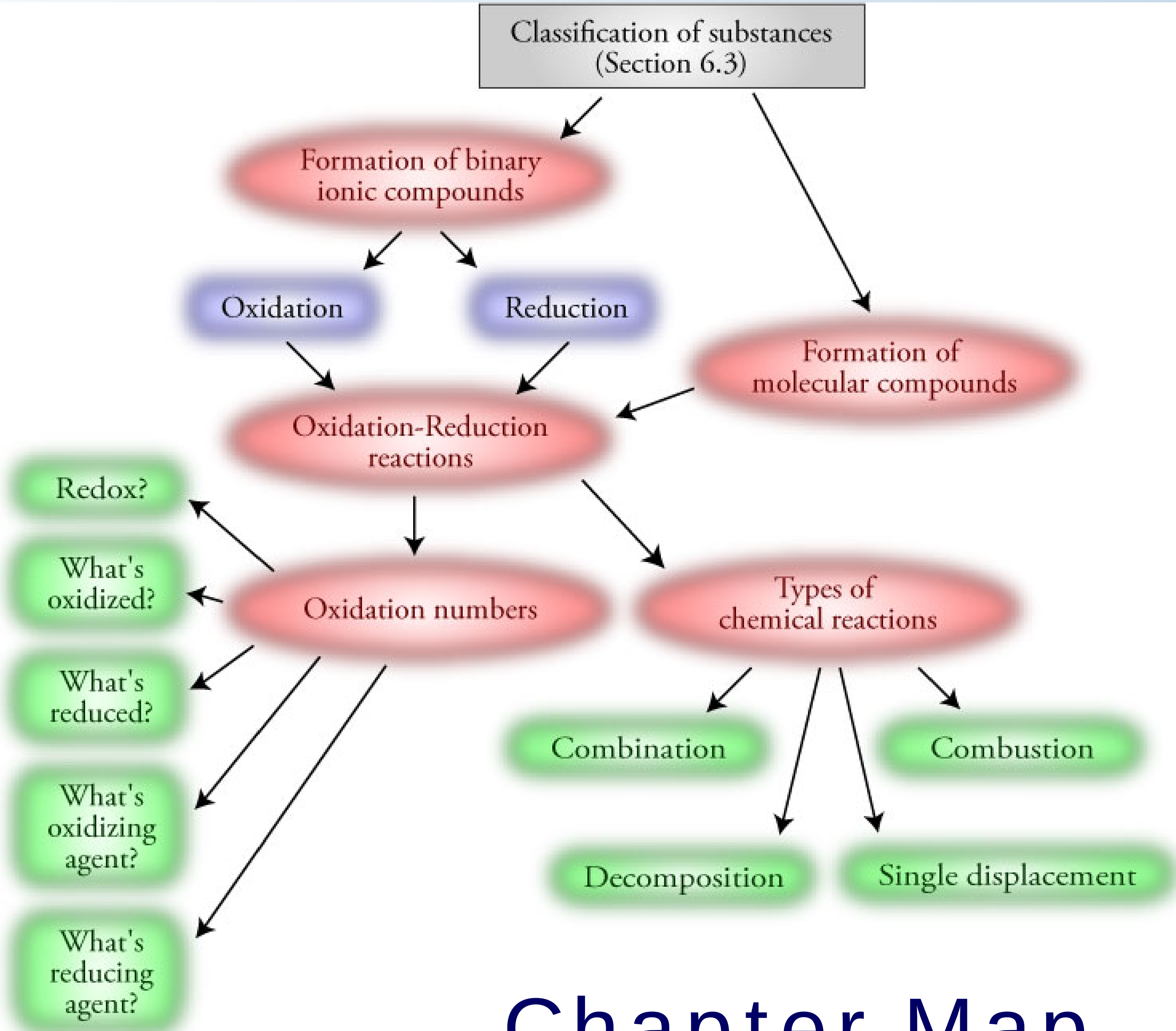
# Chapter 7

## Oxidation-Reduction Reactions


Classification of substances
(Section 6.3)
Formation of binary ionic compounds
Oxidation
Reduction
Formation of molecular compounds
Oxidation-Reduction reactions
Redox?
What's oxidized?
What's reduced?
What's oxidizing agent?
What's reducing agent?
Oxidation numbers
Types of chemical reactions
Combination
Combustion
Decomposition
Single displacement

