G12 Chemistry

Electrochemistry

Class 15

Overall Expectations

- Analyse technologies and processes relating to electrochemistry, and their implications for society, health and safety, and the environment
- Investigate oxidation-reduction reactions using a galvanic cell, and analyse electrochemical reactions in qualitative and quantitative terms
- Demonstrate an understanding of the principles of oxidation-reduction reactions and the many practical applications of electrochemistry

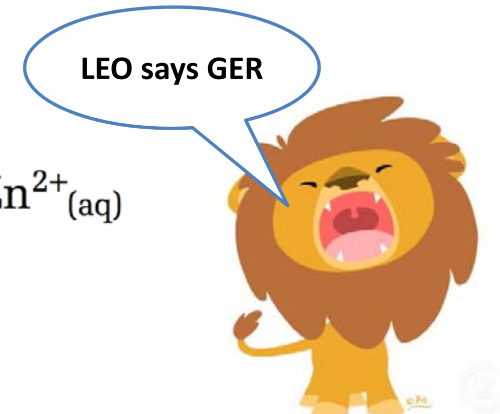
Oxidation and Reduction

- **Oxidation** – When an atom loses an electron; its oxidation number increases
- **Reduction** – When an atom gains electrons, the oxidation number decreases

gains $2e^-$

$$Zn_{(s)} + Cu^{2+}{}_{(aq)} \rightarrow Cu_{(s)} + Zn^{2+}{}_{(aq)}$$

loses $2e^-$



Oxidizing and Reducing Agents

$$Zn_{(s)} + Cu^{2+}{}_{(aq)} \rightarrow Cu_{(s)} + Zn^{2+}{}_{(aq)}$$

- reducing agent
- donates electrons
- undergoes oxidation

- oxidizing agent
- accepts electrons
- undergoes reduction

- **Reducing Agent**: The substance that loses or gives up electrons to another substance
- **Oxidizing Agent:** The substance that gains or removes electrons from another substance

Half Reactions

- To monitor the transfer of electrons, you can represent the oxidation and reduction separately

Oxidation: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

Reduction: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

Overall: $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

- Half-reactions always come in pairs

Checkpoint

Given the following net ionic equation, identify the oxidation and reduction half-reactions. State which is the reducing agent and the oxidizing agent:

a) $Al(s) + Fe^{3+}(aq) \rightarrow Al^{3+}(aq) + Fe(s)$

b) $Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$

Oxidation Number

- Also known as Oxidation State – signifies the number of charges the atom would have in a molecule or ionic compound if electrons were transferred completely
- Developed to treat molecular compounds (covalent) as redox compounds since molecular compounds do not transfer electrons

+1 -1	+1 -2 +1
NaCl	**H-O-H**
Actual Charge	Hypothetical Charge

Rules:

1. All atoms in elements have an oxidation number of 0
   – Ex: H_2, Br_2, Be, K, Na, P_4 = 0
2. The oxidation number of an element in a monoatomic ion equals the charge of the ion
   – Al^{3+} = +3
   – Se^{2-} = -2
   – O^{2-} = -2

3. The oxidation number of oxygen in most compounds is -2, but in H_2O_2 and O_2^{2-} it is -1

Li_2O KNO_3 H-O-O-H OF_2

4. The oxidation number of hydrogen in its compounds is +1 except in metal hydrides where it is -1.

H_2S CH_4 NaH CaH_2

5. Fluorine has (-1) for all compounds. Other halogens have negative oxidation numbers when they are halide ions. When combined with oxygen, they have positive oxidation numbers
6. In a neutral molecule, the sum of all the oxidation numbers is 0. In polyatomic ions, the sum of all the oxidation numbers is the charge of the ion
7. Oxidation numbers do not have to be integers

