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Tetrataenite in Metallic Grains of the Antarctic L6 Chondrite Alha 76009

by

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Mössbauer, X-ray diffraction and electron microscopy studies revealed that segregation and ordering occurred in the metal particles of the Antarctic L6 chondrite Alha 76009. The ordered crystal structure of AuCu type (tetrataenite) was detected coexisting with the disordered 50-50 taenite.

Key-words: Tetrataenite; Chondrites; Antarctic meteorites.

I. INTRODUCTION

The Fe_{50}-Ni_{50} ordered phase with $L1_0$ superstructure (AuCu) was first produced only by neutron or electron irradiation of the disordered alloy /1,2/, because the diffusion process of the metallic atoms is very slow at the ordering temperature Tc=320° C.

Since 1977 it has been known that an ordered alloy occurs in slow-cooled meteorites that contain taenite (f.c.c. iron-nickel alloy). Some years later this naturally occurring compound was given the name *Tetrataenite* /3/. In many meteorites it is a common accessory mineral and in some it is more abundant than taenite.

The Fe-Ni ordered phase (tetrataenite) has been detected by Mössbauer spectroscopy (MS) and X-ray diffraction (XRD) in the taenite lamellae of octahedrites /4/, Ni-rich ataxites /5/ and metal particles of chondrites /6/ . The identification of the $L1_0$ superstructure in Fe-Ni alloys by MS is based on the fact that the ordered phase exhibits an asymmetric 6-line spectrum due to a quadrupole splitting arising from the non-cubic environment of the atoms in this structure.

The presence of tetrataenite has been investigated in metal particles of the Antarctic L6 chondrite ALHA 76009. This chondrite found in January 1977 in Allan Hills, South Victoria Land, Antarctica /7/, is the largest in size of Antarctic stony meteorites, the total weight being 407.041 kg /8/.

In this paper we report on MS, XRD, Scanning Electron Microscopy (SEM) and magnetic measurements on the ALHA 76009 L6 chondrite.

II. EXPERIMENTAL

The transmission ^{57}Fe Mössbauer spectra were obtained at room temperature (RT) and at 4.2 K using a Co/Rh source in a conventional Mössbauer spectrometer.

The thermomagnetic curves of silicate and metallic phases extracted by a magnet were obatined under 1 Tesla external field in 10^{-4} Pa vacuum.

III. RESULTS AND DISCUSSION

We investigated the presence of tetrataenite in metal particles of ALHA 76009 using magnetically separated fractions that have been purified from troilite and iron silicates.

SEM/EDS Ni mapping clearly showed two different regions: a Ni-rich one with composition of ~ 50% Ni and another one with low Ni composition < 30% Ni. The weak lines of the superstructure $L1_0$ were detected by XRD.

The Mössbauer spectrum of the magnetically enriched sample before chemical treatment is rather complex. Due to the presence of silicates and troilite in the sample only after a complete separation of the metals it is possible to detect the Fe_{50}-Ni_{50} ordered phase (tetrataenite) with $L1_0$ superstructure.

The Mössbauer spectrum at RT of the metal enriched sample shows the coexistence of Fe-Ni γ-phases with different compositions. In figure 1a we can see an overlap of: a) a magnetic phase with a quadrupole splitting, corresponding to the ordered Fe_{50}-Ni_{50} (tetrataenite); b) a magnetic phase without quadrupole splitting, corresponding to a ferromagnetic disordered taenite Fe_{50}-Ni_{50} ; c) a paramagnetic γ-phase due to the Ni-poor taenite with less than 30% Ni .

At 4.2 K (fig. 1b) the Mössbauer spectra showed a remarkable change in the single line corresponding to the taenite with < 30% Ni, that exhibits a drastically broadening at this temperature (Γ = 1.80 mm/s). This appears to represent the onset of a magnetic ordering at low temperatures, giving rise to a small magnetic hyperfine field of ~ 2.5 Tesla as estimated from the broadening. Even at this low temperature no martensitic transformation to the α-phase was observed. The line broadening of the low-Ni taenite (< 30% Ni) in this chondrite is bigger than the one observed for the Santa Catharina meteorite /12/ probably due to differences in the dimension of the submicron domains. Detailed experiments are in progress and will be published elsewhere. The line broadening for the sextets can be attributed to hyperfine field distributions induced by different magnetic interactions between the intergrown domains of tetrataenite and disordered taenite phases.

