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High Precision Iron Isotope Measurements in Meteorites

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Meteorites preserve important records of the early history of the solar system, and the study of natural variations in stable isotope abundances has had profound influence in this field of research. Fe, as one of the most abundant elements in the solar system and as an element which is relatively volatile and exists in multiple oxidation states, is a particularly interesting target for isotope investigations. However, realising the potential offered by Fe isotopes in both terrestrial and extraterrestrial materials has been hampered by the absence of suitable techniques for precise Fe isotope determinations. Here we report the first results of high precision Fe isotope ratio measurements of meteorites, using plasma source mass spectrometry.

Meteorite samples, including carbonaceous chondrites, ordinary chondrites, and iron-meteorites, were digested using HF and HNO_3. The dissolved samples were purified using ion exchange chromatography with 100% yields for Fe. Fe isotope ratio measurements were performed on a Nu Instrument multiple collector inductively coupled plasma source mass spectrometer. $^{57}Fe/^{54}Fe$ and $^{56}Fe/^{54}Fe$ ratios of a sample are expressed in terms of $\varepsilon^{57}Fe$ and $\varepsilon^{56}Fe$ units, which are deviations in parts per 10000 from the Fe isotope reference standard IRMM-14. An external precision of better than 0.6ε at 95% confidence level is achieved for both $\varepsilon^{57}Fe$ and $\varepsilon^{56}Fe$.

An overall variation of ca.15 $\varepsilon^{57}Fe$ units with $-8.8 < \varepsilon^{57}Fe < 6.0$ has been observed from the measured meteorites. Whereas the chondrules in Allende (CV) meteorite show light isotope enrichment, the bulk sample of Orgueil (CI) meteorite and the matrix of Chainpur (LL) meteorite are most enriched in heavy isotope. In contrast to chondrites, Fe isotopes in Fe-meteorites are rather homogeneous, and the Fe isotope composition for the 7 analysed Fe-meteorite samples varies in $\varepsilon^{57}Fe$ from 0.1 to 2.0, which are very close the Fe isotope composition for the bulk samples of Allende and Muielison (CM) meteorites. Furthermore, the $\varepsilon^{57}Fe$ and $\varepsilon^{56}Fe$ values of the meteorites together with those of terrestrial materials fall on a single mass fraction line on a three-isotope plot. This implies that Fe isotopes in these meteorites and terrestrial material originated ultimately from a single uniform source, and the Fe isotope variations recorded in these samples preserve information about processes operating at various stages of the solar system evolution.

Compared to the Mg isotope measurements of the same samples which show variation of ca. 0.2 permil, the variation of Fe isotopes observed in this study is surprisingly large. The great contrast between Fe and Mg isotopes measured from the same samples implies that these meteorites must have experienced some processes which fractionate Fe isotopes but not Mg isotopes. One obvious possibility is redox process. As an element with multiple valency states, Fe isotope fractionation may occur between different Fe-oxidation states during meteorite formation and/or the subsequent alteration. But the redox process should cast no effects at all on Mg isotopes. In that case, the Fe isotope differences between these meteorites and condrules may reflect primarily the oxidation states of their formation environments. Alternatively, decoupling between Fe and Mg isotope variation can be resulted in some circumstances from volatilisation, because Fe is more volatile that Mg. However, the Fe-isotope variation pattern observed in this study, which shows light isotope enrichment in chondrules, is not compatible with mass fractionation induced by volatilisation.

In all, this contribution represents the first study of high precision measurements of Fe isotopes in meteorites. It shows that Fe isotopes in meteorites vary significantly, and further demonstrates the great potential offered by Fe isotopes in the studies of meteorites and solar system formation.