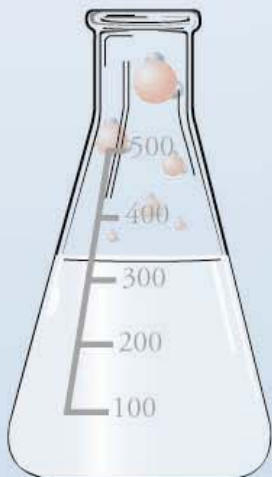
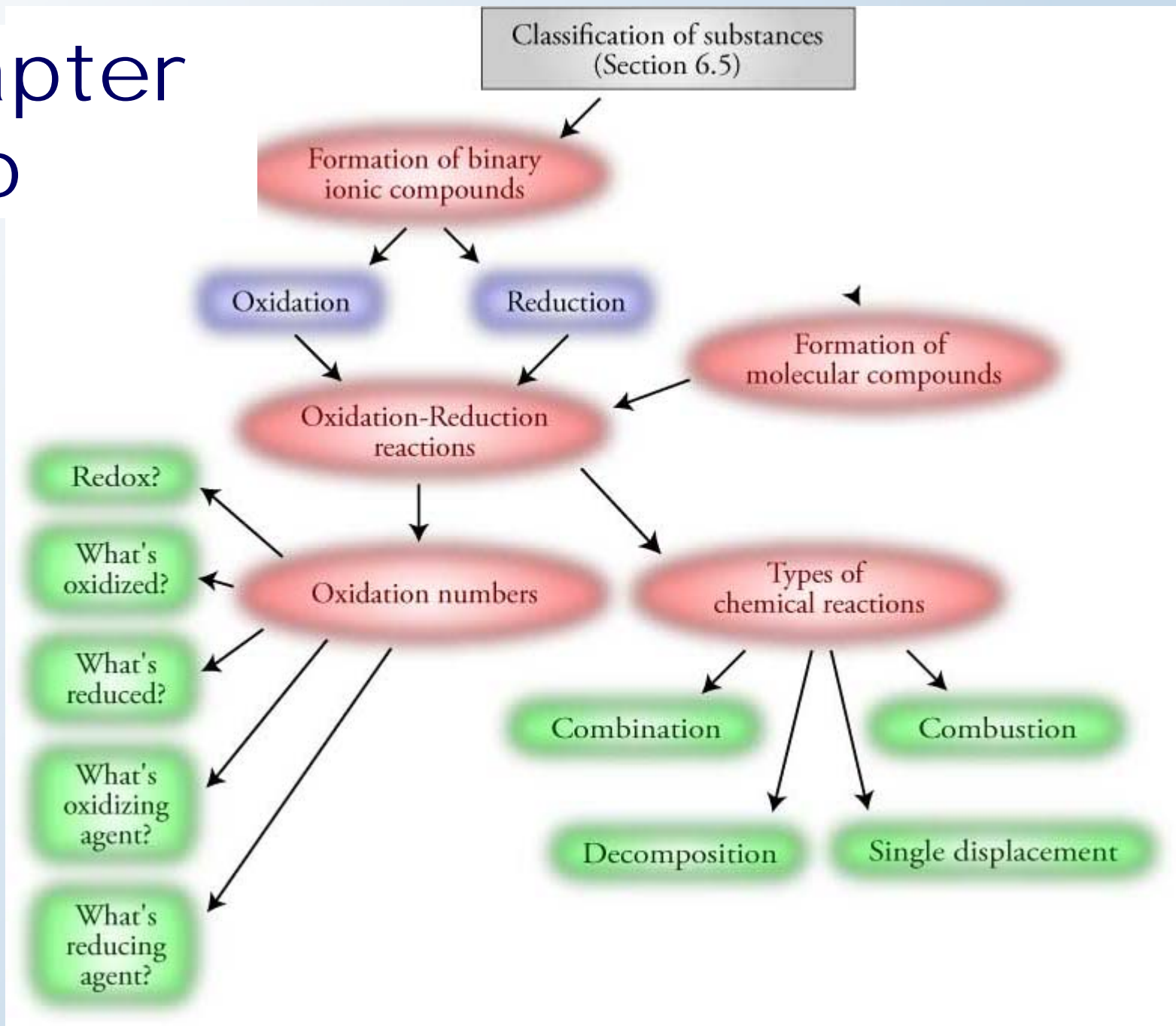


Chapter 9

Oxidation-Reduction Reactions

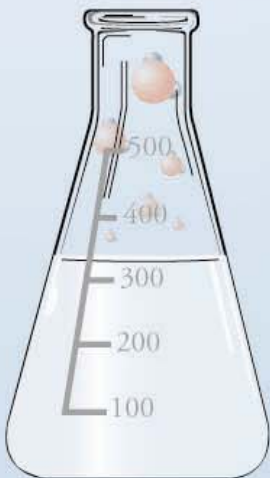
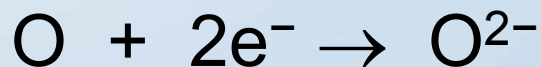
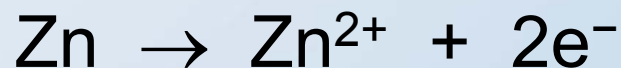
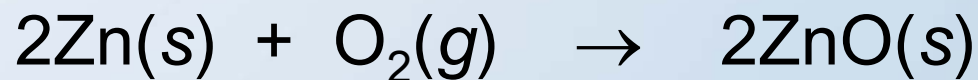


Chapter Map



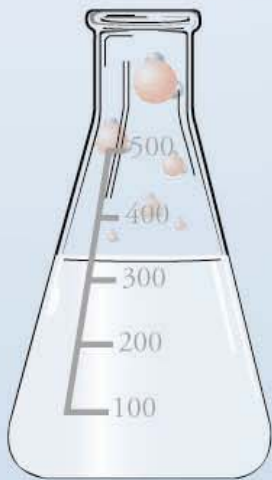
Oxidation

- Historically, oxidation meant reacting with oxygen.



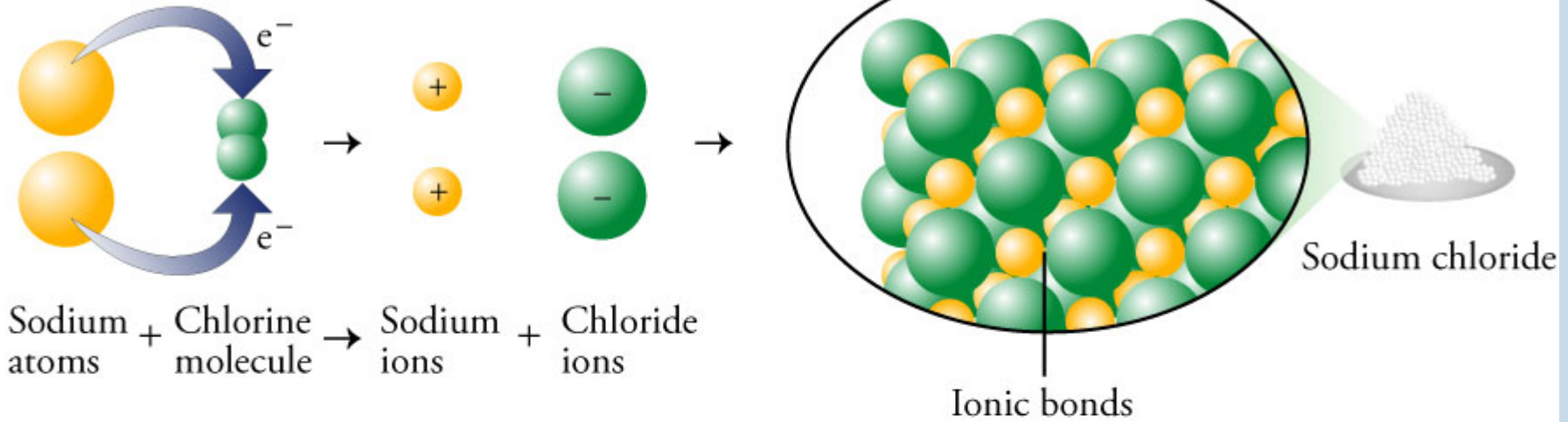
Oxidation Redefined (1)

- Many reactions that are similar to the reaction between zinc and oxygen were not considered oxidation.
- For example, both the zinc-oxygen reaction and the reaction between sodium metal and chlorine gas (described on the next slide) involve the transfer of electrons.

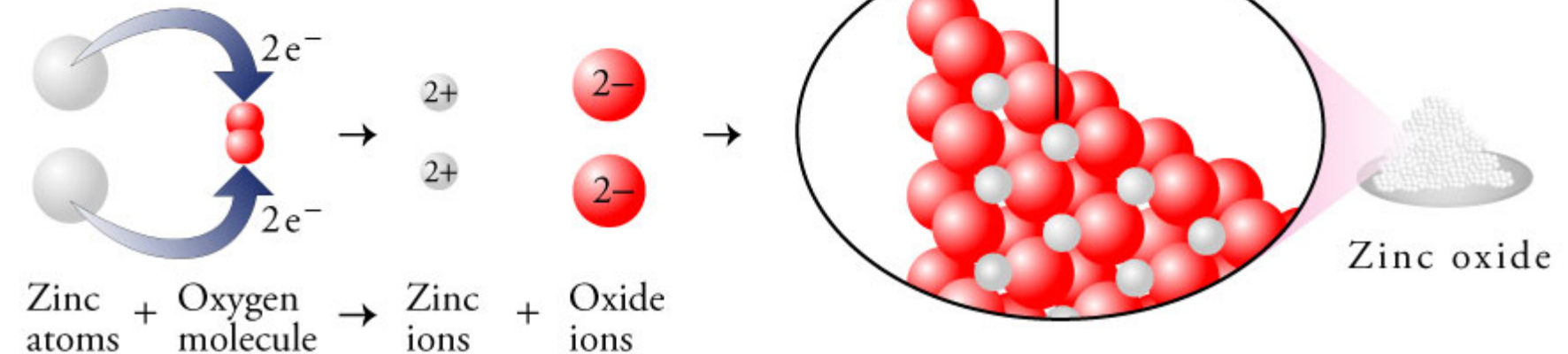


Oxidation and Formation of Binary Ionic Compounds

Formation of NaCl

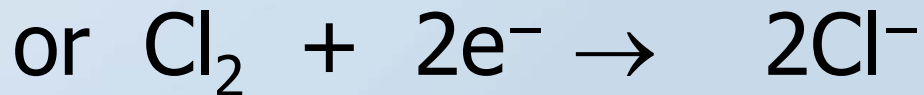
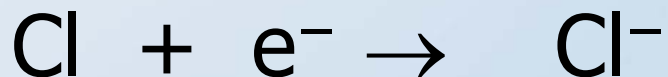
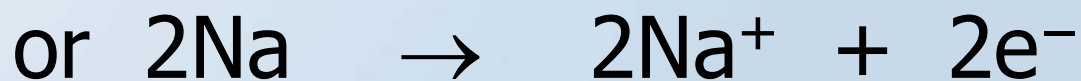
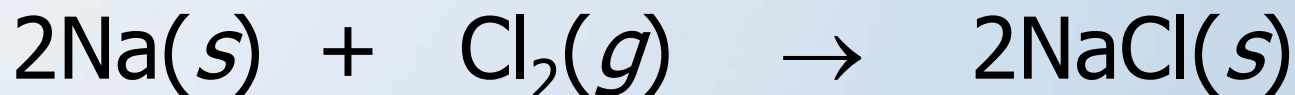


