CONDUCTING MOLAR CONDUCTIVITY

Conductivity of Ionic Solutions & Molar Conductivity

This article delves into the concept of molar conductivity, exploring the nature of ionic solutions and methods for assessing their conductivity. Initially, we will examine the distinctions between two types of compounds—ionic and covalent. The properties of these compounds differ based on various factors, which we will explore further in this article. We'll begin by gaining an understanding of ionic solutions and discerning any disparities between ions and electrolytes. Let's embark on this exploration together.

Ionic Solutions

An ionic solution is characterized as a solution containing ions that facilitate the conduction of electricity. When an electrolyte dissolves in a solution, it undergoes ionization. Electrolytes that ionize can conduct electricity only in molten or aqueous states, as these ions do not conduct electricity in a solid state. Examples of ionic solutions include KNO_3, NaCl, KCl, and others.

Factors Influencing the Conductivity of Ionic Solutions The conductivity of ionic solutions plays a crucial role in the development of batteries and other essential devices. The conductivity of such solutions is influenced by various factors.

Concentration of Ions

The primary factor contributing to electrical conduction is the presence of ions. When the quantity of ions in a solution is elevated, the conductivity of the solution likewise increases. The augmented number of ions results in an increased abundance of charge carriers, enhancing the overall conductivity of the solution.

Nature of Electrolyte

The character of electrolytes influences the conductance of ionic solutions. A greater dissociation of ions in the solution leads to an increased ion count, resulting in higher conductivity in ionic solutions. Consider the example of CH_3COOH (acetic acid), which exhibits a limited degree of dissociation, resulting in fewer ions in the solution.

Compounds with minimal dissociation, like acetic acid, fall under the category of weak electrolytes. On the other hand, electrolytes such as KNO3 undergo substantial dissociation, easily breaking into ions. Solutions containing compounds with high dissociation levels have a greater concentration of ions compared to other solutions and are referred to as good ionic solutions.

Temperature

The temperature significantly influences the creation of an ionic solution. As per observations, elevating the temperature of a solution enhances the solubility of ions in that solution. This heightened solubility of ions consequently leads to an augmented level of ionic conduction.

Molar Conductivity

Molar conductivity refers to the ability of a solution to conduct electricity when one mole of an electrolyte is dissolved in it. The molar conductivity of an ionic solution is influenced by multiple factors. To determine the electrical conductivity of an ionic solution, the concept of molar conductivity is employed. The formula for molar conductivity is as follows.

$$\lambda_m = \frac{\mathrm{K}}{c}$$

Where,

λ_m is the molar conductivity

Measurement of The Conductivity of Ionic Solutions

In the process of determining the molar conductivity of an ionic solution, the utilization of a Wheatstone bridge is imperative. When faced with the task of identifying unknown resistance, the Wheatstone bridge stands as the singular method at hand. The conductivity cell utilized in this process is furnished with a pair of platinum electrodes meticulously coated with platinum black. These electrodes possess a designated cross-sectional area, denoted as "A," while the distance separating them is symbolized by "l." Hence, the computation of the resistance within the solution column follows a specific formula:

$$R = P(1/A).$$

Conclusion

Conductivity, measured in ohm-1 cm-1, is inversely related to resistivity. In the International System of Units (SI), length (l) is typically measured in meters, while the cross-sectional area is expressed in square meters, resulting in conductivity values denoted in Sm-1. The conductivity of a substance is influenced by its inherent properties. Specifically, an ionic solution contains ions that enable the flow of electric current through the solution, thus facilitating electrical conduction. Molar conductivity, also known as molar conductance, serves as a metric of electrical conductivity and signifies the combined conductance of all ions produced upon dissolving one mole of an electrolyte in a solution.

Effect of concentration on conductivity & molar conductivity

Upon dilution, molar conductivity experiences an increase, while conductivity decreases. This is due to the fact that during dilution, the rate of volume increase surpasses the rate of increase in ions.

Variation of Molar Conductivity with Concentration

The values of both conductivity and molar conductivity for an electrolyte in a solution exhibit changes in response to variations in the electrolyte's concentration. The conductivity of all electrolytes consistently diminishes with a decrease in concentration because it is the conductance of all ions within a unit volume, and the number of ions per unit volume decreases as the concentration diminishes.