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** +1 −1																	2 **He**
3 **Li** +1	4 **Be** +2											5 **B** +3	6 **C** +4 +2 −4	7 **N** +5 +4 +3 +2 +1 −3	8 **O** +2 $-\frac{1}{2}$ −1 −2	9 **F** −1	10 **Ne**
11 **Na** +1	12 **Mg** +2											13 **Al** +3	14 **Si** +4 −4	15 **P** +5 +3 −3	16 **S** +6 +4 +2 −2	17 **Cl** +7 +6 +5 +4 +3 +1 −1	18 **Ar**
19 **K** +1	20 **Ca** +2	21 **Sc** +3	22 **Ti** +4 +3 +2	23 **V** +5 +4 +3 +2	24 **Cr** +6 +5 +4 +3 +2	25 **Mn** +7 +6 +4 +3 +2	26 **Fe** +3 +2	27 **Co** +3 +2	28 **Ni** +2	29 **Cu** +2 +1	30 **Zn** +2	31 **Ga** +3	32 **Ge** +4 −4	33 **As** +5 +3 −3	34 **Se** +6 +4 −2	35 **Br** +5 +3 +1 −1	36 **Kr** +4 +2
37 **Rb** +1	38 **Sr** +2	39 **Y** +3	40 **Zr** +4	41 **Nb** +5 +4	42 **Mo** +6 +4 +3	43 **Tc** +7 +6 +4	44 **Ru** +8 +6 +4 +3	45 **Rh** +4 +3 +2	46 **Pd** +4 +2	47 **Ag** +1	48 **Cd** +2	49 **In** +3	50 **Sn** +4 +2	51 **Sb** +5 +3 −3	52 **Te** +6 +4 −2	53 **I** +7 +5 +1 −1	54 **Xe** +6 +4 +2
55 **Cs** +1	56 **Ba** +2	57 **La** +3	72 **Hf** +4	73 **Ta** +5	74 **W** +6 +4	75 **Re** +7 +6 +4	76 **Os** +8 +4	77 **Ir** +4 +3	78 **Pt** +4 +2	79 **Au** +3 +1	80 **Hg** +2 +1	81 **Tl** +3 +1	82 **Pb** +4 +2	83 **Bi** +5 +3	84 **Po** +2	85 **At** −1	86 **Rn**

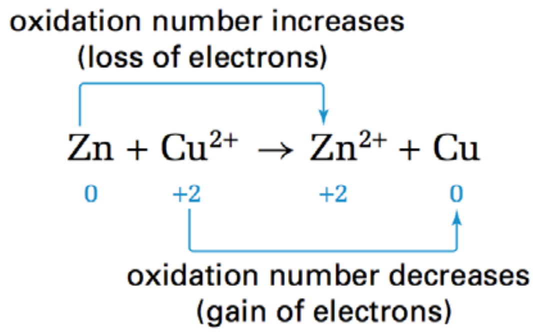
Checkpoint

Assign an oxidation number to each element.

a) $SiBr_4$ b) $HClO_4$ c) $Cr_2O_7^{2-}$

d) PF_3 e) MnO_4^- f) Fe_3O_4

Oxidation States and Redox Reactions



- **Oxidation** – increase in oxidation number
- **Reduction** – decrease in oxidation number

- **Disproportionate Reaction** – an element in one oxidation state is simultaneously oxidized and reduced

$$H_2\overset{-1}{O_2}\ (aq) \rightarrow 2H_2\overset{-2}{O}(l) + \overset{0}{O_2}(g)$$

- All redox reactions must contain a change in oxidation number. No oxidation change means the reaction is not redox.

Checkpoint

Determine whether each of the following reactions is a redox reaction. If so, identify the oxidizing agent and the reducing agent.