Oxidation of zinc



A series of water molecules, each consisting of one red oxygen atom and two white hydrogen atoms, are shown falling from the top left towards a flask at the bottom left. The flask is a standard Erlenmeyer flask with a scale on its side, ranging from 100 to 500. The water level is currently at approximately 350. The molecules are arranged in a vertical column, with some appearing to be in the process of entering the flask.

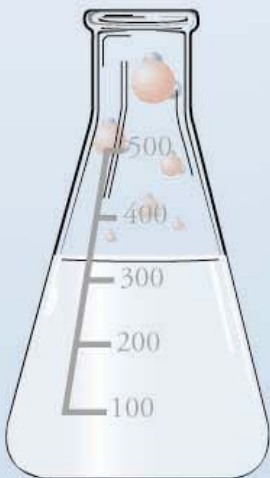
Similar to Oxidation of Zinc



Oxidation = Loss of Electrons

Oxidation Redefined (2)

- To include the similar reactions in the same category, ***oxidation*** was redefined as any chemical change in which at least one element loses electrons.

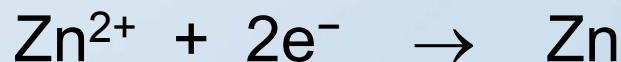


Zinc Oxide Reduction

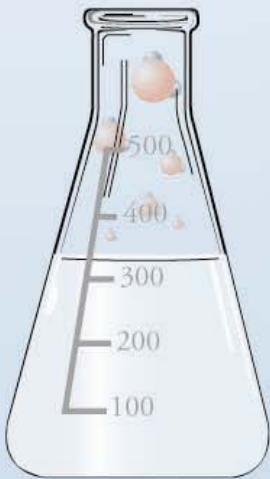
- The following equation describes one of the steps in the production of metallic zinc.



- Because zinc is reducing the number of bonds to oxygen atoms, historically, zinc was said to be *reduced*.
- When we analyze the changes taking place, we see that zinc ions are gaining two electrons to form zinc atoms.



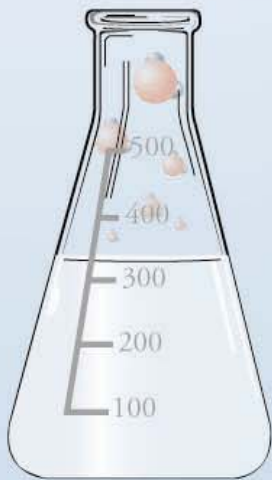
- The definition of reduction was broadened to coincide with the definition of oxidation. According to the modern definition, when something gains electrons, it is *reduced*.



A series of water molecules (H₂O) are arranged in a descending arc from the top left towards the center. Each molecule consists of one large red sphere (oxygen) and two smaller black spheres (hydrogen).

Reduction

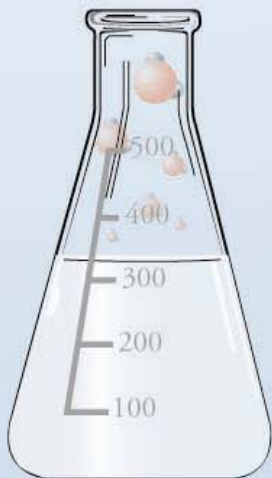
- The loss of electrons (oxidation) by one substance is accompanied by the gain of electrons by another (reduction). **Reduction** is any chemical change in which at least one element gains electrons.



Memory Aid

Oxidation
Is
Loss

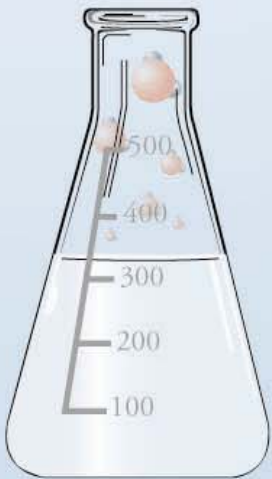
Reduction
Is
Gain



A series of water molecules (H₂O) are arranged in a vertical column on the left side of the slide. Each molecule consists of one red oxygen atom and two smaller black hydrogen atoms. The molecules are positioned at various heights, with some appearing to rise from a flask at the bottom.

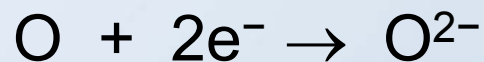
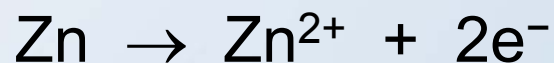
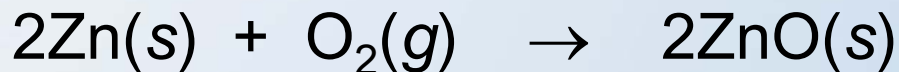
Oxidizing and Reducing Agents

- A ***reducing agent*** is a substance that loses electrons, making it possible for another substance to gain electrons and be reduced. The oxidized substance is always the reducing agent.
- An ***oxidizing agent*** is a substance that gains electrons, making it possible for another substance to lose electrons and be oxidized. The reduced substance is always the oxidizing agent.

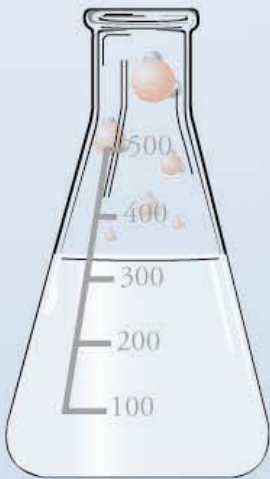




Identifying Oxidizing and Reducing Agents

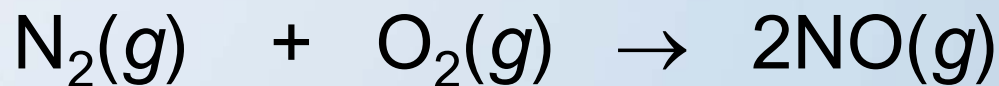


- Zinc atoms lose electrons, making it possible for oxygen atoms to gain electrons and be reduced, so zinc is the reducing agent.
- Oxygen atoms gain electrons, making it possible for zinc atoms to lose electrons and be oxidized, so O_2 is the oxidizing agent.

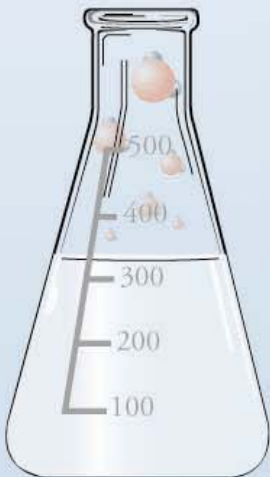




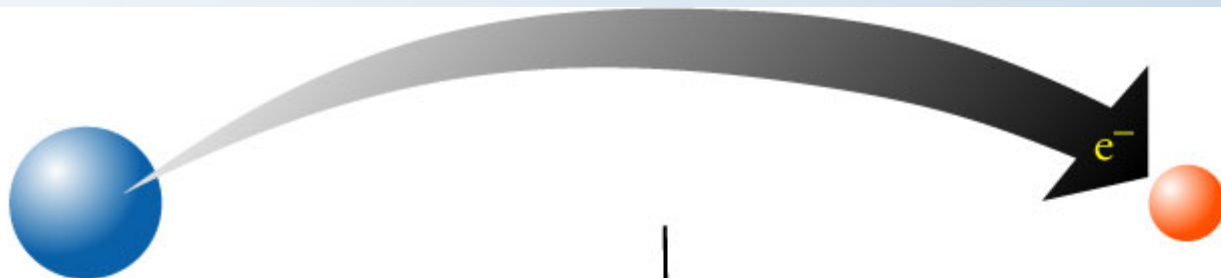
Partial Loss and Gain of Electrons



- The N-O bond is a polar covalent bond in which the oxygen atom attracts electrons more than the nitrogen atom.
- Thus the oxygen atoms gain electrons *partially* and are reduced.
- The nitrogen atoms lose electrons *partially* and are oxidized.
- N_2 is the reducing agent.
- O_2 is the oxidizing agent.



Redox Terms (1)

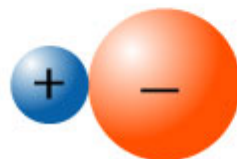


The reducing agent loses electrons and thus is oxidized in the reaction.

The oxidizing agent gains electrons and thus is reduced in the reaction.

Complete transfer of electrons

Partial transfer of electrons



Ionic bond

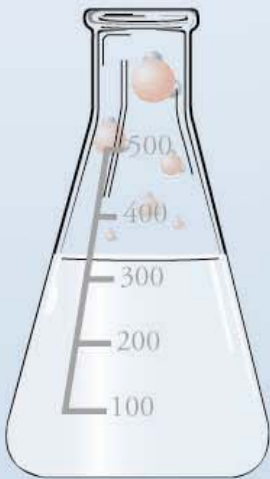


Polar covalent bond

A decorative border on the left side of the slide consists of several water molecules (H₂O) represented by a red sphere (oxygen) and two smaller black spheres (hydrogen).

