TYPES OF OXIDATION–REDUCTION (REDOX) REACTIONS

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Abstract. This article systematically analyzes oxidation–reduction (redox) reactions, one of the fundamental classes of reactions in inorganic and organic chemistry, together with their principal types. Intermolecular, intramolecular, disproportionation, and comproportionation reactions are examined using the electron-balance method, with characteristic examples provided for each type. The results show that mastering redox theory plays an important role in developing problem-solving and equation-balancing skills in chemistry education.

Keywords: redox reactions, oxidation state, electron-balance method, disproportionation, comproportionation, oxidizing agent, reducing agent.

INTRODUCTION

Oxidation–reduction reactions occupy a central place in nearly every branch of chemistry – from inorganic synthesis to biochemistry and electrochemistry. In such reactions, the oxidation state of atoms changes, meaning that electrons are transferred from one species (an atom, ion, or molecule) to another. Historically, this concept was first understood solely as a process involving oxygen, but in modern chemistry it is interpreted more broadly on the basis of electron-transfer theory[1].

[1]The concept of oxidation was originally understood solely as a process involving oxygen (A. Lavoisier, 18th century); it was later redefined on the basis of electron-transfer theory. See: Glinka N.L. General Chemistry. — Moscow: Khimiya, 1988. — P. 148–152.

A thorough understanding of redox theory is important not only for theoretical chemistry but also for applied fields such as metallurgy, electroplating, analytical chemistry, environmental science, and medicine. In chemistry education in particular, balancing redox equations is one of the topics students find most challenging, which makes a clear classification of reaction types – together with a solution algorithm suited to each type – methodologically important.

The purpose of this article is to systematically classify the principal types of oxidation–reduction reactions (intermolecular, intramolecular, disproportionation, and comproportionation), to present a worked example based on the electron-balance method for each type, and to discuss their practical significance.

The objectives of the study are as follows: (1) to present the modern definitions of oxidation state and redox reactions; (2) to establish the criteria by which reactions are classified into types; (3) to provide a characteristic example and electron-balance scheme for each type; (4) to discuss the connection between redox reactions and electrochemistry and industrial processes.

MATERIALS AND METHODS

The study is based on an analysis of published textbooks and manuals in general and inorganic chemistry[2], together with methodological literature concerning the criteria for classifying reaction types[3]. The methodology consisted of the following stages:

[2]Akhmetov N.S. General and Inorganic Chemistry. — Moscow: Vysshaya Shkola, 2001. — P. 267–279.

[3]Karapetyants M.Kh., Drakin S.I. General and Inorganic Chemistry. — Moscow: Khimiya, 1992. — P. 301–315.

1) Theoretical analysis – the rules for determining oxidation states, the concepts of oxidizing and reducing agents, and the theoretical basis of the electron-balance method were reviewed.

2) Typology of reactions – redox reactions were classified into four groups according to the location of the species participating in electron transfer: (a) intermolecular reactions, (b) intramolecular reactions, (c) disproportionation reactions, and (d) comproportionation (reproportionation) reactions.

3) Practical verification – for a representative reaction from each group, oxidation states were determined and the equation was balanced using the electron-balance method.

Throughout the examples, standard notation is used: the number above an element denotes its oxidation state, while the symbols "−e" and "+e" denote the loss or gain of electrons, respectively.

RESULTS

1. Intermolecular oxidation–reduction reactions

In this type of reaction, the oxidizing and reducing atoms belong to different substances (molecules). This is the most widespread type of redox reaction and the one most frequently encountered in educational practice.

Example: the reaction between zinc and copper(II) sulfate solution:

$$Zn^0 + Cu^{2+}SO_4 \rightarrow Zn^{2+}SO_4 + Cu^0$$

Electron balance:

$$Zn^0 - 2e^- \rightarrow Zn^{2+} \quad \textit{(reducing agent, oxidized)}$$

$$Cu^{2+} + 2e^- \rightarrow Cu^0 \quad \textit{(oxidizing agent, reduced)}$$

Since the number of electrons donated equals the number of electrons accepted (2 = 2), no further balancing of coefficients is required.

2. Intramolecular oxidation–reduction reactions

In this type, the oxidizing and reducing atoms belong to the same molecule but to different elements. Such reactions are most commonly observed during thermal decomposition.

Example: the thermal decomposition of potassium chlorate:

$$2KCl^{+5}O_3^{-2} \rightarrow 2KCl^{-1} + 3O_2^0$$

Electron balance:

$$Cl^{+5} + 6e^- \rightarrow Cl^{-1} \quad (oxidizing\ agent)$$

$$2O^{-2} - 4e^- \rightarrow O_2^0 \quad (reducing\ agent)$$

To equalize the total number of electrons, the first half-reaction is multiplied by 2 and the second by 3, giving $12e^- = 12e^-$, which accounts for the coefficient of 3 before O_2.

