Experimental and the Theoretical Studies of the Dielectric Properties of DMSO–H₂O Mixtures

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Abstract This paper focuses on the measurement of the permittivity of dimethyl sulfoxide (DMSO)–water (H₂O) mixture solutions, at 2.45 GHz by using a resonant cavity perturbation method. A specific phenomenon was found, in that the imaginary part of the permittivity for the mixture solution was larger than the imaginary part for each component. Theoretical calculation indicated that the reason for that phenomenon was that the high frequency friction of the mixture was larger than that of each component. When comparing the theoretical results with the experimental data, it was found that the classical Debye equation must be modified in order to calculate the complex permittivity.

Keywords DMSO–H₂O · Permittivity · Specific phenomenon · Mixture formula

1 Introduction

As early as 1980, the use of microwaves was proposed for accelerating chemical reactions by their efficient heating of the reactants. For better application of microwaves in chemistry, the interaction between microwaves and the mixtures needed to be further studied [1, 2]. Usually, the permittivity was used to describe the molecular polarization in the mixture and consequently to calculate the reflection and absorption of microwaves [3]. Thus, the most important fundamental issue is to know the molecular polarization in the mixture at the microwave frequency.

The dielectric properties of dimethyl sulfoxide (DMSO) and its mixtures have aroused much interest among scientists in the last several decades [4–6]. DMSO is an important reactant and a “super solvent”, being highly polar and having excellent electron-donor properties [7, 8]. Also, water as the source of life, has been extensively studied and focused
on by scientists. To investigate the absorption and reflection of microwaves by both water and DMSO, it is necessary to know their dielectric properties. For the simple mixtures of DMSO and water, a combination of strong hydrogen bonds and hydrophobic interactions leads to remarkably non-ideal physical properties, such as decreased density, longer rotational reorientation relaxation times, lower diffusion coefficients, and negative changes in molar enthalpy and volume [9–17]. Additionally, the freezing point shows a strong dependence of concentration. Generally, the permittivity of mixtures lie between the permittivities of its components. Thus, in this paper the permittivity of DMSO–H2O mixture solutions was measured by a resonant cavity perturbation method at 2.45 GHz, and the relaxation time was calculated using thermodynamic, statistical perturbation theory and Eyring’s theory.

2 Experimental

The measurement system (Fig. 1) consists of a vector network analyzer Aglient E8362B and H105 rectangular resonant cavity of waveguide BJ26. The rectangular resonant cavity technique based on the perturbation theory is a popular method for measuring the permittivity using perturbation formula [18].

The permittivity of DMSO and deionized H2O mixture system with different volume ratios were measured at 298 K. The results are shown in Fig. 2. A specific phenomenon can be seen from Fig. 2, that the imaginary part of permittivity for the mixtures is greater than that of each component. Meanwhile, the permittivity of the mixtures reaches a maximum when the DMSO–H2O volume ratio is 0.65. Obviously, this specific phenomenon violates the general classical mixture theory.

3 Results and Discussion

3.1 Mixture Formulas Analysis

The effective complex permittivity of a mixture can be obtained using the classical medium theory. Suppose that the medium is isotropic and spherical, when solvent $i$ is mixed into the isotropic base solvent $e$, the effective complex permittivity of the mixture can be implicitly described in the following formula [19]:

$$\frac{\varepsilon_{\text{eff}} - \varepsilon_e}{\varepsilon_i + \varepsilon_e + \nu(\varepsilon_{\text{eff}} - \varepsilon_e)} = \alpha \cdot \frac{\varepsilon_i - \varepsilon_e}{\varepsilon_i + \varepsilon_{\text{eff}} + \nu(\varepsilon_{\text{eff}} - \varepsilon_e)}$$

(1)