Nuclear systematics

Part III: The source of solar luminosity

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The Sun emits about \(3 \times 10^{43} \, ^1\text{H}\) per year in the solar wind (SW). Solar luminosity and the outflow of SW-protons come from the collapsed supernova core, a neutron star (NS), on which the Sun formed. The universal cradle of the nuclides indicates that the energy of each neutron in the Sun’s central NS exceeds that of a free neutron by \(+10–22\) MeV. Solar luminosity and SW-protons are generated by a series of reactions: (a) escape of neutrons from the central NS, (b) decay of free neutrons or their capture by heavier nuclides, (c) fusion and upward migration of \(^1\text{H}\) through material that accreted on the NS, and (d) escape of \(^1\text{H}\) in the SW.

Introduction

This is the third paper in a series using nuclear systematics to elucidate the Sun’s origin, composition, and source of energy. The first paper\(^1\) confirmed that Fe is the most abundant element and that, except for H, elemental abundance in the Sun is linked with nuclear stability\(^2\) as might be expected of elements made near the core of a supernova. The second paper\(^3\) identified a universal cradle of nuclear matter that is used here to clarify the source of the Sun’s energy.

According to the Standard Solar Model (SSM),\(^4\) the Sun formed as a homogeneous body. It consists mostly of the two lightest elements, H and He, and its energy comes from fusion of H into He in the core of the Sun:\(^5\)

\[
4 \, ^1\text{H}^+ + 2 \, e^- \rightarrow ^4\text{He}^{++} + 2 \, \nu + 26.73 \, \text{MeV} \quad (1)
\]

According to this model, the Sun consumes \(3.4 \times 10^{38} \, ^1\text{H}^+\) per second in order to generate its radiant energy.

The transformation of reactants into products is usually confirmed by showing that reactants are consumed and/or that products are generated. That has not been done for the above reaction. In fact, the results of several studies seem to conflict with predictions of the SSM and H-fusion as the source of solar energy.

(1) One product of Eq. (1), the neutrino (\(\nu\)), readily escapes from the solar core, but the measured output\(^5\) of solar neutrinos is only a fraction of that expected if the Sun’s radiant energy comes solely from H-fusion. The other product has not been observed as excess \(^4\text{He}\) and may still be trapped in the Sun’s core.

(2) The Sun apparently produces more \(^1\text{H}\) than it consumes. Thus the reactant shown in Eq. (1) is actually emitted by the Sun. An emission rate of about \(2.7 \times 10^{43} \, ^1\text{H}/\text{yr}\), i.e., an annual solar mass loss of \(=2 \times 10^{-14} \, \text{Mo}\), is required to produce the measured SW-flux\(^6\) of \(3 \times 10^8 \, ^1\text{H}^+\) per cm\(^2/s\) at 1 AU.

(3) There is a systematic enrichment of the lighter mass isotopes of elements in the SW, as if an outward flow of \(^1\text{H}\) from the Sun’s interior selectively carries the lighter mass isotopes of each element to the solar surface.\(^1\)

(4) When photospheric abundances of elements are corrected for the mass fractionation observed across the isotopes of SW-elements,\(^7\) the seven most abundant elements in the bulk Sun (Fe, Ni, O, Si, S, Mg and Ca) are those that comprise about 99% of the material in ordinary meteorites\(^2\) and nuclear stability is linked with elemental abundance, except for an obvious excess of \(^1\text{H}\).

Thus, the H-fusion reaction shown in Eq. (1) may generate part of the Sun’s radiant energy, but the Sun consumes more \(^1\text{H}\) than it consumes. The excess \(^1\text{H}\) escapes from the surface of the Sun, apparently after moving upward through material with the elemental composition of ordinary meteorites. In the next section, these observations are combined with information in papers of this series\(^1,3\) to develop an alternative explanation for the Sun’s radiant energy.

Nuclear systematics

EVANS\(^8\) notes that “Any pair of nuclei which can be made from each other by interchanging all protons and neutrons are called mirror nuclei.” (p. 33). Thus, each pair of isobaric intercepts shown on the cradle of nuclear matter\(^3\) at \(Z/A = 0\) and \(Z/A = 1\) are mirror nuclei. None of these mirror nuclei actually exist in nature, except for the \(^1\text{n}\), \(^1\text{H}\) pair at \(A = 1\). Before using the cradle of the nuclides\(^3\) to explain the source of the Sun’s energy, it is instructive to compare the properties of real nuclides with cradle predictions for nuclides with extreme charge densities.

