A Demonstration of the Magnetic Domain and the Spontaneously Broken Symmetry by Magnetic Compasses

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On a crystal of a magnetic compass, we can enjoy ferromagnetism, anti-ferromagnetism, and spontaneously broken symmetry as natural phenomena, by our naked eyes, quite easily without any difficulty.

1. The magnetic compass

We use many ball-shaped magnetic compasses, each of which has a plastic rotator containing a small ferrite magnet of magnetic flux density 15Gauss at the maximum point on this device floating and confined in oil in a transparent spherical plastic container of diameter 3.0 cm and rotatable freely around the vertical axis. This magnetic compass was designed originally as an automobile accessory, and we marked a visible arrow on the rotator by luminous paint parallel to the magnetic dipole of the ferrite. These compasses have a very large magnetic dipole moment, to ensure that their mutual interaction is large compared to the Earth's field. Fig.1 shows the interaction on the case of several magnetic compasses.

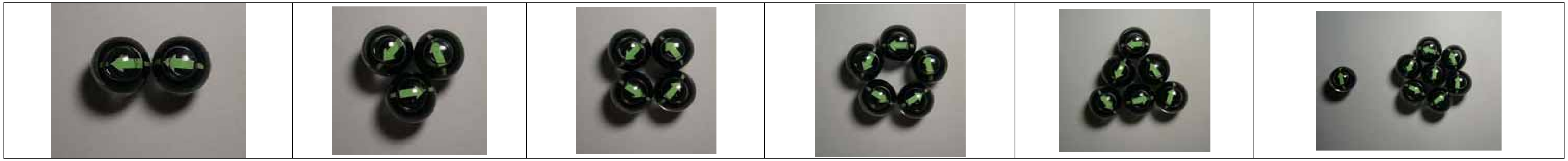


Fig.1

2. Ferromagnetism on 2-dimensional triangle lattice crystal of magnetic compass

We put the 1000 magnetic compasses densely onto a circular tray and got the two-dimensional triangle lattice crystal with some defects. The ferromagnetism can be observed as follows,

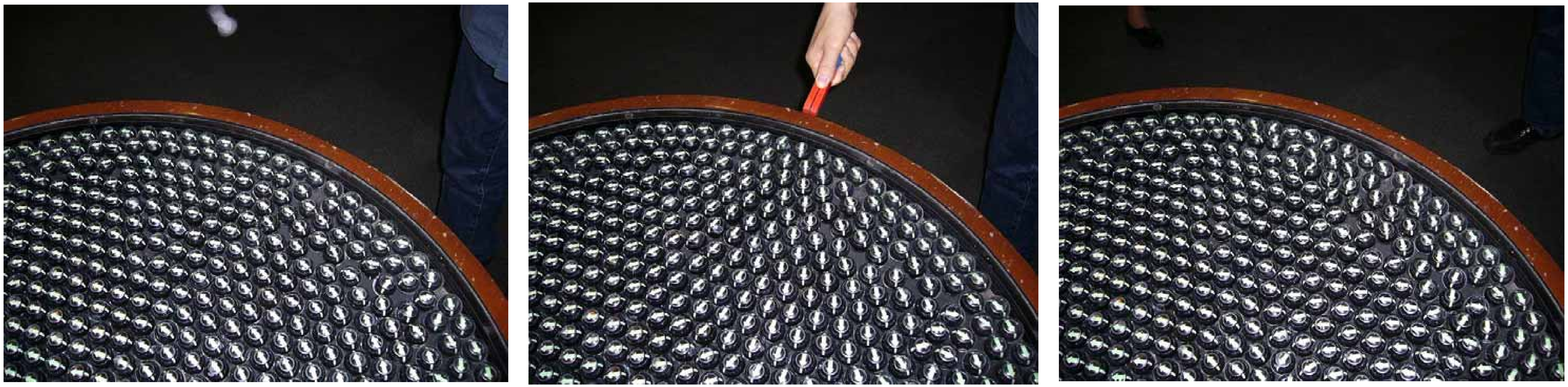
1. there are domains in which all the magnetic dipoles point one and the same direction independent to the Earth magnetic field direction,
2. the magnetic dipoles on the surface of the crystal point a surface tangential direction so that lines of magnetic force does not go out as much as possible.

Fig.2 Magnetic domains on a crysal of 1000 magnetic compasses

3. Magnetization

The magnetization can be observed as shown in Fig.3. Fig.3A shows an initial state without external magnetic field on this demonstration. At first, a bar magnet was put in a right side of the crystal (Fig.3B). The magnetic dipoles by the bar magnet pointed the direction of the external magnetic field. Fig.3C shows a state without external magnetic field after the bar magnet was taken away from Fig.3B. Magnetic hysteresis can be observed comparing Fig.A with Fig.C.

