NOTIZEN

The Origin of Anomalous Xe^{129} in Meteorites

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Several authors [1–4] have discussed the possibility that the Xe^{129} special anomaly found in meteorite xenon has arisen from the incomplete mixing of Xe^{129} formed by the decay of I^{129} in the solar nebula prior to the formation and cooling of meteoritic solids. A considerable amount of evidence has been accumulated in recent years by the present authors and others which indicates quite forcibly that this is not the case, but that the Xe^{129} originated from the decay of I^{129} within the meteorite itself. Four lines of evidence may be invoked: variations in the Xe^{129}/Xe^{132} ratio among meteorites and in different phases of the same meteorite; variations in the Xe^{129}/Xe^{132} ratio in whole meteorites or meteorite minerals with temperature during gas release; correlation of radiogenic Xe^{129} release (Xe^{129R}) with Xe^{128} produced artificially from I^{127} in meteorites by neutron irradiation (Xe^{128*}); and close agreement between these correlations for several different meteorites manifested by a similarity in calculated formation intervals. We may consider these observations in turn.

Zähringer and Gentner [2–4] have commented upon a proportionality between Xe^{129} and primordial gases in several meteorites and suggested that this observation supported the incomplete mixing hypothesis. If I^{129} decay occurred prior to formation of the meteoritic solids, and subsequent homogenization of the gases occurred, xenon from all meteorites would show similar Xe^{129}/Xe^{132} ratios. If complete mixing did not occur after I^{129} decay, differences in this ratio might be expected among meteorites which formed in different places or at different times, but different components from a given meteorite would be expected to contain xenon of identical composition, unless these components themselves formed at different times and places.

Wide variation in the Xe^{129}/Xe^{132} ratio are observed not only among meteorites of various classes, but even among meteorites of the same class. For example, the enstatite chondrites Abee and Indarch have ratios of 6.4 and 4.0, respectively, whereas values for the hypersthene chondrites Bjurböle and Bruderheim are 1.8 and 1.3, respectively [3]. In a study of four minerals and eight chondrule fractions from Bruderheim, Merrihue [5] reported ratios varying from 1 to 4, compared to the value of 1.2 characterizing the bulk meteorite. Such wide variations in the composition of the xenon in the solar nebula seem unlikely, especially in view of the overall constancy in isotopic and elemental abundances exhibited by meteorites in general.

A correlation between Xe^{129R} and xenon abundance was observed among the major Bruderheim minerals, similar to the correlations between Xe^{129} and primordial gases in several meteorites noted by Zähringer. An essential point for the Bruderheim minerals was an observed correlation between the Xe^{129}/Xe^{132} ratios and the total xenon content. On the incomplete mixing hypothesis, such a Xe^{129}/X^{132}-xenon correlation would require that the components richest in xenon formed in regions of the nebula characterized by high Xe^{129}/Xe^{132} ratios and were later mixed with components which formed in a region of lower xenon pressure and lower Xe^{129}/Xe^{132} ratio. Furthermore, Bruderheim chondrules often show quite high Xe^{129}/Xe^{132} ratios but low xenon contents, requiring an ad hoc explanation to fit them into the model. The Xe^{129}/Xe^{132}-xenon correlation does not appear to contradict the *in situ* decay hypothesis, assuming high solubility for xenon in certain minerals is associated (though not in direct proportion) with high solubility for iodine [5].

Jeffery and Reynolds [6] observed a variation with temperature in Xe^{129}/Xe^{132} during a heating experiment on the enstatite chondrite Abee which they interpreted as evidence for *in situ* decay of I^{129}. Zähringer [3, 4] questioned this interpretation, suggesting that variation in Xe^{129}/Xe^{132} ratios in Jeffery and Reynold's experiment resulted from changing proportions of air contamination. Two possible sources of air contamination are leakage into the systems and adsorption of air on the surface and in cracks of the sample. In the former case, dilution with air xenon would be accompanied by dilution with air argon. The Ar^{36}/Xe^{132} ratio in air is 1345. In the experiment on Abee, the Xe^{129}/Xe^{132} ratio reached a striking minimum of about 3 at 900 °C, which contrasts with maxima of more than 7 at higher and lower temperatures. No abnormal Ar^{36} release was observed at 900°, so air leakage into the

* Dr. Craig Merrihue was killed in a climbing accident on Mount Washington, New Hampshire on March 14th, 1965.

