Redox Reactions

Skills to Develop

- Describe what occurs in a redox reaction
- Identify redox patterns in the periodic table

Redox reactions are reactions in which electrons shift allegiance. Allegiance means loyalty or commitment to a group, like your allegiance to your family or your country. If you decide to leave your home and become a citizen of a new country, you have shifted allegiance. Of course, you might be able to share your allegiance between your old country and your new country by being a citizen of both countries at the same time. This is similar to what electrons do. They have allegiance to a nucleus, and sometimes during a reaction they will shift allegiance to a different nucleus. They might shift allegiance completely, if the new nucleus is much better for them than the old one, or they might shift partially, and share their loyalty between the two. (Also, electrons, like people, can spend some time near nuclei they don't belong to, just like you can visit countries where you don't live, and then go back near their main nucleus, although electrons' trips are much shorter than ours!)

Redox Patterns in the Periodic Table

All neutral atoms have a population of electrons equal to their number of protons. Atoms, just like countries, always have elite citizens that they treat really well (power, money...) and these elite citizens are way too comfortable to shift allegiance unless they get kidnapped or something. Unlike countries, atoms always have only a small number of non-elite citizens, between 0 and 8, roughly, but usually no more than 3 or 4. These non-elite electrons will easily shift allegiance if they get a better offer.

What are the good parts of the periodic table? Fluorine is like heaven for electrons, they will basically never leave. If fluorine is accepting immigrants, electrons will leave anywhere else to move to F. Oxygen is second best. (Fluorine seems nasty to us because we don't want our citizen electrons to leave us for fluorine. We have jobs for them to do!) The noble gases are aloof nations, their populations of electrons hardly ever change. Their citizens don't want to leave, and they don't want any troublesome immigrants either. In general, the upper right corner of the periodic table are good comfortable nations to live in. The bottom left is such a bad place to live that electrons will destroy property in their rush to leave. (Watch this video for an example) This shows "standard of living" across the periodic table. Red elements will tend to keep their own electrons and attract electrons from other nuclei; yellow elements will tend to lose their non-elite electrons.

Ionic substances are like alliances between nations with really different standards of living. The non-elite electrons of the metal will try to shift allegiance to the non-metal. In molecular substances, also called covalent, the electrons will have dual citizenship, although they might have slightly greater loyalty to one nuclei than another, because these are alliances between similarly comfortable non-metal nuclei.

Another illustration of the redox patterns on the periodic table. The elements existing in nature with a negative charge are those that usually accept immigrants (electrons). Meanwhile the elements existing in nature with a positive charge are those that usually lose electrons.

Oxidation States: Redox from the Nuclei's Perspective

With all these dual citizen electrons, with partial loyalty to several nuclei, it can get hard to count the population of electrons at each nucleus. **Oxidation number** is one procedure for counting. In this procedure, electrons are counted as belonging completely to the nuclei they feel the greatest loyalty to. The number of electrons that feel primary loyalty to each nucleus is counted, and subtracted the number of protons in that nucleus. But there are shortcuts to make this faster using valence rules. For example, in CO_2, oxygen has a normal valence of 2. This means that it can accept 2 extra citizen electrons per nucleus, so it has an oxidation number of -2. Therefore, because there are 2 O nuclei, carbon loses 4 citizen electrons, who transfer their primary loyalty to O. Thus, carbon has an oxidation number of +4, because it has 4 fewer truly loyal electrons than protons.

How to count oxidation states:

- In elemental form, all nuclei have oxidations number 0
- In single-nucleus ions, the oxidation number is the charge
- Alkali nuclei always have an oxidation number of +1, unless in metallic form
- Alkaline earth nuclei always have an oxidation number of +2, unless in metallic form
- Oxygen nearly always has an oxidation number of -2, unless it is in an O-O unit like peroxide

- Non-metals have negative oxidation numbers when bound to metals and positive oxidation numbers when bound to O or F.
- Halogens have oxidation number of -1 unless bound to O or F. F is always -1 unless in elemental form.
- The sum of all the oxidation numbers of a molecule or ion is its overall charge (0 if neutral, +2 if a dipositive cation, etc)

Types of Redox Reactions

Oxidation refers to a process in which something loses electrons, and has its oxidation number increase. This usually happens to compounds that react with oxygen gas, which is why it is called oxidation. **Reduction** refers to a process in which something gains electrons, and its oxidation number is reduced. Actually this is not quite where the word came from. When a metal oxide is reduced to the elemental metal and an elemental non-metal or non-metal compound, the mass of solid decreases because the non-metal usually leaves as a gas. This reduction in quantity is where the word comes from. When you think about it, for one thing to be oxidized, another thing must be reduced (because electrons can't appear out of nowhere), which is why we often use the combination word redox.

An example of a redox reaction with the oxidation numbers above their respective elements (i.e. Mn in MnO_2 has an oxidation number of +4).

Many of the reaction types we've already seen involve redox. For instance, combination of elements is a redox reaction. Decomposition reactions are often redox reactions. Combustion reactions are redox reactions. (Dissolution/precipitation and acid-base are not redox reactions.) The examples of redox you've already seen involve electrons shifting loyalty at the same time that new bonds are made between nuclei. It's also possible for electrons to abandon one nucleus for another separate nucleus that isn't bonded to the first one. For example, if an elemental metal is placed in a solution of salt or acid, the metal can lose some electrons to the cation in the solution. The metal forms cations, and the former cation usually leaves the solution, forming hydrogen gas or elemental metal. Here are some examples:

$$Zn(s) + 2HBr(aq) \rightarrow ZnBr_2(aq) + H_2(g) \tag{1}$$

$$Fe(s) + Pb(NO_3)_2(aq) \rightarrow Fe(NO_3)_2(aq) + Pb(s) \tag{2}$$

All that happened in these reactions is that the disloyal electrons left a less-comfortable home country for a more comfortable one. These are called **displacement reactions** because one cation is displaced (replaced) by another. To predict what reactions will occur on this pattern, you can use the **activity series**, which is a ranking of "worst places to live". It's pretty good for making predictions, because in general electrons will move to places later on the list, but it doesn't take into account all the specific circumstances, like current population pressures. You'll learn more reliable ways to make predictions later. The activity series is:

1. Worst place to live/easiest to oxidize: the alkali and alkaline earth metals
2. Bad: the active metals, aluminum, zinc, iron, and others from the middle of the transition metals
3. Better: tin, lead, hydrogen from acid, copper
4. Best place to live, hardest to oxidize: the noble metals, silver, mercury, platinum, gold

Copper metal doesn't react with acid, because copper comes after hydrogen in the list. However, some acids have other oxidants in them that are stronger than hydrogen ions. For instance, nitrate ions are oxidizing, and Cu will react with nitric acid. Even gold reacts with a concentrated acid mixture, aqua regia, made of nitric and hydrochloric acids.

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