Meteorites

The demise of established dogmas on the formation of the Solar System

from P.K. Swart

FOR at least the past 10 years, a mild controversy has simmered in meteoritical and astrophysical circles regarding the strange distribution of xenon isotopes found in certain meteorites, known variously as CCF-Xe (carbonaceous chondrite fission), DME-Xe (demineralized acid etched) or Xe-X. Was this component formed in a supernova? Or was it merely a fortuitous combination of mass fractionation and other well established xenon reservoirs?

CCF-Xe is characterized by an excess of the light and heavy isotopes relative to ^{132}Xe and is contained within a mainly carbonaceous host phase constituting a small proportion of the total carbon in primitive meteorites such as Allende (C3V) and Murchison (CM2). The carbon isotopic composition of the carrier phase of CCF-Xe has provided us with no indication of any exotic origin for CCF-Xe, being essentially similar to Solar System values around (δ = -35 per mill PDB). Now, the results of two crucial experiments, reported at a recent meeting*, have led the principal defendants in the argument over the origin of CCF-Xe to concur in favouring the supernova hypothesis.

The first of these results, reported by Lewis, Anders, Shinamura and Lugmair, involved the examination of the isotopic composition of elements, such as barium and samarium, comparable in mass to xenon. These elements should, according to the fission hypothesis, show CCF-type anomalies. No such patterns were found. The absence of such anomalies is strong evidence that CCF-Xe does not arise from fission, although one escape clause remains. During the harsh acid treatment to which these meteorites were subjected in order to concentrate the anomalous gases, some CCF-Xe may have been left behind, and the hypothetical anomalous Ba and Sm removed.

The second result was the discovery by Wright, Norris and Pillinger, in conjunction with the Chicago group, of nitrogen with an extreme depletion in the heavier isotope of nitrogen (δ^{15}N = -330 per mill AIR). Such an isotopic composition is extremely unlikely to result through normal kinetic fractionation and although ion-molecule reactions are a possibility, most people think the nitrogen associated with CCF-Xe is the result of nuclear effects. If this is so, there now seems to be independent evidence that so-called CCF-Xe is derived from a supernova involving both p- and r-processes, as first suggested by Manuel *et al.* (*Nature* **240**, 99; 1972). The workers in this field must now come to some kind of consensus on what to call this component.

While searching for a barium isotope anomaly, Lugmair uncovered excesses in ^{143}Nd and ^{142}Nd which he and his co-workers concluded were a result of the α-decay from ^{147}Sm and ^{146}Sm. Thus ^{146}Sm appears to have been 'alive and kicking' during formation of the Solar System.

A second interesting development relating to Xe was the discovery by Swart, Grady and Pillinger in conjunction with Anders and Lewis, that carbon associated with s-Xe (xenon formed principally by slow neutron capture) has an isotopic composition of + 1,100 per mill (PDB): such a value clearly represents a remnant of a distinctive nuclear process. The value extends the range of δ values previously measured on all types of terrestrial and extraterrestrial material in the laboratory by almost two orders of magnitude, thus bringing respectibility to the measurements of astronomers who claim to have been measuring such high ^{13}C values in extra-Solar System objects for some considerable time. The association of isotopically heavy carbon with s-Xe places interesting constraints on the formation of grains and the implantation of isotopic anomal gases into them and I hope will spawn many attempts at interpretation. Nitrogen associated with this material appears from present measurements to be isotopically 'normal'.

Opportunity was provided for meteoriticists to hear and react to the controversial results of Thiemens and Heidenreich (*Science* **219**, 1073; 1983), which threaten established interpretation of the three-isotope oxygen system. Through experiments conducted in the laboratory (oxygen was dissociated to produce ozone), Thiemans was able to produce oxygen with an isotopic composition which did not fall on the line of slope 0.52 in the three-isotope plot of δ^{18}O against δ^{17}O. Instead the data plotted on a line of slope 1; the effect is believed to be caused by optical shielding of the minor isotopes.

Hitherto data plotting on such a line have been interpreted by meteoriticists as being the result of mixing between a normal Solar System component and some ^{16}O-rich end member. Thiemans suggested that the experimentally produced fractionation along a line of slope 1 may indeed be an explanation for the same trend seen in meteorites. The fact that no nuclear effects are required could then very well explain the paucity of nuclear effects in the same FUN (fractionation and unknown nuclear effect) inclusions seen in other multi-isotope systems such as silicon (as reported by Molino-Velsko, Mayeda and Clayton), titanium and magnesium (Hutcheon, Steele, Wachel, Macdougall and Phinney).

Surprisingly, most debate at the conference was directed not at the remarkable fact that effects which would be normally construed as nuclear could be produced in the laboratory, but at the mechanism for producing the ultraviolet for dissociating the oxygen-containing molecules. Thiemans suggested that T-Tauri stars, whch are enhanced in UV by 10^4, could be a source, a possibility later confirmed by Cameron during the discussion. This point was seized upon by several questioners. It is rather ironic that the major criticism levelled at workers in the field of carbon, hydrogen and nitrogen isotopes was that nuclear effects could not be ascertained because these elements only have two isotopes. With oxygen on the other hand, nuclear effects were clearly evident. Now the situation has apparently been reversed. Extreme enrichments and depletions in nitrogen and carbon have been classified as nuclear in origin, whereas oxygen shows only modest deviations from normal terrestrial values and data falling off the much heralded three-isotope plot can now be explained through simpler processes, not requiring a nuclear explanation.

An important point emerging from the various groups working on the stable isotopic composition of light elements (carbon, nitrogen and hydrogen) and their associations with noble gases in meteorites is that there are so far no simple and immediately obvious associations between distinctive carbonaceous phases, nitrogen and noble gases such as CCF-Xe. The distinctive isotopic composition of these light elements can be produced through a wide range of mechanisms whereas CCF-Xe may be limited to one scenario. Thus the discovery of light nitrogen in the iron meteorites reported by Prombo and Clayton is not necessarily the same nitrogen as that associated with CCF-Xe. For the same argument the apparent wide distribution of meteorites showing esoteric compositions of carbon and nitrogen reported at this meeting does not mean *a priori* associations with noble gas types. □

*The 14th Lunar and Planetary Science Conference was held in Houston on 14-18 March 1983.

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