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Potentiometric Titration as an Instrumental Method Applicable in Science

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Abstract

In the age of analytical technology, potentiometric titration (PT) has become a fundamental method for the quantitative determination of substances in various solutions. As an instrumental technique, it measures changes in electrode potential to determine the equivalence point without the need for visual indicators, making it indispensable in analyses where sample transparency is limited. This method represents an ideal integration between classical chemistry and modern technology, providing researchers with tools to achieve high accuracy and full reproducibility.

Keywords: Potentiometric Titration, Instrumental Analysis, Analytical Chemistry, Electrochemical Methods, Ion-Selective Electrodes, Quantitative Determination.

1. Principles of Potentiometric Titration

PT is based on measuring the potential of a galvanic cell during the gradual addition of a titrant to an unknown solution. When the equivalence point is reached, the change in potential is at its maximum, signaling the end of the chemical reaction (Christian & Purdy, 2013; Bujar H. Durmishi, 2023). Traditionally, a reference electrode (usually Ag/AgCl) and an indicator electrode (e.g., a glass electrode for H^+ ions) are used to form a stable measuring system (Bard & Faulkner, 2001). The main advantage lies in the fact that no chemical indicator is required that might interfere with the reaction or cause turbidity in the solution (Danzer & Currie, 2011). In accordance with electrochemical theory, electrode potential is a logarithmic function of ion activity in solution (the Nernst equation), making potentiometric titration particularly sensitive to small changes in concentration (Atkins & de Paula, 2018).

2. Applications

The method finds wide application in environmental analysis laboratories for determining metallic ions such as Pb^{2+}, Cd^{2+}, Cu^{2+}, and Zn^{2+}, as well as in industrial water analysis (Lurie, 2010). In pharmacy, it is used for determining active substances such as organic acids and pharmaceutical bases, where colorimetric methods are unsuitable (Kissinger & Heineman, 1996). In biochemistry, PT has been applied to evaluate enzyme

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activity and monitor redox reactions in biological cells (Bard & Faulkner, 2001; Wang et al., 2020). Furthermore, its integration with automatic sampling and computer-based analytical systems has enabled the development of real-time titration control systems (Danzer & Currie, 2011). Recent research on electrochemical sensors has employed the principles of PT in designing intelligent electrodes capable of recognizing specific ions through functionalized interfaces (Wang, 2018).

3. Advantages

Compared with classical acid–base titration, PT presents several major advantages: higher precision, independence from sample color, and the possibility of automation (Skoog et al., 2014; Harris, 2016). Moreover, measurements can be conducted even under limited laboratory conditions, since the instruments are relatively simple and robust. Another important aspect is its efficiency in small-volume analyses, particularly in fields where samples are expensive or rare, such as pharmaceutical chemistry and biotechnology (Christian & Purdy, 2013). Because of these advantages, many research laboratories use PT as a standard method for calibration and quality control (Danzer & Currie, 2011; Lurie, 2010).

4. Modern Developments

With the development of ion-selective electrodes and automated analytical systems, PT is experiencing a modern revival in scientific laboratories (Atkins & de Paula, 2018). For example, in complexometric analyses of transition metals, this method can be applied to determine very low concentrations (10^{-6} M), which previously required much more expensive instruments (Wang et al., 2020). In environmental sciences, its use in determining the acidity of atmospheric precipitation and water pollution has become a standard practice in regional water-quality monitoring (Christian & Purdy, 2013; Harris, 2016).

5. Conclusion

PT remains one of the main pillars of instrumental analysis, linking the precision of classical methods with the efficiency of modern technology. As a research tool, it not only offers precision but also flexibility in interdisciplinary applications. At a time when scientific research seeks automation, lower error margins, and energy efficiency, potentiometric titration continues to prove that simplicity built upon strong theoretical foundations can remain an indispensable instrument for contemporary science (Skoog et al., 2014; Bard & Faulkner, 2001; Harris, 2016).

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