Observation and Quantification of a Liquid Motion under a Magnetic Field Gradient

Olivier Devos and Ryoichi Aogaki*
*National Research Laboratory for Magnetic Science, Japan and Science Technology Corporation,
1-1-56 Shibashimo, Kawaguchi, Saitama 333-0848*

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A new dynamic phenomenon in high magnetic field, *i.e.*, an expanding liquid ring formation according to parabolic distribution of magnetic field, was discussed. Then, a new experimental technique by using this phenomenon was developed in order to observe and quantify such motion of paramagnetic or diamagnetic liquid.

Recent investigations about the magnetic field effect on paramagnetic or diamagnetic materials have highlighted the existence of the magnetic force generated by the magnetic field gradient. So called Mose's or reverse Mose's effect is a good example that a liquid surface placed in high magnetic field remarkably descends or ascends corresponding to the magnetic field distribution.[1-3] Kitazawa *et al.* have lately proposed a new type of magnetic levitation by utilizing the same effect.[4] These phenomena are based on the mechanical equilibrium by the magnetic force. However, non equilibrium phenomena also can be considered.

In the present paper, we first present a new non equilibrium dynamic phenomenon, that is, an expanding liquid ring induced by the interaction between a paramagnetic liquid and the magnetic field with parabolic distribution. Then, in comparison with the usual method using a micro-balance, a new method to measure the magnetic property of the liquid is proposed.

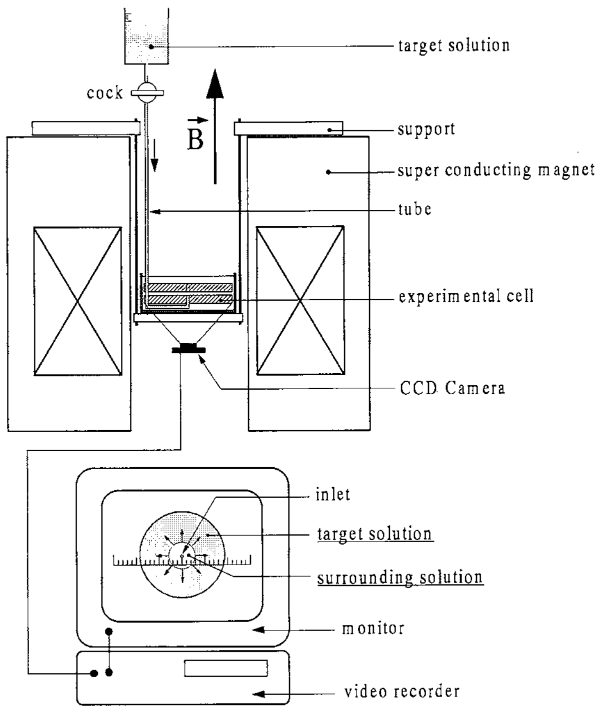

Figure 1. Schematic representation of the experimental device.

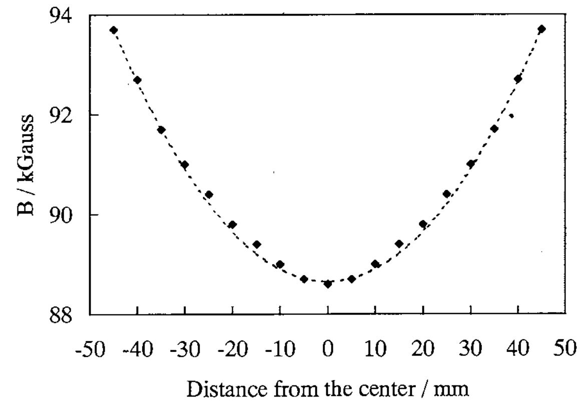

Figure 2. Magnetic field distribution in horizontal axis. Sumitomo Heavy Industries, HF-10-110VHF.

Firstly, let's imagine that a liquid called target solution (in the present case, containing sufficient amount of copper sulfate) is introduced into a cell illustrated in Figure 1. The cell consists of two round acrylic plates (8 cm in diameter) separated by a small gap (0.5 mm) being immersed in a large volume of another liquid, *i.e.*, surrounding solution (in this case, pure water). The whole keeps the cell horizontal inside the bore space of a superconducting magnet (Sumitomo Heavy Industries, HF-10-110VHF) (the bore diameter is 10 cm and the maximum magnetic field density is 10 T). Though the magnetic field distribution inside the bore changes with the vertical position, a typical horizontal parabolic distribution used in the present case

