NEW NICKEL VAPOR PRESSURE MEASUREMENTS: POSSIBLE IMPLICATIONS FOR NEBULAR CONDENSATES 1,2 N. M. Johnson, 3 A. Meibom, 4,5 F. T. Ferguson, and 1,5 J. A. Nuth, III, 1 NASA-Goddard Space Flight Center, Astrochemistry Branch, Code 691, Greenbelt, MD 20771, 2National Research Council Research Associate, Geological and Environmental Sciences, 320 Lomita Mall, Stanford University, CA 94305, 3Department of Chemistry, Catholic University of America, Washington, DC.

Introduction: Temperatures high enough to vaporize even refractory solids existed in the midplane of the solar nebula during its earliest evolutionary stages and played an important role in the processing of materials that went into the formation of the inner planets and asteroids. A variety of such high-T materials have been identified in primitive chondritic meteorites [1]. These include chemically zoned FeNi metal grains that are generally believed to have formed directly by gas-solid condensation from a gas of approximately solar composition (Fig. 1) [2,3,4,5]. These FeNi particles provide important information about the timescales of formation and physical transport mechanisms in the nebula, as well as formation temperature, pressure and gas chemistry [2,3,4,5]. Currently, however, the interpretation of the chemical signatures in these FeNi particles rests on less than perfect information about the condensation sequence of siderophile elements. For example, if not all, of the thermodynamic data for the vapor pressures of moderately refractory metals, such as Fe, Ni and Co, do not cover the desired temperature range. As a result, quite large extrapolations are needed. These extrapolations can be complex and uncertain due to factors such as oxygen fugacity or the presence of hydrogen gas [6].

In general, Fe, Ni, and Co show relatively little fractionation relative to each other in processed chondritic metals [7]. Although their vapor pressures are quite similar, they do diverge enough so that significant differences in condensation temperature are predicted (e.g., see ref. [4]) and are expected to be apparent in pristine nebula condensates. In order to make such predictions more accurate we need to have precise vapor pressure measurements relevant to the P-T regimes encountered in the solar nebula.

Recently, we have reported the vapor pressures of Fe and Co to temperatures near 2000 K under low total pressure conditions (less than 0.01 Pa) [8,9]. The resulting vapor pressure lines are shown in Fig. 2. Not surprisingly, the Fe and Co vapor pressure lines run roughly parallel to each other with cobalt having a lower vapor pressure than iron. Nickel was also measured and initial results presented [10]. However, additional and ongoing experiments suggest that the relation of nickel vapor to iron and cobalt may be a compelling indicator of formation temperature.

Experiments: We measure vapor pressure by using a commercial Thermo-Cahn Thermogravimetric system capable of vacuum (P_{TOT} less than 0.01 Pa) operation to 1975 K. This system is capable of measuring mass loss with microgram accuracy provided that the sample plus cell is 100 gram or smaller. We determined the mass loss rate of pure nickel metal under vacuum from 1100 to 1975 K. The metal is placed in a simple effusion cell (constructed of alumina) that contains a small hole for vapor escape. The temperature and mass loss are recorded simultaneously. Over the past year, modifications were made to the setup to increase the signal to noise ratio. Experimental details are given in Ferguson et al. (2004) [8,9].

Results: Our most recent nickel data suggest that the vapor pressure line of nickel crosses that of Co at ~1900 K and that of Fe at ~1750 K such that the vapor pressure of nickel is greater than Co and Fe below these temperatures, respectively (Fig. 2). We are continuing these measurements and will present specific results at this workshop.

Discussion: The chemically zoned FeNi metal particles have Co/Ni ratios that are roughly solar, which is consistent with the interpretation that they represent direct gas-solid condensates from the solar nebula. However, from the outset it was observed that the Co/Ni ratios in the center of the particles were generally higher than predicted by the applied thermodynamic condensation models. This was initially explained as an effect of partial diffusional equilibration of the FeNi particles as they grew in the nebula [11]. The available literature suggested that the diffusion coefficient of Ni in low Ni fcc FeNi alloy was about a factor of three higher than that of Co. Diffusional equilibration would therefore tend to increase the Co/Ni ratio by allowing Ni to diffuse away from the center of the particle faster than Co [12]. However, a more recent determination of the diffusion coefficient of Ni and Co clearly show that these elements diffuse at essentially the same speed and partial diffusional equilibration can therefore not explain the higher than predicted Co/Ni ratios [13]. The vapor pressure data obtained in this study are relevant to this issue. We will address this problem and explore the more general issue of how the new vapor pressure data for Ni, Co and Fe influence the interpretation of the chemical zonation observed in chondritic FeNi metal grains.

Figure 1. a) Electron microprobe traverse across a chemically zoned FeNi metal grain in the QUE 94411 metal-rich chondrite. b) Co and Cr plotted against Ni. There is a strong positive correlation between Co and Ni, in general agreement with thermodynamic calculations of metal condensation from a gas of roughly solar composition at representative nebula pressures (10 Pa) (solid lines and crosses) [4]. Note however, that in the center of the metal particle, the Co/Ni ratio is substantially higher than predicted (not depicted).

Figure 2. Vapor pressure lines of iron, cobalt, and nickel. Note the crossover of nickel line over iron at ~1750 Kelvin and that of cobalt at ~1900 Kelvin.

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