The movement of the magnetic wall, however, has not been observed yet. If the crystal was put into a spatially constant magnetic field changing slowly, the movement of the magnetic wall might be observed. It is very difficult to get such a magnetic field since the crystal is too huge.



A B C

Fig.3

4. Spontaneously broken symmetry (SBS) on the magnetic compass crystal

1. SBS

A Numerical simulation shows that the triangle lattice dipolar crystal has the 6-fold rotational symmetry and 6-fold degenerate groundstates as shown in Fig4. In Fig.2, it can be observed, locally, that the 6-fold rotational symmetry is spontaneously broken and some groundstate with a direction occurs in each domain. This is SBS which is one of the most important keywords in modern physics. For example, a domain in Fig.2 gives an analogous of SBS of Higgs filed. Higgs field is a basic field on the elementary particle physics and takes a role of the origin of mass. Higgs field has a rotational symmetry and infinite degenerate groundstates. The rotational symmetry is spontaneously broken and a groundstate with a direction is realized. Then, elementary particles, such as a quark or an electron have mass.

2. Nambu-Goldstone theorem

If one disturbs a magnetic compass in the ordered domain by putting a small magnet closer by hand, propagation of the local directional disturbance to the whole of the ordered domain can be observed. This demonstrates the Nambu-Goldstone theorem, that is, the creation of the long-range correlation wave in the system with SBS.

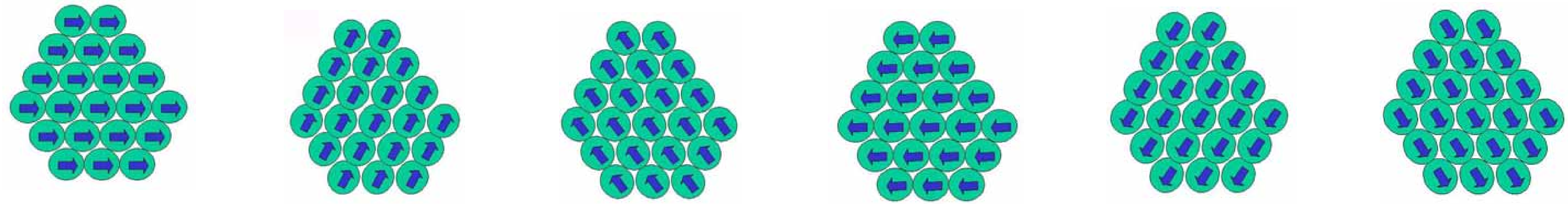
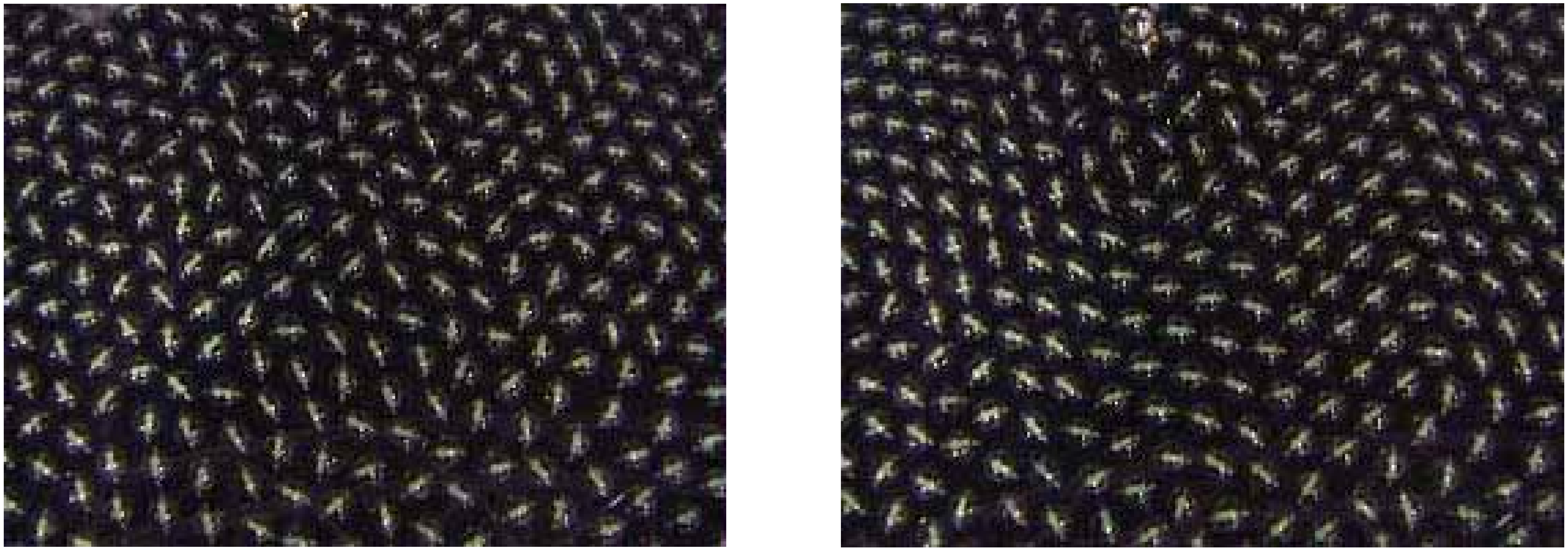


