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CONDUCTIVITY OF SODIUM HALIDES IN BINARY MIXTURES OF ETHYLENE AND PROPYLENE GLYCOL WITH WATER

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Abstract

The conductivity behavior of sodium halides (NaBr and NaCl) in binary solvent mixtures of water with ethylene glycol (EG) and propylene glycol (PG) is crucial for optimizing electrolyte formulations in industrial applications. This study investigated the effects of varying glycol mole fractions (0 to 0.9) and salt concentrations (0.01 g to 0.13 g) on specific conductivity. The measurements were performed using a calibrated conductivity meter at room temperature (30 ± 2°C). The results revealed distinct patterns affected by solvent composition and salt type. In PG-water mixtures, specific conductivity increased with higher PG content; NaBr values rose from 1.02 µS/cm at a 0 mole fraction to 5.78 µS/cm at a 0.9 mole fraction for 0.01 g of NaBr. NaCl showed a similar but less pronounced trend, ranging from 0.4 µS/cm to 2.02 µS/cm under comparable conditions. Conversely, EG-water mixtures exhibited decreasing conductivity with increasing EG content, as NaBr values declined from 7.45 µS/cm at 0 mole fraction to 0.67 µS/cm at 0.9 mole fraction. These higher conductivity values of NaBr were attributed to its larger ionic radius and greater ionic mobility. These findings shed lights on ion–solvent interactions in mixed-solvent systems and have potential applications in electrolytic processes, energy storage, and industrial formulations requiring precise conductivity control.

Keywords: *binary solvent systems, ion–solvent interactions, solvation dynamics, specific conductivity, viscosity effects.*

Introduction

Studies of electrolytic conductivity are fundamental to physical chemistry, as they provide insights into the behavior and transport of ions in various solvent environments (Mizuhata, 2022). Beyond deepening understanding of ion interactions in solution, these investigations are crucial for numerous industrial processes, including battery production, electrolyte development, and pharmaceutical formulations (Shao et al., 2024). Conductivity measurements facilitate the exploration of ion-solvent interactions, which play a pivotal role in disciplines such as electrochemistry and materials science. The behavior of ions in mixed solvent systems is especially significant, as such systems exhibit tunable properties that are advantageous for industrial and chemical applications (Dufrêche et al., 2005; Yang & Wu, 2022).

Binary mixtures, such as those comprising ethylene glycol and propylene glycol with water, introduce unique physicochemical characteristics, making them ideal for conductivity studies (Dabagh et al., 2024). Ethylene glycol and propylene glycol are versatile organic solvents with wide-ranging applications, from antifreeze solutions to pharmaceutical formulations (Bezuglaya et al., 2023). When mixed with water, these solvents display distinct properties, including altered viscosity, dielectric constants, and hydrogen bonding capacity, directly affecting ion transport and solvation dynamics. These solvent systems offer a controlled environment for probing the effects of solvent composition on ionic behavior, thereby serving both academic research and practical innovation (Azizian & Hemmati, 2003).

Sodium halides, particularly NaCl, NaBr, and NaI, are frequently employed as model electrolytes due to their well-characterized ionic nature (Qie et al., 2020). Their simplicity and prevalence in natural and industrial systems make them ideal candidates for studying ion-solvent interactions. Although the behavior of sodium halides in binary solvent mixtures such as ethylene glycol–water and propylene glycol–water is not yet fully understood, investigating these systems has promising implications for industries that depend on precise control of ionic conductivity (Zarghampour et al., 2024). Gaining a deeper understanding of these systems could lead to technological advancements in cooling systems, pharmaceuticals, and electrolytic processes (Cookey & Iboroma, 2023).

Despite ongoing progress in characterizing ion behavior in various solvents, a notable knowledge gap persists regarding the specific conductivity of sodium halides in these particular mixed solvent systems. While prior research has examined their conductivity in single-solvent systems or alternative mixed solvents, limited attention has been paid to ethylene glycol and propylene glycol mixtures (Uchida & Kiyobayashi, 2021).

This study's primary objective was to investigate sodium halides' conductivity in binary mixtures of ethylene glycol and propylene glycol with water under varying solvent compositions. By systematically varying these parameters, this study aimed to comprehensively understand how solvent composition affected ionic conductivity and ion-solvent interactions.

Methodology

Study Area

This study was conducted in the Chemistry Laboratory of Rivers State University, Port Harcourt, Rivers State, Nigeria. Port Harcourt is a major city in the Niger Delta region, known for its contributions to industry and academia, particularly in science and technology. The experiment was conducted in August 2024, utilizing the laboratory's modern equipment to investigate the conductivity of sodium halides in glycol-water mixtures under controlled conditions.

