Oxidation-Reduction (redox) reactions take place in the world at every moment. In fact, they are directly related to the origin of life. For instance, oxidation of nutrients forms energy and enables human beings, animals, and plants to thrive. If elements or compounds were exposed to oxygen, after a series of reactions the oxygen will be converted into carbon dioxide or water (combustion). To fully understand redox and combustion reactions, we must first learn about oxidation states (OS).

### Introduction

An oxidation state is a number that is assigned to an element in a chemical combination. This number represents the number of electrons that an atom can gain, lose, or share when chemically bonding with an atom of another element. The terms “oxidation state” and “oxidation number” are often used interchangeably. The transfer of electrons is described by the oxidation state of the molecule. One might mistaken formal charge for oxidation state but they are different. Oxidation state is commonly used to determine the changes in redox reactions and is numerically similar to valence electrons, but different from formal charge. Formal charge determines the arrangement of atoms and the likelihood of the molecule existing.

### Oxidation State Rules

To effectively assign oxidation states to a compound, the seven basic rules must be followed in order. Remember to use the rule that comes first if two rules conflict with each other. These rules hold true for most compounds.

- **RULE 1:** Any individual atom uncombined with other elements has the oxidation state of 0 (zero).

  Ex.) The OS for Ag is 0. The oxidation state for O (oxygen) or O\(_2\) is 0 as long as it is uncombined with any other element.

- **RULE 2:** The total sum of the oxidation state of all atoms in any given species is equal to the net charge on that species.

  a.) In neutral species, the total sum of the oxidation state of all atoms is 0.

  Ex.) The sum of OS for NaCl is 0 since the OS of Na = +1 and the OS of Cl = -1, therefore NaCl total OS = 0

  b.) In ions, the total sum of the oxidation state is the charge of the ion.

  Ex.) The OS of Ca\(^{2+}\) (Calcium) is = +2. The total sum of the OS of all atoms in CrO\(_4^{2-}\) (Chromate ion) is -2. The total sum of the oxidation states of all atoms in CH\(_3\)COO\(^-\) (Acetate ion) is -1.

- **RULE 3:** In a compound, the Oxidation state for Group 1(1A) metal is +1 and for Group 2(2A) metal, the oxidation state is +

  Ex.) In NaCl, Na has the oxidation state of +1 since it is a Group 1 Alkali metal. Cl would have an oxidation number
of -1 to make the sum of the oxidation states 0 (Rule 2). In MgCl₂, Mg has the oxidation state of +2, since it is a Group 2 Alkaline Earth metal. Cl would have an oxidation state of -1, and since there are 2 Cl atoms, the overall charge of the species would again be 0 (Rule 2).

• **RULE 4:** The oxidation state of FLOURINE is -1 in a compound.

  Ex.) OS of F is -1 in HF, SF₆

• **RULE 5:** The oxidation state of HYDROGEN is +1 in a compound.

  Ex.) OS of H is +1 in H₂, CH₄, NH₄⁺

• **RULE 6:** The oxidation state of OXYGEN is -2 in a compound.

  Ex.) OS of Oxygen is -2 in OH⁻, H₂O, CO₃²⁻

• **RULE 7:** In two-element compounds with metals, Group 15(3A) elements have the oxidation state of -3, Group 16(6A) elements have the oxidation state of -2, and Group 17(7A) elements have the oxidation state of -1.

  Ex.) In MgBr₂, Br has the oxidation state of -1, since it is a Group 17 element. In Li₂S, S has the oxidation state of -2, since it is a Group 16.

**Example 1**

Find the oxidation state of Cr in CrO₄²⁻

**SOLUTION**

1. From Rule #2, we know that the sum of OS for this compound is -2.
2. From Rule #6, we know that Oxygen in a compound is -2. Since we have four oxygen, -2 x 4 = -8.
3. With those information, set up an short equation

   \[|\text{Cr} + (-8) = -2|\]

So the oxidation state of Cr is +6

**Example 2**

Find the oxidation state of C in C₂H₃O₂⁻

**SOLUTION**
1. From Rule #2, we know that the sum of OS for this compound is -1
2. From Rule #5, we know that Hydrogen in a compound is +1. Since we have three Hydrogen, +1 x 3 = +3
3. From Rule #6, we know that Oxygen in a compound is -2. Since we have two oxygen, -2 x 2 = -4
4. With those information, set up an equation
   \[2C + (+3) + (-4) = -1]\]
   Rewrite as
   \[2C + 3 - 4 = -1\]
   \[2C = 0\]
   \[C = 0/2 = 0\]

   The oxidation state for C is 0.

Example 3

Find the oxidation state of S in S₂O₃⁻².

SOLUTION

1. From Rule #2, we know that the sum of OS for this compound is -2
2. From Rule #6, we know that Oxygen in a compound is -2. Since we have three oxygen, -2 x 3 = -6
3. With those information, set up an equation 2S + (-6) = -2
   Rewrite as
   \[2S - 6 = -2\]
   \[2S = 4\]
   \[S = 4/2 = 2\]

   The oxidation state for S is 2.

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**Fractional Values for Oxidation States**

The oxidation states are usually in whole numbers, but in some cases, they are in fractional numbers. Consider Fe₃O₄.

- Using rule #2, the sum of the oxidation state of all atoms is 0
Using rule #6, the O has the oxidation state of -2. $4x(-2) = -8$

Equation: $3\text{Fe} + (-8) = 0$

$3\text{Fe} = 8$

$\text{Fe} = 8/3$

In most cases, atoms of the same element in a given compound have the same oxidation states, but each atom can have a different state than the other. For $\text{Fe}_3\text{O}_4$, two Fe atoms have an oxidation state of +3 and one of +2, which makes the total oxidation state of $\text{Fe} = 8/3$.

