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Short-Lived ^{10}Be in a Refractory Inclusion from the Allende Meteorite: A Case for Intense Irradiation of the Protosolar Nebula ?

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The presence in the protosolar nebula of short-lived radioactive isotopes is attested by the finding of excesses of their radioactive daughters in Ca-Al-rich inclusions of primitive chondrites (CAIs). This is for instance the case of ^{26}Al ($T_{1/2}$=0.7 Myr) for which excesses in the daughter ^{26}Mg are present in CAIs and are correlated with the abundances of the stable isotope ^{27}Al of the radioactive parent (Lee et al., 1976). Recently, evidence was brought for the occurrence in CAIs of ^{41}Ca which has an even shorter half life of 0.1 Myr (Srinavasan et al., 1996). Obviously, the presence in CAIs parent melts of these radionuclides impose that the formation of CAIs in the protosolar nebula follows shortly the nucleosynthesis of these elements. However, the implications on the timescales for the formation of the Solar system and its isolation from the surrounding interstellar medium remain controversial since two very different types of scenario are classically invoked for the nucleosynthesis of these radionuclides. They may result either from (1) nucleosynthesis in stellar environments such as supernovae or from (2) nuclear reactions induced by the collision of energetic particles on ambient dust or gas. The second type of process could have occurred within the Solar system since recent observations of Young Stellar Objects (YSOs) demonstrate that part of the protosolar nebula was most likely intensively irradiated by the young Sun.

The existence of nucleosynthesis by irradiation of either the presolar or the protosolar nebula has been invoked for B from (1) the discrepancy between the average ^{11}B/^{10}B ratio of the Solar System (around 4) and that of B in the interstellar medium (around 2.5) and (2) the presence of variations of several tens of permil of the ^{11}B/^{10}B ratio in primitive meteorites. In such models (Cassé et al., 1995 ; Chaussidon et al., 1995) various amounts of B with high ^{11}B/^{10}B ratio (up to 5 or 6) are mixed with interstellar B to make an average ^{11}B/^{10}B ratio of 4 for the Solar system. Interestingly, cross sections of nuclear reactions indicate that significant amounts of the stable isotope of Be (^{9}Be) and of the short-lived isotope of Be (^{10}Be) must be produced together with B. Since ^{10}Be is not produced in stellar environments, its presence in CAIs would be a decisive evidence for an early irradiation of the protosolar nebula. A search for ^{10}Be ($T_{1/2}$= 1.5 Myr) was thus undertaken in CAIs.

Three coarse-grained type B inclusions from the Allende meteorite were investigated by ion microprobe (Cameca IMS 1270 at CRPG-CNRS Nancy) for the presence of ^{10}Be. Analytical techniques were similar to those previously described (Chaussidon et al., 1997) but special care was taken (1) to remove surface contamination and (2) to monitor the background of the mass spectrometer and of the counting system. The concentrations of the different isotopes of Li, Be and B were measured on each spot, one measurement corresponding to approximately 2 hours of counting. Concentrations were found to be highly variable for Li (3-750 ppb), Be (0.05-3 ppm) and B (6-150 ppb with one spot at 900 ppb) excluding one sample with anomalously high B contents of 1 to 10 ppm. Be is apparently preferentially concentrated in melilite in accordance with previous experimental work. Li isotopic ratio were found to be slightly variable with a maximum range of 50 per mil around the average terrestrial ^{7}Li/^{6}Li ratio of 12.0192. At variance large variations of the ^{11}B/^{10}B ratio, up to 410 per mil, were observed in one inclusion, the excesses of ^{10}B (daughter product of ^{10}Be) being linearly correlated with the ^{9}Be concentrations. These measurements demonstrate that Be with a ^{10}Be/^{9}Be ratio of approximately 0.0009 was present in the Solar nebula when this CAI formed.

The most straightforward origin of this ^{10}Be is an intense irradiation of the protosolar nebula by the young Sun. Such an irradiation also produces heavier nuclides such as ^{26}Al or ^{41}Ca but the fluence required from ^{10}Be seems to be too low to account for all the ^{26}Al found in CAIs.

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