# Chapter Map

# Oxidation

- Historically oxidation meant reacting with oxygen.

$$2Zn(s) + O_2(g) \rightarrow 2ZnO(s)$$

$$Zn \rightarrow Zn^{2+} + 2e^-$$

$$\text{or } 2Zn \rightarrow 2Zn^{2+} + 4e^-$$

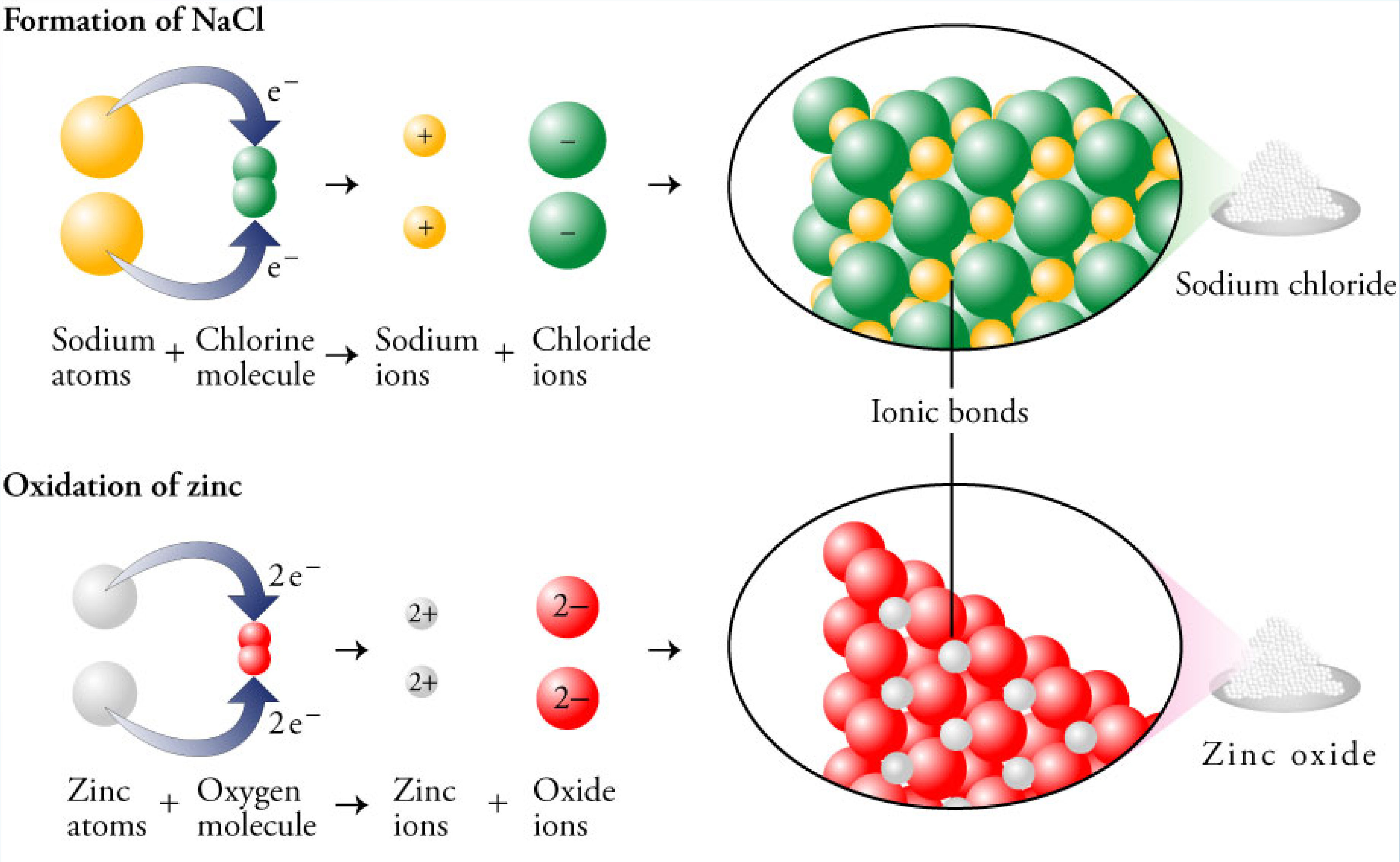
$$O + 2e^- \rightarrow O^{2-}$$

$$\text{or } O_2 + 4e^- \rightarrow 2O^{2-}$$

# 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



# Similar to Oxidation of Zinc

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

