Balancing Redox Equations
(Oxidation-Number Method)

Learning Goals:

- ☐ I will be able to write balanced chemical equations for oxidation-reduction reactions using the oxidation number method (in neutral, acidic, and basic solutions).

1. BALANCING REDOX EQUATIONS IN **NEUTRAL** OR **ACIDIC** SOLUTION

Example 1: In an acidic aqueous solution, permanganate ions and methanol react to produce manganese (IV) oxide and carbon dioxide. Write the balanced chemical equation for this redox reaction.

Step 1: *Write the unbalanced equation (the "acidic" condition is not important at this point).*

$$MnO_4^-(aq) + CH_3OH(aq) \rightarrow MnO_2(s) + CO_2(g)$$

Step 2: *Assign oxidation numbers.*

+7 -2 -2 +1 -2 +1 +4 -2 +4 -2

$$MnO_4^-(aq) + CH_3OH(aq) \rightarrow MnO_2(s) + CO_2(g)$$

Step 3: *Determine the number of electrons gained and lost by the reactants.*

Each manganese atom gains 3 electrons (+7 to +4).
There is one Mn in each MnO_4^-.
Therefore, there is a gain of 3 electrons for every MnO_4^- that reacts.

gain of 3 e^- per MnO_4^-

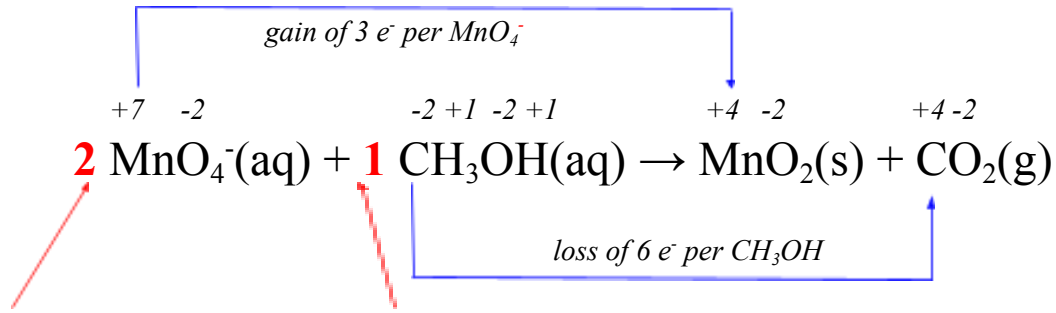
+7 -2 -2 +1 -2 +1 +4 -2 +4 -2

$$MnO_4^-(aq) + CH_3OH(aq) \rightarrow MnO_2(s) + CO_2(g)$$

loss of 6 e^- per CH_3OH

Each carbon atom loses 6 electrons (-2 to +4).
There is one C in each CH_3OH.
Therefore, there is a loss of 6 electrons for every CH_3OH that reacts.

Step 4: *Add coefficients to the reactants to balance the electron transfer.*



Two MnO_4^- ions must react with one CH_3OH molecule to balance the electron transfer – Two MnO_4^- will gain 6 electrons and one CH_3OH will lose 6 electrons.
(The "1" is not normally written in the equation but is included here for clarity.)

Step 5: *Balance all elements except oxygen and hydrogen.*

$$2\ MnO_4^-(aq) + CH_3OH(aq) \rightarrow \mathbf{2}\ MnO_2(s) + CO_2(g)$$

Two MnO_2 are needed to balance the Mn atoms.
The carbon atoms are already balanced (one on each side).
Do not balance oxygen or hydrogen at this point.

Step 6: *Balance oxygen using water molecules.*

$$2\ MnO_4^-(aq) + CH_3OH(aq) \rightarrow 2\ MnO_2(s) + CO_2(g) + \mathbf{3\ H_2O(l)}$$

There are 9 oxygen atoms on the reactant side and only 6 oxygen atoms on the product side.
Three water molecules must be added to the product side to balance the oxygen atoms.

Step 7: *Balance hydrogen using hydrogen ions.*

$$\mathbf{2\ H^+(aq)} + 2\ MnO_4^-(aq) + CH_3OH(aq) \rightarrow 2\ MnO_2(s) + CO_2(g) + 3\ H_2O(l)$$

There are 4 hydrogen atoms on the reactant side and 6 hydrogen atoms on the product side.
Two hydrogen ions must be added to the reactant side to balance the hydrogen atoms.

Step 8: *Check the equation for balanced atoms and charge.*

$$2\ H^+(aq) + 2\ MnO_4^-(aq) + CH_3OH(aq) \rightarrow 2\ MnO_2(s) + CO_2(g) + 3\ H_2O(l)$$

6 hydrogen atoms	6 hydrogen atoms
2 manganese atoms	2 manganese atoms
9 oxygen atoms	9 oxygen atoms
1 carbon atom	1 carbon atom
0 charge (2 positive and 2 negative)	0 charge

2. BALANCING REDOX EQUATIONS IN **BASIC** SOLUTION

Example 2: Chlorate ions and iodine react in a basic aqueous solution to produce iodate ions and chloride ions. Write the balanced chemical equation for this redox reaction.

