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In Situ Measurements of Solution Conductivity in Microwave Field

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Abstract: The curves of the conductivity as a function of temperature for 24 kinds of solutions have been in situ measured both in the microwave field and in absence of microwave field. The results indicated that the relationship between the conductivity in microwave field ($\overline{L}_w$) and temperature (T) can be expressed by an equation $\overline{L}_w = a' + b'T + c'T^2$, similar to the one that is valid in absence of the microwave field $\overline{L}_n = a + bT + cT^2$. Conductivity in the absence and presence of microwave field can be linked by the equation $\ln \overline{L}_w = A + B\overline{L}_n + C\overline{L}_n^2$.

Key words: Microwave, Solution, Conductivity

CLC Number: O 646 **Document Code:** A

1 Introduction

The dynamic properties of the water solution consist of mobility, conductance, migration, diffusion and viscosity, etc. There are internal relations among them. One property can be deduced from another[1]. Solution conductivity is a physical quantity that expresses the conductive capability of solution. It depends on the temperature, concentration, electrode area, and electrode distance. According to Debye-Hückel-Onsager conductance theory, the conductivity is related to the electric field force and electrophoretic force in microcosm or to the dielectric constant, medium viscosity, temperature, and concentration of the solution in macrocosm. Microwave, which is an electromagnetic wave of high frequency, has effect on the properties above. To better study the electric-chemical properties of the solution un-

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der microwave field, the in situ conductivity of solution under microwave irradiation was measured, and the theoretic model has been proposed in this paper.

2 Experimental Devices and Process

Microwave irradiation causes solution temperature increase. The conductivity of solution under microwave irradiation ($\overline{L}_w$) was in situ measured successively in different temperatures and the conductivity of the solution heated ($\overline{L}_w$) in the same way by electric furnace was also measured. The influence of the microwave irradiation can be assessed by comparison of the two.

The devices used in the present experiment are schematically shown in Fig. 1. In Fig. 1 microwave furnace (1) has power of 750 w, frequency of 2450 MHz. The support (3) can rotate to make the concentration and the temperature of solution well distributed. In the case of conventional heating, the stirrer (9) plays the same role. Thermocouple (5) and conductance electrode (6) were placed in the solution in same position to reduce the error from the possible difference of temperature and concentration. Conductance electrode must not be affected by microwave, and should have good chemical stability. Before experiments, platinum conductance electrode sparks, and silver did not have good chemical stability. Copper can reflects microwave, so copper conductance electrode is not affected by microwave irradiation, and has better chemical stability. Copper conductance electrode consisted of a couple of copper wires (12), Al_2O_3 ceramic tube (11) and copper coil (10). Epoxide resin has been used to seal the tube, see Fig. 1(c). The copper coil (10) was used to shield off microwave. The copper conductance electrode was inserted for 5 minutes to the boiling solution, which conductivity would be measured, to make its surface stable. Then the electrode constant was standardized with 0.1 mol/L standard KCl solution. This conductance electrode should be

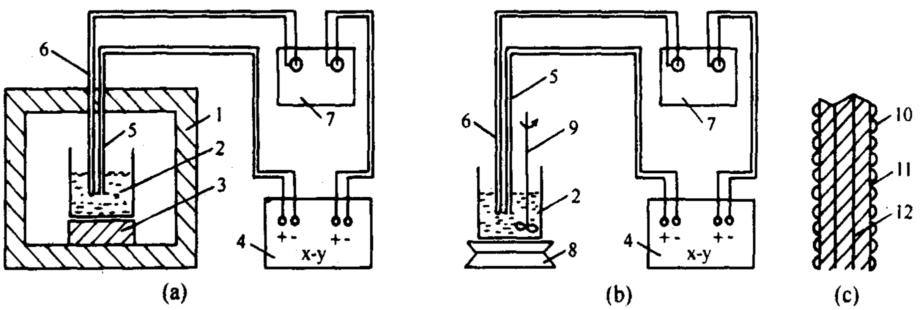

Fig. 1 Experimental device

1. microwave furnace; 2. solution; 3. suport; 4. x-y functional recorder; 5. conductance electrode; 6. thermocouple; 7. conductivity apparatus; 8. electric furnace; 9. stirrer; 10. copper coil; 11. Al_2O_3 ceramic tube; 12. copper wire

used to measure the solution conductivity $\overline{L}_n$ and microwave conductivity $\overline{L}_w$.

In measuring process, the copper conductance electrode was directly linked with the conductivity apparatus (DDS-11A). The conductivity of the solution was changed into electric potential difference by the conductivity apparatus, and was transmitted to Y-axis of X-Y functional recorder (XWTD-264). The electric potential difference of the thermocouple was transmitted directly to X-axis The curve of conductance (S)～ electric potential difference (mV) was been drawn in X-Y functional recorder. Electric potential difference of the thermocouple was translated into the temperature (℃), and the conductivity $\overline{L}_n$ or microwave conductivity $\overline{L}_w$ was also gotten by calculation. The conductivity ($S \cdot m^{-1}$)～ temperature (℃) curve could be drawn.

