Fractionation of Iron in the Solar System

Harris and Tozer¹ have recently suggested that magnetostatic attraction between cosmic iron particles is responsible for the observed variation in iron abundance between the inner and outer planets of the solar system. I should like to point out that a crucial assumption in this model is "the uniform single-domain nature" of iron particles in the size range 10^{-4} – 10^{-3} cm. The calculations which follow show that iron particles of only a limited size range can take part in magnetostatic accretion.

At room temperature, 300° K, iron is superparamagnetic² below the critical size of 125 Å. This implies that such particles have no net magnetic moment because of thermal fluctuations. Above that diameter, iron is definitely a single domain but the critical diameter for the onset of multidomain behaviour is very close, 150 Å. As Table 1 shows, at 950° K, the temperature of accretion considered by Harris and Tozer, the superparamagnetic critical size is raised to 184 Å and an upper limit of 3300 Å emerges for the multidomain behaviour. This upper limit comes from the well known fact that a single-domain particle has to be smaller than the domain wall width at the temperature being considered. The width of 3300 Å at 950° K is derived from the data given by Kittel³. The sizes considered by Harris and Tozer, 10^{-4} – 10^{-3} cm, are far larger than the ones shown in Table 1, and thus will have to be multidomained.

Temperature	Superparamagnetic critical diameter	Single-domain critical diameter
300° K	125 Å	150 Å
950° K	184 Å	< 3300 Å

Why is it so important for the particles to be single-domained? Because, for a multidomain particle of iron tumbling in a maximum field of 100γ (10^{-3} oersteds), the net moment would be negligible. The value used by Harris and Tozer is 200 gauss, but the real moment could not be greater than a hundredth of this. Because the product of the moments is responsible for the attractive force, the magnetostatic attraction for 10^{-4} cm particles could be a ten thousandth of what Harris and Tozer have assumed. The influence of magnetism on the gravitational attraction will indeed be there but it will be too small to cause an effective change in the capture cross-section.

It might be argued that at some time in the past the particles could have gone through an intense magnetic field emanating from the Sun, and this could have saturated the 10^{-4} – 10^{-3} cm particles. But even so, for a sphere of iron of which the crystalline anisotropy energy at 950° K is low (about 10^4 ergs/cm³) and the demagnetizing factor is so large, this saturation moment would be very unstable with time, instantly decreasing to the steady state remanence of about a tenth or a hundredth of one gauss, as discussed before.

My conclusion therefore is that, although the mechanism suggested by Harris and Tozer is ingenious and interesting, it is of little importance for the size of particles they have discussed. In order to be effective, the particles have to fall in a very limited range of sizes as shown in Table 1. It may be possible to postulate that the original particles were indeed in this critical range because of some vagary of cosmology and that the observed particle sizes are larger because of grain growth on sintering.

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S. K. BANERJEE*

Ampex Corporation,
Redwood City, California.

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* On leave of absence from the School of Physics, University of Newcastle upon Tyne.

¹ Harris, P. G., and Tozer, D. C., *Nature*, **215**, 1449 (1967).

² Morrish, A. H., in *The Physical Principles of Magnetism*, 340 (John Wiley and Sons, 1965).

³ Kittel, C., in *Introduction to Solid State Physics*, 430 (John Wiley and Sons, 1957).

Banded Flints

BANDED flints have long been known to occur in small numbers together with ordinary flints, which are the nodules of chalcedonic silica found in the chalk (Upper Cretaceous) of England and elsewhere. The bands may be observed on fractured surfaces and show up as a variation in colour within the normal colour range of unbanded flints. The exterior of the affected nodule may be ridged in a pattern conformable to the banding.

Formerly, authors, such as Woodward¹ and Sollas², explained the banding as being caused by some kind of infiltration, as would be ascribed nowadays to a natural chromatographic process. Geinitz³ suggested rhythmic precipitation and Gebhardt⁴ regarded a particular example as a test case in the recognition of Liesegang's rings as a natural phenomenon. Cayeux⁵ figured a similar specimen and noted that the effect, *silix zonaire*, involved the normal constituents of flint only, but he was unable to suggest any cause.

That these bands follow the patterns formed in experimental stress analysis does not seem to have been previously noted. Such stress patterns may be preserved by the "freezing" of an elastic component in a medium which is only plastic during loading. Synthetic resins, which provide both components, were discovered in 1935, and have since been used experimentally⁶. Comparison leaves no doubt that banded flints have been subjected to stresses, probably through collision with other flints.

Fig. 1. A sketch of a banded flint. This banded flint is from the collection of Dr W. Hunter, at the University of Glasgow. It is specimen JF 1177 in the Hunterian Museum (Geology).

The specimen illustrated in Fig. 1 shows one half of a flint from the collection of Dr William Hunter at the University of Glasgow. The pattern is in black, white, red and yellow according to the amount of compression and subsequent iron-staining. The source of the banded flint is not given but is presumed to be from the oolitic iron-ores of Baden, West Germany, a commercial source for so-called "red Egyptian Jasper", in the eighteenth century. I was privileged to examine Dr Hunter's collection in 1963. A recent article⁷ recorded the development of preferred orientation of quartz during recrystallization of flint in conditions of annealing. I suggest here that the naturally banded flints would similarly develop preferred orientation, as a result of the stress "frozen" in the specimen. This is regardless of the demonstration of preferred orientation in a naturally stressed flint, which has not been attempted. The evidence shows that annealing of flint results in preferred orientation which cannot be considered as free from stress, although