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Dynamical Pattern-formation in Temperature Barkhausen Effect

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The detailed measurement of magnetization Ms of a ferromagnet under infinitestimally weak field by sensitive SQUID magnetometer just below Tc are presented. We find the appearence of fluctuating development of Ms which is especially notable near Tc in the course of decreasing temperature. This fluctuation on one way temperature variation, we call as Temperature Barkhausen Effect. The fluctuation shows curious memory and hysteresis. We started computer simulation of development of magnetization in 2 dimensional ferromagnetic Ising spin system. The patterns of + and - spin islands on open sea of randomly fluctuating spins are obtained at $T > Tc$. The competition of + and - spin domains are observed at $T < Tc$. We also observed the propagation of correlation area from an impurity spin to the surroundings.

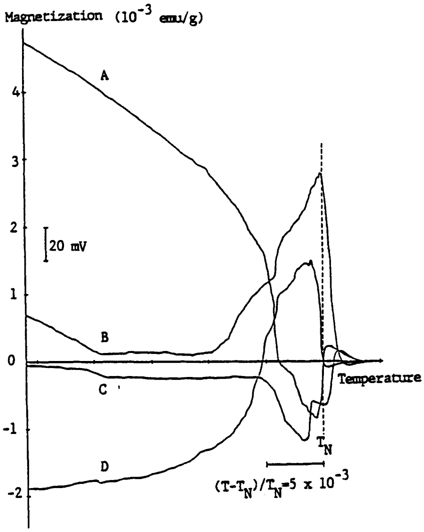
INTRODUCTION

Coming out of nuclei of spin clusters and growing up of them to domains in a ferromagnet in the course of decreasing temperature will give nice examples for the study of dynamical pattern-formation.

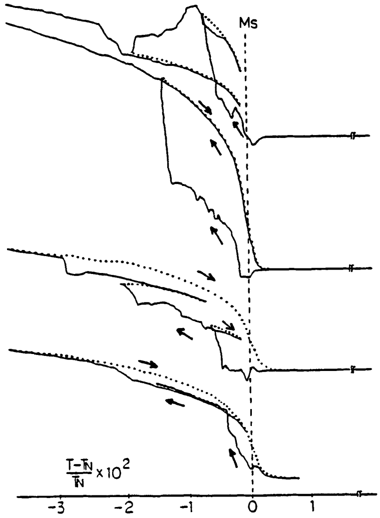
We investigate the problem by the experiment with real magnetic substance on one hand, and by computer experiment with the most simple spin system on the other hand. We put the condition of the infinitestimally weak external magnetic field. The variaion of sizes of + and - spin clusters and the competition of + and - domains invading each other in the course of growing up of magnetization are reflected on the variation of total magnetization in both experiments. Computer experiment gives the variation of the patterns of + and - spins as well. Comparing the patterns with the magnetization curves of both real and computer experiments, we intend to get information about the mechanism of pattern formation.

TEMPERATURE BARKHAUSEN EFFECT

Recently, it becomes possible to measure experimentally the development of magnetization in detail by the use of very sensitive SQUID magnetometer in various conditions. We measure the spontaneous magnetization along the easy axis of a ferromagnet approaching to its ferromagnetic transition temperature Tc from higher temperature under extreamly weak

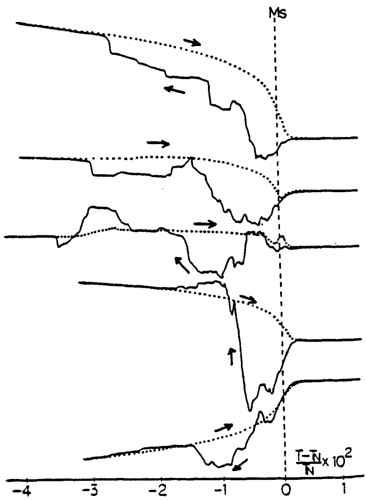


(a) Fluctuation of Ms around T_N



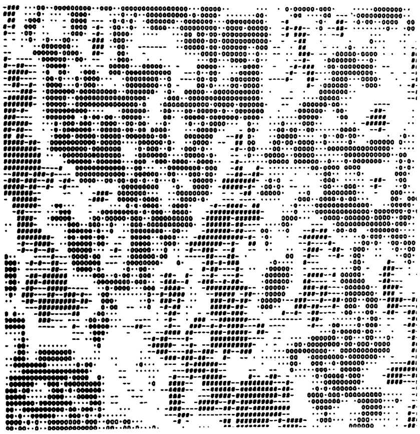
(c) Memory of Ms

Figs.1 T.B.E. in real experiment of Mn formate $2H_2O$.

