

CHONDRULE MAGNETIC PROPERTIES P. J. Wasilewski, and M. V. O'Bryan, Astrochemistry Branch, NASA, Goddard Space Flight Center, Greenbelt, Maryland.

CHONDRULE MAGNETIC PROPERTIES: Magnetically speaking, the chondrules contain a considerable range of ferromagnetic material; the distribution of this material is isotropic to anisotropic with clustering often observed. The NRM (remanence initially measured - 'natural remanence') vector records range from ultra stable to random when demagnetized, and evidence exists for a wide range of magnetic recording scenarios including the need to invoke external fields of at least several milli Tesla (tens of Gauss) to explain the results. The chondrules from each meteorite studied (Allende (C3V), Chainpur (LL3), Bjurböle (L4), and Allegan (H5)) exhibit a wide range of properties attributable to amount and geometric aspects of the ferromagnetic material, and the cooling history (the characteristics of the M shaped diffusion profile in taenite grains). However, the chondrules from each meteorite are different from those coming from another meteorite. These important differences include remanence characteristics that are not easily explained by differences in coercivity spectra (magnetic hardness) or composition of the ferromagnetic fraction.

CHONDRULES FROM THE SAME METEORITE: Regardless of the wide variation in the amount of ferromagnetic material, the chondrules appear to have similar thermomagnetic curves (thermomagnetic curve shapes are mostly defined by tetrataenite and other characteristics of the M shaped diffusion profile - the amount of kamacite is simply background in the thermomagnetic curve). These results suggest, as is often emphasized, that little mixing occurred among chondrules. The thermomagnetic curves for chondrules from one meteorite are characteristically different compared to those from another chondrite.

Saturation remanence (SIRM) demagnetization curves for chondrules are similar or bimodal (essentially reflecting the coercivity spectrum i.e. magnetic hardness due to grain size, tetrataenite and properties of the M shaped profile).

NRM stability to demagnetization is variable, the behavior of the NRM vector direction ranges from ultra stable to random, often these will be definite excursions. This means that during the processing of the chondrules different scenarios for remanence imprinting did indeed exist.

REM values range over 3 orders of magnitude. Some chondrules have REM values >0.1 suggesting that a field of greater than several milli Tesla was required to produce the observed magnetizations. In the terrestrial environment, REM values >0.1 are almost always associated with lightning struck samples.

REM VALUES: REM is the ratio of NRM (remanence initially measured - 'natural remanence') to SIRM (saturation remanence in 1 Tesla field). In Allende chondrules the REM range is 0.0005 (2366) to 0.03 (23); in Allegan the REM range is 0.0004 (2360) to 0.034 (112). The numbers in parentheses are SIRM values ($10^{-4} \text{Am}^2\text{K}^{-1}$). For Allende and Allegan there appears to be a systematic relationship between REM and the SIRM, which is not related to the size of the magnetic carriers. For example, in Allegan, all chondrules have $H_C^{1/2}$ (field at which one half the saturation remanence is demagnetized) values greater than 100 milli Tesla.

The SIRM for Bjurböle chondrules range from 104 to 27470; those with the highest SIRM values ($>10,000$) have the smallest REM values (<0.008) but for other chondrules with SIRM ($<10,000$) the REM values are quite variable ranging from 0.004 to 0.4. REM values for the Chainpur chondrules range from 0.0009 to 0.013 with no relationship to the SIRM.

The SIRM values of a chondrule will not change with time in a museum or laboratory, but the NRM will be subject to change. In handling the chondrules we use copper - Beryllium tweezers which are essentially non magnetic. "Non magnetic" stainless steel tweezers are quite magnetic and can result in contamination of the NRM.

CONCLUDING REMARKS: The preliminary field estimates for chondrules magnetizing environments range from minimal to at least several mT (tens of Gauss). These estimates are based on REM values and the characteristics of the NRM thermal demagnetization compared to SIRM demagnetization. We expect to have the magnetic recording scenarios for chondrules established and petrologic aspects of the ferromagnetic fraction in the chondrules documented. This will enable interpretations appropriate to chondrule formation.