## III) Oxidation Numbers

An oxidation number is the real (for atoms, ions, and ionic compounds) or apparent (for covalent compounds) charge that a particle possesses. It is very similar to 'combining capacity'. (number of bonds an atom "wants" to form)

What are oxidation numbers for the ionic compound NaCl?

$Na^+$ $Cl^-$

ionic – the charge of the ion

What are the oxidation numbers for the covalent compound $H_2O$?

* assume ionic...and assign oxidation # $H^+$, $O^{2-}$

### Guidelines for Assigning Oxidation Numbers

When assigning oxidation numbers, the guidelines must be followed **IN ORDER**.

* The sum of the positive and negative charges must equal the overall charge of the substance.

A) For neutral ATOMS, the oxidation number is 0 (atoms in elemental form, have no charge)

| | | | | |
|---|---|---|---|---|
| Examples : | Al | 4x0 $P_4$ | $N_2$ | $S_8$ |
| Oxidation #: | 0 | 0 | 0 | 0 |

B) For ions, the oxidation number equals the charge. any monatomic ions oxidation # = ion charge

| | | | | | |
|---|---|---|---|---|---|
| Examples: | $Mn^{2+}$ | $Br^-$ | $S^{2-}$ | $Cu^+$ | $Al^{3+}$ |
| oxidation #: | +2 | −1 | −2 | +1 | +3 |

C) Polyatomic ions can be assigned a total oxidation number, which would be its ionic charge, or each element in the ion can be assigned its own oxidation number (part D will explain how this is done).

Find the TOTAL oxidation number: $SO_4^{2-}$ −2 $OH^-$ −1 $PO_4^{3-}$ −3

−2 +1 = −1

D) To assign individual elements an oxidation number in a compound or polyatomic ion, perform the following steps in order:

*ionic charge

1) alkali metals are +1
2) alkaline earth metals are +2
3) Other metals with only one possible oxidation number (combining capacity)
4) oxygen is −2
5) hydrogen is +1 (unless part of a metal hydride in which case -1)

ex) $CaH_2$ Ca is +2, so each H is −1.

6) halogens are -1 (but can also be +1, +3, or +5 in certain compounds)
7) Lastly, assign any 'hard to predict' atoms that are left over.

overall charge ∅

$CaH_2$ 0

+2 −1 −1 = ∅

$\boxed{+2 + x = 0}$

*Since oxidation numbers are apparent for atoms in covalent compounds, sometimes an atom may an oxidation number that's a fraction. (very rare)

**Practice Questions:** Determine the oxidation numbers of each element.

overall charge

a) $MnO_4^-$ b) $SO_2$ c) $SO_4^{2-}$ d) $PCl_5$ e) $Cu_2O$ f) $HBiO_3$ g) $OCl^-$

oxidation numbers

a) ? $-2 \times 4 = -1$; $+7$ $-8 = -1$; ∴ Mn

b) $-2 \times 2 = 0$; $+4$ $-4 = 0$; $+4, -2$

c) $-2 \times 4 = -2$; $+6$ $-8 = -2$; $+6, -2$

f) $+1$ ? $-2 \times 3 = 0$; $+1$ $+5$ $-6 = 0$; $+1, +5, -2$

h) $NH_2OH$ i) $NO_3^-$ j) $I_2$ k) $Cr^{3+}$ l) Cr m) $N_2O_5$ n) $H_4P_2O_7$

h) ∴ $+1$; $-1$; $+1 \times 2$; $-2$ $+1$; $-1$ $+2 = +1$

j) single element $\varnothing$

k) ion $+3$

l) neutral atom $\varnothing$

n) $+1 \times 4$ $+5 \times 2$ $-2 \times 7 = 0$; $+4$ $10$ $-14 = 0$; H: +1, P: +5, O: −2

**How are oxidation numbers helpful?**

When an atom undergoes oxidation (→ lose $e^-$) during a redox reaction, its oxidation number (→ more +) will ___INCREASE___ as it changes from reactant to product (it loses electrons, therefore it becomes more positive).

When an atom undergoes reduction (→ gain $e^-$) during a redox reaction, its oxidation number (→ more −) will ___DECREASE___ as it changes from a reactant to product (it gain electrons, therefore it becomes more negative).

