An oxidation-reduction (redox) reaction is a type of chemical reaction that involves a transfer of electrons between two species. An oxidation-reduction reaction is any chemical reaction in which the oxidation number of a molecule, atom, or ion changes by gaining or losing an electron. Redox reactions are common and vital to some of the basic functions of life, including photosynthesis, respiration, combustion, and corrosion or rusting.

Rules for Assigning Oxidation States

The oxidation state (OS) of an element corresponds to the number of electrons, $e^{-}$, that an atom loses, gains, or appears to use when joining with other atoms in compounds. In determining the oxidation state of an atom, there are seven guidelines to follow:

1. The oxidation state of an individual atom is 0.
2. The total oxidation state of all atoms in: a neutral species is 0 and in an ion is equal to the ion charge.
3. Group 1 metals have an oxidation state of +1 and Group 2 an oxidation state of +2
4. The oxidation state of fluorine is -1 in compounds
5. Hydrogen generally has an oxidation state of +1 in compounds
6. Oxygen generally has an oxidation state of -2 in compounds
7. In binary metal compounds, Group 17 elements have an oxidation state of -1, Group 16 elements of -2, and Group 15 elements of -3.

The sum of the oxidation states is equal to zero for neutral compounds and equal to the charge for polyatomic ion species.

Example \(\PageIndex{1}\): Assigning Oxidation States

Determine the Oxidation States of each element in the following reactions:

a. \(\text{Fe}_{(s)} + \text{O}_{2(g)} \rightarrow \text{Fe}_2\text{O}_3(g)\)

b. \(\text{Fe}^{2+}\)

c. \(\text{Ag}_{}(s) + \text{H}_2\text{S} \rightarrow \text{Ag}_2\text{S}_{(g)} + \text{H}_{2(g)}\)

Solutions

A. Fe and O₂ are free elements; therefore, they each have an oxidation state of 0 according to Rule #1. The product has a total oxidation state equal to 0, and following Rule #6, O has an oxidation state of -2, which means Fe has an oxidation state of +3.

B. The oxidation state of Fe corresponds to its charge; therefore, the oxidation state is +2.

C. Ag has an oxidation state of 0, H has an oxidation state of +1 according to Rule #5, S has an oxidation state of -2 according to Rule #7, and hence Ag in Ag₂S has an oxidation state of +1.

Example \(\PageIndex{2}\): Assigning Oxidation States
Determine the Oxidation State of the bold element in each of the following:

a. \( \text{Na}_3\text{PO}_3 \)

b. \( \text{H}_2\text{PO}_4^- \)

Solutions

a. The oxidation numbers of Na and O are +1 and -2. Because sodium phosphite is neutral, the sum of the oxidation numbers must be zero. Letting \( x \) be the oxidation number of phosphorus, \( 0 = 3(+1) + x + 3(-2) \). \( x \) = oxidation number of \( P \) = +3.

b. Hydrogen and oxygen have oxidation numbers of +1 and -2. The ion has a charge of -1, so the sum of the oxidation numbers must be -1. Letting \( y \) be the oxidation number of phosphorus, \( -1 = y + 2(+1) + 4(-2) \). \( y \) = oxidation number of \( P \) = +5.

Example: Identifying Reduced and Oxidized Elements

Determine which element is oxidized and which element is reduced in the following reactions (be sure to include the oxidation state of each):

a. \( \text{Zn} + 2\text{H}^+ \rightarrow \text{Zn}^{2+} + \text{H}_2 \)

b. \( 2\text{Al} + 3\text{Cu}^{2+} \rightarrow 2\text{Al}^{3+} + 3\text{Cu} \)

c. \( \text{CO}_3^{2-} + 2\text{H}^+ \rightarrow \text{CO}_2 + \text{H}_2\text{O} \)

Solutions

a. Zn is oxidized (Oxidation number: 0 → +2); \( \text{H}^+ \) is reduced (Oxidation number: +1 → 0)

b. Al is oxidized (Oxidation number: 0 → +3); \( \text{Cu}^{2+} \) is reduced (+2 → 0)

c. This is not a redox reaction because each element has the same oxidation number in both reactants and products:
(For further discussion, see the article on oxidation numbers).

An atom is oxidized if its oxidation number increases, the reducing agent, and an atom is reduced if its oxidation number decreases, the oxidizing agent. The atom that is oxidized is the reducing agent, and the atom that is reduced is the oxidizing agent. (Note: the oxidizing and reducing agents can be the same element or compound).

Oxidation-Reduction Reactions

Redox reactions are comprised of two parts, a reduced half and an oxidized half, that always occur together. The reduced half gains electrons and the oxidation number decreases, while the oxidized half loses electrons and the oxidation number increases. Simple ways to remember this include the mnemonic devices \textbf{OIL RIG}, meaning "oxidation is loss" and "reduction is gain," and \textbf{LEO says GER}, meaning "loss of \( e^- \) = oxidation" and "gain of \( e^- \) = reduced." There is no net change in the number of electrons in a redox reaction. Those given off in the oxidation half reaction are taken up by another species in the reduction half reaction.
The two species that exchange electrons in a redox reaction are given special names. The ion or molecule that accepts electrons is called the **oxidizing agent**; by accepting electrons it causes the oxidation of another species. Conversely, the species that donates electrons is called the **reducing agent**; when the reaction occurs, it reduces the other species. In other words, what is oxidized is the reducing agent and what is reduced is the oxidizing agent. (Note: the oxidizing and reducing agents can be the same element or compound, as in disproportionation reactions).

