ADSORPTION OF NEBULAR GASES ON PROTOPLANETARY CORES. R. O. Pepin, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455.

Introduction. Noble gases lighter than Xe in the atmospheres of Earth and Mars and in the carbonaceous chondrites display a relative abundance pattern which appears to be smoothly mass-fractionated with respect to solar elemental abundance ratios, with lighter species progressively more depleted [1-5]. The similarity of this pattern to those obtained in laboratory measurements of noble gases adsorption on a variety of mineral and carbonaceous materials [1-4] suggests that these planetary and meteoritic noble gases may derive from adsorption of ambient solar nebula volatiles onto nebular dust [1-6]. In such models these carrier dust grains later accreted into planets and meteorite parent bodies and, on planets, their adsorbed gases were subsequently outgassed from planetary interiors into present-day atmospheres.

There are, however, a number of problems with scenarios of this kind: (1) Venus has a quite different (much more solar-like) Ar/Kr ratio, arguing against a common, dominant carrier for all three terrestrial planets [5,6]; (2) Xe/Kr in planetary atmospheres falls below the range of laboratory adsorption data for this ratio, suggesting that the evolutionary histories of planetary Xe on the one hand, and the lighter noble gases on the other, were somehow decoupled [5]; (3) Since neither adsorption nor outgassing is likely to fractionate isotopes, one would expect planetary atmospheric noble gases derived from the nebula by just these processes alone to display solar isotopic signatures —but they do not [5]; (4) Gas/dust partition coefficients k_M (grams of adsorbed noble gas M per gram dust per atmosphere partial pressure of M in the gas phase) obtained in most laboratory adsorption experiments [1-4] are many orders of magnitude smaller than required to account for the abundances of planetary and meteoritic noble gases, if adsorption on carrier dust occurred in an open, solar-composition nebula at currently estimated total pressures of a few microbars [7]. In what follows we explore one possible solution to the last of these problems; some approaches to the others are discussed in [6].

Adsorption in gravitational condensations of nebular gases. The difficulty, if one accepts the laboratory results as applicable to the natural regime, is that pressures <u>in the nebula itself</u> were simply too low for adsorption on preplanetary nebular dust to supply the noble gas inventories observed in terrestrial planet atmospheres. The situation could have been quite different if adsorption occurred instead on dusty materials at the surfaces of planetary cores that were accreting while the nebula was still present, under ambient temperature conditions such that the cores were able to efficiently condense surrounding nebular gases by gravitational capture. To illustrate how such conditions might have arisen during planetary growth, we consider a purely hypothetical two-stage variant of the Wood and Morfill accretion disk model [7] in which solar growth proceeds at a rate of 10^{-6} solar masses/yr until the sun is 90% formed, and then at 1/8th this rate until it is fully accreted and the disk dissipates at ~1.7×10^6 years (Fig. 1, top). Planetary accumulations along the Wetherill accretion curves [8], arbitrarily assumed to initiate 10^5 yrs prior to the decrease in solar growth rate, are shown in the same panel. Corresponding nebular pressures p_n and temperatures T_n at the present-day radial distances of Venus, Earth, and Mars, calculated from the Wood-Morfill equations, are plotted in the middle panel of Fig. 1. Temperatures at these distances are ~320K, 200K, and 105K respectively in the terminal solar accretion stage, and during this stage (shaded area of Fig. 1) the cores of Venus and Earth grow from approximately lunar to martian mass, and the Mars core from ~1 to 2.5 lunar masses. The resulting values for surface pressures p_s on these cores due to gravitationally captured nebular gases, given approximately by Hunten's [9] barometric law for isothermal condensation under these conditions of slow capture and relatively low final pressures (10's and 100's of millibars for Venus and Mars, 10's of bars for Earth), are shown along with Hunten's equation in the lower panel of Fig. 1. Although none of these captured atmospheres are very substantial, they still result in increases of noble gas partial pressures by many orders of magnitude over those in the open nebula, particularly on proto-Earth and proto-Mars, and correspondingly larger abundances of volatiles adsorbed on core surface materials. The point of this exercise is not to argue for the validity of this particular, arbitrary variant of the Wood-Morfill accretion disk model; it is rather to illustrate effects of similar low-temperature conditions, should they have occurred at certain stages of disk evolution and planetary accumulation.

