Solar Abundance of the Elements

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Abstract. When photospheric abundances are corrected for the mass fractionation seen across the isotopes of solar wind implanted noble gases, the most abundant elements in the bulk Sun are the same ones Harkins [1] found in 1917 to comprise 99% of ordinary meteorites: Fe, Ni, O, Si, S, Mg and Ca. The nuclei of these elements are products of advanced stellar evolution. Nuclear systematics suggest the possibility of a short-range n-n repulsion (10-22 MeV/nucleon) that might generate part of its luminosity if the Sun formed on the collapsed core of a supernova [2]. The remainder may then come from fusion of ^{1}H generated by neutron decay.

INTRODUCTION

In 1917 Harkins [1], noting that the Earth's crust and the Sun's gaseous envelope may not represent the overall compositions of these bodies, used chemical analyses on 443 ordinary meteorites to conclude that seven, even-Z elements are most abundant: Fe, O, Ni, Si, Mg, S and Ca.

In the 1920's Cecilia Payne [3] and Russell [4] used lines in the solar spectrum to show that hydrogen (H) is the most abundant element in the Sun's <u>atmosphere</u>. However, Payne regarded the high value derived for the abundance of H as '*spurious*' (p. 186) and Russell regarded this as a puzzle that remained to be solved.

In his autobiography Hoyle [5] notes that the results of Payne (later Payne-Gaposchkin) and Russell were for the atmospheres, not for the deep interiors of stars, and that he, Eddington, and others in the astronomical community continued to believe in an iron-rich model of the Sun until after the Second World War.

Perhaps encouraged by the development of fusion-based weapons, the scientific community adopted thehydrogen-rich model of the Sun after the Second World War despite Harkins' earlier warning about using atmospheric abundances and Russell's comment [4] that *"The calculated abundance of hydrogen in the sun's atmosphere is almost incredibly great"* (p. 70). Most modern estimates for the abundance of H, He and other light, volatile elements are based on line spectra of the solar photosphere [e.g., 6].

STRANGE ISOTOPIC RATIOS

In 1969, the Apollo mission returned the first lunar samples to Earth for analysis and the Allende meteorite fell in Mexico. Strange isotopic ratios were reported in both of these extra-terrestrial samples. The majority opinion is that these observations provide no important new information on the abundance of the elements.

Lighter mass isotopes are enriched in many elements implanted in lunar soils and breccias by the solar wind (SW)**.** The largest effects are in the two lightest elements, SW-implanted H and He. The prevailing view is that the high values of ^{1}H/^{2}H and ^{3}He/^{4}He in the solar wind indicate that ^{2}H was converted into ^{3}He in an early, deuterium-burning stage of the Sun [7,8].

Likewise, the strange isotopic ratios observed in grains and mineral separates of Allende and other meteorites are widely believed to represent a small amount of alien nucleogenetic products added to the solar system from a multiplicity of stellar sources [9-11].

However, the purpose of this note is to explore the implications of a minority opinion that these strange isotopic ratios may contain important new information on the Sun's origin, composition and source of energy. These data and our conclusions do not necessarily apply to other stars. Several chapters of a recently published book [12] use seismology, neutrinos, and isotopic ratios from the Sun to estimate its internal composition. The results do not necessarily support for the standard solar model [13].

THE SUN'S ORIGIN, COMPOSITION AND SOURCE OF ENERGY

Below are observations on isotopes in meteorites and Apollo samples that may lend support to Harkins'

original conclusions [1]:

1. The possibility of a common mass-fractionation across the isotopes of planetary and SW-implanted Ne and Xe was noted in 1970 [14].

2. Analyses of gases in mineral separates of Allende and other meteorites during the 1970s revealed isotopically strange Xe trapped in the same sites as ordinary, planetary-type He and Ne [2, 15]. Elemental abundance of He correlates with excess ^{136}Xe, for example, and these correlations always yield isotopically 'normal' Xe at the intercept where the elemental abundance of planetary-type He is zero. These observations were the basis for the suggestion that isotopically 'normal' high-Z elements in the solar system may have originated in the interior of a massive star, where fusion had consumed low-Z elements like He, and isotopically 'strange' high-Z elements like Xe and isotopically 'normal' low-Z elements like He came from the outer layers of this same star [2].

3. A 1983 comparison of the isotopic abundances of He, Ne, Ar, Kr and Xe in lunar soil # 12001 with those in air and in a mineral separate of the Allende meteorite revealed a systematic enrichment of the lighter mass isotopes of each SW-implanted element [16]. For each gas the lighter isotopes of mass, m_L, are enriched relative to the heavier isotopes of mass, m_H, by a factor, f, where

$$f = (m_H / m_L)^{4.56}. \qquad (1)$$

It was suggested that the smooth mass fractionation pattern [16] observed from ^{3}He to ^{136}Xe was the result of a mass fractionation process that selectively enriches lighter nuclides at the Sun's surface.

4. When Eq. (1) was used to correct photospheric abundance [17] for fractionation, the most abundant elements indicated for the bulk Sun [18] were the same seven, even-Z elements that Harkins [1] found to be most abundant in meteorites: Fe, Ni, O, Si, S, Mg and Ca. It was also noted that the light isotopes of He, Ne, Mg and Ar in solar flares are less enriched, as if solar flare events effectively by-pass $\approx$ 3.5 stages of mass fractionation [18].