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2 J. Zähringer and W. Z. Gentner, Z. Naturforschg. **16 a**, 239 [1961].
3 J. Zähringer, Z. Naturforschg. **17 a**, 460 [1962].
4 J. Zähringer, Am. Rev. Astron. Astrophys. **2**, 121 [1964].
5 C. M. Merrihue, to be published [1965].
6 P. M. Jeffery and J. H. Reynolds, Z. Naturforschg. **16 a**, 431 [1961].

vacuum system evidently did not occur. For adsorbed atmospheric gases, it is probable that argon would be degassed more readily than xenon, so the preceding argument would not apply. If differing levels of adsorbed air xenon caused the Xe^{129}/Xe^{132} variations, correlated variations should have appeared in the anomalies in the other xenon isotopic ratios. Data on these xenon general anomalies were not reported for Abee, but similar experiments have been performed subsequently on several other meteorites. For example, we may cite the experiment on the chondrite Renazzo [7]. The release pattern for Renazzo showed variations in the Xe^{129}/Xe^{132} ratio which were totally uncorrelated with changes in any of the other isotopic ratios. For xenon released in heatings between 500 °C and 1300 °C the Xe^{128}/Xe^{132}, Xe^{130}/Xe^{132} and Xe^{131}/Xe^{132} ratios remained constant to within $\frac{1}{2}\%$, while the Xe^{129}/Xe^{132} ratio varied over a range of 20%. Similar experiments on Bruderheim minerals and chondrules likewise revealed wide variations in Xe^{129}/Xe^{132} not correlated with anomaly variations in the other major isotopes [4, 8]. On the incomplete mixing hypothesis xenon from separated minerals from a particular meteorite might contain differing Xe^{129}/Xe^{132} ratios if each mineral formed at a different time or place. During heating experiments, then, the Xe^{129}/Xe^{132} ratio variations should have been correlated with variations in other anomalous ratios, in contrast to the observations.

The Kr^{84}/Xe^{132} ratio is about 27.5 in air and close to unity for meteorites. Accordingly, it is a useful indicator for the presence of air contamination. No inverse correlation of Xe^{129}/Xe^{132} ratio with Kr^{84}/Xe^{132} was observed in any of the experiments cited above. It is not possible to explain the Xe^{129}/Xe^{132} variations in a variety of samples by the presence of air contamination.

While Xe^{129} appears to be released in a totally different way from the other xenon isotopes, it is found that if part of the I^{127} in meteorites is converted to Xe^{128} by thermal neutron irradiation, the Xe^{128*} so produced shows a release pattern remarkably similar to that of the anomalous Xe^{129R} [9]. This implies that the Xe^{129R} resides in the same mineral sites as the I^{127} as it would if it were produced by the *in situ* decay of I^{129}. Since these initial experiments, work has been carried out on irradiated samples of Richardton [10], Renazzo [6], Bruderheim and a Bruderheim chondrule [4], Pantar (light and dark) and Bjurböle [11].

In the cases of the Bruderheim chondrule, Pantar dark and Bjurböle, the correlations between Xe^{129} and Xe^{132} release are particularly striking. In most cases no correlation is observed at low temperatures, a feature which could easily arise either through prior loss of Xe^{129} or recent contamination of the meteorites by trace amounts of iodine. In all cases there is a good correlation if only the high temperature xenon fractions are considered, a fact which implies an I^{127} to Xe^{129R} correlation, as expected if I^{127} and I^{129} were incorporated together into meteorites. If iodine and tellurium are concentrated in the same minerals, which Goles and Anders [12] suggest, the correlations are also consistent with a Xe^{129}-tellurium correlation, as might be expected if I^{129} derived partly from neutron capture in Te^{128}, as proposed by Fowler et al. [13]. Whatever the origin of the I^{129}, the observed correlations support *in situ* decay of I^{129}. On the incomplete mixing hypothesis, no correlation is expected between the pile-produced Xe^{128*} and the Xe^{129}, just as there is no correlation between the Xe^{128*} and Xe^{132} release.

We have just referred to $I^{127}-Xe^{129R}$ correlations in individual meteorites. The *in situ* decay hypothesis is strengthened even more when one considers all of the meteorites analyzed. Of the meteorites listed above, Renazzo, Bruderheim, the Bruderheim chondrule, Bjurböle, Pantar dark and Pantar light were all irradiated together (but in separate sealed quartz ampules), and thus received essentially the same flux of neutrons. It is found that all six meteorites show roughly similar correlations and the ratios of Xe^{129R} to I^{127} calculated from the high temperature ($\geqq 900$ °C) xenon fractions for five of the six samples are the same within $\pm 17\%$. Such a spread would correspond on the *in situ* decay hypothesis to a range of formation intervals for these meteorites of 7 million years. The sixth sample, Bruderheim, has a significantly higher Xe^{129*}/I^{127} ratio, which may reflect a shorter formation interval; but even including this sample the spread in the ratio is about a factor of 2 corresponding to a 14 million-year range information intervals. We do not see any explanation for this relative constancy of the anomalous Xe^{129R}/I^{127} ratio on the incomplete mixing hypothesis. In fact, we would expect the ratio to vary at least as much as the Xe^{132}/I^{127} ratio in these meteorites, that is, by a factor of 6 or so. We are led to conclude that the evidence available strongly supports an *in situ* decay origin of the special Xe^{129} anomaly in meteorites.

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