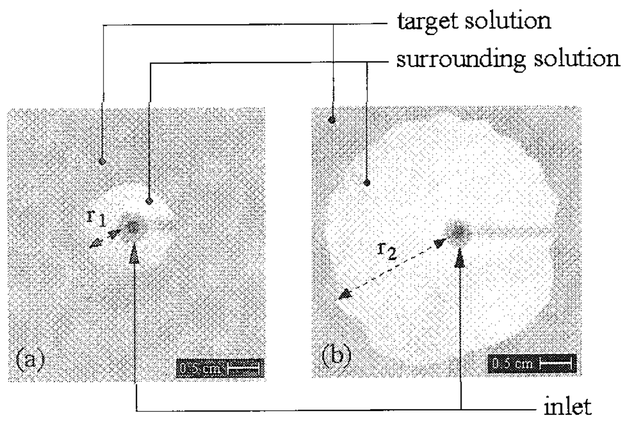

Figure 3. Photos obtained from the CCD camera after closing the cock. Colorless surrounding solution passed through the upper inlet and replaced the violet target solution. (a) t = 1 s, (b) t = 9 s. B = 5 T.

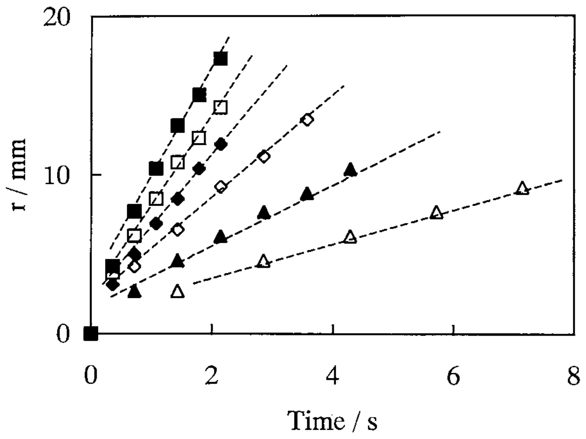

Figure 4. Inner radius of the ring versus time for different magnetic field intensities. (△) B = 3 T, (▲) B = 4 T, (◇) B = 5 T, (◆) B = 6 T, (□) B = 7 T, (■) B = 8 T.

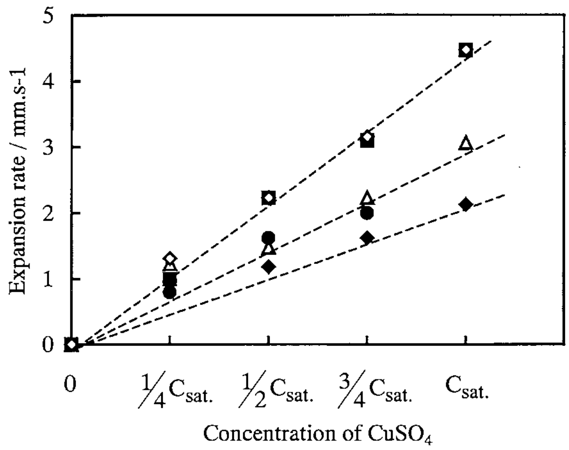

Figure 5. Expansion rate of the target solution versus concentration of the copper sulfate for different values of magnetic field. (◆) B = 5 T, (●) (△) B = 6 T, (■) (◇) B = 7 T. $C_{sat.}$: saturated concentration of copper sulfate.

is indicated in Figure 2, which has a minimum value at the bore center. The target solution was injected through a flexible tube connected to an inlet drilled at the center of the lower plate. After injection, the solution started to move outside where the magnetic field density is the strongest. From the other inlet of the upper plate, the surrounding solution flew into the gap to replace the target solution. As a result in Figure 3, an expanding ring of the target solution was observed. The inner and outer areas of the ring were filled with the surrounding solution. The motion was recorded by using a CCD camera placed under the cell. The target solution was a mixture of copper sulfate, Rhodamine B and potato starch; Rhodamine B was added to increase the contrast of the ring image for the camera, and the starch was used to hold the ring form of the solution. Owing to paramagnetism of copper sulfate solution, following the magnetic field distribution shown in Figure 2, an outward magnetic force was acted on the target solution, so that we can reasonably explain the expanding motion of the liquid ring observed in Figure 3.

Figure 4 shows the inner radius of the ring of the target solution against expansion time in various magnetic fields; the expansion rate increases with magnetic flux density. This result clarifies the effect of the magnetic force generated by paramagnetism which drives the solution outside. After a few seconds, all the data follow a straight line. The expansion rate was thus determined by the slope of this straight portion of the plot in Figure 4. As shown in Figure5, we can observe the rate obtained is proportional to the concentration of copper sulfate. The susceptibility of the target solution is in proportion to the concentration, so that the magnetic force induced is also expected to increase with the concentration.

From the quantitative dependence of the solution rate on the magnetic flux density and the concentration, these results allow us to quantify unknown magnetic susceptibility of liquid. We are now developing the theoretical approach of this phenomenon especially to determine characteristic parameters of liquids, such as susceptibility and concentration.

References and Notes

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