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On the Memory Effect of the Remanent Magnetization Through the Low-Temperature Magnetic Transition in αFe_2O_3

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Several experiments have been made on the memory effect through the magnetic transition temperature (≈ -15°C) of αFe_2O_3, using sintered pure specimens which do not have the so-called isotropic part of the weak ferromagnetism. It has been found that the specimens used are weakly ferromagnetic at low temperatures far below the magnetic transition temperature. The specimen in the remanent state cooled down through the transition temperature shows a small amount of the residual magnetization, which may be considered as acting as the seed for the memory of the magnetization. The magnetic field higher than 50 kOe applied at liquid air temperature on the way of the cooling-heating cycle can change the amount and direction of the magnetization "memorized" at room temperature. Moreover, it has been observed that the virgin specimen brought to the remanent state by an application of the strong magnetic field at liquid air temperature shows the magnetization at room temperature.

1. Introduction

As is well known, αFe_2O_3 has a weak ferromagnetism superposed on the antiferromagnetism.[1] The direction of the antiferromagnetic spin is in the (111) plane at room temperature and it changes to the [111] axis below the magnetic transition point at about -15°C. It has been reported[2),3)] that the remanent magnetization acquired by αFe_2O_3 at room temperature recovers after it was subjected to a thermal cycle through the transition point. We have made several experiments on this curious memory effect, of which the results are reported briefly here.

2. Specimens and experimental apparatus

Specimens used were prepared from pure ferric nitrate ($Fe(NO_3)_3 \cdot 9H_2O$) and sintered finally at 1100°C in an oxygen gas stream.

The hysteresis loop measurements were made by means of a pendulum magnetometer using strain gauges as the transducer,[4)] and the measurements of the strength and direction of the magnetization were made using a self-compensating torque magnetometer.

3. Experimental results

The hysteresis loop measured at room temperature is shown by the curve (a) in Fig. 1. The remanent magnetization and coercive force are 0.204 emu/g and 3.37 kOe, respectively. On the other hand, the hysteresis loop measured at -192°C below the magnetic transition temperature is a perfectly straight line passing through the origin, as shown by the curve (b) in the same figure. It has been known that, although common αFe_2O_3 specimens have an isotropic part of ferromagnetism which is not sensitive to the magnetic transition and has a low coercive force of about 0.5 kOe,[2)] the "pure" stoichiometric specimens do not have the isotropic part.[5)] Thus, it may be said that the specimens used here are "pure" αFe_2O_3.

As shown in Fig. 2, the hysteresis loop, measured at -192°C on the specimen which was brought to the remanent state at room temperature by applying the magnetic field of plus or minus 12.6 kOe, is also a straight

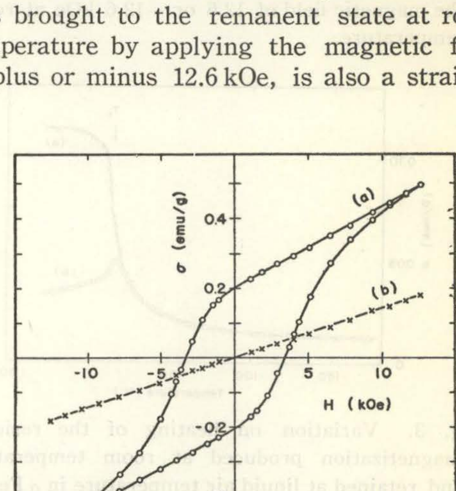

Fig. 1. Hysteresis loops of αFe_2O_3 at room temperature (a) and at -192°C (b).

line, but it is displaced by 0.013 emu/g upwards (b) or downwards (c) from that of the virgin specimen (a) depending upon whether the remanent magnetization acquired at room temperature is directed towards the plus or minus direction. These data indicate that our αFe_2O_3 specimen without an isotropic part has really a weak ferromagntism at low temperatures and that the coercive force of this ferromagnetism is very large and the direction of the magnetization is dependent on the remanent state produced at room temperature. It is to be noted that, according to our experiments, a specimen which has an isotropic part also shows a displaced hysteresis loop at liquid air temperature after it was cooled in the remanent state and the amount of the displacement is exactly the same as that of the "pure" specimen.

