ISOTOPIC FRACTIONATION OF Kr and Xe IMPLANTED IN SOLIDS AT VERY LOW ENERGIES; T. J. Bernatowicz, B. E. Hagee and A. J. Fahey, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130 USA.

Previous investigators [1,2] have shown that carbonaceous material synthesized in electrical discharges can efficiently trap Kr and Xe, and that the trapping results in strong (~ 1 %/amu) isotopic fractionation of these gases. Bernatowicz and Fahey [3] subsequently demonstrated that isotopically fractionated Xe was trapped in pyrex when this material was subjected to electrical discharges in rarefied air, and concluded that in their experiments and in the previous synthesis experiments the observed isotopic fractionations were due to very low energy (tens to hundreds of eV) ion implantation. To further test this hypothesis, we have implanted Kr and Xe in tungsten at very low energies (50-500 eV) using a modified ion gauge, and measured the isotopic compositions of both the trapped and residual gas phases. The implantations were carried out for different times (5-41 hour) to vary the amount of gas trapped [4].

We determined that the implantation efficiency for the lowest energies (50-100 eV) is quite small, of the order 10^{-4}, but implantations carried out for several hours or more lead to measurable retention of gas in the target. Diffusional release of the implanted gas at room temperature was also observed, although at slightly higher energies (250-500 eV), this does not appear to be important. From the observation of an inverse dependence of the amount of Kr and Xe trapped on total gas pressure, we inferred that sputtering of implanted atoms by gas phase ions is an important gas release mechanism in these experiments. Implantation dominates the gas behavior initially, but with increasing implantation time a situation of steady state obtains in which the amount of gas trapped reaches a constant value due to a balance of implantation and gas release. In these experiments Xe was trapped more efficiently than Kr, presumably due greater backscattering of Kr from the W target.

In Figure 1 we show an example of the observed isotopic compositions of Xe in one of the 50 eV implantation experiments, displayed as per mil deviations, Δ, from unfractionated Xe composition. The positive mass fractionation of the trapped gas and negative fractionation of the residual gas is characteristic of the behavior of Kr and Xe in these experiments. The overall fractionations $\Delta/\delta m$ are derived by least-squares analysis of the isotopic data, and in Figure 2 we show the $\Delta/\delta m$ values as a function of trapped gas fraction for all of our 50 eV and 100 eV implantations, normalized to mass so that Kr and Xe may be plotted in the same figure. It is clear that low energy implantation leads to significant isotopic fractionation of the implanted gas. We also compare the data with two limiting models: one in which there is no release of implanted gas (curves), and another in which a steady state exists between gas trapping and release (dashed lines). Either of these models implies that the overall mass dependence for the implantation process is near m^1 ($n = 1$), so that at low trapping levels the fractionation scales approximately as $\delta m/m$ for both Kr and Xe. The corresponding residual gas fractionations (not shown) at low trapping levels are small, as expected from mass balance considerations. We infer that the observed fractionation arises in a combination of implantation, sputtering of gas from the surface and diffusion, all of which are mass dependent mechanisms.

These results lead to the conclusion that Kr and Xe may be quantitatively trapped even at energies 2 to 3 orders of magnitude lower than in the solar wind (~ 1 keV/amu). If such low energies were available in the early solar system, this mechanism may have made important contributions to the acquisition of fractionated noble gases by solids.

[1] Frick U. et al. (1979) *Proc. Lunar Planet. Sci. Conf. 10th*, 1961-1973; [2] Dziczkaniec et al. (1981) *Lunar Planet. Sci. XII*, 246-248.; [3] Bernatowicz T. and Fahey A. (1986) *Geochim. Cosmochim. Acta* **50**, 445-452; [4] Bernatowicz T. and Hagee B. (1987) *Geochim. Cosmochim. Acta*, (submitted).

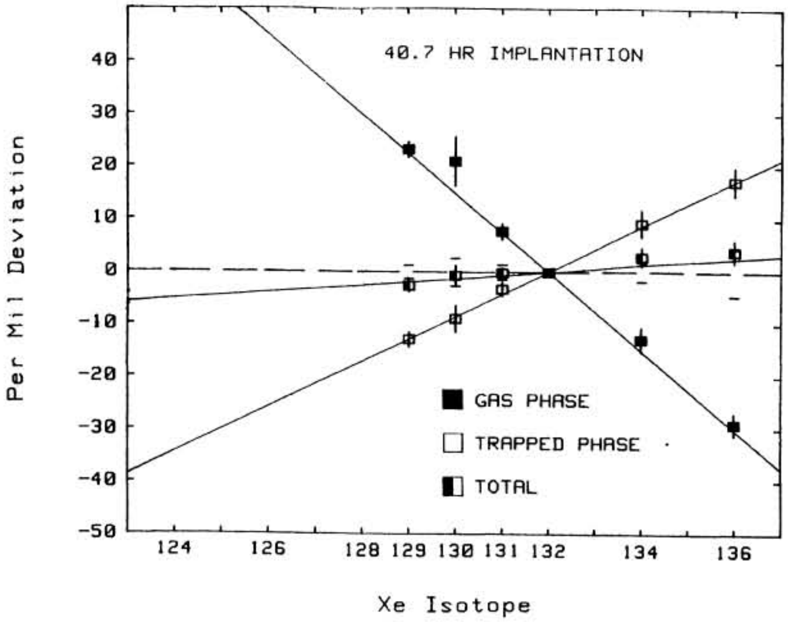

Figure 1: Xe isotopic compositions for 40.7 hour 50 eV implantation, compared with unfractionated air Xe.

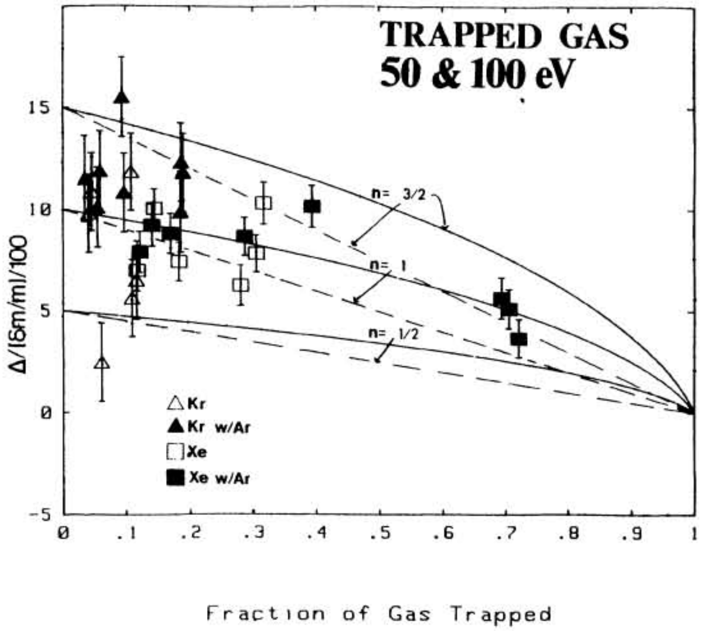

Figure 2: Overall isotopic fractionation Δ/δm of Kr and Xe trapped in tungsten at 50 eV and 100 eV, as a function of total available gas trapped. The data are compared with theoretical predictions of fractionation for implantation alone (curves) and for implantation in steady state with gas release (dashed lines). Predictions for various overall mass dependences m^n are shown. Data and theoretical curves are normalized to m/100. Boxes are for Xe and triangles for Kr. Closed symbols are for runs in which Ar dominated the gas phase total pressure; open symbols are for lower pressures where only contaminant gases were present with Kr and Xe. See text for discussion.