

## Pattern Formation of Metallic Particles in Electric and Magnetic Fields\*

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**Abstract.** Polarizable particles form characteristic patterns in electric and magnetic fields. A model based on the equations of electrostatics reproduces the experimental results quite well.

### 1 Introduction

Several recent observations have stimulated this work on pattern formation of polarizable particles in fields:

i) Mischel et al. (1983) observed the fusion of yeast cells applying di-electrophoresis.

ii) Haken (1979) pointed out that models of morphogenetic processes based for example on the principle of long range inhibition and short range activation can be developed.

iii) Meakin (1983) found a diffusion-controlled cluster formation in 2-6-dimensional space.

iv) During the first German spacelab mission the astronauts Ockels and Furrer (1986) observed three-dimensional terms and chain formation of magnetic spheres in the gravitational environment.

### 2 Iron Balls in a Magnetic Field

Two millimeter diameter steel balls (ball-bearing) are exposed to a quasi homogenous magnetic field, produced by a Helmholtz coils set-up (50 cm diameter). The balls are isotropically placed in a 20 × 20 acrylic-box. To reduce the friction between the balls and the container the acrylic-box is shaken by a vibrator - vibrating amplitude 3 mm, vibrating frequency 10 Hz. Increasing the magnetic field to a maximal value of

34 m Tesla we observe an increasing tendency of the balls to a string formation parallel to the field-lines. To complete this pattern formation higher magnetic fields or mechanisms to a stronger reduction of the friction are necessary. The dipole-dipole interaction between the magnetic balls is attractive and depends on the magnitude of the magnetic field. The friction is among others a function of the length of the formed strings. This mechanism of string-formation can directly be translated for computer simulation. The increase of the magnetic field corresponds to the iterative growth of the interaction growth of the particular strings. Figure 1a shows the initial distribution of the real balls and Fig. 1b the initial random distribution of the balls for the computer simulation. The string formation in a field of 34 m Tesla is reproduced in Fig. 2a for the real experiment and in Fig. 2b for the computer simulated experiment. Lowering the friction by increasing the amplitude of the shaking vibrators results in a growth of the string length pictured in Fig. 3a for the real and in Fig. 3b for the computer simulated experiment. The length of the strings and the distances from string to string represent important characteristics of the structure. The number of the ball strings as a function of their length is plotted in Fig. 4a for the physical experiment and in Fig. 4b for the computer simulated model and demonstrates a good agreement.

### 3 Iron Powder in Electric Field

An acrylic box (7 × 7 × 5) is placed according to Fig. 5 between the two metal plates of a capacitor. The box contains castor oil with iron powder (grain-size 150 μm). Initially the iron particles are concentrated around the positive plate. Applying a high voltage of 40 kV between the two plates, the iron particles start to move toward the negative plate. The formed structure does not show any periodicity (Fig. 6a). The approxi-

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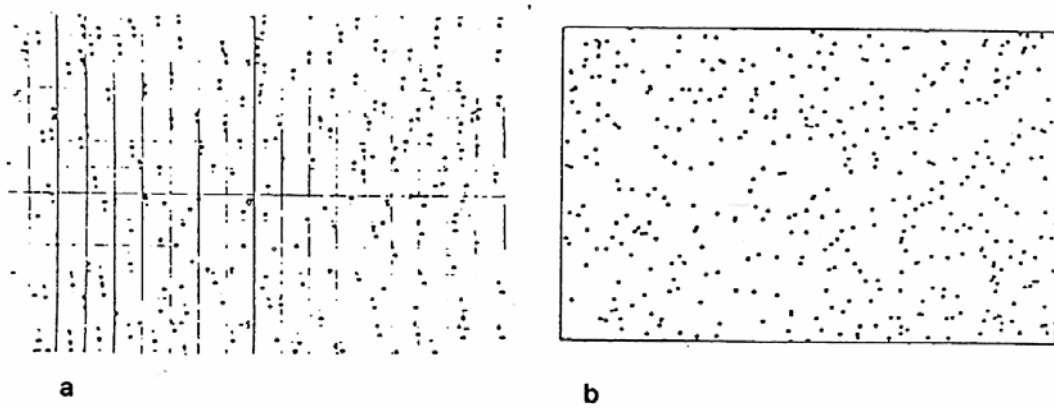