For that purpose, data from the sixth edition of Nuclear Wallet Cards\(^9\) were first used to compute negatron-decay energies for the light-weight, odd-A, mirror nuclides close to the line of \(\beta\)-stability. These are shown in the familiar plot\(^8\) of \(\beta\)-decay energies versus \(A^{2/3}\) in Fig. 1 for values \(A = 1–41\).
Fig. 1. The negatron decay energy, $E_\beta = M(A = 2Z+1) - M(A = 2Z-1)$, versus $A^{2/3}$ for the real, mirror image nuclei with $A = 1-41$ amu. The slope of the line for these light-weight nuclei near the line of $\beta$-stability yields a reasonable value for the coefficient of the Coulomb energy term, $\alpha_c = 0.702$ MeV.

For negatron emission of these real nuclides with $Z/A = 0.50$, the parent has $A = 2Z+1$, the daughter has $A = 2Z-1$, and the difference in Coulomb energies of these mirror nuclei determines their decay energy, $E_\beta = M(A = 2Z+1) - M(A = 2Z-1)$. The slope of the least-squares line in Fig. 1 yields a value of $\alpha_c = 0.702$ MeV for the coefficient of the Coulomb energy term, where

$$\text{Coulomb energy} = \alpha_c Z^2/A^{1/3} \quad (2)$$

To show that the cradle of the nuclides\textsuperscript{3} yields reasonable values for the mass per nucleon of hypothetical nuclides with extreme charge densities, $Z/A = 0$ and $Z/A = 1$, the average negatron decay energy per nucleon, $E_\beta/A = M(A,0)/A - M(A,A)/A$, is plotted versus $A^{2/3}$ for this set of mirror image nuclei in Fig. 2.

Except at $A = 1$ all members of this set of mirror nuclei are hypothetical, with values $M(A,0)/A$ and $M(A,A)/A$ extrapolated from isobaric parabolas through the cradle of the nuclides.\textsuperscript{3,10} As in Fig. 1, the data in Fig. 2 are for $A = 1-41$.

The least-squares line from Fig. 1 has been arbitrarily inserted in Fig. 2. This line was obtained from the $\beta$-decay of mirror nuclides close to the line of $\beta$-stability, with $Z/A = 0.50$. It can be seen in Fig. 2 that the $\beta$-decay energies of hypothetical mirror nuclei with extreme charge densities of $Z/A = 0$ and $Z/A = 1.0$ lie along the same line. This suggests that the cradle of the nuclides\textsuperscript{3,10} yields reasonable values for the average potential energy, or mass per nucleon, even for nuclides with extreme charge densities.

The average potential energy, or mass per nucleon, for nuclides composed only of neutrons can be obtained by extrapolating isobaric parabolas through the cradle of nuclides to $Z/A = 0$. These values of $M(A,0)/A$ are shown in Fig. 3.

The scatter of data in Fig. 3 does not reflect a problem in extrapolating isobaric parabolas to the extreme value of $Z/A = 0$. The rhythmic scatter shown in Fig. 3 for the energy of nuclei composed only of neutrons is mirrored in a rhythmic scatter of data for the energy of nuclei composed only of protons ($Z/A = 1.0$). Yet differences in the energies of these extreme mirror nuclides (i.e., their $\beta$-decay energies) follow the trend line shown in Figs 1 and 2.

Note in Fig. 3 that the mass or energy per nucleon for the free neutron at $A = 1$ is less than it is for any of the heavier nuclei composed only of neutrons. This is a source of potential energy in heavy nuclei with $Z/A = 0$.

Fig. 2. The average negatron decay energy per nucleon, $E_\beta/A = M(A,0)/A - M(A,A)/A$, versus $A^{2/3}$ for the set of mirror image nuclei with $A = 1-41$ amu and extreme charge densities of $Z/A = 0$ and $Z/A = 1.0$. Except at $A = 1$ all members of this set of nuclides are hypothetical. The values $M(A,0)/A$ and $M(A,A)/A$ were obtained by extrapolation of isobaric parabolas through the cradle of the nuclides.\textsuperscript{3,10} The $\beta$-decay energies of these hypothetical nuclei lie along the same line defined by the data for real nuclei from Fig. 1.

Fig. 3. The average potential energy, or mass per nucleon, for nuclides composed only of neutrons. The values shown here were obtained by extrapolating odd-$A$ isobaric parabolas through the cradle of nuclides to $Z/A = 0$. Even-$A$ nuclides at $Z/A = 0$ follow the same trend shown here but clutter the graph with separate values for odd-odd and even-even nuclides at each value of $A$. This figure is reproduced from Ref. 10.