



The Effects of Supporting Electrolyte and Tonicity on Ionic Strength and Conductivity of Physiological Solutions

Benevolent Orighomisan Atolaiye, Edward-Ekpu Douglas Uwagbale*

Department of Chemistry, Nasarawa State University, Keffi, Nigeria

Email address:

mbatolaiye@gmail.com (Atolaiye B. O.), douglassony@yahoo.com (Edward-Ekpu D. U.)

*Corresponding author

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Abstract: This study was aimed at providing information on the effects brought on by hypotonicity and supporting electrolytes on ionic strength and conductivity of physiological solutions. Isotonic and 50% hypotonic solutions of chloride and chloride+sulphate salts were prepared, taking into account their molecular weight and osmotic concentration. Their specific conductivity and molar conductivity were measured at 25°C using a pH/conductivity meter. There was a decrease in specific and molar conductivity of all the electrolyte studied as a result of 50% hypotonicity except for $\text{CaCl}_2 + \text{CaSO}_4$ solution. Tonicity had more effect on the molar conductivity of weak electrolytes. The addition of supporting electrolyte resulted in an increase in the calculated ionic strength and molar conductivity. It also resulted in an increase in the specific conductivity of the resultant supported solutions except $\text{CaCl}_2 + \text{CaSO}_4$ and $\text{MgCl}_2 + \text{MgSO}_4$ solutions. The relative ionic strengths of the electrolytes could not be determined from their specific conductivity because the contribution of multivalent supporting electrolyte ions to ionic concentration is not evident in the specific conductivity of the resultant solutions.

Keywords: Supporting Electrolyte, Tonicity, Ionic Strength, Conductivity, Chlorides, Sulphates

1. Introduction

All known higher life forms require a subtle and complex electrolyte balance between the intracellular and extracellular environments because osmotic balance between intracellular and extracellular fluids in the body is required for proper functioning of the body [1]. In particular, the maintenance of precise osmotic gradients of electrolytes is important [2]. Such gradients affect and regulate the hydration of the body as well as blood pH, and are critical for nerve and muscle functions [3]. The concentration of osmotically active particles in a solution known as osmolarity [4] is based on the total number of particles of both penetrating and non-penetrating solutes in a solution. As such it is dependent on the number of “active” particles in a solution and not on the type of particle. Different electrolyte solutions can vary in the osmotic pressure they exert, depending on the degree of dissociation of the particular electrolyte in the solvent [5] while the relative concentration of only non-penetrating solute molecules determines the tonicity of a physiological

solution [6]. The determining factor in the rate of electrolyte efflux in body cells is the ionic strength of an electrolyte rather than the specific cations or anions, and the effects are completely reversible [7]. Cell transport also depends strongly on the local ion concentrations near the membrane surface [8]. Mathematically ionic strength is defined as:

$$\mu = 1/2([a]z_a^2 + [b]z_b^2 + [c]z_c^2 + \dots)$$

where μ represents ionic strength, [a], [b], [c]... represent the molar species concentrations of ions a, b, c... and z_a , z_b , z_c ... are their ionic charges.

At high ionic strength there is an increase in the effective concentration/activity of an electrolyte or the activity coefficient which results in an increase in dissociation [9] and therefore the electrolyte's overall conductivity [10]. The concentration of ions and their electrical charge present in a solution is proportional to electrical conductivity [11] and so electrolytic conductance or conductivity can be used to

determine the relative ionic strength (RIS) of solutions [12-13]. While specific conductivity is concentration dependent, molar conductivity is not, and since measured values for different solutions are not easy to compare directly using specific conductivity, molar conductivity is used [14-15]. Compounds that exhibit molar conductivity that do not change significantly with concentration are referred to as strong electrolytes, and include salts such as KCl [12]. The addition of supporting electrolyte to an electrolyte solution can affect the ionic strength of that electrolyte solution [16]. According to IUPAC, a supporting electrolyte is an electrolyte solution, whose constituents are not electroactive in the range of applied potentials being studied, and whose ionic strength and, therefore, contribution to the conductivity is usually much larger than the concentration of an electroactive substance to be dissolved in it [17]. The effect of added electrolyte on the equilibria of solutions with ionic strength of 0.1 M or less is independent of the chemical nature of the electrolyte but depends on the ionic strength. In analytical applications, adding a supporting electrolyte increases the electrolyte's overall conductivity [10]. It also maintains constant ionic strength and constant pH [18]. To understand or predict how human body responds to a changing extracellular environment, brought on by hypotonicity and the addition of supporting electrolytes, studying their effects on major physiological solutions is

necessary. The aim of this work was to study the effects of 50% hypotonicity and sulphate supporting electrolytes on the ionic strength and conductivity of physiological Na, K, Ca and Mg chloride solutions at normal body pH.