Molar conductivity of an electrolyte is contingent not only upon the nature of the electrolyte but also on its concentration. Based on the molar conductivity values, electrolytes can be categorized into two groups:

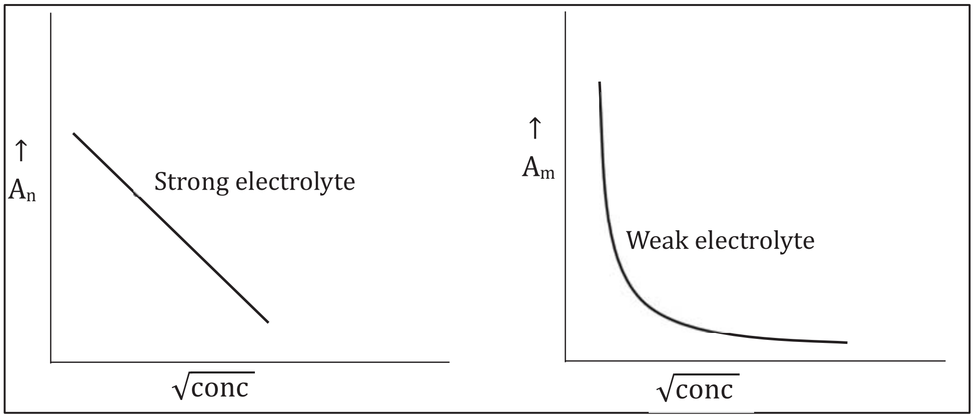
(i) strong electrolytes

(ii) weak electrolytes.

For the same concentration, the molar conductivity of a strong electrolyte surpasses that of a weak electrolyte because a strong electrolyte is fully ionized at all concentrations, whereas a weak electrolyte is only partially ionized in the high concentration range.

As the concentration of an electrolyte decreases, the molar conductivity of a strong electrolyte experiences a slight increase due to an increase in interionic distance upon dilution, reducing the influence of cations on anions, and vice versa. Conversely, in the case of a weak electrolyte, the molar conductivity significantly increases with decreasing concentration due to an increase in the extent of ionization upon dilution

The plot of a graph between molar conductivity (A_m) vs $\sqrt{\text{conc}}$. for a strong electrolyte and a weak electrolyte is shown in the figure.



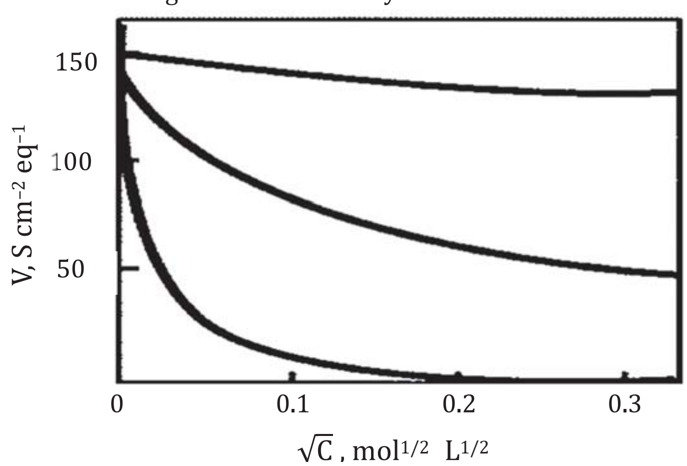
The molar conductivity of a strong electrolyte exhibits a linear relationship with the square root of concentration. Extrapolation becomes feasible as the concentration approaches zero. The molar conductivity at infinite dilution is termed the limiting molar conductivity, denoted as A_m^o or A_m^∞. Experimental determination is restricted to strong electrolytes, as A_m gradually increases linearly with dilution and is expressed as follows:

$$A_m = 40\text{-}A\sqrt{C}$$

Here, the intercept of the plot along the Y-axis represents A_m^o, and the slope is equal to (-A). The magnitude of the slope, in a given solvent and at a specific temperature, is contingent upon the charges carried by cations and anions resulting from the dissociation of the electrolyte in the solution. Consequently, electrolytes with similar charges exhibit identical values for A.

Molar conductivity

As the concentration diminishes, the molar conductivity increases, given that the total volume (V) of a solution containing one mole of electrolyte also increases. Dilution leads to a reduction in concentration. When the concentration approaches zero, the molar conductivity of the solution is identified as the limiting molar conductivity, denoted as Λ_m^o. The alteration of molar conductivity with concentration varies between strong and weak electrolytes.