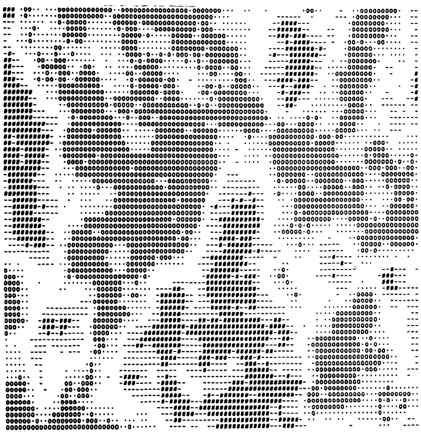


(b) Ms in the course of cooling down and warming up

external magnetic field. The direction of spontaneous magnetization can have either direction, + or - sense. We are interested in how the + and - spin clusters develop in size and shape. We expect to have a guess, at least in size variations, from the precise measurement of the development of magnetization Ms. The magnetization of a weak ferromagnet, Mn formate $2H_2O$ (transition temperature T_N=3.618K) are measured in the external field of less than few mOe. In Fig.1(a), magnetization curves are given with the parameters A>B>C>0>D which give the order of magnitude and sense of external field. Magnetization shows rather large fluctuating peaks around T_N. Fluctuations start when the external field reduces down to 1 mOe.(Ishizuka M. et al.: 1983). Noteworthy is the appearance of the fluctuation only in the course of decreasing temperature. So we named these



(a) τ = 5



(b) τ = 25

(c) τ = 100

Figs.2 Size and shape of islands at T > Tc.

phenomena the Temperature Barkhausen Effect (T.B.E.). As seen in the figure, magnetization ceases to fluctuate in lower temperature region than ε =-0.1 or so.

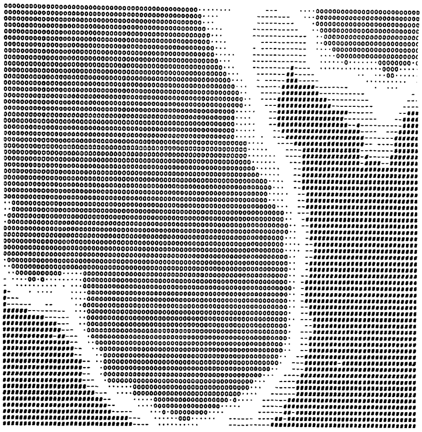
In Fig.1(b), the fluctuation and curious memories in T.B.E. are presented. We start from higher temperature and cool down the specimen to get into T.B.E. region (solid lines). At a certain temperature, we change from cooling to warming (dotted lines). As mentioned above, magnetization goes back just on the curve something like as the Brillouin function up sometime even to T_N. When we change from warming to cooling again (solid lines), curiously enough magnetization goes on the Brillouin curve smoothly just to the temperature of the turning point, and below that temperature T.B.E. phenomena start to appear again. The behavior of this curious hysteresis and memory can be seen most apparently on the curves in Fig.1(c).

COMPUTER SIMULATION EXPERIMENT

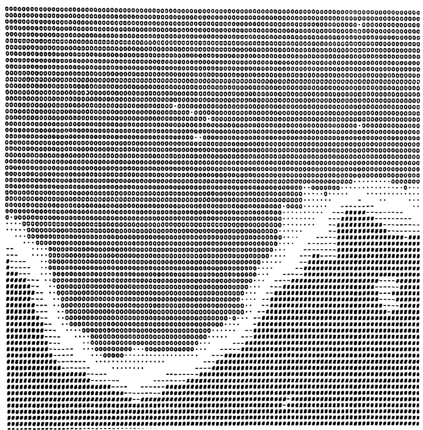
We investigate the nucleation and development of ferromagnetic ordered area in 2 dimensional 128 x 128 square lattice of Ising spin system with periodic boundary condition by Monte Carlo simulation experiment.