Step 1: *Write the unbalanced equation (the "basic" condition is not important at this point).*

$$ClO_3^-(aq) + I_2(aq) \rightarrow IO_3^-(aq) + Cl^-(aq)$$

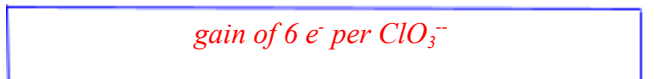
Step 2: *Assign oxidation numbers.*

+5 -2 0 +5 -2 -1

$$ClO_3^-(aq) + I_2(aq) \rightarrow IO_3^-(aq) + Cl^-(aq)$$

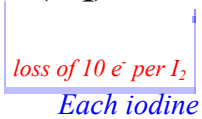
Step 3: *Determine the number of electrons gained and lost by the reactants.*

Each chlorine atom gains 6 electrons (+5 to -1).
There is one Cl in each ClO_3^-.
Therefore, there is a gain of 6 electrons for every ClO_3^- that reacts.



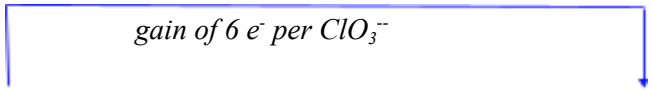
+5 -2 0 +5 -2 -1

$$ClO_3^-(aq) + I_2(aq) \rightarrow IO_3^-(aq) + Cl^-(aq)$$



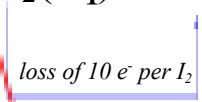
Each iodine atom loses 5 electrons (0 to +5).
There are two iodine in each I_2.
Therefore, there is a loss of 10 electrons for every I_2 that reacts.

Step 4: *Add coefficients to the reactants to balance the electron transfer.*



+5 -2 0 +5 -2 -1

$$\mathbf{5}\ ClO_3^-(aq) + \mathbf{3}\ I_2(aq) \rightarrow IO_3^-(aq) + Cl^-(aq)$$



Five ClO_3^- ions must react with three I_2 molecules to balance the electron transfer – Five ClO_3^- will gain 30 electrons and three I_2 will lose 30 electrons.

Step 5: *Balance all elements except oxygen and hydrogen.*

$$5\ ClO_3^-(aq) + 3\ I_2(aq) \rightarrow \mathbf{6}\ IO_3^-(aq) + \mathbf{5}\ Cl^-(aq)$$

Six IO_3^- are needed to balance the iodine atoms.

Five Cl^- are needed to balance the chlorine atoms.

Do not balance oxygen or hydrogen at this point.

Step 6: *Balance oxygen using water molecules.*

$$\mathbf{3\ H_2O(l)} + 5\ ClO_3^-(aq) + 3\ I_2(aq) \rightarrow 6\ IO_3^-(aq) + 5\ Cl^-(aq)$$

There are 15 oxygen atoms on the reactant side and only 18 oxygen atoms on the product side.
Three water molecules must be added to the product side to balance the oxygen atoms.

Step 7: *Balance hydrogen using hydrogen ions.*

$$3\ H_2O(l) + 5\ ClO_3^-(aq) + 3\ I_2(aq) \rightarrow 6\ IO_3^-(aq) + 5\ Cl^-(aq) + \mathbf{6\ H^+(aq)}$$

There are 6 hydrogen atoms on the reactant side and 0 hydrogen atoms on the product side.
Six hydrogen ions must be added to the reactant side to balance the hydrogen atoms.

Step 8: *When the reaction occurs in the* ***basic*** *solution, hydrogen ions cannot be part of the overall equation and must be eliminated from the balanced equation. This step is not done when the reaction occurs in neutral or acidic solution. This step has three sub-steps.*

(a) Add hydroxide ions to both sides of the equation.

$$\mathbf{6\ OH^-(aq)} + 3\ H_2O(l) + 5\ ClO_3^-(aq) + 3\ I_2(aq) \rightarrow 6\ IO_3^-(aq) + 5\ Cl^-(aq) + 6\ H^+(aq) + \mathbf{6\ OH^-(aq)}$$

There are 6 hydrogen ions in the equation. Therefore, add 6 hydroxide ions to both sides of the equation (the ions are added to both sides to keep the equation balanced).

(b) Combine hydrogen ions and hydroxide ions to form water molecules.

$$6\ OH^-(aq) + 3\ H_2O(l) + 5\ ClO_3^-(aq) + 3\ I_2(aq) \rightarrow 6\ IO_3^-(aq) + 5\ Cl^-(aq) + 6\ H^+(aq) + 6\ OH^-(aq)$$

$$\rightarrow \mathbf{6\ H_2O(l)}$$

The 6 hydrogen ions and 6 hydroxide ions on the product side are combined to form 6 water molecules.

(c) Reduce the water molecules if necessary.

$$6\ OH^-(aq) + \cancel{3\ H_2O(l)} + 5\ ClO_3^-(aq) + 3\ I_2(aq) \rightarrow 6\ IO_3^-(aq) + 5\ Cl^-(aq) + \cancel{6\ H_2O(l)}$$

$$\mathbf{3\ H_2O(l)}$$

Three water molecules can be removed from each side. Three water molecules left on the product side.

Step 9: *Check the equation for balanced atoms and charge.*

$6\ OH^-(aq) + 5\ ClO_3^-(aq) + 3\ I_2(aq) \rightarrow 6\ IO_3^-(aq) + 5\ Cl^-(aq) + 3\ H_2O(l)$

21 oxygen atoms	21 oxygen atoms
6 hydrogen atoms	6 hydrogen atoms
5 chlorine atoms	5 chlorine atoms
6 iodine atoms	6 iodine atoms
-11 charge	-11 charge