A good example of a redox reaction is the thermite reaction, in which iron atoms in ferric oxide lose (or give up) O atoms to Al atoms, producing Al₂O₃.

\[ \text{Fe}_2\text{O}_3(s) + 2\text{Al}(s) \rightarrow \text{Al}_2\text{O}_3(s) + 2\text{Fe}(l) \]

Example (\cite{PageIndex4}): Identifying Oxidized Elements

Using the equations from the previous examples, determine what is oxidized in the following reaction.

\[ \text{Zn} + 2\text{H}^+ \rightarrow \text{Zn}^{2+} + \text{H}_2 \]

**Solution**

The oxidation state of H changes from +1 to 0, and the oxidation state of Zn changes from 0 to +2. Hence, Zn is oxidized and acts as the reducing agent.

Example (\cite{PageIndex5}): Identifying Reduced Elements

What is reduced species in this reaction?

\[ \text{Zn} + 2\text{H}^+ \rightarrow \text{Zn}^{2+} + \text{H}_2 \]

**Solution**

The oxidation state of H changes from +1 to 0, and the oxidation state of Zn changes from 0 to +2. Hence, H⁺ ion is reduced and acts as the oxidizing agent.

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**Combination Reactions**

**Combination** reactions are among the simplest redox reactions and, as the name suggests, involves "combining" elements to form a chemical compound. As usual, oxidation and reduction occur together. The general equation for a combination reaction is given below:

\[ A + B \rightarrow AB \]

Example (\cite{PageIndex6}): Combination Reaction

Consider the combination reaction of hydrogen and oxygen

\[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} \]
Solution

\[0 + 0 \rightarrow (2)(+1) + (-2) = 0\]

In this reaction both H\(_2\) and O\(_2\) are free elements; following Rule #1, their oxidation states are 0. The product is H\(_2\)O, which has a total oxidation state of 0. According to Rule #6, the oxidation state of oxygen is usually -2. Therefore, the oxidation state of H in H\(_2\)O must be +1.

Decomposition Reactions

A decomposition reaction is the reverse of a combination reaction, the breakdown of a chemical compound into individual elements:

\[AB \rightarrow A + B\]

Example (PageIndex{7}): Decomposition Reaction

Consider the decomposition of water:

\[H_2O \rightarrow H_2 + O_2\]

Calculation:

\[(2)(+1) + (-2) = 0 \rightarrow 0 + 0\]

Explanation: In this reaction, water is "decomposed" into hydrogen and oxygen. As in the previous example the H\(_2\)O has a total oxidation state of 0; thus, according to Rule #6 the oxidation state of oxygen is usually -2, so the oxidation state of hydrogen in H\(_2\)O must be +1.

Single Replacement Reactions

A single replacement reaction involves the "replacing" of an element in the reactants with another element in the products:

\[A + BC \rightarrow AB + C\]

Example (PageIndex{8}): Single Replacement Reaction

Equation:

\[Cl_2 + Na\underline{Br} \rightarrow Na\underline{Cl} + Br_2\]

Calculation:

\[(0) + ((+1) + (-1) = 0) \rightarrow ((+1) + (-1) = 0) + 0\]

Explanation: In this equation, Br is replaced with Cl, and the Cl atoms in Cl\(_2\) are reduced, while the Br ion in NaBr is
oxidized.

Double Replacement Reactions

A double replacement reaction is similar to a single replacement reaction, but involves "replacing" two elements in the reactants, with two in the products:

\[ AB + CD \rightarrow AD + CB \]

Example: Double Replacement Reaction

\[ MgSO_{4(aq)} + Na_2C_2O_{4(aq)} \rightarrow MgC_2O_{4(s)} + Na_2SO_{4(aq)} \]

Combustion Reactions

Combustion reactions almost always involve oxygen in the form of O\(_2\), and are almost always exothermic, meaning they produce heat. Chemical reactions that give off light and heat and light are colloquially referred to as "burning."

\[ C_{xH_y} + O_2 \rightarrow CO_2 + H_2O \]

Although combustion reactions typically involve redox reactions with a chemical being oxidized by oxygen, many chemicals "burn" in other environments. For example, both titanium and magnesium burn in nitrogen as well:

\[ 2Ti(s) + N_2(g) \rightarrow 2TiN(s) \]
\[ 3 Mg(s) + N_2(g) \rightarrow Mg_3N_2(s) \]

Moreover, chemicals can be oxidized by other chemicals than oxygen, such as Cl\(_2\) or F\(_2\); these processes are also considered combustion reactions.

Disproportionation Reactions

In disproportionation reactions, a single substance can be both oxidized and reduced. These are known as disproportionation reactions, with the following general equation:

\[ 2A \rightarrow A^{+n} + A^{-n} \]

Where \((n)\) is the number of electrons transferred. Disproportionation reactions do not need begin with neutral molecules, and can involve more than two species with differing oxidation states (but rarely).

Example: Disproportionation Reaction

Disproportionation reactions have some practical significance in everyday life, including the reaction of hydrogen peroxide, H\(_2O_2\) poured over a cut. This a decomposition reaction of hydrogen peroxide, which produces oxygen and water. Oxygen is present in all parts of the chemical equation and as a result it is both oxidized and reduced. The reaction is as follows:
\[2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})\]

DISCUSSION

On the reactant side, H has an oxidation state of +1 and O has an oxidation state of -1, which changes to -2 for the product H\textsubscript{2}O (oxygen is reduced), and 0 in the product O\textsubscript{2} (oxygen is oxidized).

References


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