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Experimental study of meteorites and Ca–Al-inclusions

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To study the vaporization processes of the meteorites matter there were carried out some experiments by Knudsen cell method. We vaporized: Murshison chondrite (CM), Krymka chondrite (LL3), chondruls of Saratov chondrites (L4) and two types (A and B) Ca–Al-inclusions (CAI) from Efremovka chondrite (CV).

The Knudsen effusion method was used in combination with the mass spectrometric analysis of the vapor phase (MS-1301 mass spectrometer) [*Semenov et al.,* 1976]. This method allowed us to determine quasi-equilibrium parameters (temperature and partial pressures of the components) in the melt–vapor system within a wide temperature range (up to ~2600°C) and measure the partial pressures of the components at a level of 10^{-7} mm Hg. The upper pressure limit was 10^{-1} to 10^{-2} mm Hg. The experiments were carried out using stepwise heating with a temperature step of ~50°C. The duration of exposure at a temperature step depended on the time needed to record the whole mass spectrum of the sample and was ~15 min. Such stepwise heating conditions allowed maintaining the molecular regime of vapor effusion at a given sample mass and minimized the duration of experiments. The total duration of the experiment from a sample temperature of ~900°C to its complete evaporation was ~5 hr. Noteworthy is the quasi-equilibrium regime of evaporation: on the one hand, conditions approaching melt–vapor equilibrium were attained at any given temperature step in the Knudsen cell, and, on the other hand, continuous vapor flow through the effusion hole occurred in the molecular regime. Since the rate of vapor emission was much lower than the rate of equilibration, the experimental conditions allowed us to consider the evaporation as an equilibrium process, and the emission of vapor during the measurement of the partial pressures of components did not significantly affect the composition of melt and vapor.

The Knudsen cell was heated by an electron beam. Temperature was measured using an optical pyrometer in the the pyrometric hole of the cell, which imitated the conditions of black body radiation. The accuracy of temperature measurement was ±1°C. Partial pressures were determined by the calibration method, which involved sequential measurements of the intensities of ionic currents of a standard and the material of interest occurring in the same cell. Gold was used as a standard. Evaporation was conducted in a tungsten effusion cell. In order to minimize the interaction of tungsten with melt, a 15 mg sample was loaded into a rhenium boat placed on the bottom of the cell. Evaporation in the rhenium container strongly depressed the reducing activity of tungsten, although did not eliminate it completely. This is suggested by the presence of WO_2 and WO_3, as well as Ca and Mg tungstates in the vapor.

Mass spectrometric analysis showed that the melt evaporation was accompanied by the dissociation of oxide components. The vapors contained metallized forms (K, Na, Fe, Mg, Ca, and Al), suboxides, oxides (SiO, TiO, TiO_2, AlO, Al_2O, and Al_2O_2), and atomic and molecular oxygen (O and O_2). The measurement of the partial pressures of these species allowed us to calculate their evaporation rates using the Hertz–Knudsen equation. In turn, the evaporation rates were used to determine the compositions of residual melts and vapors at various temperatures and evaporation mass losses. Temperature and mass losses are are interrelated during evaporation, but in a real process, mass loss is a rather complicated function depending on the evaporation rate of particular components at a given temperature and duration of evaporation.

The experimental results on the vaporization of Murshison chondrite, Krymka chondrite, chondruls of Saratov chondrites have showed that the main characteristic of vaporization namely temperature successiveness of the component vaporization was practically identical and it did not differ from famous basalt vaporization data [*Markova et al.,* 1986]. In the fig. 1 the experimental results on the Murshison chondrite vaporization are presented. They showed that at the initial vaporization stages the alkali components were prevailed. The calculation of complimentary vapor composition have showed that at the relatively low temperature (up to 1300°C) the K_2O contents reached 5–10 wt. % and the Na_2O contents up to ~70 wt. %. In the temperature interval 1400–1700°C the Fe vapor was prevailed and reached ~40 wt. %. It is important to note that at the temperature 1800°C and higher the SiO disappeared in the vapor phase while the Al_2O_3 and CaO increased. The Al_2O_3 contents reached 60-65 wt. % at the temperature ~2000°C.

