METHODS FOR BALANCING OXIDATION–REDUCTION REACTIONS

Eshquvvatova Nargiza Norjigitovna

Senior Chemistry Teacher, Academic Lyceum of Chirchiq State Pedagogical University

Abstract. This article provides a comparative analysis of the two principal methods for constructing oxidation–reduction (redox) equations – the electron-balance method and the ion-electron (half-reaction) method. The application of both methods is demonstrated using the reactions of potassium permanganate in acidic, neutral, and alkaline media, and their respective advantages and limitations are discussed. The results highlight how the reaction medium affects the composition of the products and underscore the importance of selecting the appropriate balancing method accordingly.

Keywords: redox reactions, electron-balance method, ion-electron method, half-reactions, potassium permanganate, medium effect.

INTRODUCTION

Correctly constructing the equations of oxidation–reduction reactions is one of the practical foundations of chemistry as a discipline. Historically, this problem was first addressed on a purely empirical basis, through trial and error, until the development of electron-transfer theory in the 20th century gave rise to systematic approaches – the electron-balance method and the ion-electron method[1].

In practice, balancing redox equations remains one of the most challenging topics for students, particularly when the reaction products change depending on the medium (acidic, neutral, or alkaline). A classical illustration of this is the set of

reactions involving potassium permanganate, which yield entirely different products in different media – a fact that requires the correct method to be chosen deliberately.

The purpose of this article is to provide a comparative analysis of the two principal methods for constructing redox equations, to demonstrate the practical application of each using potassium permanganate as an example, and to clarify how the medium affects the reaction products.

The objectives of the study are as follows: (1) to present the theoretical basis of the electron-balance and ion-electron methods; (2) to balance the reactions of potassium permanganate in three different media using the ion-electron method; (3) to compare the two methods and identify the scope of application of each; (4) to discuss the practical significance of these methods in analytical chemistry (titrimetry).

MATERIALS AND METHODS

The study is based on an analysis of published textbooks and manuals in general and inorganic chemistry[2], together with additional literature concerning the methodological aspects of balancing techniques[3]. The methodology consisted of the following stages:

1) Theoretical analysis – the theoretical basis of the electron-balance method (based on the overall change in oxidation state) and the ion-electron method (based on half-reactions that explicitly account for medium species such as H^+, OH^-, and H_2O) was reviewed.

2) Practical application – three characteristic reactions of potassium permanganate (in acidic, neutral, and alkaline media) were selected, since manganese is reduced to three distinctly different oxidation states in these reactions (Mn^{2+}, MnO_2, MnO_4^{2-}), clearly illustrating the effect of the medium.

3) Comparative analysis – each reaction was balanced using both methods, and the two approaches were evaluated in terms of convenience, accuracy, and susceptibility to error.

Throughout the half-reactions, standard notation is used: the number of electrons is denoted by "e^-", and medium species are added to the appropriate side of the equation as required.

RESULTS

1. Acidic medium: reduction of permanganate ion to Mn^{2+}

Example: the reaction of potassium permanganate with iron(II) sulfate in a sulfuric acid medium.

Half-reactions (ion-electron method):

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O \quad (reduction)$$

$$Fe^{2+} - 1e^- \rightarrow Fe^{3+} \quad (oxidation)$$

To equalize the number of electrons, the second half-reaction is multiplied by 5, giving the overall equation:

$$MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$$

In molecular form:

$$2KMnO_4 + 10FeSO_4 + 8H_2SO_4 \rightarrow 2MnSO_4 + 5Fe_2(SO_4)_3 + K_2SO_4 + 8H_2O$$

2. Neutral medium: reduction of permanganate ion to MnO_2

Example: the reaction of potassium permanganate with sodium sulfite in an aqueous (neutral) medium.

$$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2\downarrow + 4OH^- \quad (reduction)$$

$$SO_3^{2-} + H_2O - 2e^- \rightarrow SO_4^{2-} + 2H^+ \ (oxidation)$$

Equalizing the number of electrons (the first × 2, the second × 3) gives the overall equation, in which the H^+ and OH^- ions neutralize each other to form H_2O:

$$2KMnO_4 + 3Na_2SO_3 + H_2O \rightarrow 2MnO_2\downarrow + 3Na_2SO_4 + 2KOH$$

3. Alkaline medium: reduction of permanganate ion to manganate ion

Example: the reaction of potassium permanganate with sodium sulfite in a concentrated alkaline medium.

$$MnO_4^- + 1e^- \rightarrow MnO_4^{2-} \ (reduction)$$

$$SO_3^{2-} + 2OH^- - 2e^- \rightarrow SO_4^{2-} + H_2O \ (oxidation)$$

The overall equation:

$$2KMnO_4 + Na_2SO_3 + 2KOH \rightarrow 2K_2MnO_4 + Na_2SO_4 + H_2O$$

It can be seen that a single oxidizing agent – $KMnO_4$ – forms three fundamentally different products (Mn^{2+}, MnO_2, MnO_4^{2-}) depending on the medium; this clearly demonstrates that a redox equation cannot be correctly constructed without accounting for the medium as a factor.

4. Comparative analysis of the two methods

The same three reactions were also balanced using the electron-balance method, and the results were confirmed to fully agree with those obtained by the ion-electron method. The difference lies solely in the solution process: in the electron-balance method, only the change in oxidation states is tracked, and medium species are added at the end by balancing the atom count; in the ion-electron method, medium species are incorporated into each half-reaction from the outset, which

reduces the likelihood of error in reactions involving complex ions and coordination compounds.

DISCUSSION

The results obtained show that for reactions involving simple substances with well-defined molecular formulas, the electron-balance method produces a fast and clear result. However, for reactions occurring in solution – particularly those taking place in an acidic or alkaline medium – the ion-electron method is preferable, since it incorporates medium species (H^+, OH^-, H_2O) as an integral part of the equation-construction process, thereby reducing the likelihood of error[4]. This is of particular practical importance in analytical chemistry – for instance, in titrimetric methods such as permanganometry and dichromatometry – since the accurate calculation of the equivalence point depends directly on the correctness of the reaction equation.

Particular attention should be paid to the sequence in which the two methods are taught: the electron-balance method should be introduced first, so that the overall logic of redox reactions (the change in oxidation state, the concepts of oxidizing and reducing agents) is mastered, after which the ion-electron method allows a deeper study of how the medium affects the reaction. Such a sequential approach enables students to master the topic step by step, without confusion.

In modern analytical chemistry, matrix methods and computer algorithms are also used to balance complex, multistep redox equations; these methods are considerably more efficient than manual balancing, particularly for reactions involving organic compounds or multiple elements[5]. At the same time, manual balancing skills remain central to the learning process, since they foster a deeper understanding of the reaction mechanism and help students grasp the process itself, not merely the final result[6].

CONCLUSION

This study has provided a comparative analysis of the two principal methods for balancing oxidation–reduction reactions – the electron-balance method and the ion-electron method – using the reactions of potassium permanganate in three different media as an example. The results show that a change in medium fundamentally alters the composition of the reaction products, and this factor must therefore be taken into account when selecting a balancing method.

These findings confirm the need to teach both methods in chemistry education in a sequential and complementary manner. Future research may extend this topic to titrimetric methods in analytical chemistry, as well as to computerized algorithms for balancing complex organic redox reactions, as a promising direction of further inquiry.

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