THE EFFECT OF AN EXTERNAL MAGNETIC FIELD ON THE SOLUBILITY OF OXYGEN IN WATER

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ABSTRACT

This work describes observations on the effect of magnetic fields on the equilibrium solubility of pure oxygen in water at 25°C. It was found that neither a weak rotating magnetic field nor a uniform static magnetic field (up to 10 kG) changed the solubility of oxygen in water within experimental accuracy (1%), in contrast to previously reported data. This supports recent findings on the size of effects due to weak and moderate magnetic fields on the physico-chemical properties of pure water and/or water solutions.

INTRODUCTION

The solubility of atmospheric oxygen in water under the effect of a magnetic field has been investigated by Klassen et al. [1]. In this work, however, the kinetics of the oxygen dissolution rather than the equilibrium solubility shift due to the magnetic field were measured. In later papers [2,3], Klassen states that the magnetic field increases the solubility of gases in water. Several similar findings concerning this effect remain on a qualitative level (see, e.g., refs. 4—6). However, numerous results of this kind relating to changes in other physico-chemical properties of water and/or water solutions induced by some type of magnetic field have later been disproved (see, e.g., ref. 7). The changes reported in pH [8], viscosity [2], absorption spectra [14], etc., were not reproduced in careful experimental studies [9—11,15].

However, there are a number of reproducible experimentally-found changes in some physico-chemical properties of water, water solutions, or pure gases. Although the changes have not yet been explained theoretically, some of them seem to be compatible with thermodynamic or quantum-mechanical analyses of the interaction between the substance studied and the corresponding magnetic field. High magnetic fields seem to have a weak effect on e.g. viscosities and diffusivities in water solutions [10,11], crystal growth or dissolution rates [12], chemical equilibrium and/or kinetics (see, e.g., ref. 13). Experimental data confirm that the effect of a magnetic field on the physico-chemical properties of water is always small, usually being of the order of 1 part in 10^2—10^6 in fields up to 10^4 Oe.

This is comparable with the energy of interaction E of a substance of molar susceptibility χ placed in a magnetic field H, $E = -\chi H^2/2$; with the

thermal energy RT, at 25°C; or e.g., with the hydrogen bond energy. Assuming the average diamagnetic susceptibility of water and a field H of about 10^4 Oe, the available magnetic interaction energy E differs from that quoted above by eight orders of magnitude. Following Schieber's derivation [12] of the relation analogous to the Clausius—Clapeyron equation, in this case for the influence of a magnetic field on the equilibrium solubility of oxygen in water, the difference in the magnetic induction of the sample of pure oxygen and that of the solution, ΔB, is given by

$$\Delta B = 4\pi H(\chi_{O_2} - \chi_{sol})$$

where χ_{O_2}, χ_{sol} are the volume susceptibilities of pure oxygen and its water solution, respectively, and H is the uniform static magnetic field intensity. Defining the Gibbs thermodynamic potential

$$G(P, T, H) = U - TS + PV - BH/8\pi$$

where the symbols have their usual meaning [12], and using

$$dU = TdS - PdV + HdB/8\pi$$

it follows that

$$dG = -SdT + VdP - BdH/8\pi$$

In equilibrium, where the Gibbs potential in pure oxygen, G_{O_2}, equals the potential in its water solution, G_{sol}, and $dG = d(G_{O_2} - G_{sol}) = 0$,

$$\left(\frac{\partial T}{\partial H}\right)_P = -\frac{\Delta B}{8\pi \Delta S}$$

Integrating the last equation between equilibrium temperatures without and with magnetic field, $T_{H=0}$ and $T_{H>0}$, respectively, and substituting for ΔB from the first equation, we obtain

$$\Delta T = T_{H>0} - T_{H=0} = -H^2(\chi_{O_2} - \chi_{sol})/4\Delta S$$

Replacing ΔS by Q/T, where Q is the latent enthalpy of oxygen dissolution in water per unit volume, and T is the equilibrium temperature at $H = 0$ Oe, the last relation becomes

$$\Delta T = -H^2 T(\chi_{O_2} - \chi_{sol})/4Q$$

Assuming that Wiedemann's law is valid here, the volume magnetic susceptibility of solution χ_{sol} is taken as the weighted sum of the volume susceptibility of oxygen gas and that of pure water. Introducing the values taken from a standard textbook [16], $Q = 5.35 \times 10^6$ erg cm^{-3} and $\chi_{O_2} - \chi_{sol} = 0.86 \times 10^{-6}$ cm^3 g^{-1}, the last relation shows that at 25°C and for a field of 10^5 Oe, the effect is the same as that caused by a temperature change of 0.12°.

