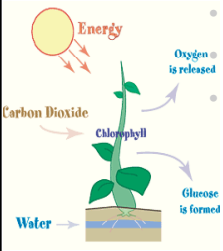
Oxidation-Reduction Reactions

- ***Oxidation-reduction reactions*** (sometimes called ***redox reactions***) are reactions involving the transfer of one electron or more from one reactant to another.

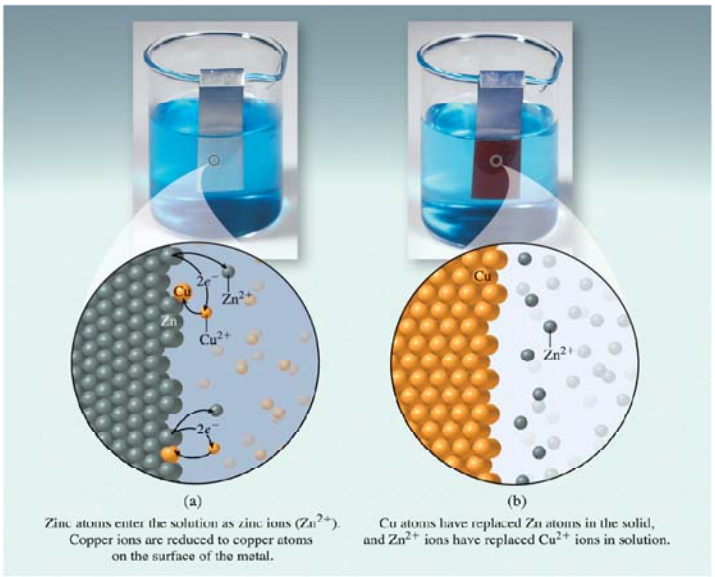
  Redox reaction also involves the change in ***oxidation states*** for molecules.
- These reactions are very common in life:



- Photosynthesis. (conversion of CO_2 and H_2O into sugar)
- Oxidation of sugar and fat in our bodies to produce energy.
- Combustion that provides humanity with power.

Oxidation-Reduction Reactions

Oxidation of zinc in a solution of copper sulfate



Oxidation-Reduction Reactions

- Oxidation is losing electrons:

$$Zn(s) \rightleftharpoons Zn^{2+}(aq) + 2e^-$$

- Reduction is gaining electrons:

$$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$$

Half-reactions

- Redox (oxidation-reduction) reactions

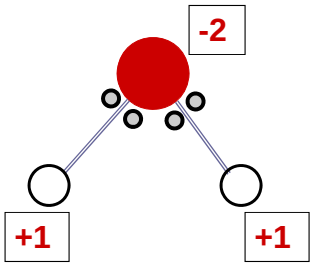
  If something in solution gets oxidized, then something else must be reduced (and vice versa).

$$Zn(s) + Cu^{2+}(aq) + \cancel{2e^-} \rightleftharpoons Zn^{2+}(aq) + Cu(s) + \cancel{2e^-}$$

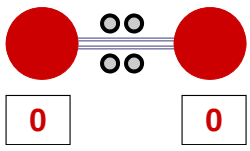
$$Zn(s) + Cu^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Cu(s)$$

Oxidation States (Oxidation Numbers)

- ***Oxidation state*** is an imaginary charge on an atom if the electrons were transferred completely to that atom. Normally, the shared electrons are completely assigned to the atoms the have stronger attraction for the electrons.



H_2O



O_2

Oxidation State Rules

TABLE 4.5 Elements with Reliable Oxidation Numbers in Compounds or Polyatomic Ions

Element	Oxidation Number	Exceptions
Fluorine	−1	
Group 1A or 2A metal	+1 or +2, respectively	
Hydrogen	+1	Any combination with a Group 1A or 2A metal to form a metal hydride. Examples: LiH and CaH_2—the oxidation number of H is −1 in both examples.
Oxygen	−2	Any combination with something higher on the list that necessitates its having a different oxidation number (see rule 2 for assigning oxidation numbers). Examples: H_2O_2 and KO_2—the oxidation number of O for H_2O_2 is 1 and for KO_2 is $-\frac{1}{2}$.
Group 7A (other than fluorine)	−1	Any combination with something higher on the list that necessitates its having a different oxidation number (see rule 2 for assigning oxidation numbers). Examples: ClF, BrO_4^-, and IO_3^-—the oxidation numbers of Cl, Br, and I are +1, +7, and +5, respectively.

- The oxidation number for any element in its ***elemental form*** is zero (O_2, F_2).
- The oxidation number in any chemical species must ***sum to the overall charge*** on the species.
- The oxidation states in ***ionic compounds*** are the same as the charge each atom has by its own (PbS, NaCl)

Assigning Oxidation States

$KMnO_4$ (a)

$KMnO_4$ (c) — +1, −2, +1, −8

$KMnO_4$ (b) — +1, +1

$KMnO_4$ (d) — +1, +7, −2, +1, +7, −8

Assigning Oxidation States

Exercise:

Assign oxidation states for all atoms in the following:

a) CO_2 b) SF_6 c) NO_3^-

CO_2

x -2 × 2

Total charge = 0 = -2(2) + x

x = +4

SF_6

x -1 × 6

Total charge = 0 = -1(6) + x

x = +6

NO_3^-

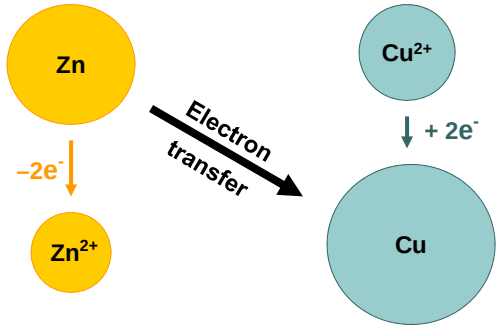
x -2 × 3

Total charge = -1 = -2(3) + x

x = +5

Oxidation-Reduction Process

$$Zn(s) + Cu^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Cu(s)$$



- Oxidized
- Losing electron(s)
- Oxidation state increases
- Reducing agent

- Reduced
- Gaining electron(s)
- Oxidation state decreases
- Oxidizing agent

Oxidation States in Redox Reactions

$2Na(s) + Cl_2(g) \longrightarrow 2NaCl(s)$

0 0 +1 -1

$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$

-4 +1×4 0 +4 -2×2 +1×2 -2

$CH_4 \longrightarrow CO_2 + 8e^-$

-4 +4

CH_4 is a reducing agent

$2O_2 + 8e^- \longrightarrow CO_2 + 2H_2O$

0 -2×2 -2

O_2 is an oxidizing agent

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Exercise

For the following two reactions:

* determine the oxidation states,
* identify the atoms that are oxidized and reduced, and
* specify the oxidizing and reducing agents.

$2PbS(s) + 3O_2(g) \longrightarrow 2PbO(s) + 2SO_2(g)$

$PbO(s) + CO(g) \longrightarrow Pb(s) + CO_2(g)$

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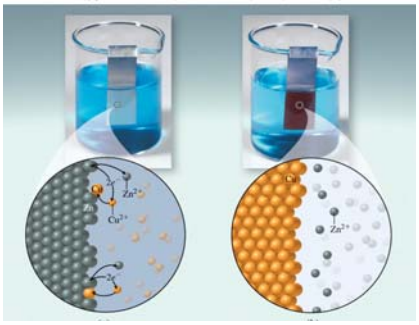
Redox Reactions in Aqueous Solutions

$$\underset{0}{Zn(s)} + \underset{+2\ \ -2}{CuCl_2\,(aq)} \longrightarrow \underset{+2\ \ -2}{ZnCl_2(aq)} + \underset{0}{Cu(s)}$$

"Displacement reaction"

- What would happen if you place copper metal into a solution of $ZnCl_2$?

  Would $Cu(s)$ be oxidized by $Zn^{2+}(aq)$ ions the way $Zn(s)$ is oxidized by $Cu^{2+}(aq)$ ions?



$$Cu(s) + ZnCl_2\,(aq) \longrightarrow \text{no reaction}$$

The Activity Series

- The ***activity series*** shows the order of ease the metal is to be oxidized.
- Metals at the top of the list are called the ***active metals***.

  Metals at the bottom of the list are known as ***noble metals***.

TABLE 4.6 Activity Series

Increasing ease of oxidation

Element	Oxidation Half-Reaction
Lithium	$Li \longrightarrow Li^+ + e^-$
Potassium	$K \longrightarrow K^+ + e^-$
Barium	$Ba \longrightarrow Ba^{2+} + 2e^-$
Calcium	$Ca \longrightarrow Ca^{2+} + 2e^-$
Sodium	$Na \longrightarrow Na^+ + e^-$
Magnesium	$Mg \longrightarrow Mg^{2+} + 2e^-$
Aluminum	$Al \longrightarrow Al^{3+} + 3e^-$
Manganese	$Mn \longrightarrow Mn^{2+} + 2e^-$
Zinc	$Zn \longrightarrow Zn^{2+} + 2e^-$
Chromium	$Cr \longrightarrow Cr^{3+} + 3e^-$
Iron	$Fe \longrightarrow Fe^{2+} + 2e^-$
Cadmium	$Cd \longrightarrow Cd^{2+} + 2e$
Cobalt	$Co \longrightarrow Co^{2+} + 2e^-$
Nickel	$Ni \longrightarrow Ni^{2+} + 2e^-$
Tin	$Sn \longrightarrow Sn^{2+} + 2e^-$
Lead	$Pb \longrightarrow Pb^{2+} + 2e^-$
Hydrogen	$H_2 \longrightarrow 2H^+ + 2e^-$
Copper	$Cu \longrightarrow Cu^{2+} + 2e^-$
Silver	$Ag \longrightarrow Ag^+ + e^-$
Mercury	$Hg \longrightarrow Hg^{2+} + 2e^-$
Platinum	$Pt \longrightarrow Pt^{2+} + 2e^-$
Gold	$Au \longrightarrow Au^{3+} + 3e^-$

Balancing Oxidation-Reduction Equations

- ***The Half-Reaction Method***:

  A half reaction is that reaction that involves either oxidation or reduction.

$$Ce^{4+}(aq) + Sn^{2+}(aq) \longrightarrow Ce^{3+}(aq) + Sn^{4+}(aq)$$

$$2\,Ce^{4+}(aq) + \cancel{2\,e^-} \longrightarrow 2\,Ce^{3+}(aq)$$

$$Sn^{2+}(aq) \longrightarrow Sn^{4+}(aq) + \cancel{2e^-}$$

$$2Ce^{4+}(aq) + Sn^{2+}(aq) \longrightarrow 2Ce^{3+}(aq) + Sn^{4+}(aq)$$

Atoms and charges (electrons) must be all balanced.