3. Disproportionation reactions

In disproportionation (self-oxidation–reduction) reactions, atoms of the same element at a single oxidation state simultaneously act as both oxidizing and reducing agents, converting into two different new oxidation states.

Example: the reaction of chlorine with cold alkali solution:

$$Cl_2^0 + 2NaOH \rightarrow NaCl^{-1} + NaOCl^{+1} + H_2O$$

Electron balance:

$$Cl^0 + 1e^- \rightarrow Cl^{-1} \quad (reduced)$$

$$Cl^0 - 1e^- \rightarrow Cl^{+1} \ (oxidized)$$

It can be seen that the two atoms of identical oxidation state in the original Cl_2 molecule are converted, over the course of the reaction, into two different products – chloride and hypochlorite.

4. Comproportionation (reproportionation) reactions

This type of reaction represents the reverse process of disproportionation: atoms of the same element at two different oxidation states react with each other to form a product with a single, intermediate oxidation state.

Example: the reaction between hydrogen sulfide and sulfur(IV) oxide:

$$2H_2S^{-2} + S^{+4}O_2 \rightarrow 3S^0 + 2H_2O$$

Electron balance:

$$S^{-2} - 2e^- \rightarrow S^0 \ (\times 2, \text{ reducing agent})$$

$$S^{+4} + 4e^- \rightarrow S^0 \ (\times 1, \text{ oxidizing agent})$$

Here, three sulfur atoms – two originating from S^{-2} and one from S^{+4} – are converted into a single common oxidation state, S^0; this is the characteristic feature of a comproportionation reaction.

DISCUSSION

The four types examined above show that classifying oxidation–reduction reactions carries both theoretical and practical significance. Intermolecular reactions form the basis of galvanic cells and electrolysis processes, while intramolecular reactions are observed in many thermal-decomposition and explosive processes –

for example, in the thermal decomposition of oxidizing substances upon heating[4]. Disproportionation reactions, in turn, are widely used industrially, particularly in the production of chlorine- and hypochlorite-based disinfectants.

The advantage of the electron-balance method is that, based on changes in oxidation state, it allows the coefficients of a reaction to be determined quickly and accurately. At the same time, for more complex reactions – especially those occurring in ionic or acidic/basic media – the half-reaction (ion-electron) method offers greater convenience, since it also accounts for the participation of H^+, OH^-, and H_2O in the medium. A comparative analysis of the two methods shows that the electron-balance method is fast and straightforward for simple substances with well-defined formulas, whereas the ion-electron method is better suited to complex, multistep, or solution-phase reactions.

The most common errors made by students are related to the following: incorrect determination of oxidation states (particularly in complex anions and coordination compounds), difficulty distinguishing disproportionation reactions from comproportionation reactions, and arithmetic mistakes made when equalizing the number of electrons donated and accepted in the electron-balance scheme. To prevent such errors, it is recommended that the oxidation state of every element first be determined individually before the elements that undergo a change in oxidation state are identified separately[5].

The close connection between oxidation–reduction reactions and electrochemistry deserves particular attention: galvanic cells, batteries, and electrolysis processes are based entirely on redox principles, in which the oxidation

[4]Housecroft C.E., Sharpe A.G. Inorganic Chemistry. — 4th ed. — Harlow: Pearson, 2012. — P. 129–138.

[5]Zumdahl S.S., Zumdahl S.A. Chemistry. — 9th ed. — Belmont: Cengage Learning, 2013. — P. 173–181.

and reduction processes are spatially separated and an electric current is generated through the difference in electrode potentials[6]. Beyond this, redox processes also play a central role in biological systems – for instance, in cellular respiration and photosynthesis – further confirming the interdisciplinary significance of the topic.

CONCLUSION

This study has systematically examined the four principal types of oxidation–reduction reactions – intermolecular, intramolecular, disproportionation, and comproportionation – using the electron-balance method. The characteristic examples provided for each type serve to clarify the mechanism and distinguishing features of each reaction category.

The results confirm that studying redox theory through a classification by type significantly improves students' skills in balancing equations and understanding reaction mechanisms in chemistry education. Future research may extend this topic to electrode potentials, the Nernst equation, and redox processes in organic chemistry – for example, the determination of oxidation states in organic compounds – as a promising direction of further inquiry.

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[6]Petrucci R.H., Herring F.G., Madura J.D., Bissonnette C. General Chemistry: Principles and Modern Applications. — 10th ed. — Toronto: Pearson, 2010. — P. 872–880.

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