Redox Terms (2)

- **Oxidation-Reduction Reaction**
 - an electron transfer reaction
- **Oxidation**
 - complete or partial loss of electrons
- **Reduction**
 - complete or partial gain of electrons
- **Oxidizing Agent**
 - the substance reduced; gains electrons, making it possible for something to lose them.
- **Reducing Agent**
 - the substance oxidized; loses electrons, making it possible for something to gain them.

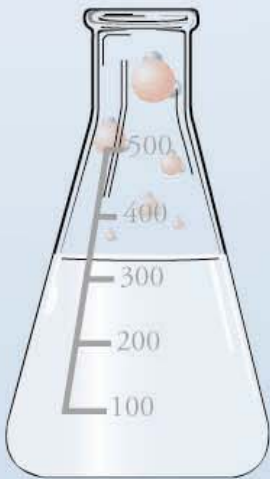


Questions Answered by Oxidation Numbers

Is the reaction redox?	If any atoms change their oxidation number, yes.
What's oxidized?	The element that increases its oxidation number
What's reduced?	The element that decreases its oxidation number
What's the reducing agent?	The substance with the element oxidized
What's the oxidizing agent?	The substance with the element reduced

Steps for Determination of Oxidation Numbers

- **Step 1:** Assign oxidation numbers to as many atoms as you can using the guidelines described on the next slide.
- **Step 2:** To determine oxidation numbers for atoms not described on the previous slide, use the following guideline.
 - The sum of the oxidation numbers for each atom in the formula is equal to the overall charge on the formula. (This includes uncharged formulas where the sum of the oxidation numbers is zero.)



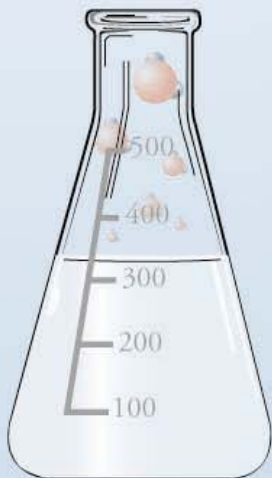
Oxidation Numbers

uncharged element	0	no exceptions
monatomic ions	charge on ion	no exceptions
combined fluorine	-1	no exceptions
combined oxygen	-2	-1 in peroxides
covalently bonded hydrogen	+1	no exceptions

A vertical column of water molecules (H₂O) is shown on the left side of the slide. Each molecule consists of one red oxygen atom and two black hydrogen atoms. The molecules are arranged in a descending staircase pattern from the top left towards the bottom left.

More Types of Chemical Reactions

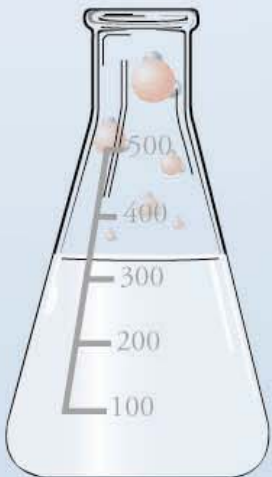
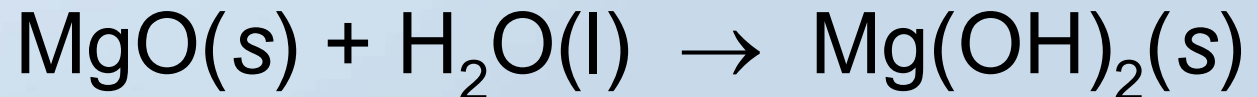
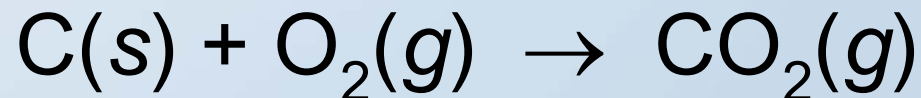
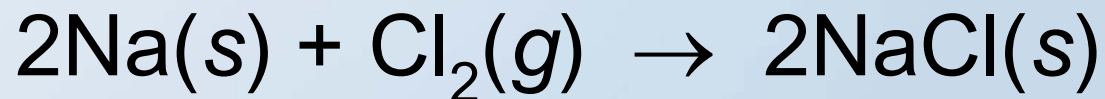
- Combination
- Decomposition
- Combustion
- Single Displacement





Combination Reactions

- In ***combination reactions***, two or more elements or compounds combine to form one compound.

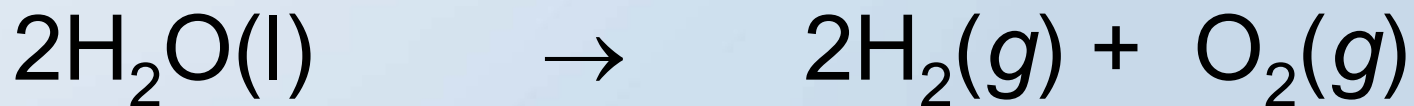




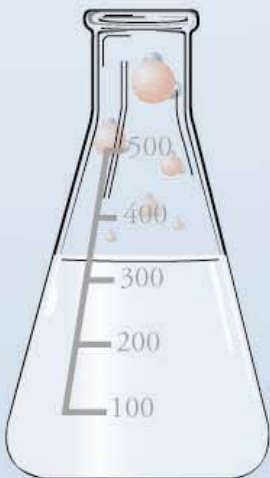
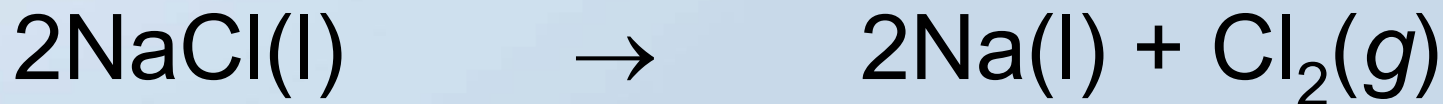
Decomposition Reactions

- In ***decomposition reactions***, one compound is converted into two or more simpler substances.

Electric current

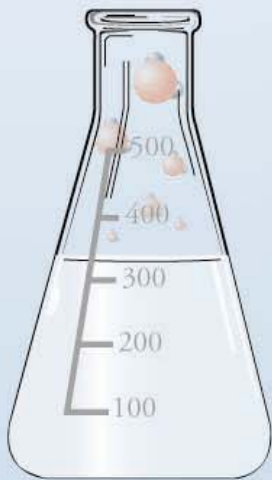
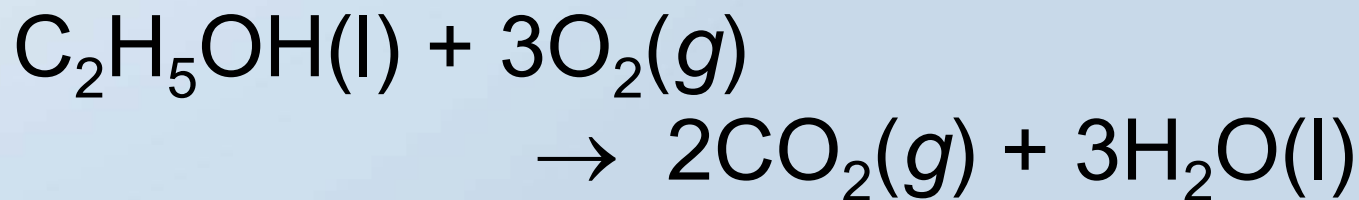


Electric current



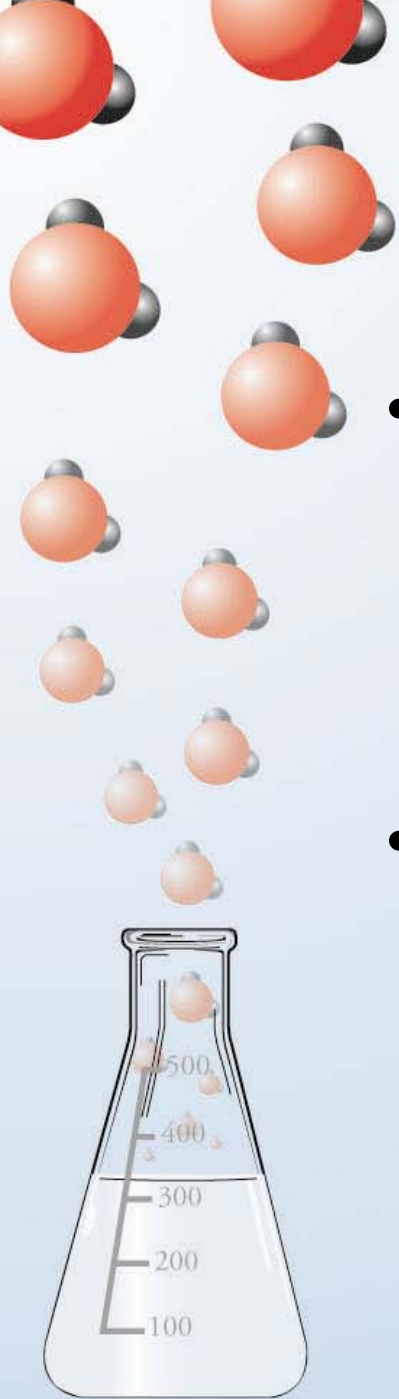
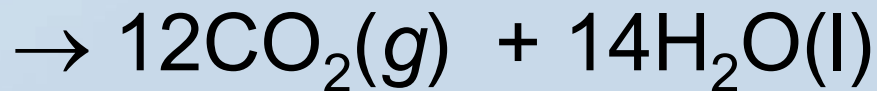
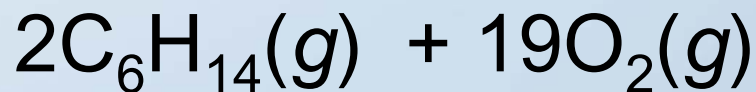
Combustion Reactions

- A ***combustion reaction*** is a redox reaction in which oxidation is very rapid and is accompanied by heat and usually light. The combustion reactions that you will be expected to recognize have oxygen, O₂, as one of the reactants.