Fig.4

5. The phase transition at Curie point

We disturbed the magnetic compass crystal with a magnet and got a similar state such as a paramagnetic state for higher temperature than Curie point as shown in Fig.5A. When we waited for several seconds, a ferromagnetic state was realized as shown in Fig.4B. These are effective as a demonstration of the phase transition at Curie point.

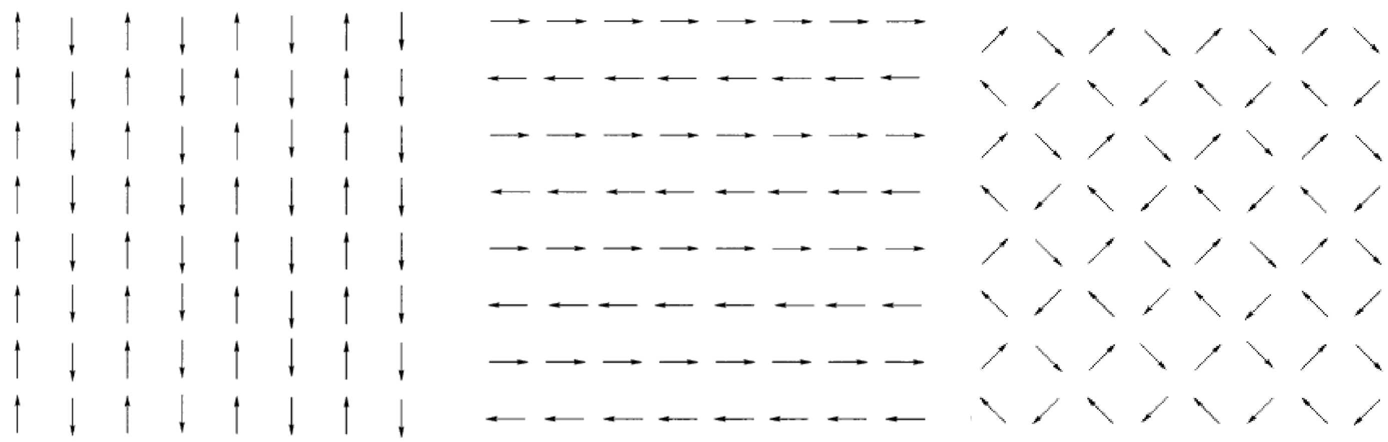


A B

Fig.5

6. Anti-ferromagnetism on 2-dimensional rectangle lattice crystal of magnetic compass

Anti-ferromagnetism can be observed on a rectangle lattice crystal of magnetic compass as shown in Fig.6, though ferromagnetism is realized on triangle lattice crystal as shown in Fig 2. Numerical simulation shows that Fig.7A is a groundstate on rectangle lattice dipolar crystal. There are continuously degenerate groundstates. These are linear summations of the dipole field for Fig.7A and one for Fig.7B. A ground state like as Fig.7C is made when the dipole field for Fig.7A adds to one for Fig.7B. These groundstates can be locally observed on Fig.6.