Instead of averaging the oxidation states, we must keep them separated. This is called fragmenting, which occurs if there is an ionic compound, and the ions can be separated. The oxidation state of the individual atoms in the different ions can be determined.

**Practice Problems**

Determine the oxidation states of the underlined elements in

1) $\text{Cl}_2$; 2) $\text{NaH}$; 3) $\text{H}_2\text{CO}$; 4) $\text{S}_2\text{O}_3^{2-}$; 5) $\text{K MnO}_4$; 6) $\text{FeCl}_3$; 7) $\text{N}_2$; 8) $\text{H}_2\text{SO}_4$; 9) $\text{HClO}_2$; 10) $\text{CuSO}_4$;

Transition metal complex

11) $[\text{Co(NH}_3)_5\text{CO}_3]\text{Br}$

**Solutions**

1. Using rule #1, Cl isn’t combine with any other element other than itself, therefore the oxidation state for Cl is 0.

2. Using rule #2, we know that the sum of the oxidation states for Na and H is 0 because NaH is a neutral compound. Now, we might be tempted to say H has the oxidation state of +1 because of rule #5. However, recall that one must use the rules in order. Because Na is in Group 1A, according to rule #3, the oxidation state of Na is +1. Thus, H must have the oxidation state of -1 so that the sum of the oxidation state for Na and H is 0.

3. Using rule #2, the sum of the oxidation state is 0. Using rule #5, H has the oxidation state of +1, and using rule #6, O has the oxidation state of -2. The equation for $\text{H}_2\text{CO}$: $2(+1) + C + (-2) = 0$ -----> $2 + C - 2 = 0$ -----> $C = 0$

4. Using rule #2, the sum of the oxidation state is 0. Using rule #6, O has the oxidation state of -2. We want to know the oxidation of S, so the equation for $\text{S}_2\text{O}_3^{2-}$: $2S + 3(-2) = -2$ -----> $2S - 6 = -2$ -----> $2S + 4$ -----> $S = 4/2$ -----> $S = 2$

5. Using rule #2, the sum of the oxidation state is 0, and using rule #3, the oxidation state for K is +1. Using rule #6, O has the oxidation state of -2. The equation for $\text{K MnO}_4$: $1 + Mn + 4(-2) = 0$ -----> $Mn = -1 + 8$ -----> $Mn = 7$

6. Using rule #2, the sum of oxidation state is 0. Using rule #7, Cl has a -1 charge. The equation for $\text{FeCl}_3$ Fe + 3(-1) = 0 -----> Fe -3 = 0 -----> Fe = 3

7. Using rule #1, N isn’t combine with any other element other than itself, therefore the oxidation state for N is 0.

8. Using rule #2, the sum of the oxidation state is 0, and using rule #5, the oxidation state for H is +1. Using rule #6, O has the oxidation state of -2. The equation for $\text{H}_2\text{SO}_4$: $2(1) + S + 4(-2) = 0$ -----> $S = -2 + 8$ -----> $S = 6$

9. Using rule #2, the sum of the oxidation state is 0, and using rule #5, the oxidation state for H is +1. Using rule #6, O
has the oxidation state of -2. The equation for \( \text{HClO}_2 \): 
\[ 1 + \text{Cl} + 2(-2) = 0 \quad \text{------} \quad \text{Cl} = -1 + 4 \quad \text{------} \quad \text{Cl} = 3 \]

10. Using rule #2, the sum of the oxidation state is 0. Using rule #6, O has the oxidation state of -2. Cu only have one charge which is +2. The equation for \( \text{CuSO}_4 \): 
\[ 2 + \text{S} + 4(-2) = 0 \quad \text{------} \quad \text{S} = -2 + 8 \quad \text{------} \quad \text{S} = 6 \]

11. \( [\text{Co(NH}_3)_5\text{CO}_3]\text{Br} \) is a transition metal complex, whatever is inside the bracket [ ] has to balance out with the outside, which is the Br in this case to make the whole complex = 0.

- Lets start off with the outside (Br) first, the OS of Br is -1 (Rule #7).
- Everything INSIDE of the bracket must equal to +1. Since Br is -1, the whole bracket is +1 = 0.
- We know that NH\(_3\) have a 0 charge.
- The charge of CO\(_3\) is -2.
- The equation for the INSIDE bracket is Co + 0(5) + (-2) = +1
- Co -2 = +1 ----> oxidation state for Co = +3

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**Video Links**

- [http://www.youtube.com/watch?v=_fNNQfGGYr4](http://www.youtube.com/watch?v=_fNNQfGGYr4)
- [http://www.youtube.com/watch?v=GA88JI4AymY](http://www.youtube.com/watch?v=GA88JI4AymY)
- [http://www.youtube.com/watch?v=XTlIaylMM8](http://www.youtube.com/watch?v=XTlIaylMM8)
- [http://www.youtube.com/watch?v=9EYRKfWIARA](http://www.youtube.com/watch?v=9EYRKfWIARA)

**Outside Links**

- [http://www.science.uwaterloo.ca/~cch.../oxidstat.html](http://www.science.uwaterloo.ca/~cch.../oxidstat.html)

**References**

4. [http://www.khanacademy.org/about](http://www.khanacademy.org/about)
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