3 Results and Discussion

The some curves of the normal conductivity $\overline{L}_n$～ T and the microwave conductivity $\overline{L}_w$～ T of 24 kinds of solutions are presented in Fig. 2 to Fig. 7, it could be divided into three types, *i. e.*, parallel, cross and separation. The parallel types were divided into slope-increasing and slope-decreasing. KCl solution was a typical slope-decreasing, see Fig. 2. $CuCl_2$ was a typical slope-increasing, see Fig. 3. The trends of the curves of the conductivity $\overline{L}_n$～ T and microwave conductivity $\overline{L}_w$～ T of parallel type were alike, but the $\overline{L}_w$ value was always higher than $\overline{L}_n$. Similar phenomena have been observed for the solutions of HCl, $NiCl_2$, $ZnCl_2$, $FeCl_3$, $MgSO_4$, Na_2CO_3, K_2CO_3.

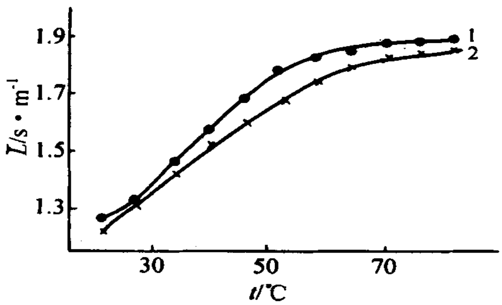

Fig. 2 $\overline{L}_n$～ T and $\overline{L}_w$～ T curves of KCl solution
1) microwave; 2) electric furnace

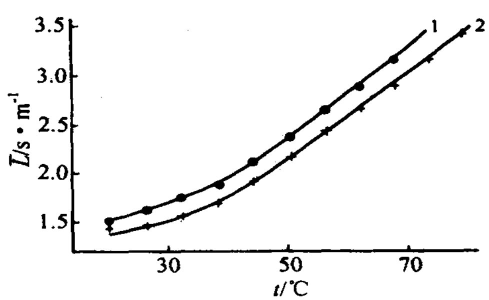

Fig. 3 $\overline{L}_n$～ T and $\overline{L}_w$～ T curves of $CuCl_2$ solution
1) microwave; 2) electric furnace

In the cross type, the curves of $\overline{L}_w$～ T and $\overline{L}_n$～ T intersect each other such as in the case of NaOH solution, see Fig. 4. At low temperature, $\overline{L}_w$ value was higher than the $\overline{L}_n$. Similar phenomena have been observed for the solutions of NH_4Cl, $CrCl_3$, KNO_3, $FeSO_4$, $Fe_2(SO_4)_3$, $CoSO_4$, $MnSO_4$, $ZnSO_4$, Na_2SO_3.

In the separation type, the distance between $\overline{L}_w$～ T and $\overline{L}_n$～ T curves increased with the

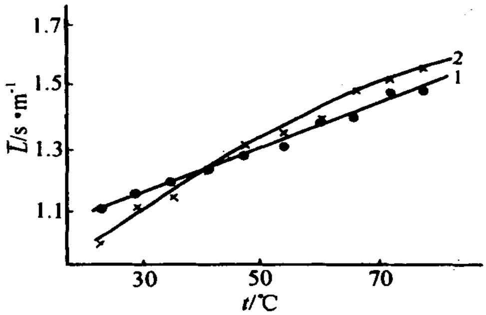

Fig. 4 $\overline{L}_n$～T and $\overline{L}_w$～T curves of KOH solution
(1 microwave; 2 electric furnace)

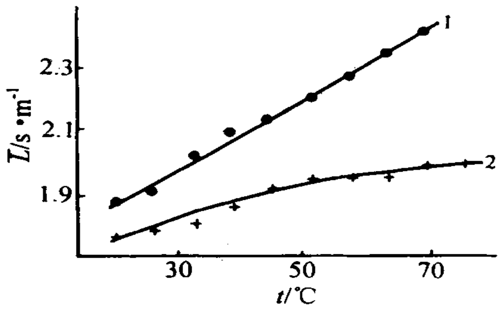

Fig. 5 $\overline{L}_n$～T and $\overline{L}_w$～T curves of H_2SO_4 solution
(1 microwave; 2 electric furnace)

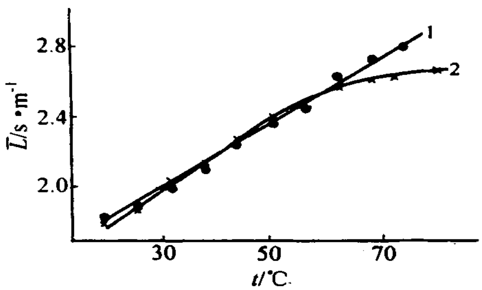

Fig. 6 $\overline{L}_n$～T and $\overline{L}_w$～T curves of $ZnSO_4$ solution
(1 microwave; 2 electric furnace)