Preparation of Solutions

All conductivity measurements were carried out using a JENWAY 4510 conductivity meter (Keison Products, Essex, England). Analytical-grade propylene glycol, ethylene glycol, sodium bromide (NaBr), and sodium chloride (NaCl) were obtained from BDH Chemicals Limited, Poole, England, through Meivene Chemicals Limited (Port Harcourt, Nigeria). Distilled water was produced in the university's Chemistry Laboratory. All chemicals were used as received without further purification. Binary mixtures of propylene glycol–water and ethylene glycol–water were prepared at various mole fractions (0, 0.1, 0.3, 0.5, 0.7, and 0.9 by mass). The mixtures were thoroughly homogenized to ensure uniform composition. Each mixture was prepared in sufficient quantity to facilitate the subsequent preparation of salt solutions (Cookey & Iboroma, 2023).

Sodium bromide and sodium chloride solutions were prepared by dissolving precise masses (0.01 g, 0.04 g, 0.07 g, 0.10 g, and 0.13 g) of each salt in 200 mL of the respective binary mixtures. Parallel solutions were also prepared using pure solvents (water, propylene glycol, and ethylene glycol) as reference systems. All solutions were prepared at room temperature and stirred thoroughly to ensure complete dissolution of the salts.

Specific Conductivity

Specific conductivity measurements were performed using the conductivity meter at room temperature (30 ± 2°C). The meter was calibrated with standard KCl solutions prior to use. Each solution was measured in triplicate, and the average value was recorded. The conductivity cell was rinsed with distilled water and dried between measurements to prevent cross-contamination. Temperature was monitored consistently throughout the experimental procedure. Conductivity values were reported in μS/cm (microsiemens per centimeter). For each salt concentration and solvent composition, triplicate measurements were averaged to determine the final reported values (Cookey & Iboroma, 2023).

Statistical Analysis

Average specific conductivity values were calculated for each combination of mole fraction and solute mass. These averages were presented in tabular form and provided a representative assessment of conductivity variations among the different binary mixtures.

Results and Discussion

The experimental investigation of sodium halides (NaBr and NaCl) in binary mixtures of water with ethylene glycol (EG) and propylene glycol (PG) reveals significant insights into their conductivity behavior across varying concentrations and compositions. As shown in Table 1 and Table 2, both sodium halides exhibited a distinctive pattern in propylene glycol-water systems where specific conductivity increased with salt concentration, particularly pronounced at lower mole fractions of the glycol component. For instance, at a 0.9 mole fraction, NaBr showed a conductivity decrease from 5.78 to 0.415 μS/cm as the mass increased from 0.01 to 0.13 g (see Table 1), while NaCl exhibited a similar but less pronounced trend, decreasing from 2.02 to 0.608 μS/cm (see Table 2). NaBr consistently demonstrated higher conductivity values compared to NaCl under equivalent conditions, which could be attributed to the larger ionic radius and enhanced mobility of the bromide ion in solution (Bezuglaya et al., 2023).

Table 1. Specific conductivity of different binary mixtures at varying compositions of propylene glycol and masses of NaBr, in μS/cm

Mole Fraction	**Mass in g**				
	0.01	**0.04**	**0.07**	**0.1**	**0.13**
0	1.02	0.6	0.15	0.12	0.06
0.1	1.471	0.772	0.289	0.205	0.098
0.3	2.485	1.537	0.59	0.312	0.25
0.5	3	2.04	1.091	0.45	0.33
0.7	3.78	3.25	1.978	0.505	0.372
0.9	5.78	5.07	2.57	0.587	0.415

Table 2. Specific conductivity of different binary mixtures at varying compositions of propylene glycol and masses of NaCl, in μS/cm

Mole Fraction	**Mass in g**				
	0.01	**0.04**	**0.07**	**0.1**	**0.13**
0	0.4	0.3	0.32	0.131	0.031
0.1	0.6	0.55	0.428	0.22	0.12
0.3	0.84	0.72	0.57	0.29	0.187
0.5	1.28	0.921	0.73	0.47	0.34
0.7	1.62	1.341	0.94	0.607	0.486
0.9	2.02	1.6	1.18	0.747	0.608

These findings are comparable to Sedghamiz and Raeissi's (2018) investigation of deep eutectic solvents derived from sodium halides and ethylene glycol. They discovered that the conductivity of these mixtures was affected by the molar ratios of the components, with higher ethylene glycol ratios resulting in increased conductivity. This aligns with the present study findings, indicating that increased glycol concentration correlated with enhanced conductivity. Furthermore, a study on the micellization of sodium dodecyl sulfate in ethylene glycol-water mixtures found that the critical micelle concentration decreased as the mole fraction of ethylene glycol increased, demonstrating stronger ion-solvent interactions in glycol-rich environments (Cookey et al., 2015). This finding supports the conclusion that higher glycol content could promote improved ionic interactions, leading to increased conductivity.