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Figure 1

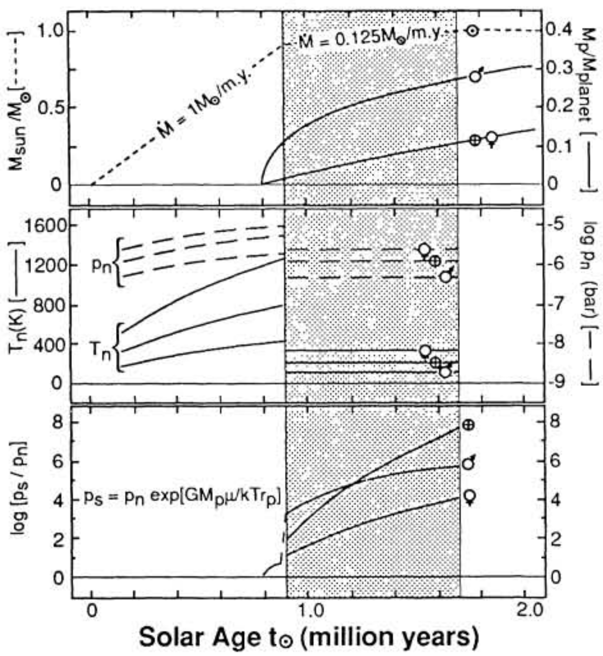
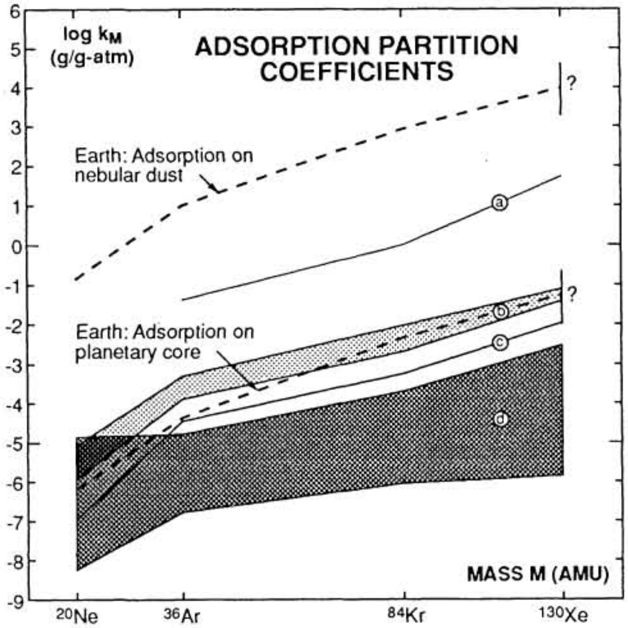


Figure 2



Adsorption partition coefficients. For given k_M and partial pressure of M in p_s, the actual abundance of each noble gas species M adsorbed on planetary core materials is readily calculated by integrating over the planetary growth and p_s curves in Fig. 1. To determine what the values of k_M would have to have been to account for present-day atmospheric inventories requires an estimate of outgassed abundances and an assumed efficiency of degassing from planetary cores to surfaces. In a recent model by the author [6], isotopically solar outgassed Kr, Ar and Ne on Earth are partially lost from the planet by hydrodynamic escape [10], with concurrent fractionation of residual inventories to their present isotopic compositions (thus addressing problem (3) above). These losses require initially outgassed abundances to be higher (by up to a factor 4 for Ne) than contemporary atmospheric inventories, and lead, assuming 50% degassing efficiency, to the "planetary core" adsorption partition coefficients plotted in Fig. 2. These are seen to fall well within the (rather broad) range of experimental k_M values represented by data fields (a) - (d) [from references 1-4 respectively]. Exactly the same values can account for these species on Mars, for ~30% degassing from its core. The much higher k_M values required for adsorption at the low pressure of the open nebula, on preplanetary dust comprising 100% of the present Earth, are shown for comparison in the upper part of Fig. 2. Core adsorption may therefore be a plausible way, nebular environment permitting, to obviate this k_M problem with the adsorption hypothesis.

References. [1] Fanale F. P. and W. A. Cannon (1972), *GCA* **36**, 319-328; [2] Niemeyer S. and K. Marti (1981), *PLPSC 12th*, 1177-1188; [3] Frick U. et al. (1979), *PLPSC 10th*, 1961-1973; [4] Yang J. et al. (1982), *GCA* **46**, 841-860; Yang J. and E. Anders (1982), *GCA* **46**, 861-875 and GCA **46**, 877-892; Wacker J. F. et al. (1985), *GCA* **49**, 1035-1048; Zadnik M. G. et al. (1985), *GCA* **49**, 1049-1059; Wacker J. F. (1989), *GCA* **53**, 1421-1433; [5] Pepin R. O. (1989), in *Origin and Evolution of Planetary and Satellite Atmospheres*, pp. 291-305, Univ. of Arizona Press, Tucson; [6] Pepin R. O. (1990), On the Origin and Evolution of Terrestrial Planet Atmospheres and Meteoritic Volatiles, to be published in *Icarus*; [7] Wood J. A. and G. E. Morfill (1988), in *Meteorites and the Early Solar System*, pp. 329-347, Univ. of Arizona Press, Tucson; [8] Wetherill G. W. (1986), in *Origin of the Moon*, pp. 519-550, Lunar and Planetary Institute, Houston; [9] Hunten D. M. (1979), *Icarus* **37**, 113-123; [10] Hunten D. M. et al. (1987), *Icarus* **69**, 532-549; Zahnle K. J. and J. F. Kasting (1986), *Icarus* **68**, 462-480; Hunten D. M. et al. (1988), in *Meteorites and the Early Solar System*, pp. 565-591, Univ. of Arizona Press, Tucson.