decay energies of these extreme forms of mirror nuclei [9]. Fig. 5 shows electron-capture decay energies of extreme, isobaric pairs for A =1-41 where E_{EC} = M(Z=A) - M(Z=0).

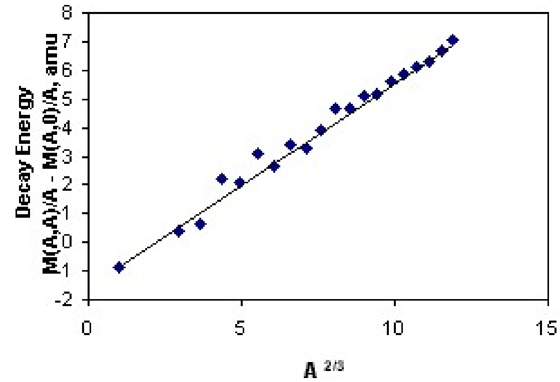

Fig. 5. Electron-capture decay energies per nucleon versus $A^{2/3}$ for extreme nuclides. The parent has Z = A; the daughter has Z = 0 (A = 1-41 amu).

The nuclides in Fig. 5 span the same mass range as those in Fig. 2, A = 1-41 amu, except that the nuclear mass data [8] do not define a unique mass parabola at A = 3 amu. That data point is missing from Fig. 5.

The line in Fig. 5 is the one obtained by a least-squares fit to the data shown in Fig. 2. The close fit of the data in Fig. 5 to this same line is significant. This confirms that the extrapolated values of mass per nucleon at Z/A = 0 and Z/A = 1 are meaningful despite the rhythmic, wave-like feature shown in Fig 4. Changes in Coulomb energy determine positron decay energies of these hypothetical nuclides (Fig. 5) almost as well as they define the positron decay energies of mirror nuclides that are close to the line of β-stability (Fig. 2).

Rhythmic variations in values of M/A versus A may indicate systematic changes in the geometry of nucleons as their numbers change. If so, this may provide useful information on interactions between nucleons.

III. A COMPARISON OF N-N AND COULOMB INTERACTIONS

Fig. 6 shows positron decay energies for all odd-A nuclides when the parent has Z =

A and the daughter has Z = 0. The parent and daughter are hypothetical nuclides at all values of A = 1-263 amu, except for the hydrogen atom and the neutron at A = 1.

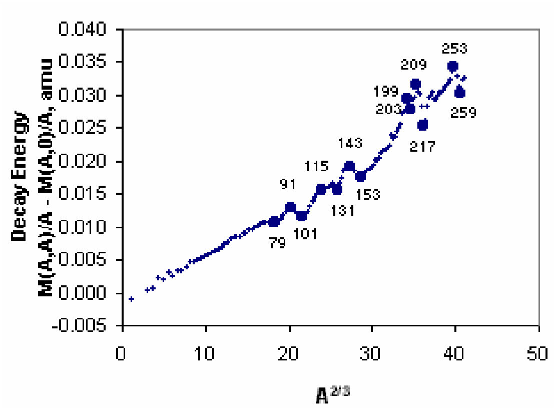

Fig. 6. Positron decay energies versus $A^{2/3}$ for the entire spectrum of extreme, odd-A nuclides. The parent has Z = A; the daughter has Z = 0 (A = 1-263 amu).

At A = 1-41 amu, the data in Fig. 6 are the same as those in Fig. 5. They therefore display the same linear relationship. Peaks and valleys appear at A > 60 amu. The mass numbers are labeled in the manner of Fig. 4.

In Fig. 6 the peaks or valleys occur when the Coulomb energy for Z = A is unusually high or low. In Fig. 4 there is no Coulomb energy since Z = 0. The peaks and valleys are instead caused by interactions between neutrons. In both figures, the peaks occur at A = 91, 115, 143, 199, 209, and 253 amu and the valleys occur at A = 79, 101, 131, 153, 203, 217, and 259 amu.

The common occurrence of peaks and valleys in potential energy at the same mass numbers from Coulomb and n-n interactions confirms that both interactions are repulsive.

At low values of A the Coulomb energy does not cause the sharp peaks and valleys seen in n-n interactions, perhaps because:

1. At low values of A the nuclear radius is ~1 F (10^{-15} m). Coulomb repulsion may force a spherical shape for the positive nuclear charges in light nuclides, independent of the physical geometry of nucleons.
2. At A = 1-41 the Coulomb energy per nucleon for Z = A is ~1-8 MeV per nucleon. This is smaller than the average potential energy from interactions between neutrons (~10 MeV per nucleon) for Z = 0 [11].
3. At A = 43-153, peaks start to appear in Fig. 6, as the Coulomb energy per nucleon increases to ~9-17 MeV per nucleon for Z = A. For Z = 0, the average potential energy from interactions between neutrons remains at ~10 MeV per nucleon [11].
4. At A = 155-263, Coulomb energy per nucleon for Z = A increases to ~20-29 MeV per nucleon but the energy generated by interactions between neutrons remains less than ~14 MeV per nucleon at Z = 0 [11].
5. Fine structure peaks appear in Fig. 6 above the region of maximum nuclear stability at A ≈ 56. Nuclear quadrupole moments also suggest that the distribution of nuclear charge more closely follows the geometry of nucleons for these higher values of A.

CONCLUSIONS AND FUTURE TESTS

The occurrence of peaks and valleys in potential energy (M/A) at the same mass numbers from n-n interactions (Fig 5) and from Coulomb interactions (Fig. 6) confirms that both interactions are repulsive [1]. Neutron repulsion may represent a major source of energy if a) the Sun formed on the collapsed core of a supernova [12,13] and b) neutron-emission from its core triggers a series of reactions that generate luminosity, solar neutrinos, and an outflow of 3 x 10^{43} H^+ per year in the solar wind [1,3,5-7,11]:

- Neutron emission from the solar core
  $<{}_0^1n> \rightarrow {}_0^1n$ + ~ 10-22 MeV
- Neutron decay or capture
  ${}_0^1n \rightarrow {}_1^1H^+ + e^- + \text{anti-}\nu$ + 0.78 MeV
- Fusion and upward migration of H^+
  $4\ {}_1^1H^+ + 2\ e^- \rightarrow {}_2^4He^{++} + 2\ \nu$ + 27 MeV
- Escape of excess H^+ in the solar wind
  Each year 3×10^{43} H^+ depart

In the first reaction, neutron emission releases up to 1.1%-2.4% of the nuclear rest mass as energy. By comparison, hydrogen fusion releases a maximum of about 0.8% of the rest mass as energy (0.7% if the end product is helium) and fission releases 0.1% of the rest mass as energy.

If these reactions power the Sun, then neutron emission generates >57% of solar luminosity, <5% is from neutron decay, <38% is from hydrogen fusion, and the Sun generates 3×10^{43} more hydrogen atoms each year than it consumes by fusion.

The following measurements may be used to test these conclusions:

1. Measure anti-neutrinos ($1.4 \times 10^{38}\ s^{-1}$ with E < 0.782 MeV) from neutron decay at the solar core. The $^{35}Cl \rightarrow {}^{35}S$ reaction in the Homestake Mine could be used to detect these antineutrinos [14].
2. Measure gravity anomalies, magnetic fields, quadrupole moment, or circular polarized light [15] from the compact neutron star (~10 km) at the solar core.
3. Measure residual microwave back-ground radiation [16] from the explosion of a supernova here 5 Gy ago [1-7].

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