Fig. 1. a Initial random distribution of the iron balls in the real experiment. b Initial random distribution of the simulated balls

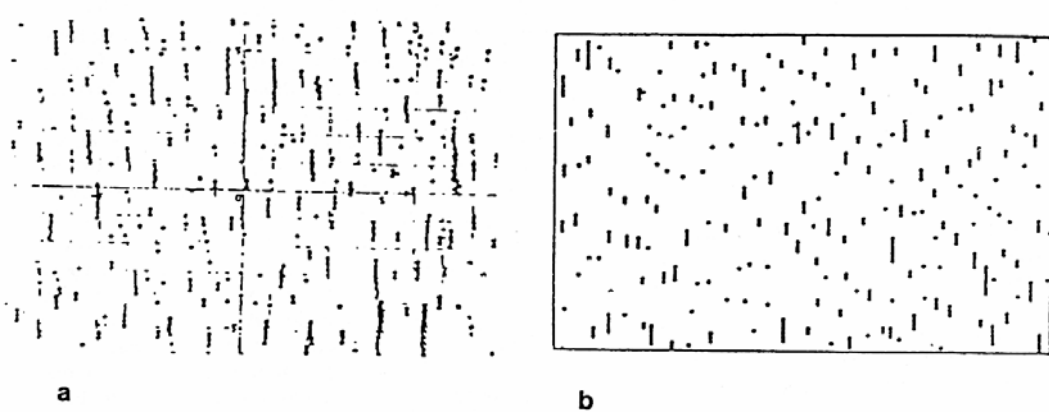


Fig. 2. a Ordering of the iron balls in a magnetic field of  $B = 3.4 \times 10^{-2}$  Tesla. b Ordering in the simulated experiment, only partial area shown

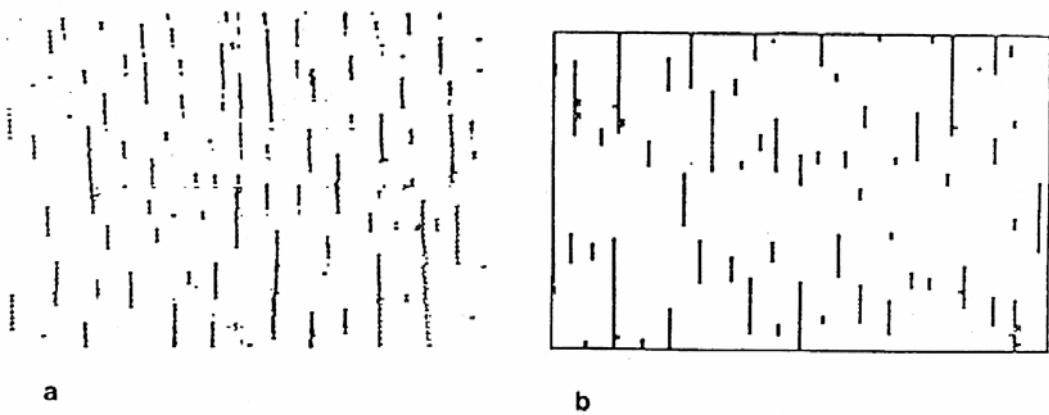


Fig. 3. a Ordering of the iron balls in a magnetic field of  $B = 3.4 \times 10^{-2}$  Tesla after shaking for lowering the friction. b Simulated experiment, full area