Variation of Molar Conductivity With concentration for strong electrolytes

In the case of strong electrolytes, the molar conductivity exhibits a gradual increase with dilution. The plot depicting the relationship between molar conductivity and $c^{1/2}$ forms a straight line with a y-intercept equivalent to Λ_m^o. The determination of the limiting molar conductivity, Λ_m^o, can be achieved through graphical analysis or with the assistance of Kohlrausch's law. The general equation for the plot is expressed as:

$$\Lambda_m^o = \Lambda_m^o - Ac^{1/2}$$

Here, -A represents a constant that is equivalent to the slope of the line. The value of "A" for a specific solvent is contingent upon the type of electrolyte at a given temperature.

Kohlrausch Law

Kohlrausch Law of independent migration of ions

Kohlrausch’s law asserts that the equivalent conductivity of an electrolyte at infinite dilution equals the sum of the conductance’s of its anions and cations.

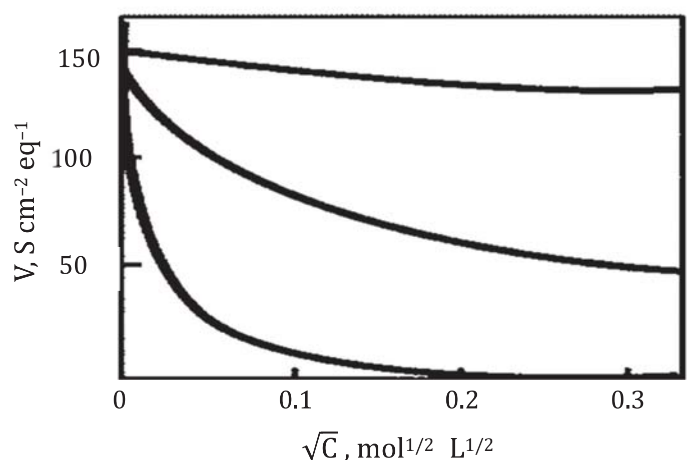
The molar conductivity of a solution at a specific concentration is defined as the conductance of the volume of the solution containing one mole of electrolyte positioned between two electrodes with a unit area of cross-section and a distance of unit length. As the concentration of the electrolyte decreases, the molar conductivity of the solution increases due to the expansion of the total volume containing one mole of the electrolyte. When the concentration approaches zero, the molar conductivity is referred to as the limiting molar conductivity, Λ_m^o.

Kohlrausch, through observations on the limiting molar conductivities of certain strong electrolytes, proposed that the limiting molar conductivity of an electrolyte can be represented as the sum of the individual contributions of its anions and cations. This principle is commonly known as Kohlrausch's law of independent migration of ions.

For instance, the limiting molar conductivity (Λ) of sodium chloride can be expressed as the sum of the limiting molar conductivities of the sodium ion and chloride ion:

$$\Lambda^\circ_{NaCl} = \Lambda^\circ_{Na+} + \Lambda^\circ_{Cl}$$

The applications of Kohlrausch's law are significant. It aids in determining the limiting molar conductivities for any electrolyte. Weak electrolytes exhibit lower molar conductivities and a reduced degree of dissociation at higher concentrations. Unlike strong electrolytes, the graph plotted between molar conductivity and $c^{1/2}$ (where c is the concentration) is not a straight line for weak electrolytes. The molar conductivity of weak electrolytes sharply increases at lower concentrations, preventing the straightforward extrapolation of molar conductivity to zero concentration. Therefore, Kohlrausch's law of independent migration of ions is employed for the determination of limiting molar conductivity (Λ) for weak electrolytes.



Kohlrausch law also helps us in determining the value of dissociation constant from the value of molar conductivity and limiting molar conductivity for a weak electrolyte at a given concentration.

$$\alpha \frac{\Lambda}{\ddot{E}m^\circ}$$

Where,

α = dissociation constant

Λ = molar conductivity

Ë$_{m}$° = limiting molar conductivity

Uses of Kohlrausch's law

- Determination of Degree of Dissociation
- Evaluation of Solubility for Sparingly Soluble Salts
- Calculation of Dissociation Constant for Weak Electrolytes
- Determination of Molar Conductivity for Weak Electrolytes at Infinite Dilution