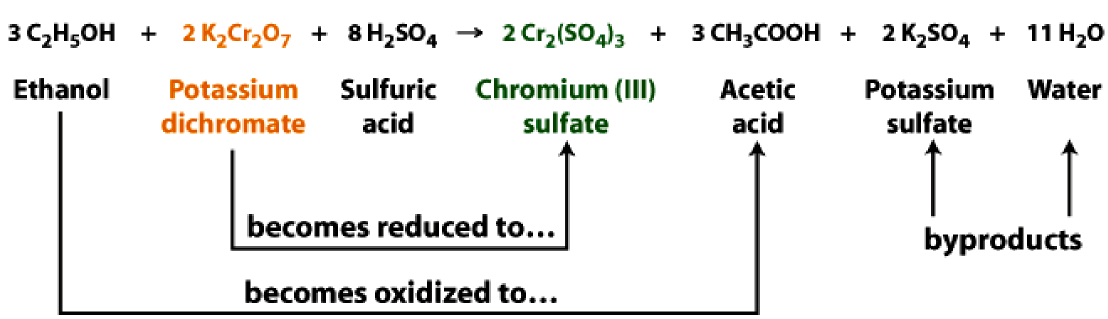
a) $CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$

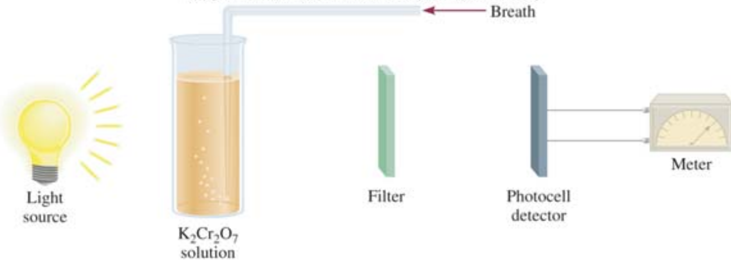
b) $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

c) $2N_2O(g) \rightarrow 2N_2(g) + O_2(g)$

Breathalyzer

- A breathalyzer is a device to test drivers suspected of drunk driving
- Uses the following redox reaction:





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- By measuring the degree of the colour change, the driver's blood alcohol level can be determined
- G1 License = 0.00%
- G2 License = 0.00%
- G License = 0.08% (0.00% under 21 years)
  - One bottle of beer OR glass of wine OR shot/hour
- Consequences:
  - 90-day license suspension
  - 7-day vehicle impoundment
  - $198 penalty

Balancing Redox Reactions

- For reactions that take place under neutral conditions, balancing half reactions is straight-forward

$$K \rightarrow K^+ + e^- \qquad \times 2$$

$$\underline{Cl_2 + 2e^- \rightarrow 2Cl^-}$$

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

- For acidic and basic conditions, more steps are involved

Balancing Half-Reactions for Acidic Solutions

Write a balanced half-reaction that shows the reduction of MnO_4^- to Mn^{2+} in an acidic solution

1) Represent the reactant and product with correct formulas
2) Balance any atoms other than hydrogen and oxygen
3) Balance any oxygen atoms by adding water
4) Balance any hydrogen atoms by adding H^+
5) Balance the charges by adding electrons

Checkpoint

Balance the following half-reaction under acidic conditions:

$$NO_3^- \rightarrow N_2$$

Balancing Half-Reactions for Basic Solutions

Write a balanced half-reaction that shows the oxidation of $S_2O_3^{2-}$ to SO_3^{2-} in a basic solution.

1) Represent the given reactant and products with correct formulas
2) Balance any atoms other than oxygen and hydrogen. Balance O and H as if they were acidic
3) Add OH^- to both sides to balance out the H^+
4) Combine the OH^- and H^+ into water molecules and simplify the equation
5) Balance the charges by adding electrons

Checkpoint

Balance $CrO_4^{2-} \rightarrow Cr(OH)_3$ under basic conditions.

Balancing by Half-Reaction Method

Write a balanced net ionic equation to show the reaction of ClO_4^- and NO_2 in acidic solution to produce Cl^- and NO_3^-.

1) Write an unbalanced net ionic equation:

$$ClO_4^- + NO_2 \rightarrow Cl^- + NO_3^-$$

2) Assign oxidation numbers to all the elements in the equation.

$$ClO_4^- + NO_2 \rightarrow Cl^- + NO_3^-$$

3) Balance the oxidation and reduction half-reaction separately.