A B C

Fig.7

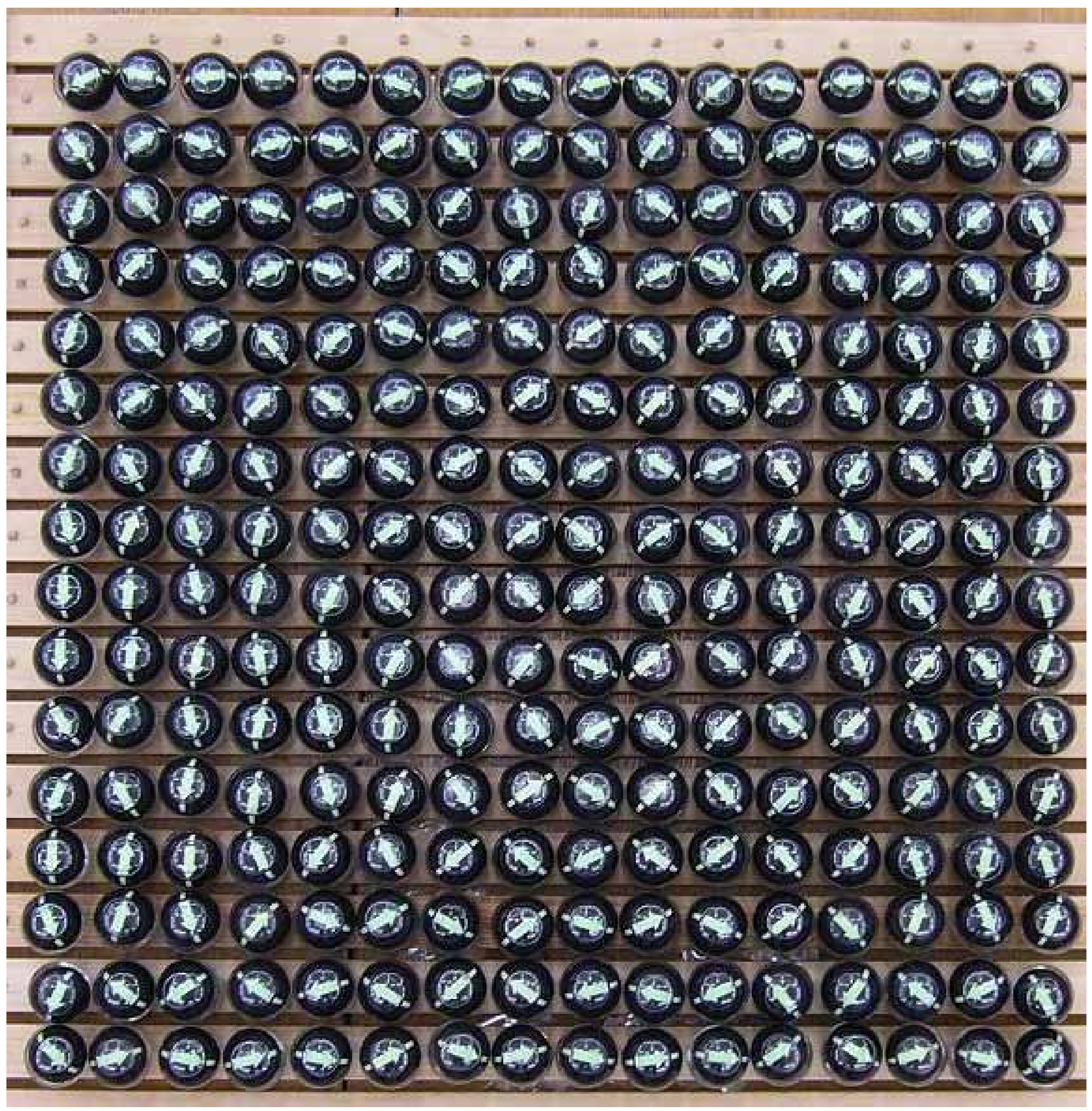
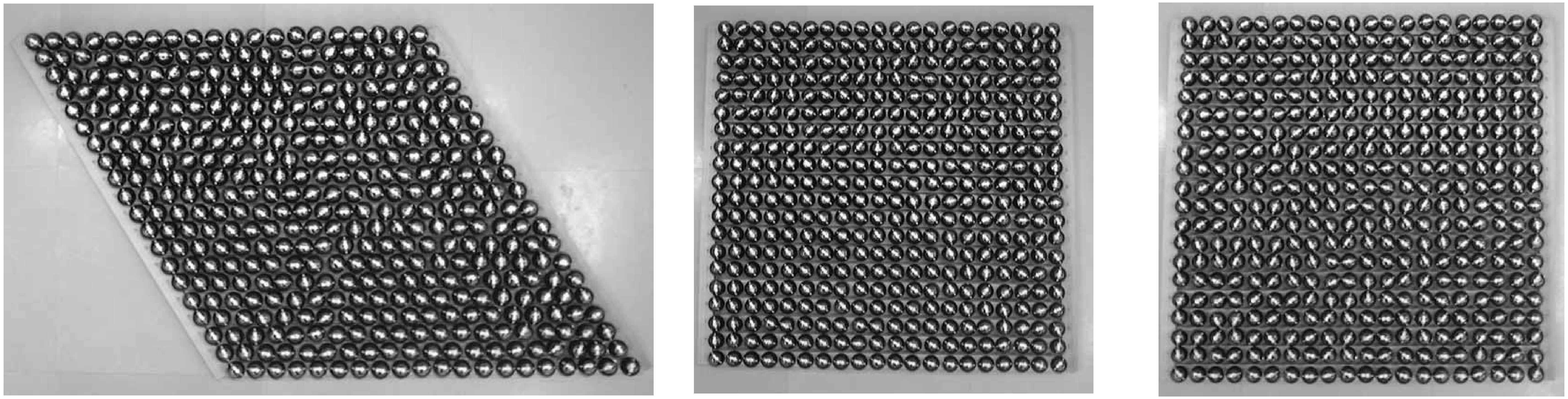