The behavior of ethylene glycol systems, presented in Table 3 and Table 4, displayed a significantly different pattern compared to their propylene glycol counterparts. NaBr and NaCl exhibited significantly higher conductivity values in EG systems, often by an order of magnitude. For example, at a 0 mole fraction and 0.13 g salt concentration, NaBr in EG showed a conductivity of 9.29 µS/cm (see Table 3), while in PG, it only reached 0.06 µS/cm (see Table 1). This striking difference suggests fundamental variations in ion-solvent interactions between the two glycol systems (Bezuglaya et al., 2023).

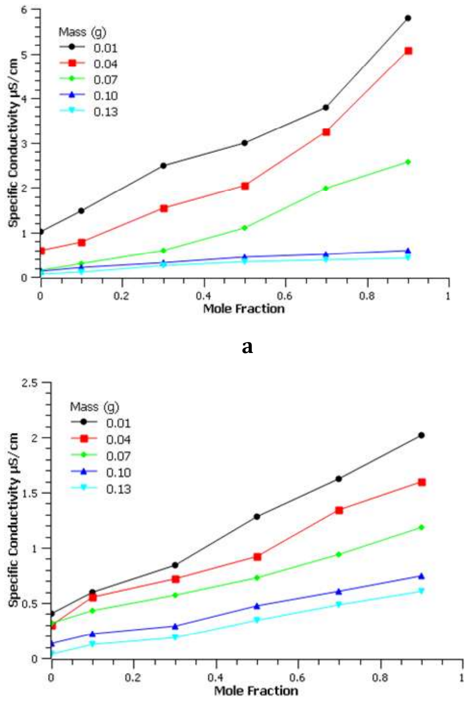
Table 3. Specific conductivity of different binary mixtures at varying compositions of ethylene glycol and masses of NaBr, in µS/cm

Mole Fraction	**Mass in g**				
	0.01	**0.04**	**0.07**	**0.1**	**0.13**
0	7.45	7.64	8.43	8.56	9.29
0.1	5.55	7.01	7.92	8.14	8.85
0.3	4.28	4.51	5.33	5.68	5.57
0.5	2.06	2.65	3.22	3.74	2.88
0.7	1.04	1.91	1.21	1.83	1.45
0.9	0.67	1.01	0.73	1.43	1.56

A significant trend emerged in propylene glycol-water mixtures, where increasing PG content led to enhanced conductivity at lower salt concentrations. As evidenced in Figure 1a, for NaBr at 0.01 g concentration, conductivity increased from 1.02 µS/cm at a 0 mole fraction to 5.78 µS/cm at a 0.9 mole fraction. Similarly, Figure 1b shows that NaCl followed the same pattern, though with lower values—increasing from 0.4 to 2.02 µS/cm.

Table 4. Specific conductivity of different binary mixtures at varying compositions of ethylene glycol and masses of NaCl, in µS/cm

Mole Fraction	**Mass in g**				
	0.01	**0.04**	**0.07**	**0.1**	**0.13**
0	5.09	6.87	6.43	5.95	7.83
0.1	3.46	4.45	5.73	5.54	7.01
0.3	2.56	2.64	3.33	3.55	4.55
0.5	2.01	1.44	1.62	1.95	2.45
0.7	1.21	0.33	1.02	1.03	1.22
0.9	0.15	0.1	0.12	0.22	0.11