2. Materials and Methods

The chemicals used in this research were bought from Bristol Scientific Company (Nig) Ltd, a representative of Sigma Aldrich. Isotonic solutions of NaCl (160 mM), KCl (160 mM), CaCl₂ (110 mM) and MgCl₂.6H₂O (110 mM) at pH 7.4 and solutions of NaCl (18 mM) + Na₂SO₄ (180 mM), KCl (18 mM) + K₂SO₄ (180 mM), CaCl₂ (26 mM) + CaSO₄ (260 mM) and MgCl₂ (26 mM) + MgSO₄ (260 mM) at pH 7.4 were prepared taking into account their molecular weight and osmotic concentration. Each of the isotonic solutions (25 mL) mentioned above were divided into two (2) volumes and a volume of each of the solutions were diluted with 25 mL of distilled water to give half their initial concentration (50% hypotonicity). The specific conductivity and molar conductivity of each solution were determined using a calibrated Jenway (Model 430) pH/conductivity meter at 25°C. The data obtained were related and compared analytically to understand the relationship of the variables of this study.

3. Results and Discussion

Table 1. Specific Conductivity of Electrolyte Solution.

Electrolyte	Iso. Conc. (M)	Ionic Strength (M)	Spec. Cond. (mS ^{cm} ⁻¹)		Incr/decr in Spec. Cond. (%)
			Iso. Solution	50% Hypo. Solution	
NaCl	0.160	0.16	13.4	8.23	-38.58
NaCl+Na ₂ SO ₄	0.052	0.23	7.77	5.68	-26.90
incr/decr in spec. cond. (%)			-42.01	-30.98	
KCl	0.160	0.16	16.8	8.69	-48.27
KCl+K ₂ SO ₄	0.052	0.23	8.90	5.58	-37.30
incr/decr in spec. cond. (%)			-47.02	-35.79	
CaCl ₂	0.110	0.28	14.4	9.47	-34.23
CaCl ₂ +CaSO ₄	0.072	0.55	3.16	3.36	6.33
incr/decr in spec. cond. (%)			-78.06	-64.52	
MgCl ₂	0.110	0.28	15.00	9.00	-40.00
MgCl ₂ +MgSO ₄	0.072	0.55	6.94	6.06	-12.68
incr/decr in spec. cond. (%)			-53.73	-32.67	

^aIso. Conc. = Isotonic Concentration, ^bSpec. Cond. = Specific Conductivity, ^cIncr/decr = increase/decrease, ^dIso. Sol. = Isotonic Solution, ^eHypo. Sol = Hypotonic Solution

3.1. Effect of Tonicity on Specific Conductivity

As shown in Table 1, 50% hypotonicity had a huge effect on the specific conductivity of NaCl, KCl, CaCl₂ and MgCl₂ solutions than on their corresponding supported electrolyte solutions, with CaCl₂ solution having the least decrease of 34.23% and KCl having the most decrease of 48.27%. The effect is more than that observed on the supported solutions, with CaCl₂+CaSO₄ solution showing a differing increase in specific conductivity of 6.33% instead of a decrease. The effect on specific conductivity of NaCl+Na₂SO₄, KCl+K₂SO₄, CaCl₂+CaSO₄ and MgCl₂+MgSO₄ solutions were relatively less with KCl+K₂SO₄ solution having the

most decrease at 37.30%. 48.27% drop in specific conductivity as a result of 50% dilution of KCl solution indicates that KCl dissociates completely at isotonic concentration. This was also observed in KCl+K₂SO₄ solution which had 37.30% drop in specific conductivity, the highest among the supported solutions.

3.2. Effect of Supporting Electrolyte on Specific Conductivity

The addition of supporting electrolytes to NaCl, KCl, CaCl₂ and MgCl₂ solutions to give isotonic electrolyte mixtures resulted to solutions of lower concentrations and

higher ionic strengths. This decrease in concentration resulted in a decrease in specific conductivity of the resultant supported solutions. The decrease was more for the isotonic solutions (42.01-78.06%) than for the hypotonic solutions (30.98% - 64.52%). The ratio of molar concentration to specific conductivity of isotonic NaCl as shown in Table 1 was observed to be 1:84 while that of NaCl+Na₂SO₄ was observed to be 1:149. The ratio for KCl was observed to be 1:105 while that for KCl+K₂SO₄ was observed to be 1:171.

Table 2. Molar Conductivity of Electrolyte Solution.