Oxidation: $NO_2 \rightarrow NO_3^-$ Reduction: $ClO_4^- \rightarrow Cl^-$

Oxidation	**Reduction**
$NO_2 \rightarrow NO_3^-$	$ClO_4^- \rightarrow Cl^-$
$NO_2 + H_2O \rightarrow NO_3^-$	$ClO_4^- \rightarrow Cl^- + 4H_2O$
$NO_2 + H_2O \rightarrow NO_3^- + 2H^+$	$ClO_4^- + 8H^+ \rightarrow Cl^- + 4H_2O$
$NO_2 + H_2O \rightarrow NO_3^- + 2H^+ + e^-$	$ClO_4^- + 8H^+ + 8e^- \rightarrow Cl^- + 4H_2O$

4) Determine the least common multiple of the number of electrons in the half-reactions.

– LCM = 8

5) Multiply the half-reaction by the LCM so that equal number of electrons are lost and gained.

Oxidation: $8NO_2 + 8H_2O \rightarrow 8NO_3^- + 16H^+ + 8e^-$

Reduction: $ClO_4^- + 8H^+ + 8e^- \rightarrow Cl^- + 4H_2O$

6) Add the half-reactions and simplify the equations.

$$8NO_2 + 8H_2O \rightarrow 8NO_3^- + 16H^+ + 8e^-$$
$$ClO_4^- + 8H^+ + 8e^- \rightarrow Cl^- + 4H_2O$$

$$8NO_2 + 8H_2O + ClO_4^- + 8H^+ + 8e^- \rightarrow 8NO_3^- + 16H^+ + 8e^- + Cl^- + 4H_2O$$

$$8NO_2 + ClO_4^- + 4H_2O \rightarrow 8NO_3^- + 8H^+ + Cl^-$$

Checkpoint

Balance the following equation by the half-reaction method:

$$Cu^{2+} + I^- \rightarrow CuI + I_3^-$$

Oxidation Number Method for Balancing Equations

- Use oxidation numbers to balance a chemical equation by ensuring that the total increase in the oxidation numbers of the oxidized element(s) equals the total decrease in the oxidation numbers of the reduced element(s)

$$\underset{-3\ +1}{NH_3} + \underset{0}{O_2} \rightarrow \underset{+4\ -2}{NO_2} + \underset{+1\ -2}{H_2O}$$

Balancing by Oxidation-Number Method

Balance the following reaction by oxidation-number method in an acidic medium:

1) Assign oxidation numbers to the atoms.

$$\overset{+7}{Mn}\overset{-2}{O_4^-}(aq) + \overset{+2}{Fe^{2+}}(aq) \rightarrow \overset{2+}{Mn^{2+}}(aq) + \overset{+3}{Fe^{3+}}(aq)$$

2) Identify the oxidized and reduced atom and write the oxidation-number change

$-5\ e^-$

$$\overset{+7}{Mn}O_4^-(aq) + \overset{+2}{Fe^{2+}}(aq) \rightarrow \overset{2+}{Mn^{2+}}(aq) + \overset{+3}{Fe^{3+}}(aq)$$

$+1\ e^-$

3) Multiply by a number that will cause the increase in oxidation number equal to the decrease in oxidation number

$-5\ e^-$

$$MnO_4^-(aq) + Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + Fe^{3+}(aq)$$

$+1\ e^-\ x\ 5$

$$MnO_4^-(aq) + \mathbf{5}Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + \mathbf{5}Fe^{3+}(aq)$$

4) Balance oxygens by adding H_2O and H^+ in acidic medium and OH^- in basic medium

$$MnO_4^-(aq) + 5Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O$$

$$8H^+ + MnO_4^-(aq) + 5Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O$$

5) Check to ensure all atoms and charges are balanced

$$\mathbf{\underbrace{8H^+ + MnO_4^-(aq) + 5Fe^{2+}(aq)}_{17\ e^-} \rightarrow \underbrace{Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O}_{17\ e^-}}$$

Checkpoint

Use the oxidation-number method to balance the following in a basic solution:

$$IO_3^-(aq) + C_2O_4^{2-}(aq) \rightarrow I^-(aq) + CO_2(g)$$