A similar simple analysis can also be carried out for water moving in a non-uniform unsteady magnetic field [17]. However, thermodynamics cannot predict the effect of a magnetic field upon the composition of a given substance. The conditions under which the above theory is valid were not investigated and therefore the question cannot be resolved theoretically with any certainty, particularly for a non-uniform rotating field. For this reason,

experimental measurement is preferred. The aim of this work was to determine experimentally whether the solubility of oxygen in water at room temperature and atmospheric pressure is significantly affected by (i) a uniform static magnetic field, or (ii) a weak rotating magnetic field.

EXPERIMENTAL

Distilled water taken from laboratory supply (conductivity $5 \times 10^{-6}\ \Omega^{-1}$ cm^{-1}) was used for both experiments. The simple apparatus depicted in Fig. 1 was employed. Two 600-ml flasks were filled with 250 ml water. The flasks were evacuated for 9—10 min and the water was then saturated with pure oxygen, again for 9—10 min; this was repeated six times, after which the apparatus was closed. The water levels in both arms of the glass U-tube connecting the flasks were equal.

An electromagnet (Type JM No. 384) of E.S.R. Spectrometer Model J.E.S. 3B Japan Electron Optics Lab. Co. Ltd., Tokyo, equipped with a regulated magnet power supply and heat exchanger was used for experiments utilizing a uniform static magnetic field. The homogeneity of the magnetic field for a 60-mm air gap using pole pieces 300 mm in diameter was within $\pm 10^{-4}\%$. One flask was placed in the magnetic field (field vectors parallel to the water—oxygen interface), while the other flask remained outside this field (though still inside the earth's magnetic field). No effect was observed at either $B = 3500$ G (the flask was exposed to the field for 5 h) or at $B = 10^4$ G (80 min exposure).

A permanent magnet was placed below one of the flasks for experiments utilizing a weak rotating magnetic field. The magnet was composed of two and/or eight ferrite slabs $45 \times 30 \times 5$-mm in size. The maximum strength of the field was 550 G at the surface of the slab, and 230 G 5 mm above its edge. In a series of four experiments (with and without a glass-covered nail
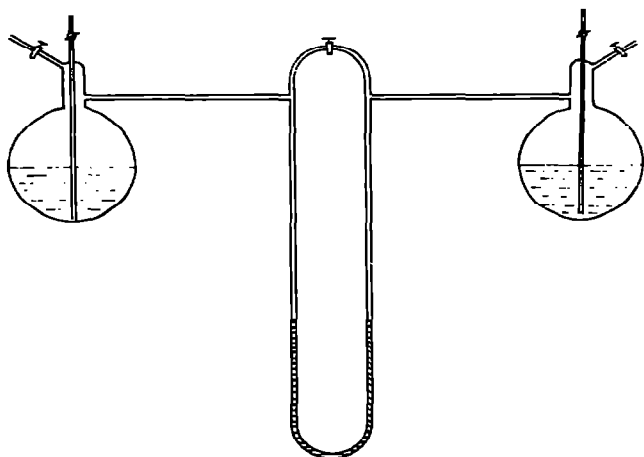

Fig. 1. Simple glass apparatus for testing the effect of a magnetic field on the equilibrium solubility of oxygen in water.

as a stirrer inside the flask) the magnet was rotated for 14 days at 200—1000 r.p.m. The experimental error of the apparatus was below 0.5% of the oxygen volume dissolved at equilibrium under the experimental conditions used. The magnetic field was found to have no effect on the oxygen solubility.

Another piece of apparatus, developed by Dr. Václav Linek from the Chemical Engineering Department of the Prague Institute of Chemical Technology was also used for this measurement. The apparatus allowed the volume of the oxygen—water system to be monitored over a long period. The experimental error was less than 0.7% of the oxygen volume dissolved at equilibrium under the experimental conditions used. Here again 100 ml water was repeatedly de-aerated in vacuo and saturated by pure oxygen. The apparatus was then closed and maintained at constant temperature ($25 \pm 0.02°C$) and pressure (about 760 torr). Both two-slab and eight-slab rotating permanent magnets were used, with, as well as without, the stirrer inside a 250-ml flask. No effects due to the weak rotating magnetic field were observed throughout four 30-day experiments.

CONCLUSIONS

These observations are consistent with the thermodynamic estimate given above. The expected shift in solubility due to the magnetic field is so small that it is below the detection limit of the experimental arrangements used. It is probable that the microstructural processes taking place in the aqueous solution of oxygen in a magnetic field are similar to those involved with observed changes in shear viscosity water in a magnetic field. The relative change in kinematic viscosity of pure water in a uniform static magnetic field increases up to 0.25% in a field of 12×10^3 G [10]. It is therefore likely that the solubility of oxygen is also altered slightly in a magnetic field, though quantitative determination of such subtle differences was not the aim of this work.

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