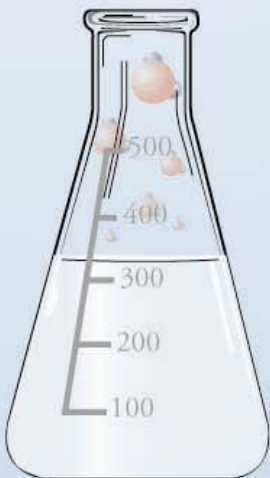
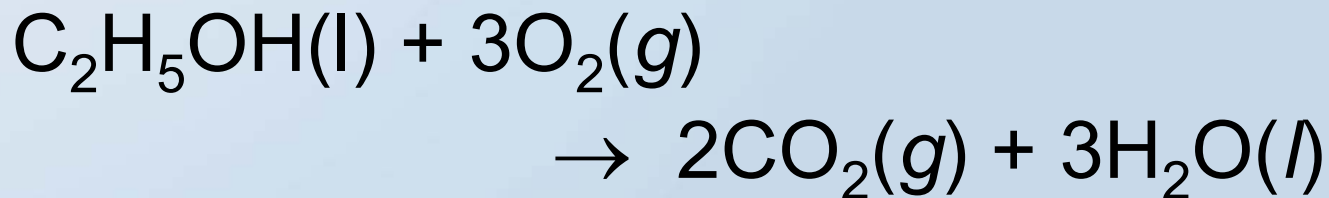
Combustion Products (1)

- When any substance that contains carbon is combusted (or burned) completely, the carbon forms carbon dioxide.
- When a substance that contains hydrogen is burned completely, the hydrogen forms water.



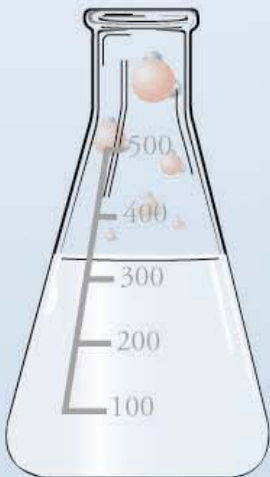
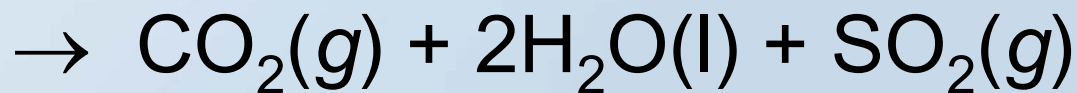
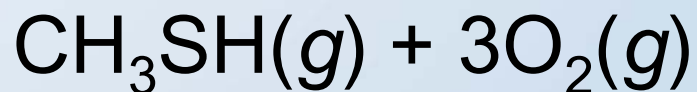
Combustion Products (2)

- The complete combustion of a substance, like ethanol, C_2H_5OH , that contains carbon, hydrogen, and oxygen also yields carbon dioxide and water.



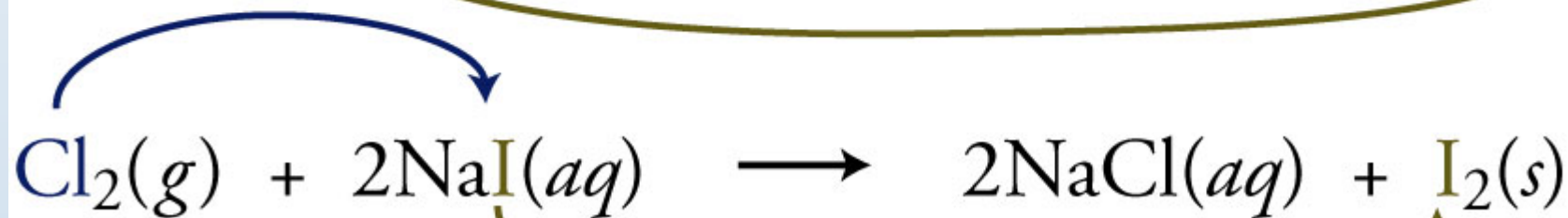
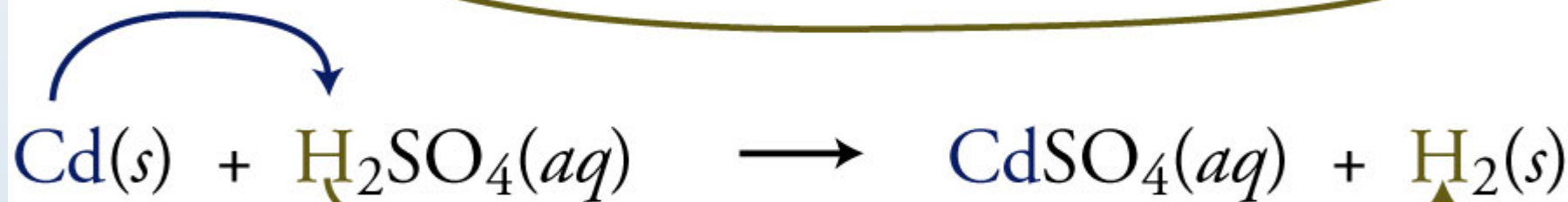
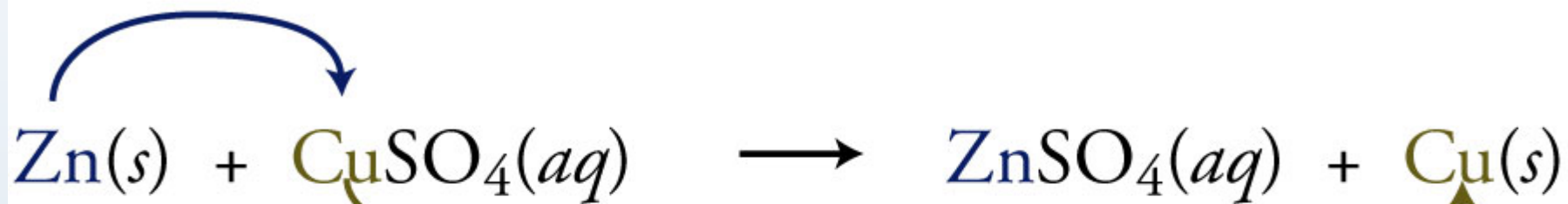
Combustion Products (3)

- When any substance that contains sulfur burns completely, the sulfur forms sulfur dioxide.



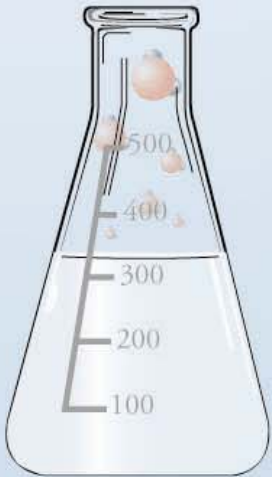
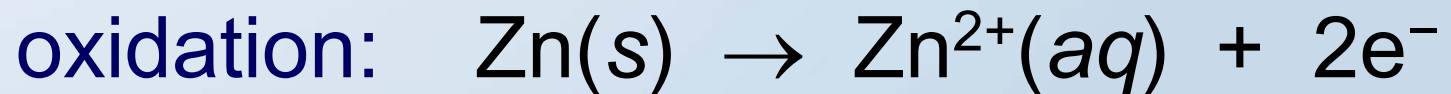
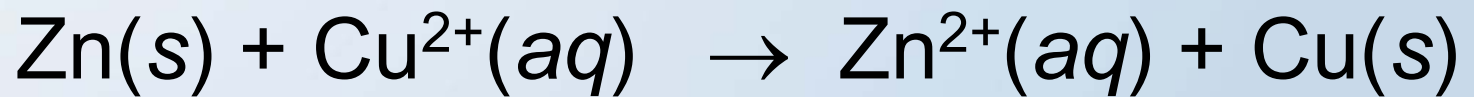
Single Displacement