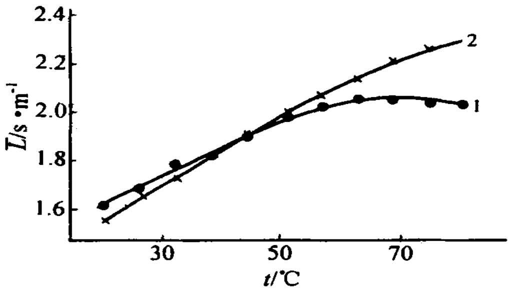

Fig. 7 $\overline{L}_n$～T and $\overline{L}_w$～T curves of HNO_3 solution
(1 microwave; 2 electric furnace)

temperature increased, and the $\overline{L}_w$ values ware always higher than $\overline{L}_n$, as in the case of H_2SO_4 solution shown in Fig. 5. These types of curves were also observed in the solutions of NaBr, $NiSO_4$ and $FeSO_4 \cdot (NH_4)_2SO_4$.

Other types of curves were nothing new but composition of parallel, cross or searate curves, such as $ZnSO_4$ solution of double cross type, see Fig. 6, the slope-decreasing cross type of HNO_3, see Fig. 7, and the slope-increasing cross type of Na_2SO_4 solution, see Fig. 8.

Despite the fact that curves were parallel, cross or separate, they all could be fitted well by quadratic equation regress. They were similar to the normal experimental formula[2], as follows:

$$\overline{L}_n = a + bT + cT^2 \quad (3)$$

and

$$\overline{L}_w = a' + b'T + c'T^2 \quad (4)$$

where $\overline{L}_n$: normal conductivity ($S \cdot m^{-1}$), $\overline{L}_w$: microwave conductivity ($S \cdot m^{-1}$), T: temperature (℃), a, b, c: coefficients of temperature influence on normal conductivity, a', b', c': coefficients of temperature influence on microwave conductivity.

At room temperature the microwave conductivity $\overline{L}_w$ of water solution in microwave field was usually higher than normal conductivity $\overline{L}_n$. When the temperature increased, both $\overline{L}_w$ and $\overline{L}_n$ increased, but in some solutions the increase rate of $\overline{L}_w$ was smaller than that of $\overline{L}_n$, the curves of $\overline{L}_w \sim T$ and $\overline{L}_n \sim T$ crossed and the $\overline{L}_w$ value was lower than the $\overline{L}_n$ at high temperature. These phenomena mainly existed in solutions of nitrates, sulfates and sometimes of chlorides as NH_4Cl, and $CrCl_3$.

The $\overline{L}_w$ and $\overline{L}_n$ were regressed according to $\overline{L}_w = f(\overline{L}_n)$ at different temperature, the equations were gotten as follow:

$$\overline{L}_w = \exp(A + B\overline{L}_n + C\overline{L}_n^2) \quad (5)$$

or

$$\ln\overline{L}_w = A + B\overline{L}_n + C\overline{L}_n^2 \quad (6)$$

where, A, B, C were coefficients.

The regression coefficient r^2 of equation (6) for each of tested solutions was over 0.99. It indicates that equation (6) could be used to relate the $\overline{L}_w$ and $\overline{L}_n$ well.

4 Explanation of Microwave Conductivity

The solution can conduct electricity, because it contains the ions. The ions can transmit electric current by directional movement under electric field. The movement of ions has great effect on intensity of conductivity of solution. The higher the speed, the larger the conductivity. Microwave is electromagnetic wave with high frequency, and can make polar molecular move, vibrate, or rotate at high speed. The conductivity of solution increases if the ions move in direction of external electromagnetic field. On the other hand, the conductivity decreases if the ions vibrate or rotate at high speed and not move or move slowly at the direction of external electromagnetic field. Further researches indicate that in microwave field, the mean energy barrier, which ions must surmount as they transit, is the function of temperature (will be published in other journal).

5 Conclusions

(1) Microwave conductivity, like normal conductivity, increases as temperature increases. It can be shown with quadratic equation, i.e.

$$\overline{L}_w = a + bt + ct^2$$

(2) Microwave conductivity can be related with normal conductivity by following formula:

$$\ln\overline{L}_w = A + B\overline{L}_n + C\overline{L}_n^2$$

References:

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[2] Jiang Hanying. Metallurgical Electrochemistry [M]. Beijing: Higher Education Publishing House, 1983: 21.

微波场溶液电导率的现场测定

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摘要: 现场测定了溶液在微波场和非微波场中的电导率~温度函数, 结果表明在微波场与非微波场中溶液的电导率($\bar{L}_w$)随温度的变化可分别用方程$\bar{L}_w = a' + b'T + c'T^2$和$\bar{L}_n = a + bT + cT^2$表述, 类似于非微波场中的溶液电导率, 而$\bar{L}_w$和$\bar{L}_n$两者的关系则可表示为$\ln\bar{L}_w = A + B\bar{L}_n + C\bar{L}_n^2$。以上 $a, b, c, \cdots A, B, C$ 等皆为经验系数。

关键词: 微波; 溶液; 电导率