In Table I the hyperfine parameters are listed, as well as the proportion of the Fe-Ni phases. The hyperfine field (H_i) and the quadrupolar interaction (ΔEq) are similar to those already observed for the ordered phases in irradiated iron-nickel alloys and in metal particles of LL and L non-Antarctic chondrites. The proportion of tetrataenite and the degree of order in this L-chondrite is smaller than the one already observed in some LL chondrites. The presence of a considerable proportion of the 50/50 disordered phase coexisting with the superstructure is remarkable.

The presence of tetrataenite in this meteorite revealed by microscopic measurements is also shown by macroscopic magnetic properties that gives independent evidences for the presence of this superstructure. In magnetic studies of meteorites, it has been noted that some of them, such as S. Sévérin (LL6 chondrite), have an unusually high magnetic coercivity, which is broken down to a low coercivity state of the disordered taenite caused by a break-down of the anisotropic ordered structure by heating above the Curie point /13/. It appears, however, that the magnetic behavior of tetrataenite phase in meteorites is fairly complicated owing to the coexistence of disordered taenites of various Ni contents, which are in close contact with the tetrataenite phase in individual metallic grains /13/.

The thermomagnetic curves of silicates and magnetic grains of ALHA 76009 are shown in fig. 2a and 2b respectively. The silicate phase exhibits an irreversible curve with the main Curie points at ~ 550 C in the heating and cooling curves. The thermomagnetic curve of the metallic phase indicated also an irreversible curve with a magnetic hump and the main Curie points 550 C and 750 C in the heating curve and 600 C in the cooling curve. The results suggest that the silicate phase also includes taenite with about 50% Ni, and the metallic phase includes taenite with 50% Ni and kamacite with 5% Ni (these samples have not been treated chemically).The heating curves around 550 C are characteristic of a tetrataenite-rich chondrite, as observed in other meteorites /14/.

The presence of tetrataenite in ALHA 76009 has been confirmed by XRD, MS and magnetic measurements. However the coexistence of tetrataenite with the corresponding disordered phase observed by MS suggests the occurrence of metallic grains with different structures (tetrataenite or disordered taenite) as a consequence of different formation histories. One of the most important problems regarding tetrataenites in chondrites is how this phase was formed in the extraterrestrial space. Several investigators have concluded that the ordered structure of tetrataenite may have been formed when the meteorite parent body slowly cooled below the order-disorder transition temperature (320° C).

For a better understanding of this order-disorder process it is important to obtain more detailed information about the events during primary cooling or secondary processes. Other experiments are currently under investigation in order to correlate the Mössbauer and magnetic results with the formation history recorded by the metallic phases of chondrites.

FIGURE CAPTIONS

Figure 1 - Mössbauer spectrum of the metal enriched sample: a) RT; b) 4.2 K.

Figure 2 - Thermomagnetic curves of: a) silicate; b) metallic particles.