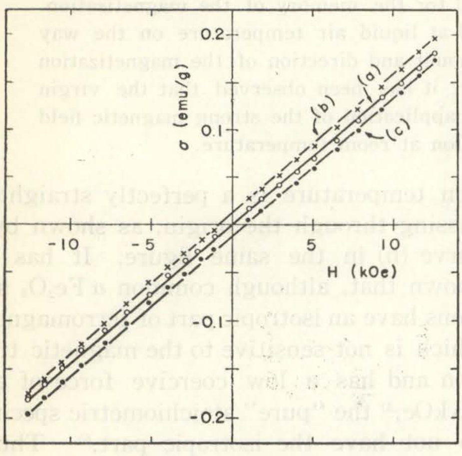

Fig. 2. Hysteresis loops of αFe_2O_3 at -192°C. (a) is the loop for the virgin specimen, and (b) or (c) is that for the specimen which acquired the remanent magnetization by an application of the magnetic field of 12.6 or -12.6 kOe at room temperature.

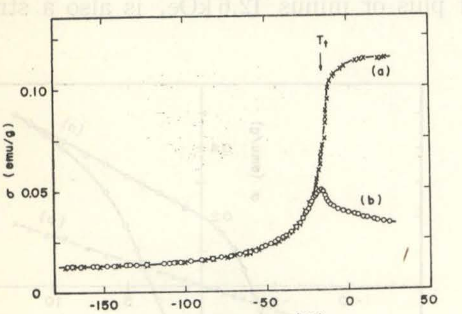

Fig. 3. Variation on heating of the residual magnetization produced at room temperature and retained at liquid air temperature in αFe_2O_3. The curves (a) and (b) are, respectively, for the magnetic fields of 0.5 and 5 kOe applied perpendicularly to the residual magnetization. T_t indicates the magnetic transition temperature locating at about -15°C.

The variation on heating of the residual magnetization produced at room temperature and retained at liquid air temperature is shown in Fig. 3, which was obtained from the torque measurements on a disc specimen under a constant measuring magnetic field applied in the direction perpendicular to the residual magnetization. Under a weak applied field (0.5 kOe), the magnetization increases quickly at the transition temperature, as shown by the curve (a). This is a usually observed memory effect. Under a higher applied field (5 kOe), the magnetization increases at first just as under a weak field, but it diminishes subsequently, making a peak at the transition temperature (curve (b)). This fact may be explained as follows: The increase in magnetization with rising temperature reduces the coercive force, and as soon as the coercive force becomes equal to the strength of the applied field, the magnetization rotates into the direction of the applied field and the increase in magnetizaton is continued in this new direction.

The remanent magnetization, σ_R, acquired at room temprature and the magnetization, σ_M, memorized by the specimen when it was once cooled to liquid air temperature and then brought back to room temperature were measured as a function of the field, H_R, applied previously at room temperature. The

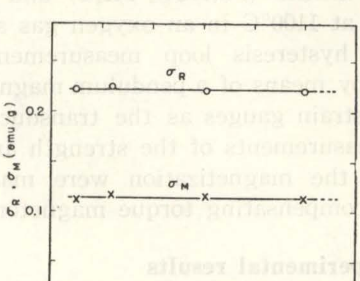

Fig. 4. Remanent magnetization, σ_R, produced by the applied magnetic field, H_R, and the memorized magnetization, σ_M, as dependent on H_R in αFe_2O_3.

results obtained are shown in Fig. 4, which shows that the values of σ_R and σ_M are invariant and their ratio is 0.52 in the measured range of H_R from 10 to 100 kOe. It is to be noted that in this and subsequent experiments the specimen was magnetized by magnetic fields up to about 150 kOe as produced by a Bitter-type solenoid connected with a controlled mercury rectifier and then the specimen in the remanent state was set on the torque meter with an error within 1°.

