Oxygen Isotope Tracing of the Solar System. T. R. Ireland, Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia

Introduction:

Our view of the early solar system is largely through the solids that remain. Oxygen isotope measurements of solar system materials show a wide range in compositions. In terrestrial systems, oxygen isotope fractionation is dominated by mass-dependent fractionation, which is characterised by distribution of compositions along a line of slope ½ on the oxygen three-isotope diagram. Conversely solar system materials (from meteorites, sample returns) are characterised by variations along slope 1 on the oxygen three-isotope diagram, which is inferred to represent change in the abundance of ^{16}O.

Recent oxygen isotope measurements:

The oxygen isotope compositions of solar system materials range from ^{16}O-rich (Δ^{17}O down to -40 ‰ [1]) to ^{16}O-poor (Δ^{17}O up to +200 ‰ [2]). The solar oxygen isotopic composition has now been determined to be isotopically enriched in ^{16}O by ca. 60 ‰ with respect to the terrestrial oxygen isotope composition. A similar enrichment in ^{16}O is found in calcium aluminum-rich inclusions. The extreme ^{16}O enrichment is observed in a chondrule (a006) from the Acfer 214 chondrite [1]. Oxygen enriched in ^{17}O and ^{18}O has been described from lunar metal spherules with Δ^{17}O ca. +27‰ [3,4], from a cosmic symplectite in Acfer 094 (Δ^{17}O up to +90‰) [5], and from acid-insoluble organic material from Yamato-793495 (Δ^{17}O ca. +270‰) [Hashizume]. With a successful measurement of the solar-wind composition, the bulk composition of the solar system is determined, defining a solar reservoir that is ^{16}O-rich relative to terrestrial (Δ^{17}O ~ -35 ‰ [6])

Source of anomalous oxygen:

While a nucleosynthetic origin was originally proposed for ^{16}O enrichment [7], this has largely fallen out of favor because of a lack of correlation with isotopic anomalies in other elements. The source of this anomalous oxygen is most likely due to photodissociation and self shielding (PSS). This process relates to dissociation of CO molecules from short wavelength (UV) photons, and self-shielding as the wavelengths responsible for dissociation of $C^{16}O$ are attenuated before wavelengths responsible for $C^{17}O$ and $C^{18}O$ dissociation. The dissociated oxygen reacts with hydrogen to form water enriched in ^{17}O and ^{18}O.

Solar System Reservoirs:

Compositions of solar system materials can be interpreted in terms of three major groupings. With planetary and meteorite representation from Earth, Moon, Mars, and asteroid belt there is a consistent picture of the solid materials in the (inner) planetary system defining a *planetary* reservoir with $\Delta^{17}O \approx 0$. The *solar reservoir* reflects the composition of the Sun and therefore the bulk solar nebula (Δ^{17}O ~ -35 ‰ [6]). Remnants of nebular materials in meteorite matrices provide an indication of the *nebula water* reservoir that is ^{16}O-poor (Δ^{17}O up to +200 ‰).

The reservoir compositions are consistent with incorporation of material that has experienced ^{16}O fractionation via PSS. The *solar* composition represents the Sun and the solar nebula [6]. The *nebula water* reservoir was likely produced by evaporation of the water ice resulting from PSS. The *planetary* composition likely represents a mixture between solar and nebula water compositions, as the original solar composition solids were hydrated and altered [8]. This likely occurred in the solar nebula as material in the accretion disk was processed at high temperatures close to the Sun, with a fraction ejected back out into the accretion disk by stellar winds.

Processing of Solids in the Solar Nebula:

The earliest solids in the solar system have experienced high temperature processing. This manifests in melting, evaporation and condensation. At such extreme temperatures, the ambient nebula gas will rapidly equilibrate with the proto-CAI and proto-chondrules. If the precursors equilibrate with a gas resulting from complete evaporation of the bul material surrounding it, then the object will attain a solar composition.

It is interesting to note that oxygen can behave variably as a volatile species (carbon monoxide, water) through to being preserved in refractory assemblages (CAI, chondrules). During thermal processing the volatile species that are evaporated become part of the ambient gas surrounding the residues. As such, the ambient nebula gas can attain a wide variety of compositions that are mixtures of the three main reservoirs simply by gas-solid partitioning, but also by the maximum temperature attained in the formation region.

References:

[1] Kobayashi S. et al. (2003) *Geochem. J.*, 37, 663-669. [2] Hashizume K. et al. (2011) *Nature Geosci.,* 4, 165-169. [3] Ireland T. R. et al. (2006) *Nature,* 440, 776-778. [4] Hashizume K. and Chaussidon M. (2009) *GCA,* 73, 3038-3054. [5] Sakamoto N. et al. (2007) *Science*, 317, 231-233. [6] McKeegan K. D. et al. (2011) Science, 332, 1528-1532. [7] Clayton R. N. et al. (1973) Science, 182, 485-488. [8] Yurimoto H. and Kuramoto K. (2004) *Science*, 305, 1763-1766.