Pure element displaces element in compound

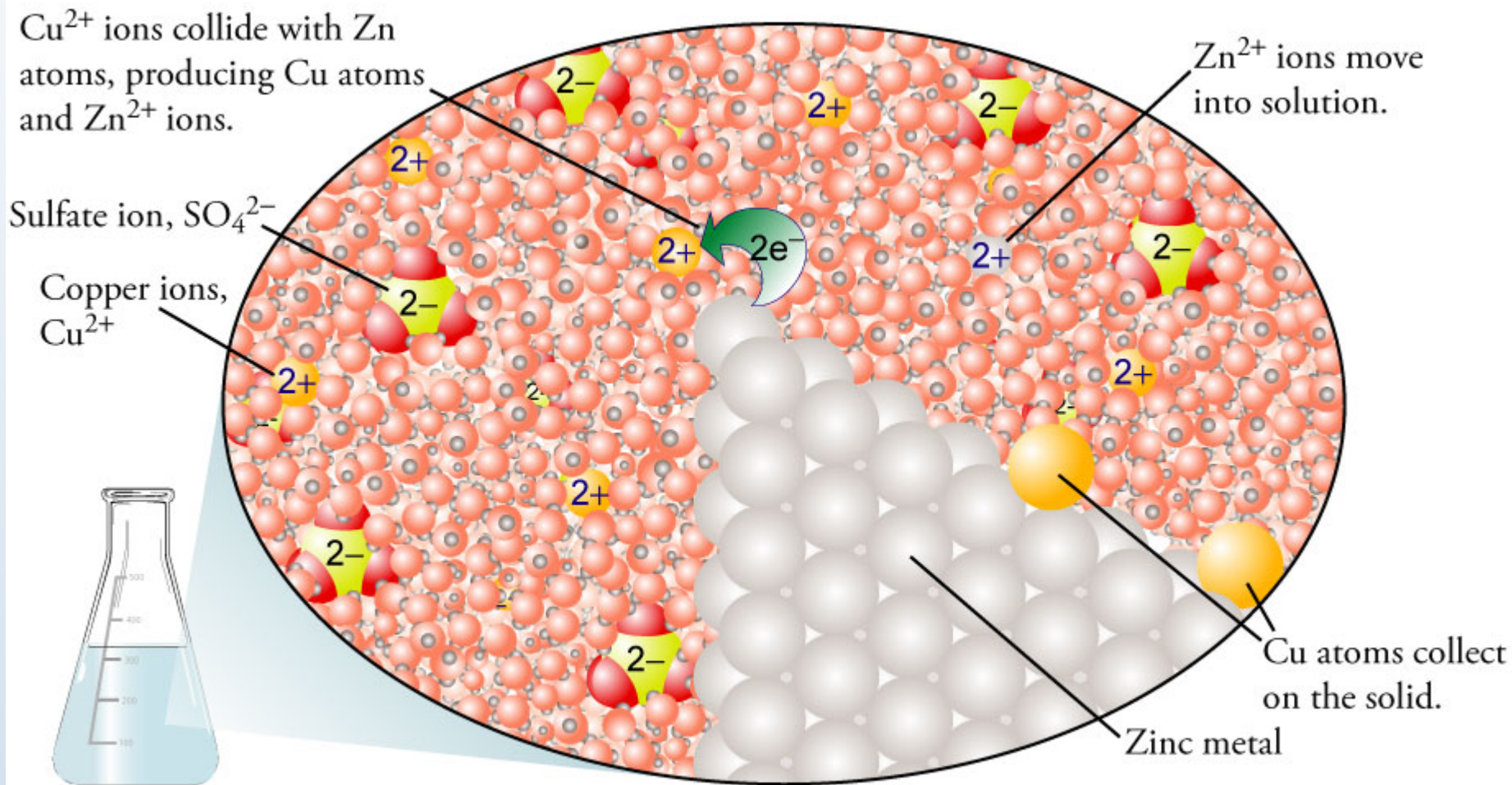


A decorative border of water molecules (H₂O) is located in the top-left corner of the slide. Each molecule consists of one red oxygen atom and two white hydrogen atoms.

Single Displacement Reaction



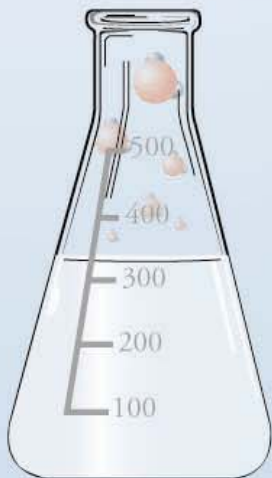
Single Displacement Reaction Example



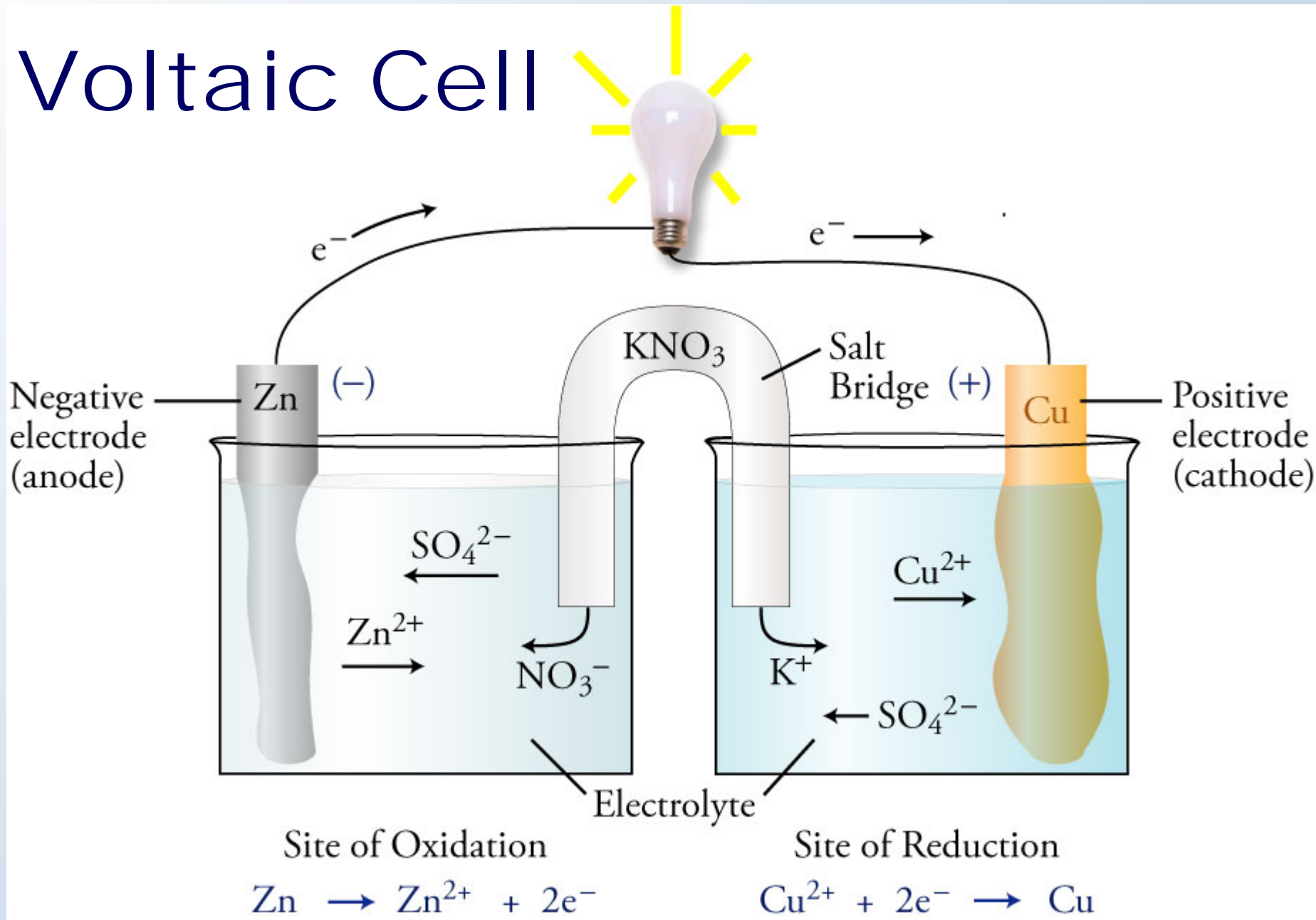
A series of water molecules (H₂O) are arranged in a vertical column on the left side of the slide. Each molecule consists of one red oxygen atom and two black hydrogen atoms. The molecules are positioned at various heights, creating a sense of a falling column.

Voltaic Cell

- The system in which two half-reactions for a redox reaction are separated allowing the electrons transferred in the reaction to be passed between them through a wire is called ***voltaic cell***.



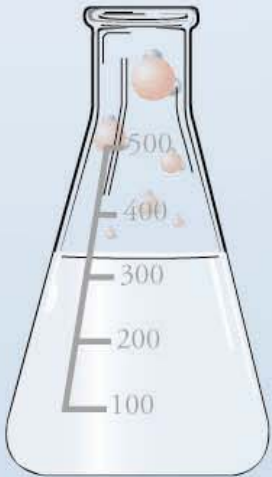
Voltaic Cell



A series of water molecules (H₂O) are arranged in a vertical column on the left side of the slide. Each molecule consists of one red oxygen atom and two black hydrogen atoms. The molecules are positioned at various heights, with some appearing to be falling into a flask below.

Electrodes

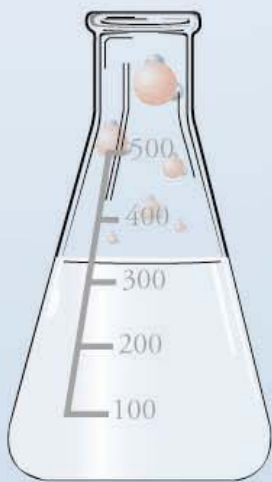
- The electrical conductors placed in the half-cells are called ***electrodes***.
- They can be ***active electrodes***, which participate in the reaction, or ***passive electrodes***, which transfer the electrons into or out of a half-cell but do not participate in the reaction.



A series of water molecules (H₂O) are arranged in a descending arc from the top left towards the center. Each molecule consists of one large red sphere (oxygen) and two smaller black spheres (hydrogen).

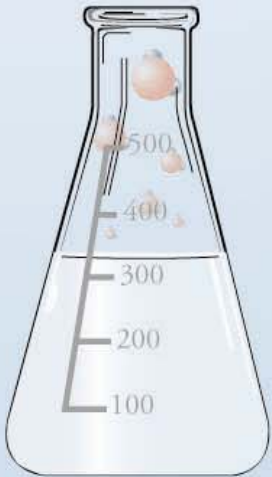
Anode

- The ***anode*** is the site of oxidation.
- Because oxidation involves loss of electrons, the anode is the source of electrons. For this reason, it is described as the negative electrode.
- Because electrons are lost forming more positive (or less negative) species at the anode, the surroundings tend to become more positive. Thus anions are attracted to the anode.



Cathode

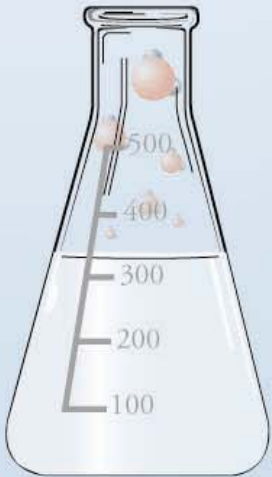
- The ***cathode*** is the site of reduction.
- By convention, the cathode is the positive electrode.
- Because electrons come to the cathode and substances gain these electrons to become more negative (or less positive), the surroundings tend to become more negative. Thus cations are attracted to the cathode.



A series of water molecules, each consisting of one red oxygen atom and two black hydrogen atoms, arranged in a vertical column on the left side of the slide. The molecules are slightly tilted and appear to be falling or floating.

Other Cell Components

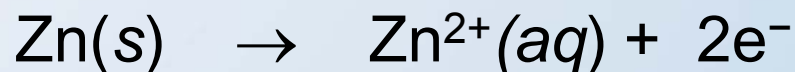
- A device called a ***salt bridge*** can be used to keep the charges balanced.
- The portion of the electrochemical cell that allows ions to flow is called the ***electrolyte***.



