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Isotopic Study of Neutron Capture Effects on Sm and Gd in Extraterrestrial Materials

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Thermalized neutrons are induced by the interaction of cosmic rays with planetary materials. Neutron capture products have been used to characterize the exposure histories of extraterrestrial materials. The isotopic shifts of $^{150}Sm/^{149}Sm$ and $^{158}Gd/^{157}Gd$ in materials allow us to estimate the time-integrated neutron flux (neutron fluence) in space, because ^{149}Sm and ^{157}Gd have large cross sections for thermal neutrons. It is known that neutron production rates depend upon the depth of the sample in an object and its chemical composition. Therefore, isotopic results of neutron capture produced Sm and Gd provide information on the shielding conditions of the samples (size and location of the meteorite in the parent body) during their irradiation in space. In addition, the combination of Sm and Gd isotopic shifts is applied to determine the energy spectrum of thermal neutrons, because ^{149}Sm and ^{157}Gd have different neutron capture resonances at 0.0973 eV and 0.0314 eV, respectively. In this study, isotopic compositions of Sm and Gd in seven lunar soils, six enstatite achondrites (aubrites), two enstatite chondrites and eight ordinary chondrites were determined to estimate the neutron fluences and determine the neutron energy spectra. A thermal ionisation mass spectrometer (TIMS) was used for the determination of isotopic composition. For the calibration between isotopic shifts and neutron fluence, aliquots of standard chemical reagents for Sm and Gd were artificially irradiated with neutrons and the isotopic compositions were measured. The analytical precision in the present TIMS technique is that 1.0×10^{14} n cm^{-2} of neutron fluence can be detected (Hidaka et al., 1995).

Drill-stem samples of Apollo 15 are best to know the depth dependence of neutron fluences, because the depth of each sample is well documented and the core has been stratigraphically little disturbed for at least 450 Ma. The precise isotopic results of Sm and Gd in lunar regolith should be applied to establish the reference data for the relation between neutron capture effects and isotopic shifts in meteorites. The comparison of the lunar data with meteoritic data may show us key information on the parent bodies of meteorites. The neutron fluence in the A-15 core is a function of depth with a symmetric peak at 190 gcm^{-2}, and the values are $(5.16\text{-}7.49) \times 10^{16}$ n cm^{-2}. Furthermore, the data suggest that the neutrons in the A-15 core are more thermalized at the lower layers than they are at the upper layers (Hidaka et al., 2000). In addition to large isotopic shifts for ^{149}Sm, ^{150}Sm, ^{157}Gd, and ^{158}Gd, isotopic excess of ^{152}Gd and ^{154}Gd derived from neutron capture for ^{151}Eu and ^{153}Eu, respectively, were also observed in all samples.

Aubrites have higher neutron fluences of $(1.17\text{-}3.99) \times 10^{16}$ n cm^{-2}, than other chondrites having neutron fluences of $(1.03\text{-}5.17) \times 10^{15}$ n cm^{-2}. This should be due to the differences of chemical compositions and cosmic-ray exposure ages between aubrites and others. Since aubrites generally have longer exposure ages and lower contents of Ti and Fe than the other meteorites, they show high neutron fluences. However, even considering the differences of chemical compositions and exposure ages, aubrites have high neutron fluences. This is interpreted that aubrites may have been located near the surface of their parent body for several hundreds of Ma (Hidaka et al., 1999). Isotopic enrichments of ^{152}Gd and ^{154}Gd were observed also in aubrites.

Besides neutron capture reactions on Sm and Gd, Ne and Kr isotopic analyses provide information on fast and epi-thermal neutron information on the basis of $^{24}Mg(n,\alpha)^{21}Ne$ and $^{79}Br(n,\gamma)^{80}Kr$, respectively (Eugster et al., 1993). Neutron energy spectra determined from the distribution of thermal, epi-thermal and fast neutron fluences in eight chondrites are used to deduce the depth of the meteorite samples inside the meteoroidal body.

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