Reduction-Oxidation Reactions

In General Biology, most of the **reduction/oxidation reactions (redox)** that we discuss occur in metabolic pathways (connected sets of biochemical reactions). Here, the cell breaks down the compounds it consumes into smaller parts and then reassembles these and other molecules into larger macromolecules. Redox reactions also play critical roles in energy transfer, either from the environment or within the cell, in all known forms of life. For these reasons, it is important to develop at least an intuitive understanding and appreciation for redox reactions in biology.

Most students of biology will also study reduction and oxidation reactions in their chemistry courses; these kinds of reactions are important well beyond biology. Regardless of the order in which students are introduced to this concept (chemistry first or biology first), most will find the topic presented in very different ways in chemistry and biology. That can be confusing.

Chemists often introduce the concepts of oxidation and reduction using the concept of oxidation states. See this link for more information: <https://chem.libretexts.org/Bookshel...ation_Numbers)>. Chemists usually ask students to apply a set of rules (see link) to determine the oxidation states of individual atoms in the molecules involved in a chemical reaction. The chemistry formalism defines oxidation as an increase in oxidation state and reduction as a decrease in oxidation state.

However, biologists don’t typically think about or teach redox reactions in this way. Why? We suspect it’s because most of the redox reactions encountered in biology involve a change in oxidation state that comes about trough a transfer of electron(s) between molecules. Biologists, therefore, typically define reduction as a gain of electrons and oxidation as a loss of electrons. We note that the biological electron-exchange view of redox reactions is entirely consistent with the more general definition associated strictly with changes in oxidation states. The electron-exchange model does not, however, explain redox reactions that do not involve a transfer of electrons, which sometimes occur in the context of a chemistry class. The biologist's view of redox chemistry has the advantage (in the context of biology) of being relatively easy to create a mental picture for. There are no lists of rules to remember or much inspection of molecular structure involved in developing at least a basic conceptual picture of the topic. We simply imagine an exchange between two parties - one molecule handing off one or more electrons to a partner who accepts them.

Since this is a biology reading for a biology class we approach redox from the “gain/loss of electrons” conceptualization. If you have already taken a chemistry class and this topic seems to be presented a little different in your biology course, remember that at its core, you are learning the same thing. Biologists just adapted what you learned in chemistry to make more intuitive sense in the context of biology. If you haven't learned about redox, yet don't worry. If you can understand what we are trying to do here, when you cover this concept in chemistry class you will be a few steps ahead. You will just need to work to generalize your thinking a little bit.

Let's start with some generic reactions

Transferring electrons between two compounds results in one of these compounds losing an electron and one compound gaining an electron. For example, look at the figure below. If we use the energy story rubric to look at the overall reaction, we can compare the before and after characteristics of the reactants and products. What happens to the matter (stuff) before and after the reaction? **Compound A** starts as neutral and becomes positively charged. **Compound B** starts as neutral and becomes negatively charged. Because electrons are negatively charged, we can explain this reaction with the movement of an electron from **Compound A** to **B**. That is consistent with the changes in charge. **Compound A** loses an electron (becoming positively charged), and we say that A has become oxidized. For biologists, **oxidation** is associated with the loss of electron(s). **B** gains the electron (becoming negatively charged), and we say that **B** has become reduced. **Reduction** is associated with the gain of electrons. We also know, since a reaction occurred (something happened), that energy must have been transferred and/or reorganized in this process and we'll consider this shortly.

$$A + B \rightarrow A^+ + B^-$$

Half reaction 1: $A \rightarrow A^+ + e^-$

Half reaction 2: $B + e^- \rightarrow B^-$

Figure 1. *Generic redox reaction with half-reactions Attribution: Mary O. Aina*

To reiterate: When an electron(s) is lost, or a molecule is **oxidized**, the electron(s) must then pass to another molecule. We say that the molecule gaining the electron becomes **reduced**. Together these paired electron gain-loss reactions are known as an **oxidation-reduction reaction** (also called a redox reaction).

