# ELECTRON SPIN RESONANCE STUDIES OF APOLLO 16 FINES*

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Electron spin resonance (ESR) studies have been carried out in the temperature range 4-300°K on the Apollo 16 lunar fines (61141-4, 64501-22 and 67601-20). The g-value, the lineshape asymmetry, and the temperature dependence of the linewidth as well as the intensity are found to be essentially similar to those observed for the Apollo 11-15 fines (1-4). On the basis of (1) no significant temperature dependence of the absorption intensity, (2) an intensity almost three orders of magnitude greater than that expected for possible paramagnetism, (3) a first-order crystalline anisotropy energy ($2K_1/M_S$) characteristic of metallic Fe, and (4) an asymmetric lineshape with a narrower appearance on the high-field side, it is concluded that the intense ESR signals ($g = 2.08 \pm 0.03$) detected in all the returned Apollo 11-16 fines are principally ferromagnetic in nature arising from metallic Fe particles in the $\alpha$-phase, and not from hematite, magnetite or other ferric oxides as suggested by other workers (3, 4).

An effective g-value of 2.08 as compared to the free electron g-value of 2.0023 indicates that these metallic Fe particles are essentially spherical in shape. Since no eddy current effects have been detected, together with the intrinsic linewidth of 300-400 G at 300°K determined for the lunar fines, it is possible to ascertain with certainty a diameter in the range of 30 Å to 1 $\mu$m for the size of these metallic Fe particles.

On the ESR time scale of observation ($10^{-9}$-$10^{-11}$ sec), any metallic Fe particle $\geq$ 30 Å in diameter would remain essentially in the ferromagnetic state at room temperature, although on the Mossbauer and static magnetic susceptibility time scale of observation ($> 10^{-9}$ sec), any metallic Fe particle with a diameter 30-130 Å is expected to exhibit superparamagnetic behavior at room temperature (5, 6). Based on the shape effect (spherical), the crystal structure (body-centered cubic), the gyromagnetic ratio ($\gamma = 18.3 \times 10^6$/sec, G) and the crystalline anisotropy energy ($2K_1/M_S$ = 350-500 G), all of which determined from ESR measurements, it is calculated that the only metallic Fe particles in the lunar fines which would carry a natural remanent magnetization (NRM) for longer than 3.0 billion years on the surface of the moon, are those with a diameter 280-380 Å. Since the value of $2K_1/M_S$ is known to be much greater for metallic Co (+7,000 G) than for metallic Fe (+500 G) and Ni (-220 G), the relaxation time of NRM is expected to increase with increasing Co content and to decrease with increasing Ni content in the metallic Fe phases of the lunar samples.

The ESR linewidth observed for the Apollo 16 fines (580 G) was found

to be close to that for the Apollo 14 fines (606 G) (3), but was found to be narrower than those for the Apollo 11 (800 G), 12 (770 G) and 15 fines (750 G) (4). A quantitative correlation is shown in Fig. 1 between the ESR linewidths of the Apollo 11-15 fines and their average Ni contents as determined by other means. By extrapolation to 580 G, the average Ni contents in the metallic Fe phases of the Apollo 16 fines are found to be 9.6 ± 1.5 wt. %. These results are summarized in Table I, together with the metallic Fe contents determined by our present ESR intensity measurements. The variation in the ESR linewidths observed for the Apollo 11-16 fines suggests that the bulk of the metallic Fe particles in the returned lunar fines cannot be due simply to meteoritic Fe.

References

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Table I. Average Ni and Metallic Fe Contents for Some Apollo 16 Fines

| Sample | Observed ESR Linewidth (gauss) | Metallic Fe Content (wt. %) | Average Ni Content: Wt. % in Metallic Fe Phase | Average Ni Content: Total Content (ppm) |
|---|---|---|---|---|
| 61141-4 | 581 ± 40 | 0.27 ± 0.05 | 9.6 ± 1.5 | 260 |
| 64501-22 | 585 ± 40 | 0.42 ± 0.05 | 9.4 ± 1.5 | 400 |
| 67601-20 | 572 ± 40 | 0.15 ± 0.05 | 9.8 ± 1.5 | 150 |

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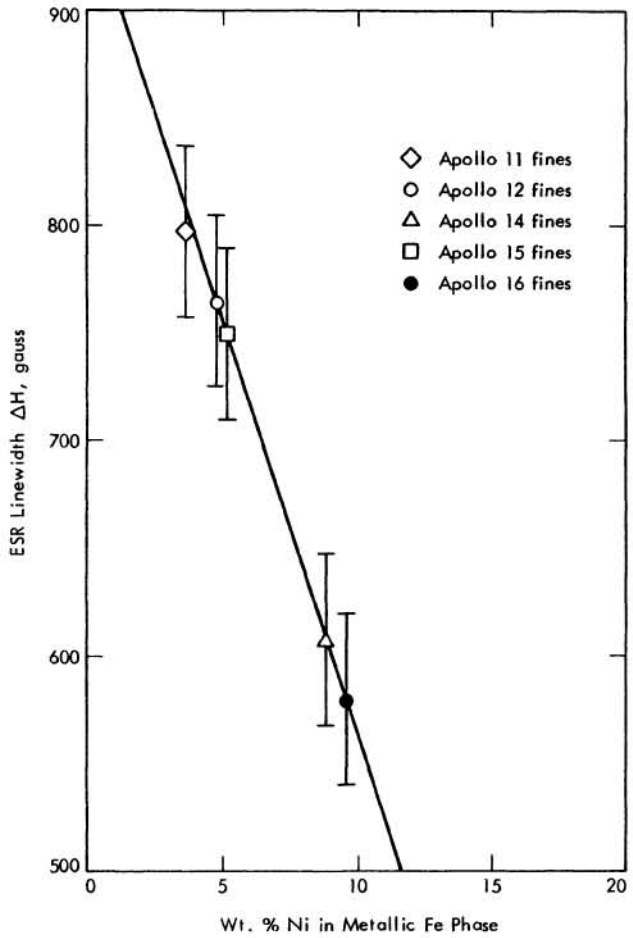
Figure 1. Correlation between the observed ESR linewidths and the average Ni contents in the metallic Fe phases of the lunar fines; Ni content for Apollo 16 fines determined from correlation for other samples.

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