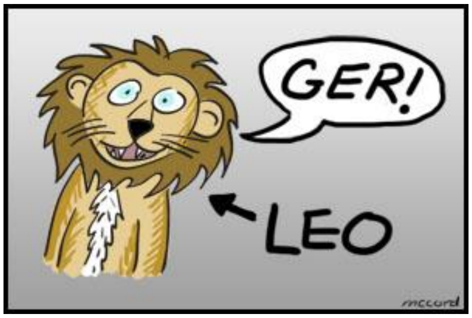
Redox Reactions



There was a lion named **Leo (lose electrons oxidized)** who roars **Ger (gain electrons reduced).** This mnemonic can be a useful way to remember what happens in oxidation and reduction half-reactions. “Oil Rig” is another one.

Oxidation: $\mathrm{Leo} \rightarrow \mathrm{Leo}^{+} + e^{-}$ or **O**xidation **I**s **L**oss of e^{-}

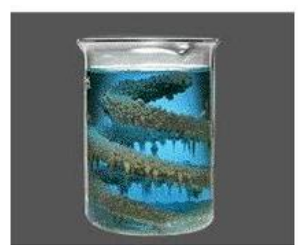
Reduction: $\mathrm{Ger} + e^{-} \rightarrow \mathrm{Ger}^{-}$ or **R**eduction **I**s **G**ain of e^{-}

The species reduced (oxidizing agent) *Ger* takes an electron from the species oxidized (reducing agent) *Leo*. In a balanced redox reaction, there must be conservation of atoms (mass), overall charge and electrons transferred. There is a systematic approach for balancing a redox reaction. First, split the reaction into two half-reactions and balance these individually. Electrons appear in the balanced half-reactions: as a “product” in the oxidation half-reaction and as a “reactant” in reduction half-reaction. Next, balanced overall # of e^{-} transferred, so that the # of e^{-} provided by oxidation equals the # of e^{-} required for reduction. Finally, put the half-reactions back together and do any simplification needed.

Consider the following unbalanced reaction: $\mathrm{Cu}_{(s)} + \mathrm{Ag}^{+}_{(aq)} \rightarrow \mathrm{Cu}^{2+}_{(aq)} + \mathrm{Ag}_{(s)}$

Oxidation half-reaction: $\mathrm{Cu} \rightarrow \mathrm{Cu}^{2+} + 2e^{-}$

Reduction half-reaction: $(\mathrm{Ag}^{+} + e^{-} \rightarrow \mathrm{Ag}) \times 2$



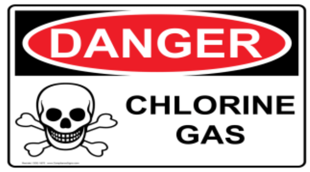
Now, we need to balance # e^{-} transferred and put the half-reactions back together to give: Balanced: $\mathrm{Cu}_{(s)} + 2\mathrm{Ag}^{+}_{(aq)} \rightarrow \mathrm{Cu}^{2+}_{(aq)} + 2\mathrm{Ag}_{(s)}$

Species oxidized/reducing agent: Cu

Species reduced/oxidizing agent: Ag^{+}

Chlorine Gas

Chlorine gas (Cl_2) is a yellowish-green toxic gas that has a smell of bleach. It is a notorious toxic gas that was used for the first time as a chemical weapon in WWII. It was used to kill thousands of soldiers and innocent people. On another hand, Cl_2 is an important ingredient for chemical industries to produce detergents, bleach, chloroform and pesticides. Let’s take a deeper look at this “double-edged sword” and practice how to balance redox reactions.



(1) Chlorine gas was first discovered by a Swedish chemist named Carl Wilhelm Schelee (right) in 1774. He heated hydrochloric acid (of moderate concentration) with a mineral, pyrolusite (containing manganese dioxide, MnO_2) and collected some yellowish-green gas. The gas was determined to be Cl_2. An unbalanced equation for the relevant chemical reaction (with spectator ions omitted) is shown below. Please balance the equation in acidic solution.

$$Cl^- + MnO_2 \xrightarrow{\text{Heat}} Mn^{2+} + Cl_2$$

$2\,Cl^- \rightarrow Cl_2 + 2\,e^-$

$4\,H^+ + MnO_2 + 2\,e^- \rightarrow Mn^{2+} + 2\,H_2O$

$4\,H^+ + MnO_2 + 2\,Cl^- \rightarrow Cl_2 + Mn^{2+} + 2\,H_2O$

(2) The above reaction requires heat and moderately concentrated hydrochloric acid. Randa and Gabe probably won't want to use this reaction to produce Cl_2 due to unavailability of the pyrolusite ore. They soon figure out a much more convenient way to obtain Cl_2 - mixing diluted hydrochloric acid with potassium permanganate ($KMnO_4$), a common disinfectant. This reaction readily takes place at room temperature and quickly generates a large amount of Cl_2. The unbalanced equation for the relevant chemical reaction (with spectator ions omitted) is shown below. Please balance the equation in acidic solution.

$$Cl^- + MnO_4^- \rightarrow Mn^{2+} + Cl_2$$

$5 \times (2\,Cl^- \rightarrow Cl_2 + 2\,e^-)$

$2 \times (8\,H^+ + MnO_4^- + 5\,e^- \rightarrow Mn^{2+} + 4\,H_2O)$

$16\,H^+ + 2\,MnO_4^- + 10\,Cl^- \rightarrow 5\,Cl_2 + 2\,Mn^{2+} + 8\,H_2O$

(3) When Cl2 dissolves in water or comes in contact with moisture, hypochlorous acid (HClO) is one of the products and it is responsible for the "bleach smell". Please balance the chemical equation in acidic solution.

$$Cl_2 \rightarrow Cl^- + HClO$$

$Cl_2 + 2\,e^- \rightarrow 2\,Cl^-$

$2 \times (Cl_2 + H_2O \rightarrow HClO + H^+ + e^-)$

$4\,Cl_2 + 2\,H_2O \rightarrow 2\,HClO + 2\,Cl^- + 2H^+$ $\div$ each by 2

$2\,Cl_2 + H_2O \rightarrow HClO + Cl^- + H^+$

Modified from an original problem set by Tianyu Liu (UCSC PhD candidate in chemistry)

(4) Chlorine gas can be recovered from seawater by electrolysis (a redox reaction that requires an external source of energy). Please balance the following equation under basic conditions.

$$Cl^- + H_2O \rightarrow Cl_2 + H_2 + OH^-$$

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

$2Cl^- \rightarrow Cl_2 + 2e^-$

$2H_2O + 2Cl^- \rightarrow H_2 + 2OH^- + Cl_2$