INTRODUCTION: Carbonaceous chondrites contain trapped noble gases that are present in different carriers. The most abundant carrier, known as "planetary" - also referred to as "Q" or "P1" [1] - is formed of carbonaceous material, the nature of which remains ill-defined. It appears to be mainly composed of aromatic moieties linked by short aliphatic chains for which the best terrestrial analog may be kerogen [2]. Trapped noble gases in chondrites (Ar, Kr, Xe) share common characteristics. First, they are tightly bound (release temperature up to 1000°C) in the carbonaceous residue obtained after acidic attack (HF, HCl) of chondrites [3]. Second, these gases are easily released upon oxidation (using HNO3) which suggests that they may be located near the external surfaces of the organic materials. [3]. Third, the noble gas elemental abundances patterns are strongly fractionated relative to Solar with marked depletions of the lighter noble gases relative to the heavy ones. The mechanism(s) leading to the trapping of noble gases in carbonaceous carriers remains poorly understood. The elemental abundances of noble gases in Q from different types of meteorites exhibit comparable fractionated pattern, which supports the assumption that one single Q reservoir existed during the accretion of planetary bodies [1] or that common processing determined the characteristics of Q.

Gas adsorption could represent one of the mechanisms leading to noble-gas concentration prior to their trapping. Previous adsorption experiments managed to reproduce the requested elemental abundance pattern but lead to very low amounts of adsorbed noble gases [4].

Here we report the results of an experiment designed to study the adsorption of Ar, Kr and of Xe at very low relative pressure, i.e. in pressure conditions more relevant than those used in [4] to the processes that could have occurred in the solar nebula. In addition, such experiments allow us to probe the most energetic surface sites of the materials investigated, i.e. the surface sites that are most likely playing a role in noble gas concentration. Low pressure adsorption isotherms were obtained for different mineral phases known to be present in Orgueil: ferrihydrite, montmorillonite and terrestrial type III kerogen (Q analog) [5]. Here we report the kerogen results as analogs for Q.

Analytical: Adsorption isotherms of Ar and Kr at 77K and Xe at 195K were determined using a quasi-equilibrium adsorption device [6] equipped with three precision pressure gauges (0-0.1 Torr; 0-10 Torr and 0-1000 Torr Baratron) allowing accurate measurements in the very low pressure range. In this set-up, the adsorbate is introduced through a calibrated microleak at a slow enough flow rate to ensure equilibrium all along the adsorption isotherm [6]. Around 1g of sample was outgassed overnight at room temperature under a residual pressure of 10⁻⁶ Torr. Surface areas were determined using the classical BET treatment, which allows to determine for each equilibrium pressure the surface coverage θ defined as V/Vm where Vm is the adsorbed volume at the monolayer derived from the BET equation. At very low pressure the adsorption isotherm is governed by Henry's law: θ = H*P (1) with:

\[ H = \frac{\left[\frac{kT}{2\pi n}\right]^\frac{3}{2} e^{\varphi_a/a}}{2\pi n V^2} \]  (2)

where k is Boltzmann's constant, \( V \) the average vibrational frequency of the adsorbed molecule and \( \varphi_a \), the energy of the normal adsorbate-adsorbent bond.

As \( P_0 \) can be written as \( \frac{\left[2\pi n\right]^\frac{3}{2} e^{\varphi_0/a}}{\left[kT\right]^\frac{3}{2}} \), when plotting θ as a function of the relative pressure P/P₀, equation (1) transforms into N= \( \frac{H'}{P_0} \) with \( H' = e^{\left(\varphi_a - \varphi_0\right)/kT} \) (3).

RESULTS: The surface area of the studied kerogen is low around 4 m²/g. For each of the three adsorbates, the isotherms exhibit at low pressure (P/P₀ ≤ 10⁻⁴), a linear shape with correlation coefficients > 0.98, allowing a reliable determination of (\( \varphi_a-\varphi_0 \)) (Table1).

<table>
<thead>
<tr>
<th>(( \varphi_a-\varphi_0 )) (Joules)</th>
<th>Ar</th>
<th>Kr</th>
<th>Xe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerogen</td>
<td>1.13x10⁻²⁰</td>
<td>9.53x10⁻²¹</td>
<td>9.57x10⁻²¹</td>
</tr>
</tbody>
</table>

Table 1: Adsorbate-adsorbent interaction parameters for heavy noble gases on kerogen.
The interaction parameters for Kr and Xe are equal whereas that for Ar is slightly higher. Such a difference could be related to the lower size of argon which may have access to smaller pores in the structure of kerogen.

Using equation (3) and data displayed in Table 1, the value of $H'$ can be calculated for any temperature between 80K and 150K. Using the partial pressures of noble gases estimated for the solar nebula [7], it is then possible using equation (3) to evaluate the amount of noble gas adsorbed on kerogen as a function of temperature. Figure 1 displays the amount of noble gases trapped in Murchinson and Dimmitt with the calculated amounts of noble gas adsorbed on kerogen.

**Discussion:** If one considers only adsorption on kerogen, it appears that the quantities of Ar and Kr adsorbed at 77K are several orders of magnitude higher than the noble gas content in meteorites. This is even more striking for xenon. For temperatures around 90-95K, adsorbed amounts are of the same order of magnitude as the abundance pattern of meteorites. For higher temperatures, the adsorbed quantities fall below the gas content of meteorites. It must be pointed out that our calculation focusing on kerogen only, strongly underestimates the amount of gas adsorbed on meteorites. Indeed, ferrhydrite and to a lesser extent, montmorillonite have high adsorption capacities due to their elevated specific surface area (400 m$^2$/g for ferrhydrite and 70 m$^2$/g for montmorillonite) and may then play an important role in the preconcentration of noble gases by adsorption.

These results suggest that for environmental temperatures $> 100$K, adsorption processes can not be invoked solely for accounting the amount of noble gases in Q. For lower temperatures, as predicted by some astrophysical models (80-100K at 3 AU at the end of collapse of the solar nebula (its hottest stage) [7,9]), noble gas adsorption on meteoritic material could well be responsible for the concentration and subsequent trapping of noble gases in Q. Furthermore, irreversible Kr and Xe adsorption has been observed for some forms of carbon and anorthosite [4,10] which may represent an additional cause for surface-correlation of trapped gases in the Q-phase.


![Figure 1: Elemental fractionation patterns for kerogen at different temperature compared to Q phase pattern. The values for Q are the element concentration in the acid-resistant meteoritic residues [3,8].](image-url)