

ON THE ORIGIN OF PLANETARY NOBLE GASES: Gary R. Huss, and E. Calvin Alexander, Jr.,
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Noble gases in meteorites fall into two broad classes: noble gases originating from in situ nuclear processes; and trapped noble gases. Trapped noble gases also contain two components: Solar noble gases, which were implanted into meteoritic material from solar wind; and Planetary noble gases (1).

Planetary noble gases are present in varying amounts in all chondritic meteorites (1). The planetary abundance pattern is characterized by a strong fractionation compared to solar system abundances, with light elements more strongly depleted than heavy elements (Fig. a). Planetary noble gases in meteorites are carried by HF-HCl insoluble phases, mostly carbonaceous material, which comprise a very small fraction of the bulk meteorites (2,3,4,5,6,12). Planetary noble gases consist of several separable components, including Ne-E, s-process Xe, CCFXe, and normal planetary gases. Normal planetary gas (60-90% of the planetary gas) is located in the HNO₃ soluble portion of the acid residues (2,3,4,5,6,12).

Average noble gas abundance patterns for three meteorite classes are shown in: Fig. a for bulk acid residues; Fig. b for acid residues treated with fuming HNO₃, and Fig. c for the HNO₃ soluble fraction as determined by difference (3,4,5). The component labeled "exotic planetary" (Fig. b) contains only about 5% of the total noble gases, and displays exotic isotopic compositions such as CCFXe. Comparison of the elemental patterns and isotopic compositions of the noble gas components, as well as the temperature release profiles (4,7), indicates that "planetary Ne" (Neon-A), and most of the He, are associated with CCFXe, not with normal planetary noble gases. The isotopic characteristics of gases in the exotic planetary component, as well as those of the "normal planetary" component (Fig. c), are listed in Table 1.

Several components of the planetary noble gases are now believed to be pre-solar (e.g. Ne-E, s-process Xe, CCFXe). The direct experimental correlation between CCFXe and the other noble gases in the exotic component suggests a pre-solar origin for the entire exotic component. On the other hand, the normal planetary gases are thought to be of solar system origin because: A) the isotopic compositions of the heavy gases are normal (i.e. similar to Solar gases), B) the composition is ubiquitous in solar system objects, and C) the normal planetary gases were not thought to be associated with other pre-solar compositions (2). The purpose of this abstract is to suggest that available evidence is compatible with a pre-solar origin of the "normal planetary" component.

The bulk of the noble gases in the pre-solar molecular cloud should comprise an isotopically homogeneous reservoir. Isotopic homogeneity is expected because noble gases spend a large portion of their interstellar lives in the gas phase and should be thoroughly mixed by turbulence in interstellar space. In a cold molecular cloud most gaseous elements condense onto grain surfaces as icy mantles (8,9). Xe, Kr, and Ar should be quantitatively condensed in these icy mantles, but all of the He and much of the Ne should remain in the gas phase (9). Noble gases in icy mantles should be elementally as well as isotopically normal.

Ion-molecule reactions during periodic evaporation and recondensation of icy grain mantles in the molecular cloud resulted in production of refractory carbonaceous mantles on dust grains (8). The quantitative presence of the heavy noble gases in the mantles during production of the organic molecules provided a setting for efficient trapping of the gases into the carbonaceous material.

Implications: The similarity of the elemental fractionation patterns in the heavy noble gases of the exotic planetary and normal planetary components, as well as in atmospheric gases trapped in terrestrial kerogen (10) and in noble gases trapped in soot (11), suggests that the fractionation is a property of carbonaceous material. The elemental fractionation was thus not mass fractionation, but resulted from variations in physical chemistry. We therefore plotted the elemental compositions against polarizability, a physical parameter, rather than mass. If the elemental fractionation was a function of physical chemistry rather than mass, no isotopic fractionation would be expected during trapping. The isotopic composition of normal planetary noble gases should be the same as that of the sun because both sampled the same well mixed noble gas reservoir. The extreme depletion of He and Ne in normal compared to exotic planetary gas (Figs. b,c) results because He and Ne were largely absent from grain surfaces during formation of carbonaceous mantles.

