Initial abundance of iron-60 in the early solar system: Implication for the formation of the early solar system

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Clear evidence that 60Fe, which decays to 60Ni with a half-life of 1.5 million years, was present in the early solar system has been found in chondrites [1-4]. Because it is produced in stars much more efficiently than by energetic-particle irradiation, its presence in the early solar system indicates that stellar nucleosynthesis contributed to the inventory of short-lived radionuclides. Initial abundances of 60Fe that are expressed as ratios to abundances of a stable isotope, (60Fe/56Fe)0, inferred for chondritic materials indicate stellar production of 60Fe shortly before the solar system formation. However, current estimates of (60Fe/56Fe)0 for the solar system are based primarily on sulfides from unequilibrated ordinary chondrites, which are easily disturbed by mild thermal metamorphism. Silicates are less susceptible to thermal and aqueous processes. Therefore, silicates may provide us with more reliable (60Fe/56Fe)0 in the early solar system.

We have measured four pyroxene-rich chondrules from unequilibrated ordinary chondrites, Semarkona (LL3.0) and Bishunpur (LL3.1), by Cameca ims-1270 ion microprobe at GSJ, AIST. Excesses of 60Ni were clearly observed in all of the chondrules. Their (60Fe/56Fe)0 range from (2.2+/-1.0)x10-7 to (4.4+/-2.0)x10-7, which are higher than those obtained for sulfides in Bishunpur and Krymka (LL3.1) [1], but smaller than that for sulfides in Semarkona [4].

Semarkona and Bishunpur are the least metamorphosed ordinary chondrites and have experienced metamorphic temperatures no higher than 550K and 580K, respectively [5-7]. No cation diffusion is expected in pyroxene at such low temperatures [8]. On the other hand, diffusion of Fe and Ni in sulfides may occur [9]. The sulfides in Semarkona may well have been produced in part or altered by aqueous alteration, and thus their (60Fe/56Fe)0 may not provide a reliable estimate of (60Fe/56Fe)0 at the time of the solar system formation.

The chondrules would have formed in a nebular reservoir in which 60Fe/56Fe was 2-4.5x10-7. If the chondrules in Semarkona and Bishunpur are undisturbed, and if they experienced last-melting events 1-2 million years after CAIs, the oldest solid objects in the solar system, as suggested by 26Al data [e.g., 10], then the 60Fe/56Fe ratio at the time the CAIs formed was between 5x10-7 and 1x10-6. The estimated range of (60Fe/56Fe)0 in the early solar system can be explained either by a massive close-by AGB star or by a close-by AGB star with low metallicity [11] although such possibilities were rejected by [12] due to their extreme rare encounters with newly forming protoplanetary systems. Another possible source for 60Fe is a type II supernova (25 Msun [13]). Because of the short lifetime of a very massive star (a few Myrs), a type II supernova may have occurred in a cluster star formation region where it was born [12, 14], and it may have contributed significantly to the inventory of short-lived radionuclides in the solar system. Furthermore, it may have played an important role in the collapse of the sun's parent molecular cloud [15].

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