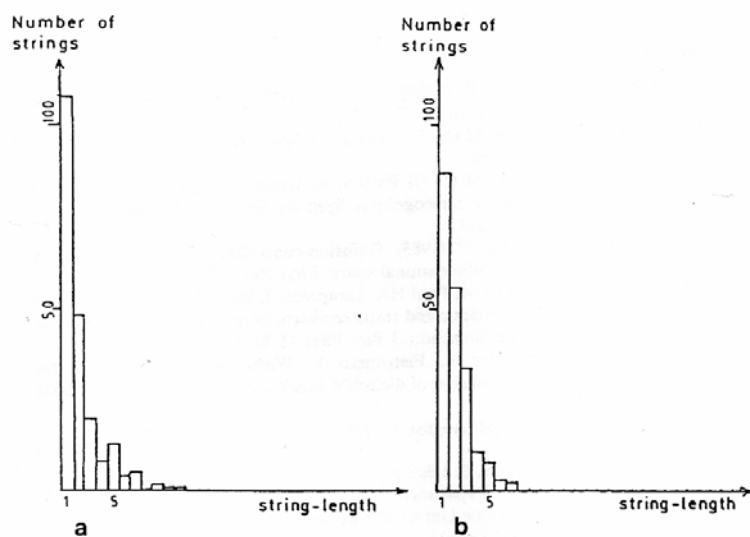


Fig. 4. a Number of the strings plotted as a function of the string length in the real experiment. b Number of the string length in the simulated experiment

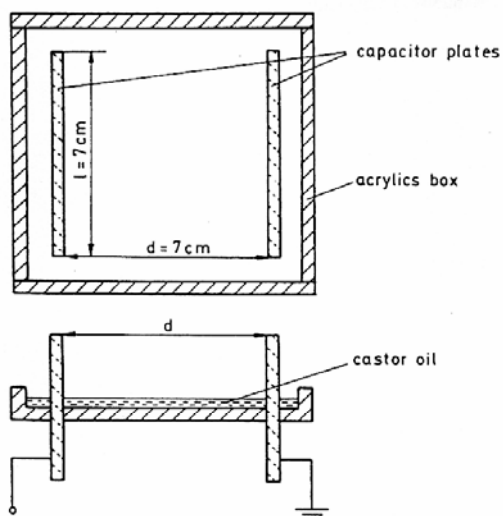


Fig. 5. Scheme of the experimental arrangement for the iron particles - castor oil emulsion

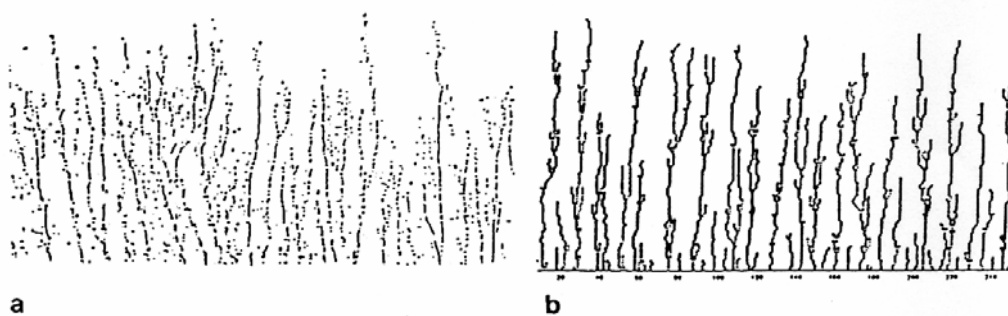


Fig. 6. a Structuring of the iron particles in the electric field of  $5.7 \text{ kV cm}^{-1}$ . b Structuring of the particles in the simulated experiment

mate direction of the formed iron particle strings is parallel to the electric field and is due to the polarizability (dipole-dipole interaction). In addition to the formation of dendritic structures a trembling of the iron particles can be observed which is due to a charge transport.

For the computer simulation we assume that the maximal growth of the electric charged strings takes place in these positions in which the electric field is very large. Long range, isotropic monopole interaction is simulated by using the diffusion model by Niemeier et al. (1984). For the simulation of the dendritic growth in field direction an anisotropic sticking probability (short-range anisotropic dipole-dipole interaction) is applied. The results of this simulation are shown in Fig. 6b.

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