

Laboratory Experiments Simulating the Results of the Magnetic Properties Experiment on Mars Pathfinder.

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Introduction and Results from Mars

As part of the magnetic properties experiments the Pathfinder lander carried two Magnet Arrays (MAs) [1-3]. The goal of the magnetic properties experiment is to determine the specific saturation magnetization σ_s of the particles sticking to the various magnets on Mars, and if possible to identify the mineral - or minerals - responsible for the magnetization of the dust suspended in the martian atmosphere.

A MA consists of two blocks of magnesium, one block carrying two bull's-eye magnets (approximately of Viking strengths) and another block carrying 3 magnets of lower and decreasing strengths, i.e. with decreasing ability to capture and hold magnetic particles. The magnets are numbered 1 through 5 from right to left.

In the Pathfinder mission the dust attracted by the magnets was imaged by the Imager for Mars Pathfinder (IMP) and the pictures transmitted to Earth.



Figure 1. Upper magnet array as imaged on sol 10 (left) and on sol 63 (right)

Figure 1 shows a series of pictures of the upper magnet array imaged at various sols. Bull's-eye patterns, testifying to adhering particles, progressively appear and grow on the different magnets and by sol 68 a bull's-eye pattern is clearly discernable also on magnet no. 4.

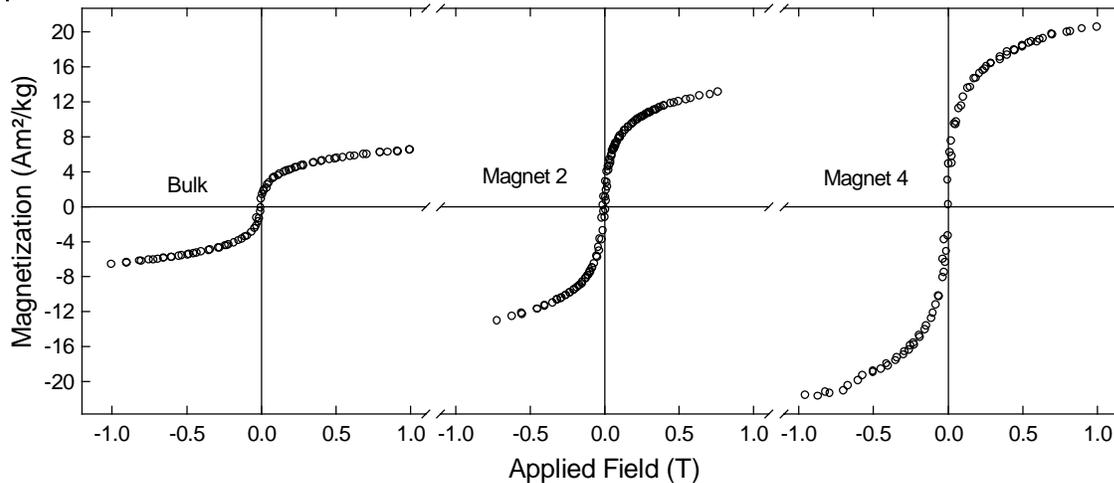


Figure 3. Magnetization curves of thermally decomposed ochre. The three curves show the bulk material and material captured by magnet number 2 and 4

Simulation by Laboratory Experiments

Ochre is a hydrated ferric oxide gel that is produced when Fe^{2+} dissolved in water oxidizes rapidly. The ochre used in this study was obtained from a water processing plant, Lejre, Denmark, and it is composed of ferrihydrite (approx. formula $\text{Fe}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$) with ~4 % by weight of organic carbon and trace amounts of minor elements. A sample of ochre was heated in air at 500°C for 24 hours. Thermally decomposed ochre is not considered as a Mars sample analogue because it consists of pure iron oxides and therefore does not have the elemental composition of the martian dust and soils. However, due to the fact that it is very fine grained, and the fact that heating at various temperatures can control its magnetic properties, it is a useful magnetic analogue to the dust on Mars.



Figure 2. Thermally decomposed ochre blown onto a magnet array.

Figure 2 shows a sample of thermally decomposed ochre blown onto a magnet array. The heated ochre sticks to 4 magnets, approximately as the dust on Mars sticks to the Pathfinder MA.

We have measured the magnetization as a function of the applied field B for the bulk of the decomposition product and for the dust that is held on the various magnets.

On figure 3 we show the magnetization curve for the bulk sample and for the dust on magnets no. 2 and 4. The saturation magnetization of the bulk sample of the thermally decomposed ochre is $\sigma_s = 5 \text{ Am}^2\text{kg}^{-1}$. The dust on magnet 2 has a saturation magnetization of $\sigma_s = 10 \text{ Am}^2\text{kg}^{-1}$ and that on magnet 4 has $\sigma_s = 17 \text{ Am}^2\text{kg}^{-1}$.