Electrolyte	Iso. ^a Conc. (M)	Ionic Strength (M)	Molar Cond. ^b (mScm ² mol ⁻¹)		Incr/decr ^c in molar cond. (%)
			Iso. Sol. ^d	50% Hypo. ^e Sol.	
NaCl	0.160	0.16	102.88	83.75	-18.59
NaCl+Na ₂ SO ₄	0.052	0.23	218.46	149.42	-31.60
incr/decr in molar cond. (%)			52.91	43.95	
KCl	0.160	0.16	108.63	105.00	-3.34
KCl+K ₂ SO ₄	0.052	0.23	214.62	171.15	-20.25
incr/decr in molar cond. (%)			49.39	38.65	
CaCl ₂	0.110	0.28	172.18	130.91	-23.97
CaCl ₂ +CaSO ₄	0.072	0.55	93.33	43.89	-52.97
incr/decr in molar cond. (%)			-45.80	-66.47	
MgCl ₂	0.110	0.28	163.64	136.36	-16.67
MgCl ₂ +MgSO ₄	0.072	0.55	168.33	96.39	-42.74
incr/decr in molar cond. (%)			2.79	-29.31	

^aIso. Conc. = Isotonic Concentration, ^bMolar Cond. = Specific Conductivity, ^cIncr/decr = increase/decrease, ^dIso. Sol. = Isotonic Solution, ^eHypo. Sol = Hypotonic Solution

3.3. The Effects of Tonicity on Molar Conductivity

The effect of tonicity on specific conductivity per mole (molar conductivity) of the electrolytes studied showed a pattern different from that of their specific conductivity as shown in Table 2. Though there was a decrease in molar conductivity of all the electrolytes studied as a result of dilution, the supported electrolytes were more affected. The most effect was observed in CaCl₂+CaSO₄. Its molar conductivity decreased by 52.97%. The least effect was observed in KCl which decreased by 3.34% and as such KCl has a molar conductivity that do not change significantly with concentration. This confirms that KCl is a strong electrolyte. CaSO₄ was found to be very insoluble in water. The results on CaCl₂+CaSO₄ solution suggests that the solution is a weak electrolytic. The decrease in concentration brought about by 50% hypotonicity and the resulting decrease in molar conductivity of CaCl₂+CaSO₄ (53%) and MgCl₂+MgSO₄ (43%) are almost in the same proportion.

3.4. Effect of Supporting Electrolyte on Molar Conductivity

The addition of supporting electrolytes to NaCl, KCl, CaCl₂ and MgCl₂ solutions had a huge effect on their molar conductivity. It resulted to an increase in molar conductivity of NaCl and KCl solutions. As shown in Table 2, the increase was more for isotonic NaCl (52.91%) and KCl (49.39%) solutions than for their respective hypotonic solutions (43.95%) and (38.65%). CaCl₂ and MgCl₂ showed a different pattern. The addition of supporting electrolytes to CaCl₂ resulted to a 45.80% decrease in molar conductivity of isotonic solution and 66.47% decrease in molar conductivity

Ratio 1:130 was observed for CaCl₂ and 1:44 for CaCl₂+CaSO₄. Ratio 1:136 was observed for MgCl₂ and 1:96 for MgCl₂+MgSO₄. This suggests that supporting electrolyte increased the specific conductivity of isotonic NaCl and KCl but reduced that of CaCl₂ and MgCl₂. The contribution of the ions of the supporting electrolytes to the ionic strength of the solutions was not evident in the specific conductivity of CaCl₂+CaSO₄ and MgCl₂+MgSO₄.

of hypotonic solution. Though isotonic MgCl₂ solution showed a low 2.97% increase molar conductivity, there was a 29.31% decrease in molar conductivity when hypotonic. Molar conductivity increase coincided with the increase in ionic strength calculated. The ionic strengths calculated suggests an increase in ionic strength with the addition of supporting electrolyte as seen with the NaCl and KCl solutions. CaSO₄ was found to be very insoluble in water. MgSO₄ has low activity coefficient, dissociates in a smaller extent, and is termed weaker electrolytes [19]. All these suggests also that CaSO₄ and MgSO₄ contributed little or nothing to the ionic strengths of CaCl₂+CaSO₄ and MgCl₂+MgSO₄ solutions respectively.

4. Conclusion

There was a decrease in specific and molar conductivity of all the electrolyte studied as a result of 50% hypotonicity except in the specific conductivity of CaCl₂+CaSO₄ solution. Specific conductivity is proportional to the active concentration of the solution studied as seen with CaSO₄. Weak electrolytes have higher specific conductivity at lower concentrations. Tonicity has more effect on the molar conductivity of weak electrolytes. The addition of supporting electrolytes to NaCl, KCl, CaCl₂ and MgCl₂ solutions resulted in an increase in the calculated ionic strength and increase in molar conductivity of the resultant supported solutions. It also resulted in an increase in specific conductivity of the resultant supported solutions except CaCl₂+CaSO₄ and MgCl₂+MgSO₄ solutions. The relative ionic strength of the electrolytes in this study could not be

determined from their specific conductivity as the contribution of the ions of the multivalent supporting electrolytes to ionic concentration is not evident in the specific conductivity of the resultant solutions measured.

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