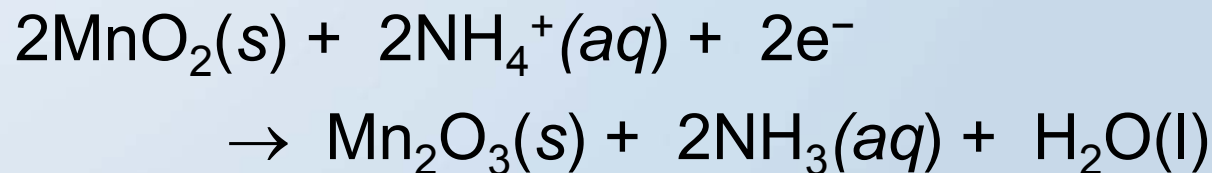
A decorative vertical column of water molecules (H₂O) on the left side of the slide, consisting of red spheres (oxygen) and white spheres (hydrogen) arranged in a descending staircase pattern.

Leclanché Cell or Dry Cell

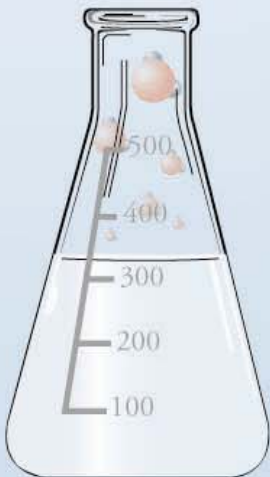
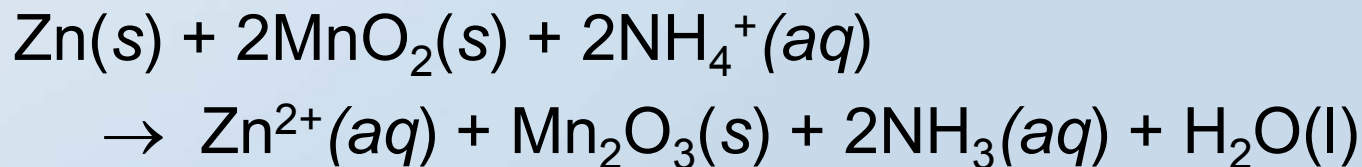
Anode oxidation:



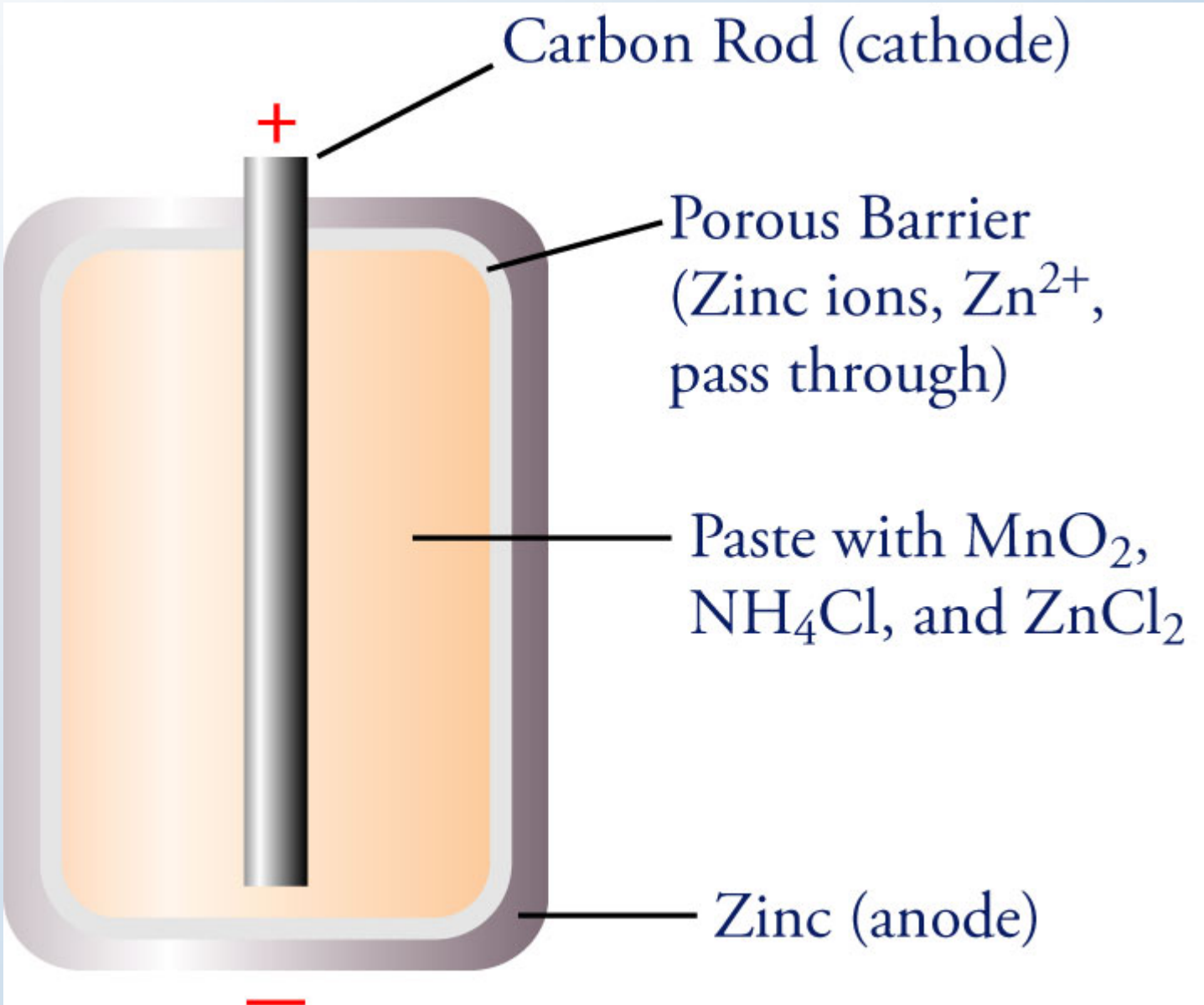
Cathode reduction:



Overall reaction:



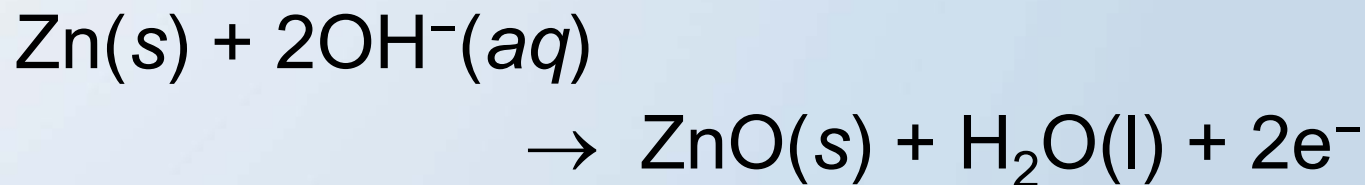
Dry Cell Image



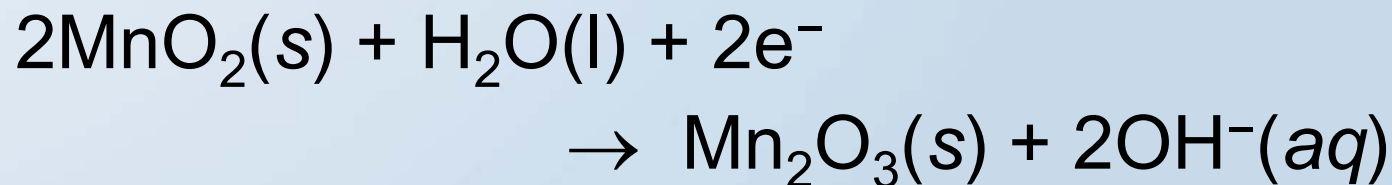
A decorative border of water molecules (H₂O) is located in the top-left corner of the slide. Each molecule consists of one red oxygen atom and two smaller black hydrogen atoms.

Alkaline Batteries

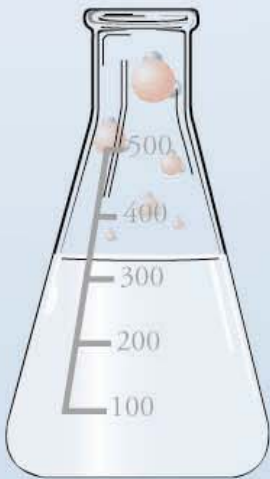
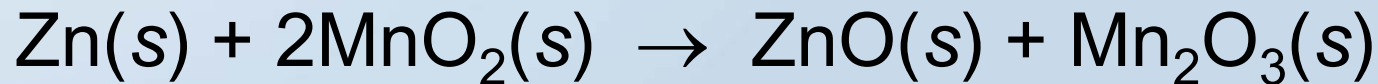
Anode oxidation:



Cathode reduction:



Overall reaction:



A series of water molecules, each consisting of one red oxygen atom and two black hydrogen atoms, are shown falling from the top left towards a flask at the bottom left. The flask is a standard Erlenmeyer flask with a vertical scale on its left side, marked with numbers 100, 200, 300, 400, and 500. The flask is partially filled with a liquid, and the water molecules are shown entering it.

Electrolysis

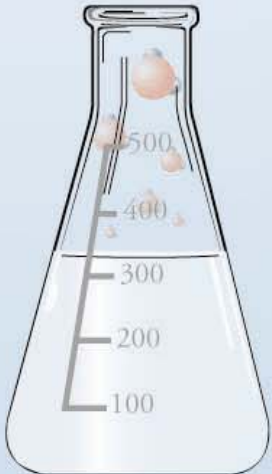
- **Voltage**, a measure of the strength of an electric current, represents the force that moves electrons from the anode to the cathode in a voltaic cell.
- When a greater force (voltage) is applied in the opposite direction, electrons can be pushed from what would normally be the cathode toward the voltaic cell's anode. This process is called **electrolysis**.
- In a broader sense, electrolysis is the process by which a redox reaction is made to occur in the nonspontaneous direction.