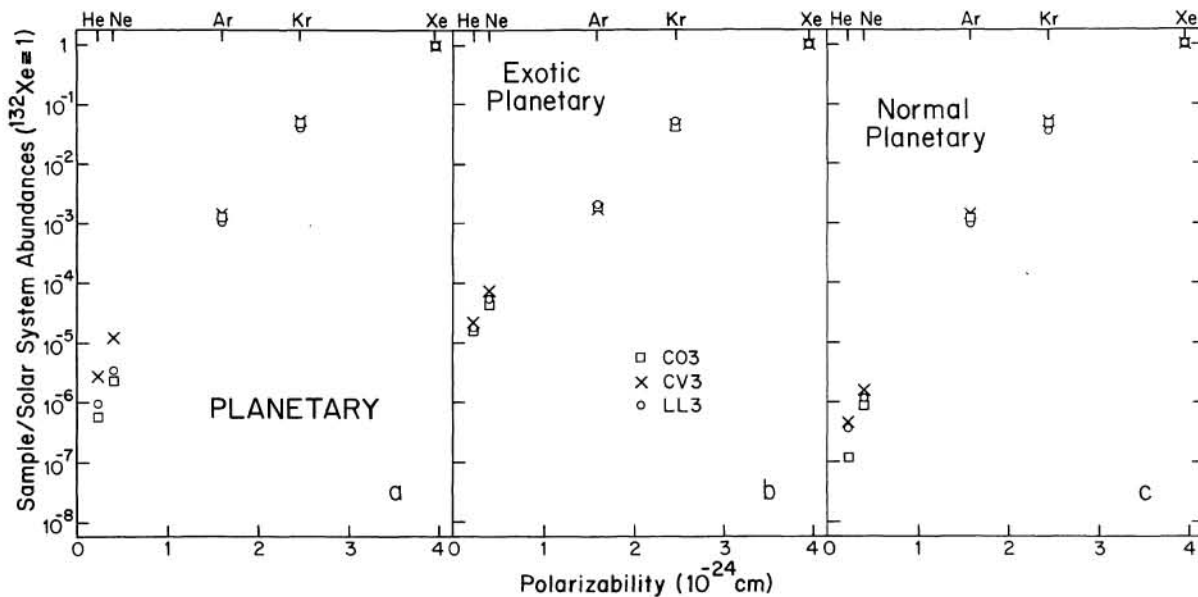
This model explains the preferential trapping of noble gases by the carbonaceous carrier phase and the near absence of trapped noble gases in other meteoritic phases. This model also explains the high noble gas content in the carrier phase, because it formed in an environment with the cosmic complement of heavy noble gases already condensed.

The widespread occurrence of the normal planetary composition does not necessarily imply a solar system origin. The fact that the exotic component is present in most primitive meteorites suggests that widespread incorporation of pre-solar grain mantles is possible. If one abandons the assumption that the solids in the solar system condensed from a hot gaseous nebula, the widespread incorporation of pre-solar grain mantles is expected.

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Table 1. Isotopic Characteristics of Components of Planetary Noble Gases

	³ He/ ⁴ He	²⁰ Ne/ ²² Ne	³⁶ Ar/ ³⁸ Ar	Krypton	Xenon
Exotic Planetary	1.47x10 ⁻⁴ (12)	≈8.5 (3,4,5,7)	≈5.2 (3,4,5)	Enriched in heavy isotopes	Enriched in light and heavy isotopes
Normal Planetary	1.47x10 ⁻⁴ (12)	10.4±0.4 (3,4,7)	≥5.34 (3,4,5)	normal	normal



Elemental Fractionation Patterns in Components of Planetary Noble Gases