This idea of paired half-reactions is critical to the biological concept of redox. Electrons don't drop out of the universe for "free" to reduce a molecule nor do they jump off a molecule into the ether. Donated electrons MUST come from a donor molecule and be transferred to some other acceptor molecule. For example, in the figure above the electron the reduces molecule B in half-reaction 2 must come from a donor - it just doesn't appear from nowhere! Likewise, the electron that leaves A in half-reaction 1 above must "land" on another molecule - it doesn't just disappear from the universe.

Therefore, **oxidation and reduction reactions must ALWAYS be paired.** We'll examine this idea in more detail below when we discuss the idea of "half-reactions".

- **A tip to help you remember:** The mnemonic LEO says GER (**L**ose **E**lectrons = **O**xidation and **G**ain **E**lectrons = **R**eduction) can help you remember the biological definitions of oxidation and reduction.

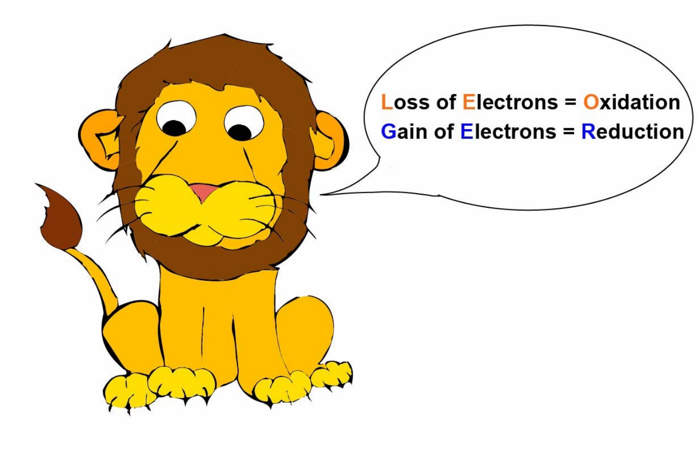


Figure 2. *A figure for the mnemonic "LEO the lion says GER." LEO: Loss of Electrons = Oxidation. GER: Gain of Electrons = Reduction. Attribution: Kamali Sripathi*

- **The vocabulary of redox can be confusing:** Students studying redox chemistry can often become confused by the vocabulary used to describe the reactions. Terms like oxidation/oxidant and reduction/reductant look and sound very similar but mean distinctly different things. An electron donor is also sometimes called a reductant because it is the compound that causes the reduction (gain of electrons) of another compound (the oxidant). In other words, the reductant is donating it's electrons to the oxidant which is gaining those electrons. Conversely, the electron acceptor is called the oxidant because it is the compound that is causing the oxidation (loss of electrons) of the other compound. Again, this simply means the oxidant is gaining electrons from the reductant who is donating those electrons. Confused yet?

Yet another way to think about definitions is to remember that describing a compound as reduced/oxidized is describing the **state** that *the compound itself* is in, whereas labeling a compound as a reductant/oxidant describes how the compound can act, to either reduce or oxidize *another compound*. Keep in mind that the term reductant is also synonymous with reducing agent and oxidant is also synonymous with oxidizing agent. The chemists who developed this vocabulary need to be brought up on charges of "willful thickheadedness" at science trial and then be forced to explain to the rest of us why they needed to be so deliberately obtuse.

The confusing language of redox: quick summary

1. A compound can be described as “reduced” - term used to describe the compound's **state.**

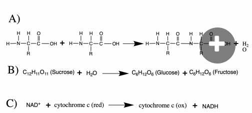
2. A compound can be a “reductant” - term used to describe a compound's **capability** (it can reduce something else). The synonymous term "reducing agent" can be used to describe the same capability (the term "agent" refers to the thing that can "do something" - in this case reduce another molecule).

3. A compound can be an “oxidant” - term used to describe a compound's **capability** (it can oxidize something else). The synonymous term "oxidizing agent" can be used to describe the same capability (the term "agent" refers to the thing that can "do something" - in this case oxidize another molecule).

4. A compound can “become reduced” or "become oxidized"- term used to describe the **transition** to a new state.

Since all of these terms are used in biology, in General Biology we expect you to become familiar with this terminology. Try to learn it and use it as soon as possible - we will use the terms frequently and will not have the time to define terms each time.

Knowledge Check Quiz



Which of the following is a redox reaction?

- B
- C
- A

Check

Reuse Embed H5P

nb.

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Submit