Electromotive Force Measurement for an Iron-Oxygen Cell in High Magnetic Field

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Using iron-oxygen reaction in sodium chloride solution, a new type of electrochemical cell operated by high magnetic field was fabricated. The electromotive force (EMF) of this cell reached about 8 mV. This value was about 100 times larger than expected by the magnetic energy.

Usual method to produce electricity by magnetic field is limited to the electromagnetic induction with electric power generator, which can be said as the conversion from mechanical energy to electric energy through magnetic field. Other types of conversion, e.g., from chemical energy to electric energy using magnetic field have not been regarded as possible targets. Because the chemical energy activated by magnetic field is much smaller than the thermal energy, electric potential changes only the order of 0.1 mV even at 10 T.[1-4] Therefore, it seems that the chemical energy conversion to electric energy triggered by magnetic field is almost impossible for usual equilibrium systems.

However, for the electrode system in nonequilibrium state, such speculation is not always acceptable.[5-7] Lately, it has been found that the metal dissolution rate in acidic solution increases or decreases with magnetic field, depending on the electrochemical conditions.[7-14] The rest potential was shifted to anodic side up to several 10 mV. If we can produce an electrochemical cell by using this phenomenon, the cell can generate much higher EMF than expected above.

The purpose of the present paper is thus to fabricate such electrochemical cell controlled by magnetic field. As to the cell having the electrodes under nonequilibrium state, we introduce the iron electrodes in NaCl solution with dissolved oxygen. In this cell, corrosion of iron occurs by dissolved oxygen on the both of the iron electrodes. This chemical dissolution reaction formally summarized as;
(i) anodic reaction[15]

$$Fe(OH)_3 + 3H^+ + 3e = Fe + 3H_2O \quad E^\circ = 0.047\ V \qquad (1)$$

(ii) cathodic reaction[15]

$$3/4O_2 + 3H^+ + 3e = 3/2H_2O \qquad E^\circ = 1.229\ V \qquad (2)$$

(iii) total reaction[15]

$$Fe + 3/4O_2 + 3/2H_2O \rightarrow Fe(OH)_3 \qquad (3)$$

Total reaction in Eq. (3) proceeds at the corrosion potential decided by the reactions in Eqs. (1) and (2). As shown in Fig. 1, the all is composed of the completely same electrodes, so that the EMF value is supposed zero in zero magnetic field.

The EMF value of this cell under high magnetic field is compared with the data of the cell having typical equilibrium electrode, i.e., copper/copper sulfate electrode. This electrode

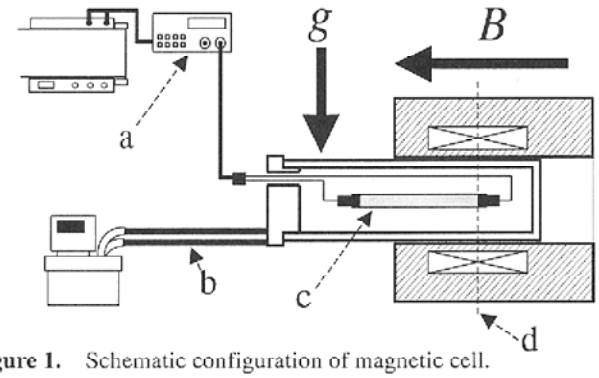

Figure 1. Schematic configuration of magnetic cell.
a; electrometer, b; outer tube to keep the temperature constant, c; magnetic cell, d; center of magnetic field, *B*; magnetic field, *g*; gravity.

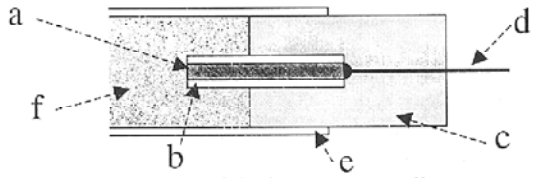

Figure 2. Electrode of the iron-oxygen cell.
a; iron rod (1 mm in diameter), b; Teflon tube, c; epoxy resin stopper, d; lead wire, e; Taygon tube,f; 0.5 moldm^{-3} NaCl solution.

composition is the same as one used by Aogaki et al for the measurement of electrode potential changing under high magnetic field.[2] The electrode reaction is expressed as[16]

$$Cu^{2+} + 2e = Cu \qquad E^\circ = 0.337\ V \qquad (4)$$

This electrode system exhibits the potential predicted by the equilibrium conditions. Therefore, as discussed above, when the completely same electrodes are used, the EMF value also can be expected zero.

Figure 1 illustrates the schematic configuration of the electrochemical cell settled in the bore space (10 cm in diameter) of the liquid-helium-free superconducting magnet (Sumitomo Heavy Industries, HF10-100VHF) under the magnetic flux density up to 10 T. The temperature of the bore space was kept at 27±1 ℃ with a water jacket.