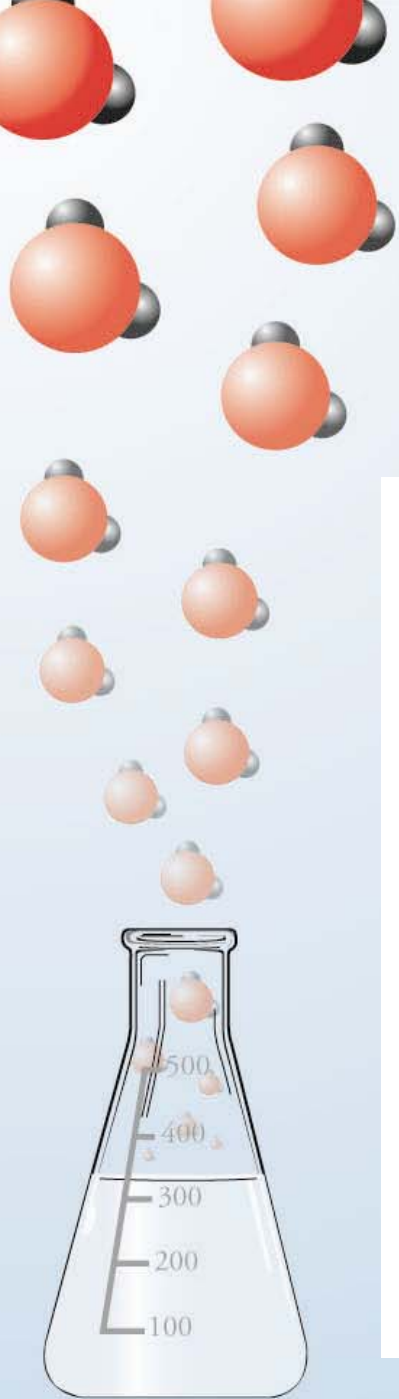
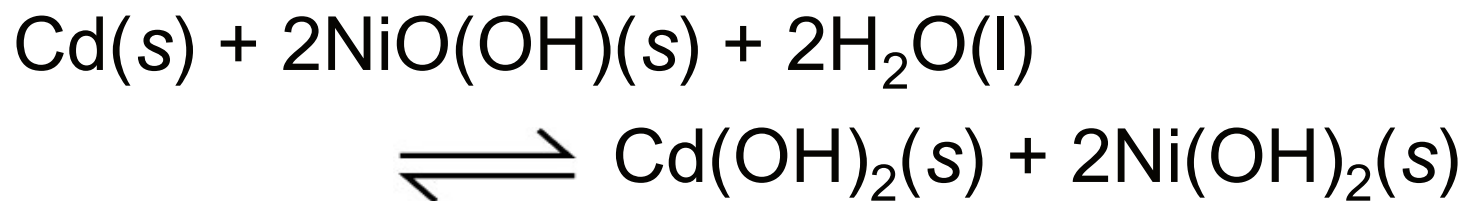
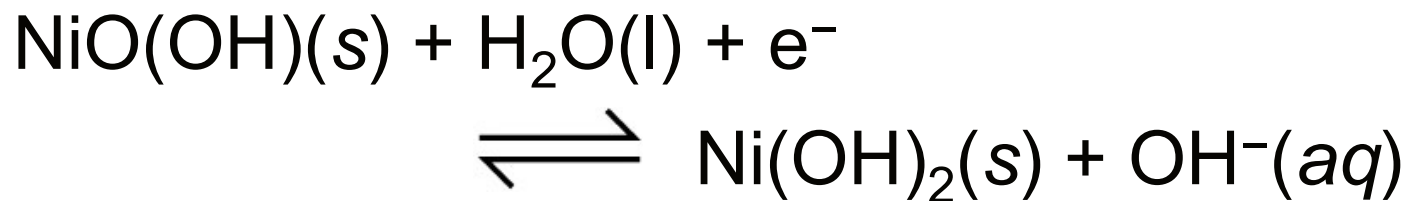
A series of water molecules, each consisting of one red oxygen atom and two black hydrogen atoms, are shown falling from the top left towards a flask at the bottom left. The molecules are arranged in a vertical line, with some appearing to be in motion as they fall.

Primary and Secondary Batteries

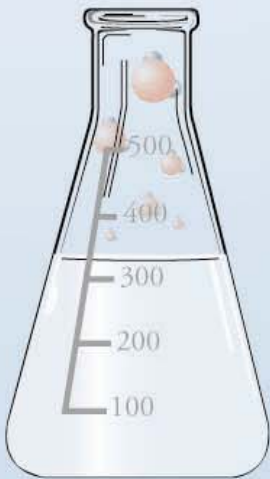
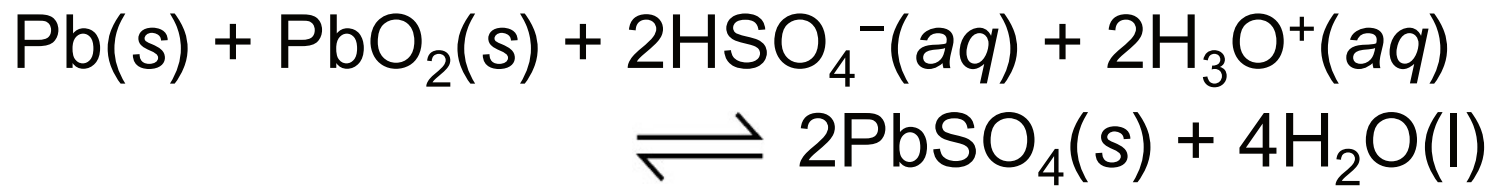
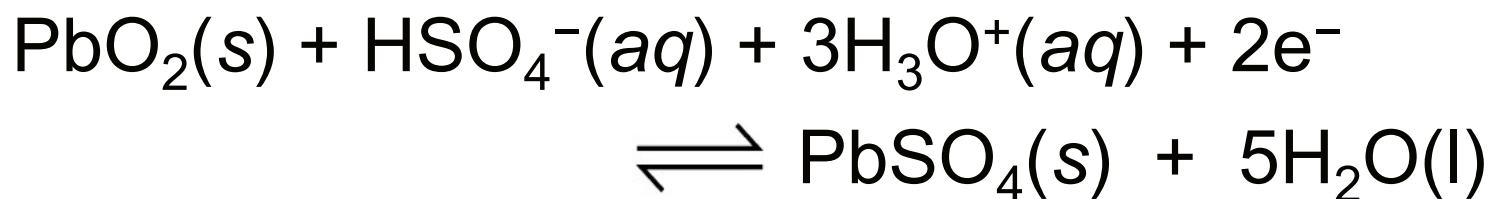
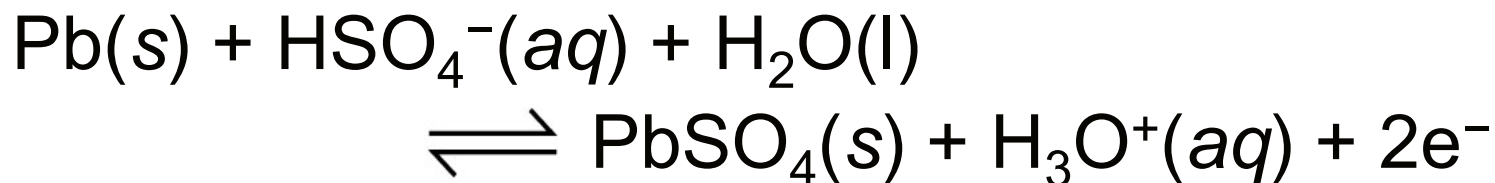
- Batteries that are not rechargeable are called ***primary batteries***.
- A rechargeable battery is often called a ***secondary battery*** or a ***storage battery***.



Nickel-Cadmium Battery



Lead Acid Battery

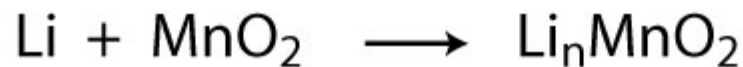
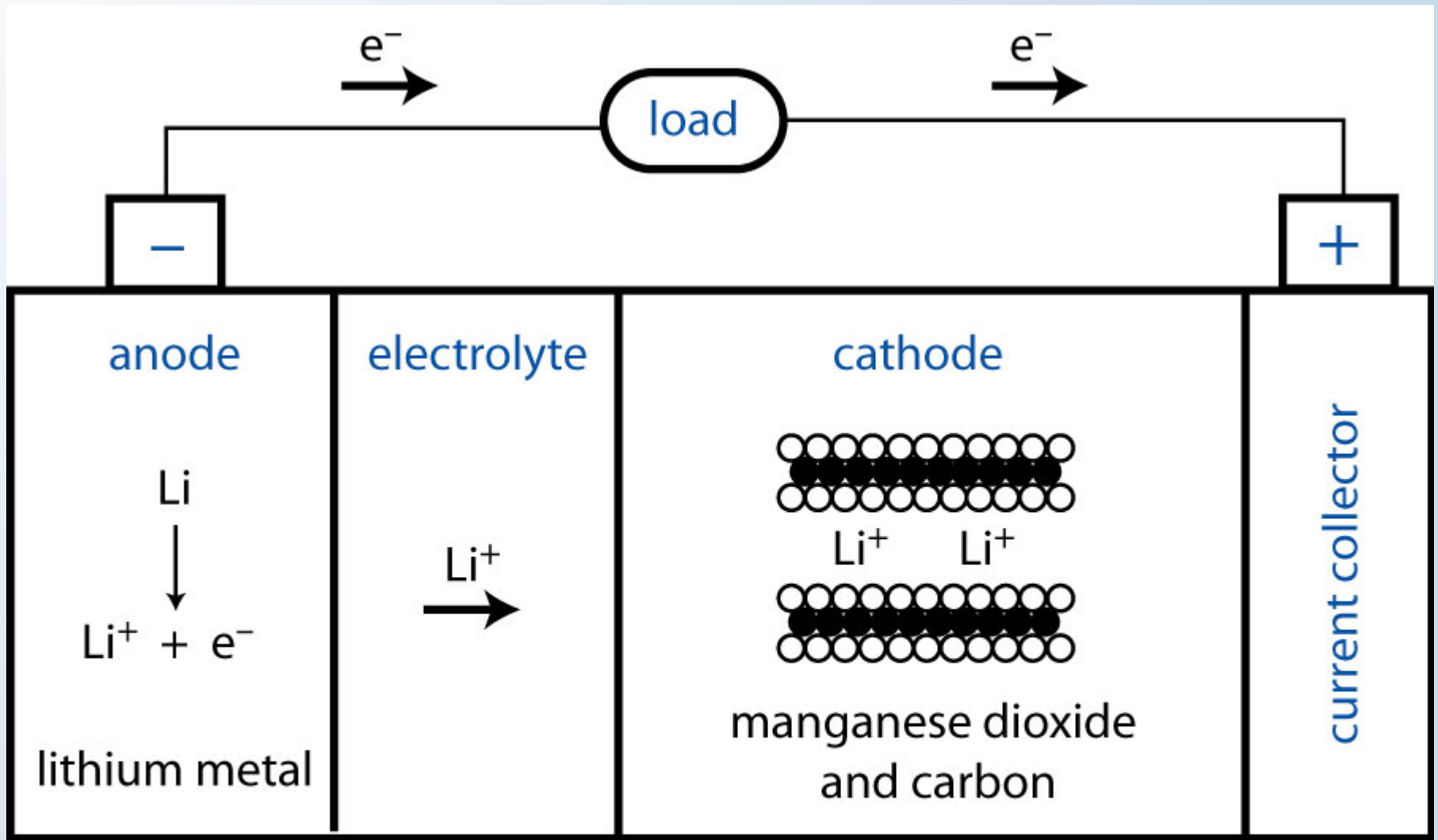