Assigning oxidation numbers to reactants and products in a chemical reaction is helpful in determining whether the reaction is, in fact, a redox reaction, and if so, which reactant is oxidizing and which reactant is reducing. → must have oxidation + reduction

**Practice Questions**

1. For the following half-reaction (with electrons not present), how does the oxidation number of chromium change? Is the chromium oxidizing or reducing?

$$Cr_2O_7^{2-} + 14H^+ \Rightarrow 2Cr^{3+} + 7H_2O$$

$+6$ → reduction → $+3$; ion = oxid. # = charge.

b/c diatomic ×2, $Cr_2$: $+6$ $-2 \times 7 = -2$; $+12$ $-14 = -2$; $+3$

$+6 \longrightarrow +3$; ∴ $3e^-$ gain; ∴ reducing

2. What happens to the oxidation # for nitrogen in the unbalanced half-reaction? Is nitrogen oxidizing or reducing?

$$NO_2 \Rightarrow N_2O_3$$

$\boxed{+4}$ $-2 \times 2$: $-4 = 0$; $\boxed{+6}$ $-2 \times 3$: $-6 = 0$

oxidation #: $+4 \longrightarrow +3$; ∴ $1e^-$ gained; ∴ reducing

3. Use oxidation numbers to identify which substance is oxidized and which is reduced in the following redox reactions.

gained 3e⁻

a) $3Cu + 2NO_3^- + 8H^+ \Rightarrow 3Cu^{2+} + 2NO + 4H_2O$

0 +5 −2 (×3 = −6) +1 +2 +2 −2 +1 (+2) −2

lost 2e⁻

Cu 0 → +2 oxidation
N +5 → +2 reduction
O −2 → −2
H +1 → +1

gain 2e⁻

b) $I_2 + 5HOBr + H_2O \Rightarrow 2IO_3^- + 5Br^- + 7H^+$

0 +1 −2 +1 +1 −2 +5 −2 (×3) −6 = −1 −1 +1

lost 5e⁻

I 0 → +5 oxidation
H +1 → +1
O −2 → −2
Br +1 → −1 reduction

4. Use oxidation numbers to determine whether the following reactions are redox reactions.

"elemental form" = 0

reducing

a) $2H_2O \Rightarrow 2H_2 + O_2$

+1 −2 0 0

oxidizing

b) $2AgCl + BaSO_4 \Rightarrow Ag_2SO_4 + BaCl_2$

+1 −1 +2 −2 +1 −2 +2 −1

Ag +1 → +1
Cl −1 → −1
SO₄ −2 → −2
Ba 2+ → +2

no oxidation + no reduction
NOT redox.

**Assignment 2:**

Read Hebden p.193-194,

1) Do Hebden p. 194 #3-6

2) For each unbalanced reaction, what is being oxidized and what is being reduced?

a) $S^{2-} + ClO_3^- \Rightarrow Cl^- + S$

b) $Cl_2 + SO_2 \Rightarrow 2Cl^- + SO_4^{2-}$

c) $Mn^{2+} + HBiO_3 \Rightarrow Bi^{3+} + MnO_4^-$

d) $FeS + NO_3^- \Rightarrow NO + SO_4^{2-} + Fe^{3+}$

3) Consider the following reaction:

$$Zn_{(s)} + 2H^+_{(aq)} \Rightarrow Zn^{2+}_{(aq)} + H_{2(g)}$$

The species being oxidized is: (circle the correct response)

A. $H_2$  B. $H^+$  C. $Zn$  D. $Zn^{2+}$

4) When $SO_4^{2-}$ reacts to form $S_2O_6^{2-}$ , the sulfur atoms

A. lose electrons and are reduced
B. gain electrons and are reduced
C. lose electrons and are oxidized
D. gain electrons and are oxidized

5) In a reaction, the oxidation number of Cr decreases by 3. This indicates that Cr is

A. reduced
B. oxidized
C. neutralized
D. a reducing agent

6) Consider the following redox reaction:

$$C_2H_5OH + 2Cr_2O_7^{2-} + 16H^+ \Rightarrow 2CO_2 + 4Cr^{3+} + 11H_2O$$

Each carbon atom loses

A. 2 electrons
B. 4 electrons
C. 6 electrons
D. 12 electrons