

OXYGEN FUGACITY VARIATIONS WITHIN AND AMONG METEORITE PARENT BODIES. Dante S. Lauretta, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85745. lauretta@lpl.arizona.edu

Introduction: Meteorites consist essentially of the silicate minerals olivine and pyroxene, iron-nickel alloys, sulfide minerals, and an enormous variety of accessory minerals. Most meteorites originate from the asteroid belt. The geologic diversity of asteroids and other rocky bodies of the solar system are displayed in the enormous variety of textures and mineralogies observed in meteorites.

Different classes of chondritic meteorites are discernable by their bulk chemistry, mainly the oxidation state and distribution of iron. Chondritic meteorite classes are subdivided by petrologic type. These designations reflect the extent to which these materials were altered by parent-body processes. Type-3 chondrites are the most primitive and have experienced minimal alteration. Silicate compositions in type-3 chondrites span a wide range of Fe-contents, reflecting a wide range of oxidation states for the formation of their varied components.

Type-1 and type-2 chondrites have experienced aqueous alteration while types 4-6 have experienced varying degrees of thermal metamorphism. Thermal metamorphism results in significant changes to meteorite textures and mineralogy. In particular, the compositions of silicate minerals become increasingly homogenous throughout the sample. Because of their varied oxidation states, silicate compositions in equilibrated chondrites vary among the different classes.

Oxygen Fugacity – An Introduction:

In many gaseous systems it is appropriate to assume that gases follow an ideal equation of state, known as the ideal gas law:

$$P \cdot V = n \cdot R \cdot T$$

P = pressure, V = volume, n = the number of moles, R is the gas constant, $82.06 \text{ cm}^3 \text{ atm mol}^{-1} \text{ K}^{-1}$, and T = temperature. However, in many systems, interactions among gas molecules result in deviations from ideality. Thus, it is often necessary to apply a correction to adjust for non-ideal behavior. A common way to correct for the effects of non-ideality is replace the pressure (P) with fugacity (f). The fugacity of a gas is related to the pressure through:

$$f_i = \gamma_i \cdot P_i$$

γ_i is the fugacity coefficient and P_i is the partial pressure of component i in the gas. For an ideal gas, $\gamma_i = 1$.

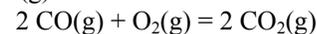
Whenever dealing with the chemical potential of a component in a gas phase, or a component that may be in a gas phase, fugacity can be used to account for the variation in the chemical potential of interest. More

precisely, since chemical potential is a quantitative measure of the reactivity of a component in a phase, fugacity is a measure of how much the chemical potential of the component in the gas deviates from the chemical potential of the pure substance in its standard state, due to changes in P and the mole fraction of the component. Therefore, f_{O_2} is a function of the mole fraction of the component in the gas phase and of the total pressure of the gas phase. A high f_{O_2} means a high chemical potential of oxygen, which indicates an "oxidized" system.

Oxygen Fugacity – Buffers:

Oxygen fugacity is a master variable used to describe geologic environments. Reducing conditions are "low f_{O_2} ", and oxidizing conditions are "high f_{O_2} ". However, thermodynamics is quantitative and, therefore, f_{O_2} must be well defined. In practice this is done by reference to well-known f_{O_2} buffers.

In the solar nebula, the most abundant O-bearing gaseous molecules were $H_2O(g)$, $CO(g)$, and $CO_2(g)$, assuming that chemical equilibrium was achieved. The f_{O_2} in such a system is controlled by the relative abundances of these molecules. For example, the f_{O_2} in a nebular system can be calculated using the ratio of $CO_2(g)$ to $CO(g)$ via:

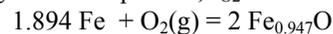


Using the equilibrium constant for this reaction (K_1), the f_{O_2} is expressed:

$$f_{O_2} = \left(\frac{f_{CO_2}}{f_{CO}} \right)^2 \cdot \frac{1}{K_1}$$

Since gaseous molecules dominated the inner region of the solar system during the formation of meteoritic components, the variation in oxidation states observed in unequilibrated chondrites suggests that either: 1) these components formed in separate regions of the solar nebula or 2) these components did not equilibrate with the nebular gases.

On asteroids, f_{O_2} may have been controlled by solid mineral buffers. For example, when both iron metal and the iron oxide wustite ($Fe_{0.947}O$) are present as pure homogenous compounds, f_{O_2} is buffered by:



In this case, f_{O_2} is expressed:

$$f_{O_2} = \frac{1}{K_2}$$

Thus, the oxidation states of equilibrated chondrites are a reflection of the oxygen fugacity established on the parent asteroid.