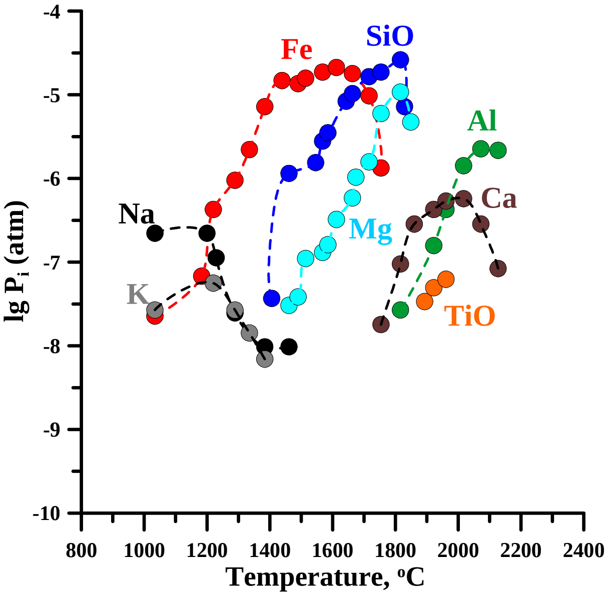

Fig. 1. Partial pressures dependences on temperature for Murchison chondrite vaporization

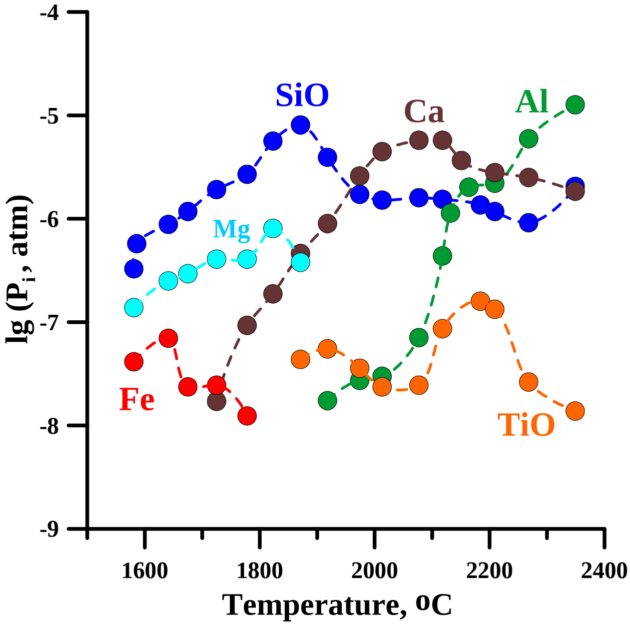

Fig. 2. Partial pressures dependences on temperature for Ca-Al-inclusion vaporization

The essential differences from chondrite vaporization were observed at the vaporization of main types ((A and B) of Ca–Al-inclusions (CAI) from Efremovka chondrite that was shown in fig. 2.

At high temperature fields (2000–-2400°C) one can see the SiO form together with low fugacity components of Ca and Al. Besides the partial pressure value of SiO is rather high (~10^{-6} bar) and it is approximately equal to partial pressures of Ca and Al. This interesting result testify that during CAI vaporization there is unknown factor which controls the SiO_2 vaporization at very high temperatures (>2000°C). The thermodynamic analyses of the conditions of CAI vaporization showed that the vaporization process proceeded at comparatively high oxygen pressure which was in 10 and 100 times higher then oxygen pressure condition at the Murchison and Krymka high temperature vaporization (table). We suggest that just extremely high oxygen partial pressure decreases SiO_2 fugacity during CAI vaporization. This conclusion may be important for CAI genesis as it stresses the specific conditions for CAI vaporization/condensation and hints on its extra solar origin.

Table. O_2 pressure about meteorite and CAI melts

Temperature, °C	Pressure, bar		
	Murchison	Efremovka, Type A	Efremovka, Type B
2020	1.9×10^{-9}		
2072	2.1×10^{-9}		
2130	2.0×10^{-9}	2.7×10^{-8}	4.5×10^{-7}
2180		6.3×10^{-9}	
2205		4.8×10^{-9}	3.7×10^{-7}
2267		7.3×10^{-8}	5.5×10^{-8}
2348		2.5×10^{-7}	

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