The electrode was, as shown in Figure 2, made of iron rod (99.5% pure) with 1 mm in diameter and 25 mm long. The whole surface except for edge was covered with a poly-tetrafluoroethylene (Teflon ®). Two same electrodes were inserted into a plastic (Tygon ®) tube from opposite sides. The tube was 4 mm in diameter and 19.6 cm long, filled with 0.5 mol

dm^{-3} NaCl solution saturated with atmospheric oxygen. The formal expression of this cell is Fe | 0.5 mol dm^{-3} NaCl, atm. O_2 | Fe. One of the two electrodes was placed at the bore center, i.e., the highest magnetic field, whereas another remained far from the center, where the magnetic flux density decreased to about 20% of the highest value.

To compare the EMF value of this cell with other cell in equilibrium state, the same type of cell composed of copper and copper sulfate solution was made. This cell is formally expressed as: Cu | 0.5 mol dm^{-3} $CuSO_4$, 1 mol dm^{-3} H_2SO_4 | Cu. The EMF values of these cells were compared under various magnetic flux densities.

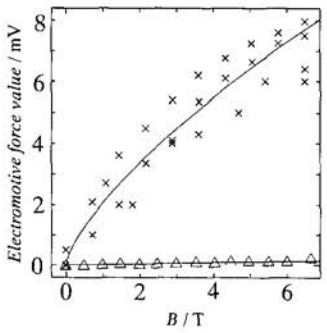

Figure 3. EMF values vs. magnetic flux density. ×; iron-oxygen cell, △; copper-copper sulfate cell. $T = 300 \pm 1$ K.

Figure 3 exhibits the EMF values against various magnetic flux densities for both cells. The EMF value obtained with the iron-oxygen cell increases as the magnetic flux density increases. At 6.5 T, the EMF value attains about 8 mV.

On the other hand, the cell for copper reaction does not generate meaningful EMF value even at 6.5 T; all the data are scattering around 0.1 mV. The energy of an electron activated by the magnetic field can be easily estimated by considering the product of the Bohr magneton and magnetic flux density of 6.5 T; 3.8×10^{-4} eV, i.e., equal to 0.38 mV in EMF. This result agrees well with the result of the copper cell.

The iron-oxygen cell yielded large EMF value in high magnetic field. It attained 8 mV, which is 100 times larger than estimated by the magnetic energy. From these results, it can be said that such unexpected EMF value is yielded from the difference of corrosion reaction rate provoked by applied magnetic field. Because of the low reaction rate, actual application of this cell as a power source can not be expected. However, if we can choose suitable materials, there may be a large possibility to fabricate high-power cells. The exact mechanism of the EMF generation is now investigating.

References

1 R. Aogaki, *Electro Magnetic Compatibility*, **8**, 92 (1995).
2 R. Aogaki, *Electro Magnetic Compatibility*, **7**, 74 (1994).
3 H. Hyashi, *Chemical Industry*, **48**, 783 (1997).
4 "Jikken Kagaku Kouza," 4th ed, ed by the Chemical Society of Japan, Maruzen, Tokyo (1991), Vol. 9, p.572.
5 R. Aogaki, K. Fueki, and T. Mukaibo, *Denki Kagaku*, **44**, 89 (1976).
6 R. Aogaki and K. Fueki, *J. Electrochem. Soc.*, **131**, 1295 (1984).
7 R. Aogaki, *Chemical Industry*, **48**, 788 (1997).
8 M. A. Ghabashy, *Anti-Corrosion*, **35**, 12 (1988).
9 A. Chiba, W.-C. Wu, and A. Terashima, *J. Mater. Sci.*, **31**, 3821 (1996).
10 A. S. Bahaj, S. A. Campbell, F. C. Walsh, and J. F. D. Stott, *Microb. Corros.*, **2**, 228 (1992).
11 W. S. - S. Yee and A. S. Bradford, *ASTM STP*, **1148**, 90 (1992).
12 A. Terlain and T. Dufrenoy, *J. Nucl. Mater.*, **212**, 1504 (1994).
13 S. Yasukawa, K. Kouichi, K. Yoshida, and K. Miyaji, *Bosyoku Gijutu*, **35**, 348 (1986).
14 F. De. Schutter, J. Dekeyser, J.-L. Walnier, and H. Tas, *Fusion Technol.*, **2**, 981 (1986).
15 N. Sato, "Electrode Chemistry," Nittetu-Gijutu-Jyoho Center, Tokyo (1994), Vol. II.
16 "Denki Kagaku Binran", 4th ed, ed by the Electrochemical Society of Japan, Maruzen, Tokyo (1985), p.72.