Fig.6

7. Meta-stable state of ferromagnetism on the rectangle lattice crystal

Though anti-ferromagnetism occurs on rectangle lattice crystals of magnetic compass, we found a ferromagnetism pattern on the rectangle lattice crystal, when a crystal structure was transformed from the triangle lattice arrangement to the rectangle one by the quasi-static process from Fig.8A to Fig.8B. The ferromagnetic pattern goes out and never come out, if we vibrate the set of compasses (Fig.8C). This ferromagnetism in Fig.8B may be a meta-stable state familiar in such as supercooling or supersaturation phenomena as Fig.8.



A B C

Fig.8

8. The line of magnetic force

We can enjoy the lines of magnetic force and their interactions, too, very easily, again and again.

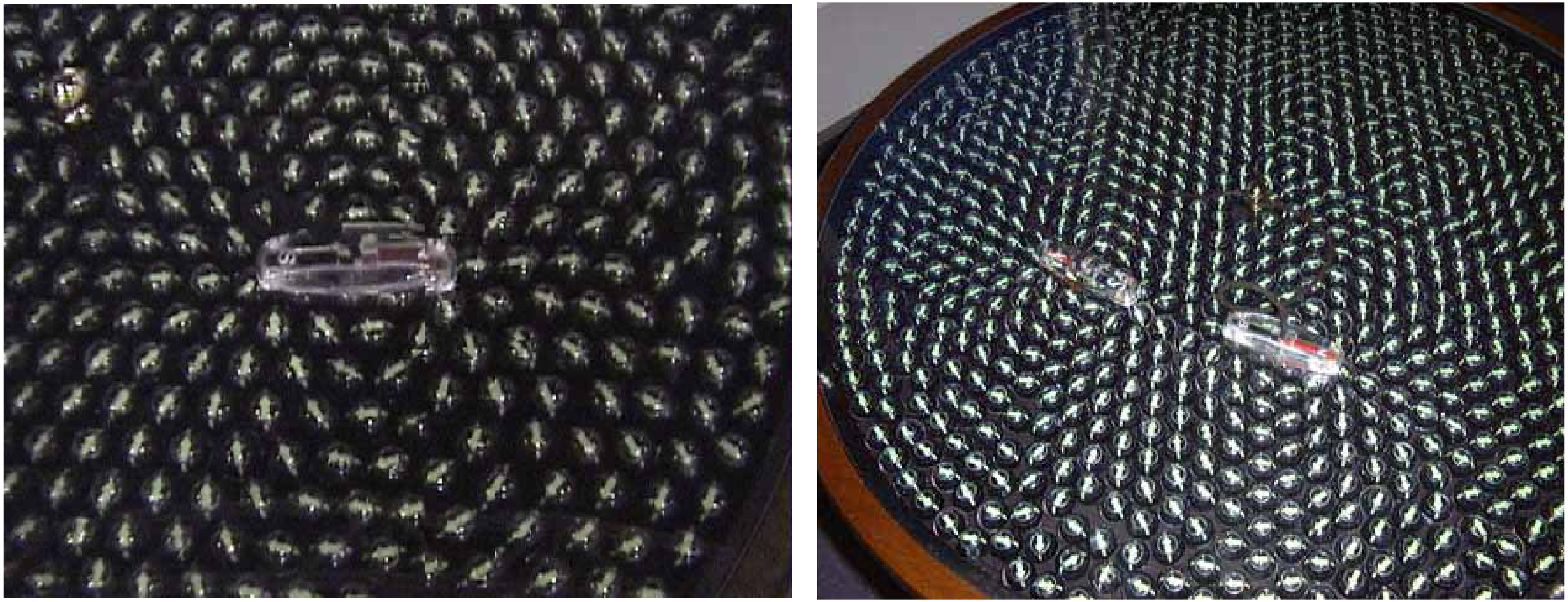


Fig.9