The particles created by the thermal decomposition of the ochre are rather strongly magnetic and the individual particles must have different values of the saturation magnetization. The results of the magnetization measurements of the

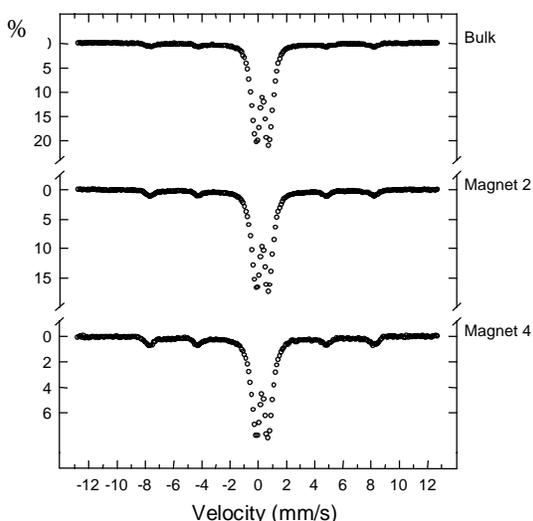


Figure 4. Mössbauer spectra of thermally decomposed ochre.

samples that are held on the different magnets unambiguously show that the different magnets are culling different populations of the grains according to their magnetization.

Figure 4 shows room temperature Mössbauer spectra of the thermally decomposed ochre in the bulk sample and the dust recovered from magnets 2 and 4.

The Mössbauer spectra each consist of a sextet and a doublet that are superimposed on each other showing that at least two iron containing phases are present. The sextet represents a magnetically ordered (possibly ferrimagnetic) component - and it is clear that the spectral area of this component relative to the central doublet increases as we go from the stronger to the weaker magnets. Therefore, the particles in the bulk sample and the particles sticking to the magnets must be composite with a variable content of the magnetic phase. The Mössbauer parameters of the magnetic component (magnetic hyperfine field, $B = 49.5 \text{ T}$, isomer shift, $\delta = 0.35 \text{ mms}^{-1}$, quadrupole shift, $\epsilon \approx 0 \text{ mms}^{-1}$) are close to those of maghemite, but the lines are very broad indicating poor crystallinity or a high concentration of defects.

Figure 4 is thus a confirmation of the fact that the different magnets - in the laboratory - have captured different populations of grains according to their content of maghemite. The grains sticking to magnet 2 contains about 12 % of maghemite and the grains sticking to magnet 4 contains up to about 20 % of maghemite by weight.

Discussion

The fact that we have seen only a weak (if any) pattern on magnet 5 indicates that particles of single-phase maghemite or magnetite is not present as free particles in the airborne martian dust in any appreciable amount.

If we compare the results of this simulation experiment with the experiment on Mars we would conclude that also in the experiment on Mars, the magnetization of the dust on the various magnets could be different. It appears that each magnet has selected a population of particles with slightly different saturation magnetization. If this is true, it implies that the particles suspended in the martian atmosphere are composite and contain varying amounts of a strongly magnetic mineral, most probably maghemite.

These more strongly magnetic particles of course have a higher probability of being caught and held by the magnets. This means that the abundance of such particles in the dust forming the patterns on the magnets is higher than in the dust in general. If our estimate of the average magnetization ($4 \text{ Am}^2\text{kg}^{-1}$ [1]) is correct, then about a third of the Fe_2O_3 in the dust will be in the form of maghemite.

From the pictures from Mars alone, however, it is not possible to decide if the dust on the various magnets has different mineralogical compositions - and thereby different magnetizations. Only the strongest magnets (1 and 2) have attracted sufficient dust for a spectroscopic comparison of the dust on the magnets. The dust on these magnets is - within the precision obtainable - indistinguishable. A comparison of the spectral properties of the dust held on magnet 4 with that on magnet 1 would have been substantially more interesting.

Nevertheless, the results of the simulation experiments support the idea that the dust sticking to the 4 magnets on Mars have different values of the saturation magnetization. This is a major reason why we believe that the particles suspended in the martian atmosphere are composite.

Conclusion

Results of laboratory simulation experiments support the notion that the particles suspended in the martian atmosphere are composite. Most of the particles are somewhat magnetic with a substantial width in the distribution of saturation magnetization of the individual particles. Maghemite, $\gamma\text{-Fe}_2\text{O}_3$, is the most probable mineral responsible for the magnetization of the particles, and the maghemite is present as a component of composite particles of silicate and ferric oxide(s) that constitute the bulk of the martian soil and dust. The iron oxides may be present as a stain on - or as cement between the silicate particles.

References

- [1] S.F. Hviid et al., *Science* 278, 1768-1770, 1997. [2] P. Smith et al., *J. Geophys. Res.* 102, 4003-4025, 1997. [3] H.P. Gunnlaugsson et al., *Space Sci.* (in print).