Post-World War II opinions [5] on the Sun's internal composition not only violate Harkins' conclusion [1] that the even-Z elements are more abundant than the odd-Z ones. They represent a major shift from the view of nuclear physics. As shown in Figure 1, among stable nuclides ^{1}H has the highest potential energy (M/A) and the highest charge density (Z/A). On the other hand, ^{56}Fe has the lowest potential energy and a very ordinary charge density. Nuclear evolution is advanced if the Sun consists mostly of ^{56}Fe but much less so if it is made of ^{1}H.
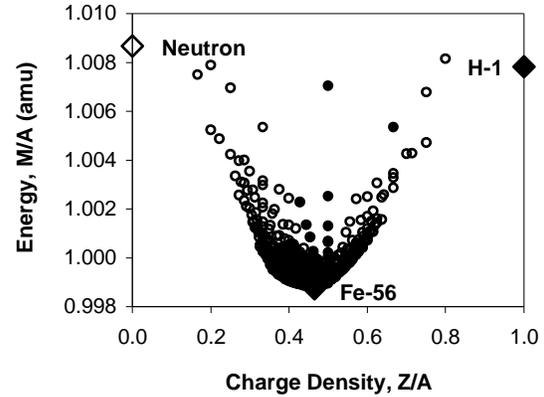

Figure 1. A plot of potential energy (M/A) *vs.* charge density (Z/A) for all stable and radioactive nuclides [19]. Open symbols represent radioactive nuclides; filled symbols are stable nuclides.

Wolszczan and Frail [20, 21] discovered Earth-like planets orbiting a collapsed supernova core, pulsar PSR1257+12, and Lin *et al.* [22] showed that such a planetary system could be produced from a rotationally-supported disk of supernova debris.

If the Sun formed on the collapsed core of a supernova [2], the data in Fig. 1 indicate a possible source for at least part of its luminosity. When the data there are sorted in a third dimension represented by A, Z, or N, then the data define families of mass parabolas representing isobars, isotopes, or isotones [23]. Extrapolation of these parabolas to Z/A = 0 consistently yields values of M/A > (M/A)$_{neutron}$. Values of M/A at the intercept where Z/A = 0 generally increase with A and suggest that the n-n repulsion in a neutron star (NS) will be $\approx$ 10-22 MeV/nucleon [23].

Thus, neutrons from a central NS may generate part of the Sun's energy, with the remainder generated by fusion reactions as most of its decay product, ^{1}H, undergoes fusion in its migration to the solar surface [23]. This flux of ^{1}H from the center of the Sun may selectively carry lighter elements and the lighter isotopes of individual elements to the surface before departing in the solar wind [23].

It should be stressed that heterogeneous accretion may have produced most of the chemical layering of the Sun, as has also been concluded for the internal structure of terrestrial planets [24, 25].

The apparent increase in the n-n repulsion with A suggests that this short-range force may be relatively weak for neutrons at the nuclear surface. This is seen in the weak repulsion between neutrons in odd-N isotopes of hydrogen, as shown in Figure 2.
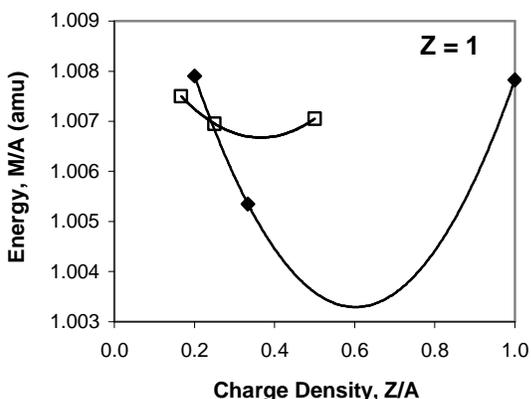
Figure 2. Parabolas defined by the potential energy (M/A) and charge density (Z/A) of the six hydrogen isotopes [19]. Isotopes with odd numbers of neutrons are represented by open symbols. Those with even numbers of neutrons are represented by filled symbols.

The mass parabola on the right with even numbers of neutrons extrapolates to $M/A \approx (M/A)_{neutron} + 4.6$ MeV at $Z/A = 0$. The parabola on the left with odd numbers of neutrons extrapolates to $M/A \approx (M/A)_{neutron} + 0.7$ MeV at $Z/A = 0$. The n-n repulsion between the odd neutrons in H is about an order of magnitude less than that in other light nuclides [23].

CONCLUSIONS

The selective transport of lighter nuclides to the solar surface offers an alternative explanation for the enrichment of light isotopes in the solar wind. When corrected for mass fractionation, the most abundant elements in the bulk Sun are the same ones Harkins [1] found in 1917 to comprise 99% of the material in ordinary meteorites: Fe, Ni, O, Si, S, Mg, and Ca. A short range n-n repulsion (10-22 MeV/nucleon) may generate part of the Sun's luminosity by neutron emission if the Sun formed on a collapsed supernova core [2]. Beta-decay and upward migration of H from the Sun's interior may contribute to the excess light isotopes in the solar wind [7, 8, 16, 18].

ACKNOWLEDGMENTS

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