A decorative graphic on the left side of the slide shows several water molecules (represented by one large orange sphere and two smaller grey spheres) falling from the top left towards a glass flask at the bottom left. The flask is partially filled with a liquid and has a scale on its side with markings at 100, 200, 300, 400, and 500. The background is a light blue gradient.

Lithium Batteries

- Because lithium metal has a very low density, and because lithium can yield high voltages in batteries, lithium batteries have very high energy to mass ratios (or energy to volume ratios), making them ideal for powering electronic devices.
- The original lithium batteries used metallic lithium. The following slide shows a typical lithium-metal battery.

Lithium-Metal Battery



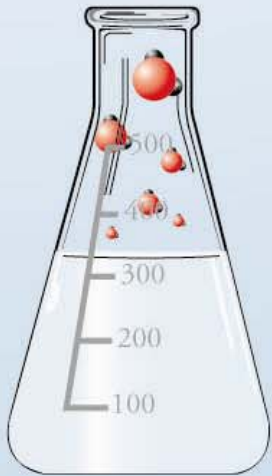
A decorative graphic on the left side of the slide shows several water molecules (represented by one red sphere and two white spheres) falling from the top left towards a glass flask at the bottom left. The flask contains a liquid and has a scale on its side with markings at 100, 200, 300, 400, and 500. The molecules are shown in various stages of falling, with some already inside the flask.

Lithium-Metal Battery (2)

- At the anode, lithium metal is oxidized to lithium ions, which migrate through the electrolyte to the cathode.
- At the cathode, lithium ions are inserted between manganese dioxide-carbon layers. Electrons must be gained at the cathode to maintain electrical neutrality.

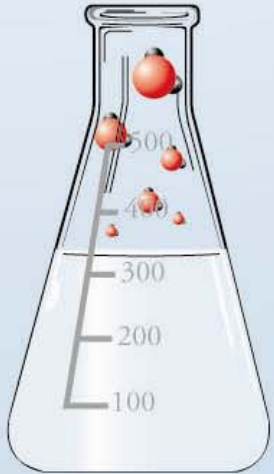
Problems with Lithium-Metal Batteries

- Lithium metal is very reactive, making lithium metal batteries somewhat dangerous.
- For this reason, modern lithium batteries are more likely to be lithium-ion batteries.



Advantages of Lithium-Ion Batteries

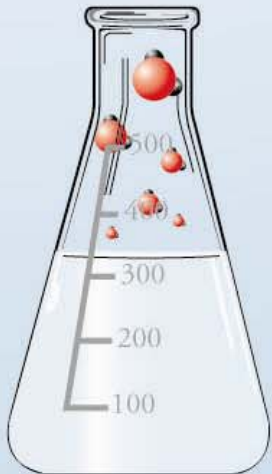
- They are safe.
- Although lithium-ion batteries have a lower energy density than lithium-metal batteries, it is still high compared to other batteries...about twice the standard nickel-cadmium battery.
- Low self discharge
- Low maintenance





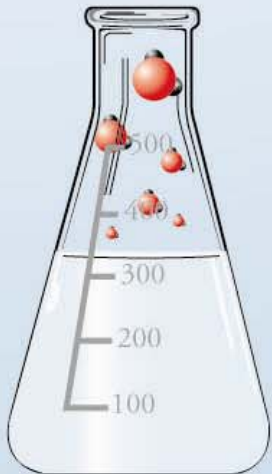
Limitations of Lithium-Ion Batteries

- Requires a protection circuit to maintain voltage and currents within safe limits.
- Expensive to manufacture.
- Subject to aging. A typical lifetime is two to three years.

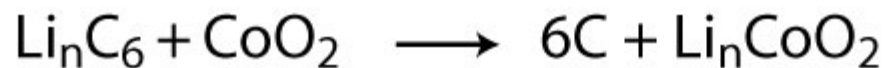
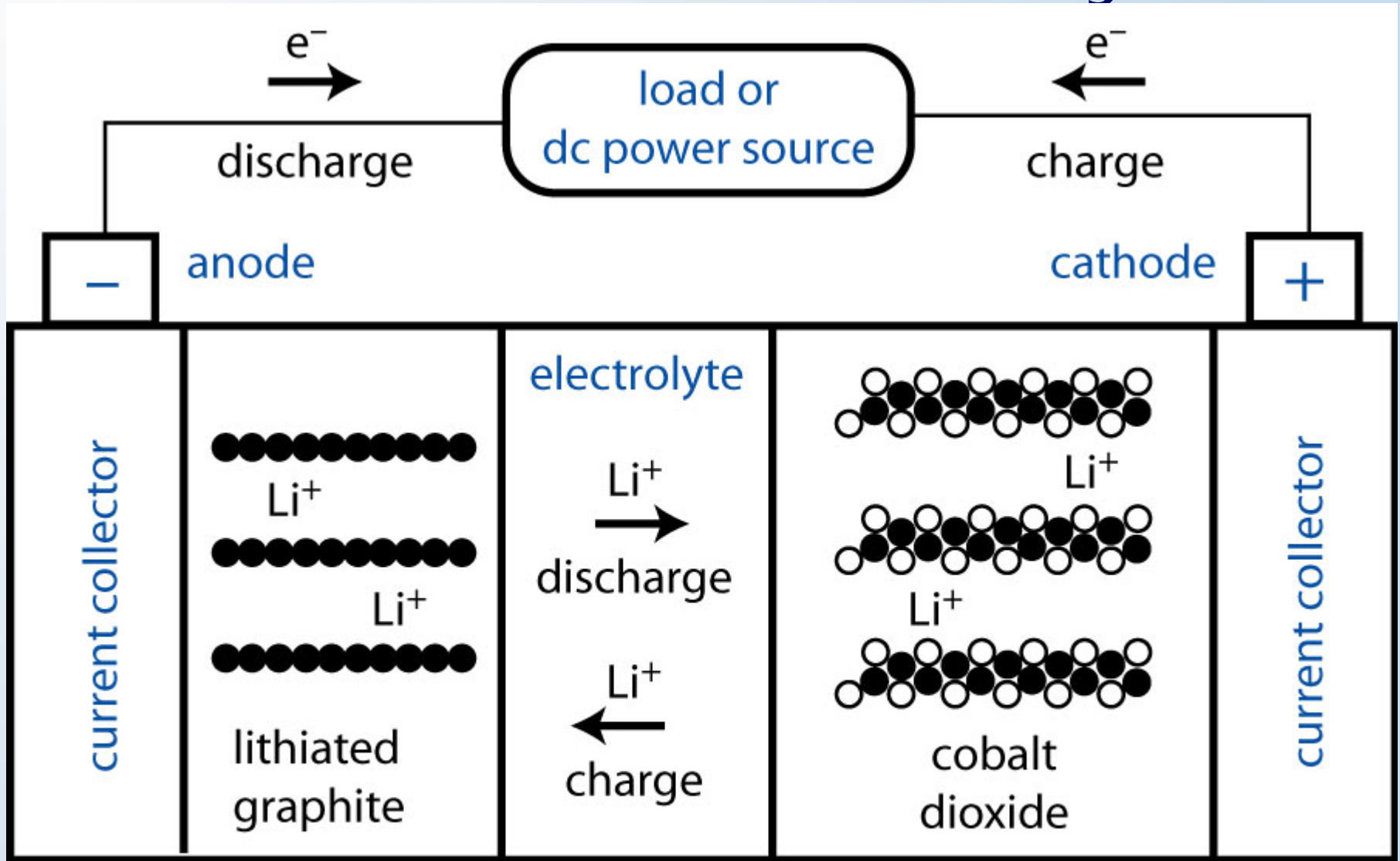


Differences in Lithium-Ion Batteries

- The technology for lithium-ion batteries is constantly evolving, leading to changes in the cathode, anode, and electrolyte.
- One example of a lithium-ion battery is shown on the next slide.



Lithium-Ion Battery



Lithium-Ion Battery (2)

- At the anode, lithium ions are trapped between graphite layers.
- During discharge, lithium ions move from the anode to the cathode through the electrolyte.
- When lithium ions are removed from the anode, electrons are lost to maintain electrical neutrality.
- When lithium ions move to the cathode, they are inserted into layers of cobalt dioxide.
- Electrons must be gained at the cathode to maintain electrical neutrality.