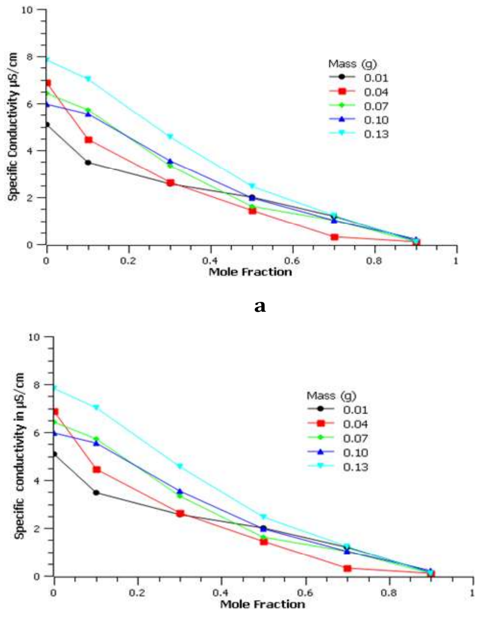


a

b

Figure 1. Specific conductivity of different binary mixtures at varying compositions of propylene glycol and masses of (a) NaBr and (b) NaCl, in µS/cm

Conversely, ethylene glycol-water mixtures displayed an opposing trend, where increasing EG content resulted in decreased conductivity. As shown in Figure 2a, the conductivity of NaBr at a concentration of 0.01 g decreased from 7.45 µS/cm at a mole fraction of 0 to 0.67 µS/cm at a mole fraction of 0.9. A similar pattern was observed for NaCl in Figure 2b, where conductivity decreased from 5.09 to 0.15 µS/cm.



a

b

Figure 2. Specific conductivity of different binary mixtures at varying compositions of ethylene glycol and masses of (a) NaBr and (b) NaCl, in µS/cm

This variation in behavior was also reported by Sharygin et al. (2001), who investigated the electrical conductivity of electrolyte mixtures in low dielectric constant solvents. They highlighted the challenges in predicting conductance behavior in mixed solvents and emphasized the critical role of solvent composition in influencing ionic interactions and mobility. Similarly, Talukdar et al. (2020) reviewed conductometric studies of electrolytes in mixed solvent systems, underlining the significance of ion–solvent interactions and the impact of solvent composition on ionic association and dissociation. Their findings support the present study's observations that solvent composition had a significant effect on the conductivity of sodium halides.

A comparison across all four tables and two figures reveals consistent trends between NaBr and NaCl in both solvent systems, with NaBr consistently exhibiting higher conductivity values. This difference was more pronounced in PG systems (see Table 1 and Table 2) than in EG systems (see Table 3 and Table 4), suggesting that the nature of the halide ion significantly affected the conductivity behavior. For instance, at a mole fraction of 0.5 and a concentration of 0.07 g, the conductivity ratio of NaBr to NaCl in PG was approximately 1.49 (1.091/0.73), whereas in EG, it was 1.99 (3.22/1.62).

The concentration dependence of conductivity reveals notable variations across systems. In PG mixtures (see Table 1 and Table 2), both salts generally showed decreasing conductivity with increasing salt concentration, particularly at higher mole fractions. In contrast, EG mixtures (see Table 3 and Table 4) exhibited a more complex pattern, with some compositions showing increases and others decreases in conductivity with rising concentration. For example, in Table 3, at a mole fraction of 0, the conductivity of NaBr increased from 7.45 to 9.29 µS/cm as the mass increased from 0.01 to 0.13 g. Meanwhile, at a mole fraction of 0.9, it fluctuated between 0.67 and 1.56 µS/cm over the same concentration range.

These systematic variations in conductivity can be attributed to several mechanistic factors. Solvation effects play a crucial role, as the different solvation characteristics of the glycols influence ion mobility, while water content significantly impacts ion dissociation. This is particularly evident in the contrasting conductivity trends between EG and PG systems at varying mole fractions (see Tables 1–4). The competition between water and glycol molecules for solvation sites appears to be a key determinant of overall conductivity behavior. Additionally, viscosity effects become increasingly relevant at higher glycol content, as elevated viscosity typically reduces ion mobility—affecting EG and PG systems differently, as reflected in the opposing conductivity trends with increasing glycol content (Bezuglaya et al., 2023; Cookey & Iboroma, 2023). These findings are anticipated to have significant implications for optimizing mixed solvent systems in various industrial applications, advancing electrolyte design and solvent engineering for energy storage, cooling technologies, and chemical manufacturing.

Conclusion

This study explored the effect of solvent composition on the conductivity behavior of sodium halides in glycol-water mixtures, offering valuable insights for optimizing electrolyte formulations in industrial and technological applications such as cooling systems, pharmaceuticals, and energy storage. The findings underscore the critical interplay between solvation effects, ion mobility, and viscosity, enhancing understanding of mixed solvent systems. This work supports researchers in identifying key aspects of ion transport and solvation dynamics that have often been overlooked in previous studies. Therefore, it may pave the way for the development of a novel theory on the mechanisms governing conductivity fluctuations in mixed solvents.

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