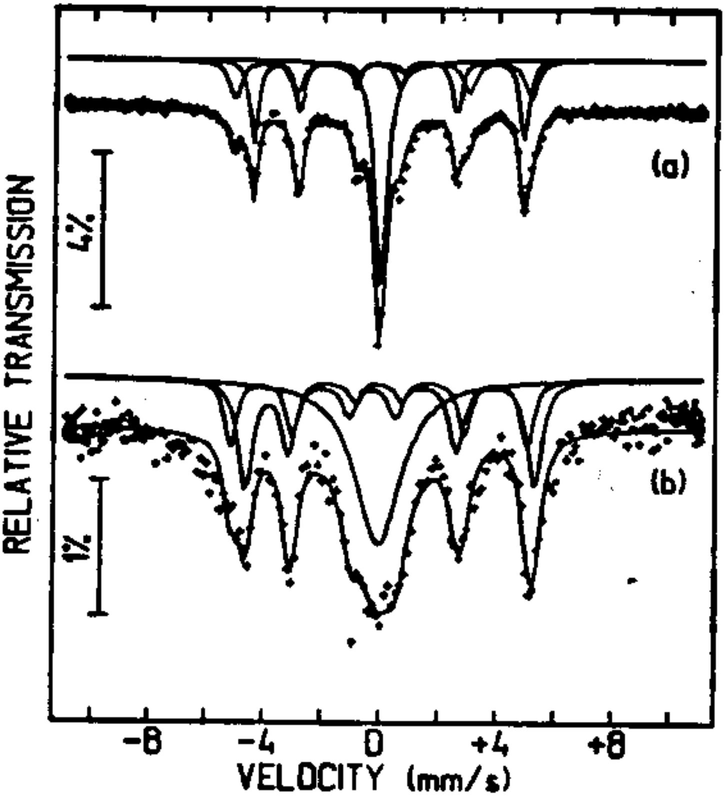

FIG. 1

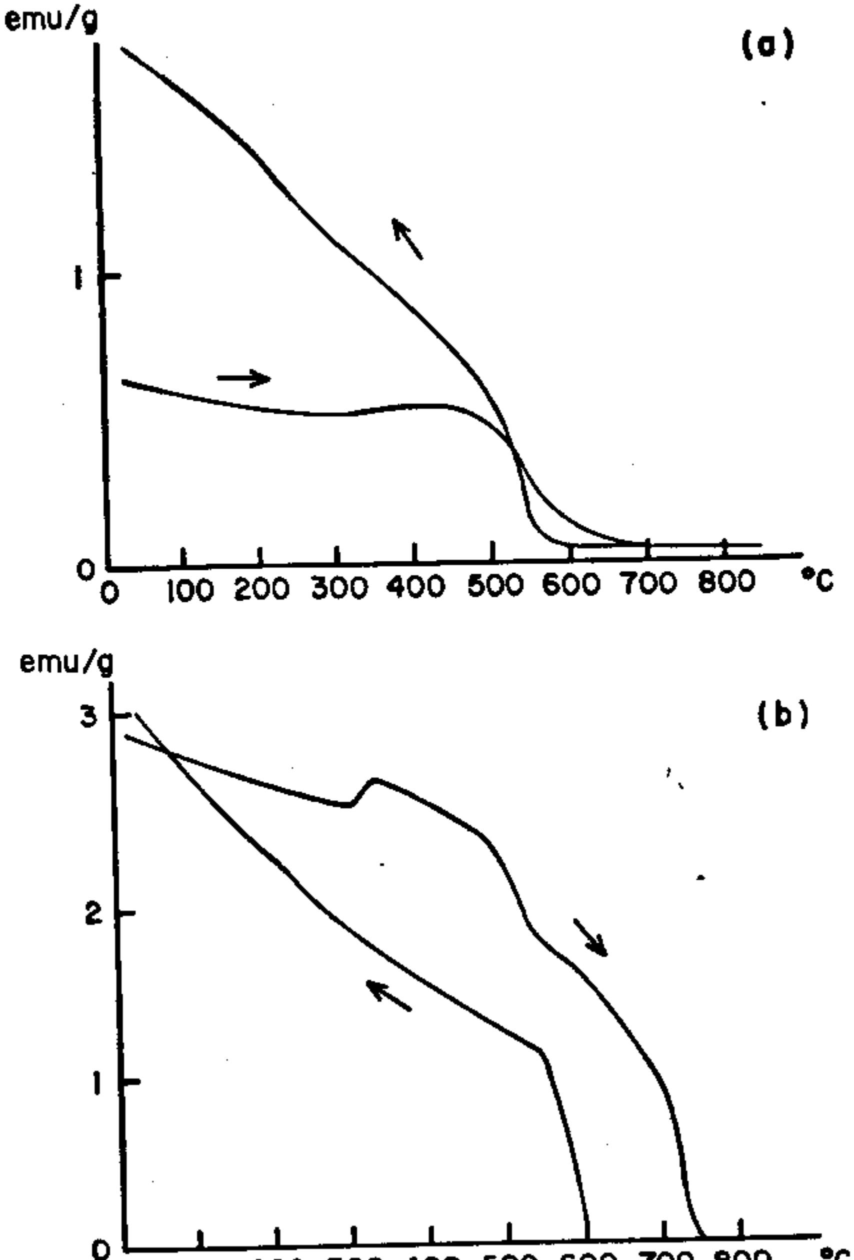
emu/g
(a)
1
0
0
100
200
300
400
500
600
700
800
°C
emu/g
(b)
3
2
1
0
0
100
200
300
400
500
600
700
800
°C

FIG. 2

TABLE I

Mössbauer hyperfine parameters of metal enriched particles of ALHA 76009 L6 chondrite

	Fe-Ni phases	Γ (mm/s)	IS (mm/s)	ΔEq (mm/s)	H_i (Tesla)	A (%)
RT	ordered 50-50	0.37	-0.07	0.18	288	39
	disordered 50-50	0.55	-0.10	0.0	314	25
	Ni-poor γ-phase	0.52	-0.17	----	----	36
4.2 K	ordered 50-50	0.45	-0.07	0.18	295	30
	disordered 50-50	0.80	-0.12	0.0	333	32
	Ni-poor γ-phase	1.80	-0.18	----	----	38

Γ = linewidth at half height (± 0.03 mm/s); IS = isomer shift relative to ^{57}Co/Rh source (±0.01mm/s); ΔEq=quadrupole splitting (±0.005 mm/s); H_i=internal hyperfine field (±0.5 Tesla); A = relative spectral area (±5%) .

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