Further, we measured the magnetization, σ_M, memorized or recovered at room temperature after the specimen having the remanent magnetization, σ_R, produced at room temperature was cooled to liquid air temperature where the strong field, H_L, was applied temporarily in the parallel or antiparallel direction to the original remanent magnetization, σ_R, and then brought back to room temperature. It has been found that H_L up to 110 kOe applied in the same direction as that of σ_R has no effect on σ_M, as shown by the curve (a) in Fig. 5. But, in the case where H_L is applied in the antiparallel direction to σ_R, σ_M decreases for H_L higher than 50 kOe, and moreover it appears in the inverse direction to σ_R for H_L higher than 90 kOe (curve (b)). Thus, σ_M seems to reverse completely at H_L of about 160 kOe. This experiment indicates that the coercive force of the weak ferromagnetism at liquid air temperature is about 90 kOe.

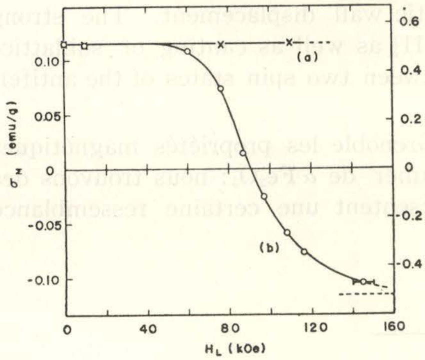

Fig. 5. Memorized magnetization, σ_M, and its ratio to the original remanent magnetization, σ_R, as dependent on the field, H_L, applied temporarily at -192°C on the way of a thermal cycle through the magnetic transition in αFe_2O_3. (a) or (b) is the data for H_L applied in the direction parallel or antiparallel to that of σ_R, respectively.

Finally, we measured the magnetization of the specimen which was brought in the remanent state by an application of the strong field, H_L, at liquid air temperature and then heated up to room temperature. It has been found that the magnetization can be detected for H_L higher than 50 kOe and it increases gradually with increasing H_L, as shown in Fig. 6.

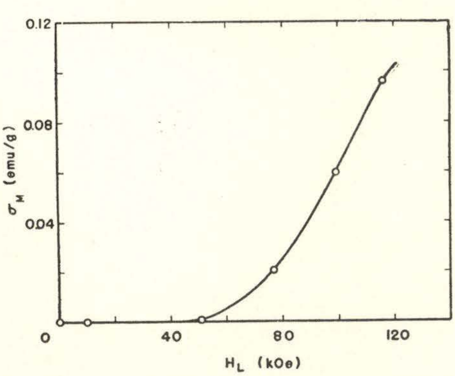

Fig. 6. Magnetization appeared at room temperature, σ_M, in αFe_2O_3 which was brought to the remanent state by an application of the magnetic field, H_L, at −192°C.

4. Conclusion

It is concluded, from the above-mentioned experiments, that the magnetization observable at room temperature in αFe_2O_3 after a thermal cycle through the low temperature magnetic transition depends completely on the very weak ferromagnetism observed at low temperatures. This ferromagnetism may act as the seed for the memory effect. The origin of this very weak ferromagnetism may be related to the antiferromagnetic domain boundaries inherent in the crystal or to some crystal distortion.

The authors thank the members of the strong magnetic field commitee of our Research Institute for giving us facilities for the performance of the strong field experiments.

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DISCUSSION

S. T. LIN: We have done some experiments on the hysteresis shift with Elba crystals. What we have observed is that the hysteresis loop shifts along the field axis toward one side below the transition and toward the other side above the transition.

S. IIDA: I would like to point out that the observed effect of applied magnetic field at low temperature is not explained easily by the presence of exchange-coupled ferrimagnetic impurities. This is because, at the transition on heating, the spin axis rotates by 90 degrees so that there are equal probabilities for the canted spin moment to have a component along the direction of the applied field with plus and minus signs. It is suggested that the record that has been made by the application of strong field is the sign of spins on a specified sublattice of the antiferromagnet, and this record has been made by the antiferromagnetic wall displacement. The strong field may induce rotation of spin axis from [111] as well as canting of sublattice spins, resulting in a difference in free energy between two spin states of the antiferromagnet with different signs of the spins.

R. PAUTHENET: Nous étudions actuellement à Grenoble les propriétés magnétiques des grains fins antiferromagnétiques et en particulier de $\alpha\,Fe_2O_3$: nous trouvons des propriétés d'aimantation thermorémanente qui presentent une certaine ressemblance avec ceux presentés dans cette communication.