THE PARAMAGNETIC REGION There was a pioneer work by the computer simulation group (Ogita et al.:1969) in which the magnetization curves were calculated and patterns of + and - spins were given as a movie pictures. In the present study, we make patterns of + and - spins by averaging every τ Monte Carlo step (τ=5,10,25,50 and 100) to make clear the appearence of the islands of + and - spin clusters on open sea of randomly fluctuating spins. Of

(a) t = 25



(b) t = 100



(c) t = 800

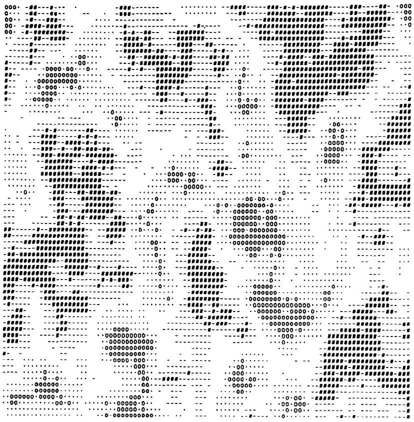
Figs.3 Competing of domains at $T < Tc$.

course in paramagnetic state, if we choose $\tau \to \infty$, all the + and - spins are averaged out and we get white open sea. In Figs.2(a),(b),and(c), the patterns are given for $\varepsilon = (T-T_N)/T_N = 0.01$ and $\tau = 5$, 25 and 100, respectively. In these figures, # and - marks represent the + spin islands and their shoals, and 0 and . marks represent the - spin islands and their shoals. By these representation we see for the first time, the appearance of + and - islands on the white open sea which appear between the shoals. At higher temperature (larger ε value) and by larger τ value, the area of open sea becomes wide. The size and shape of islands and shoals, depend on the values of ε and τ as well. The appearance of some fluctuation already seen at temperature region just above T_N shown in Fig.1(a) can be understood by these patterns.

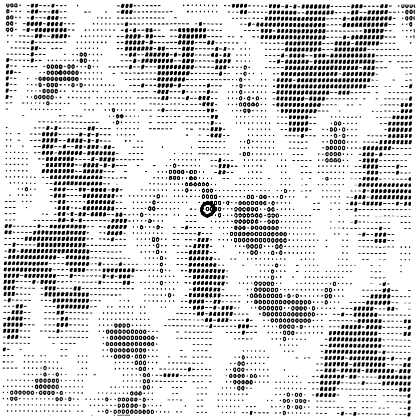
ORDERED REGION $T < Tc$ We set the temperature of the system below Tc, which is known by the Onsager's exact solution, and start Monte Carlo simulation experiment. When we get into ordered region, + and - spin clusters or islands grow up to domains and there starts the invading competition among them.

In Figs.3, $\varepsilon = -0.1$, and (a),(b) and (c) correspond to the progress of time t=25,100,800 in the unit of Monte Carlo steps, respectively. The figures give the movement of patterns along with the time progress.

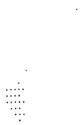
The open sea in Figs.2 can, here, be seen as a narrow canal between domains. The lines of canals complicatedly entangled at the beginning (Fig. 3(a)) turn to rather simple boundary line by the work of a certain surface tension. Movement of lines and variation of + and - area correspond to the fluctuation of magnetization. It is sure the most of the T.B.E. comes from the competing motion. The fluctuation becomes stationary when



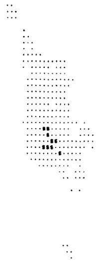
(a) with no impurity



(b) with an impurity



(c) t = 25



(d) t = 50

(e) t = 75

(f) t = 100

(g) t = 125

(h) t = 150

Figs.4 Impurity effect, Propagation of correlation area.

temperature reaches lower than $\varepsilon \simeq -0.1$. This correspond roughly to the features in Fig. 1(a). As shown in Figs.1(b) and (c), the existence of memory and hysteresis are the most important characters of T.B.E.. We are investigating the repeated cooling and warming of systems in computer experiments. The memories and hysteresis depend strongly on the rate of temperature change and the pattern at which the turning was performed. These may suggest that, if we want to reproduce some of the curious memory, it is necessary to get information of the effect of impurity in the process or development of magnetization.

EFFECT OF IMPURITY AND PROPAGATION OF CORRELATION AREA We start from two of the completely same patterns. On one of them we put an impurity spin which has only one direction, say - , Figs.4(a) and (b) give the situation. Now we proceed the Monte Carlo experiment using the same series of random numbers. At any Monte Carlo steps, both of the patterns are completely same except in the territory of the influence of the impurity. So, we subtract the pattern with no impurity (a) from the pattern with an impurity, which is marked by the circle in the figure,(b) at every Monte Carlo step. Figs. 4(c) - (h) thus obtained give the progress of development of influence of impurity to the surroundings, where $\varepsilon = 0.01$, $\tau = 25$. We can see the propagation of the correlation area.

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