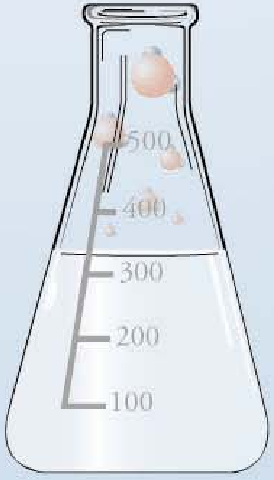
$$Na \rightarrow Na^+ + e^-$$

$$\text{or } 2Na \rightarrow 2Na^+ + 2e^-$$

$$Cl + e^- \rightarrow Cl^-$$

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

**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.

$$ZnO(s) + C(g) \rightarrow Zn(s) + CO(g)$$

- 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.

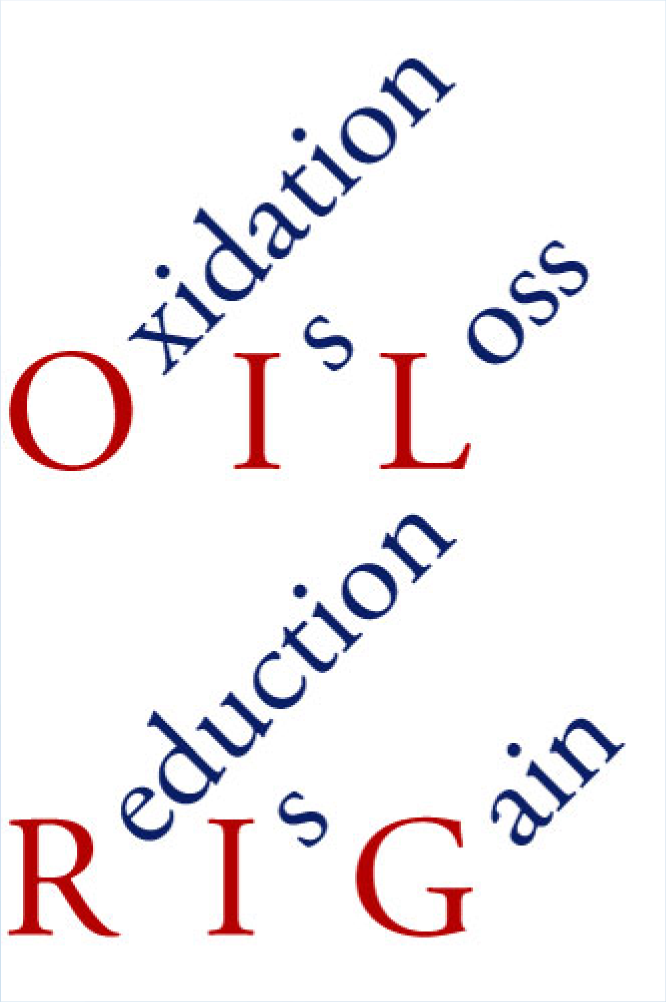
$$Zn^{2+} + 2e^{-} \rightarrow Zn$$

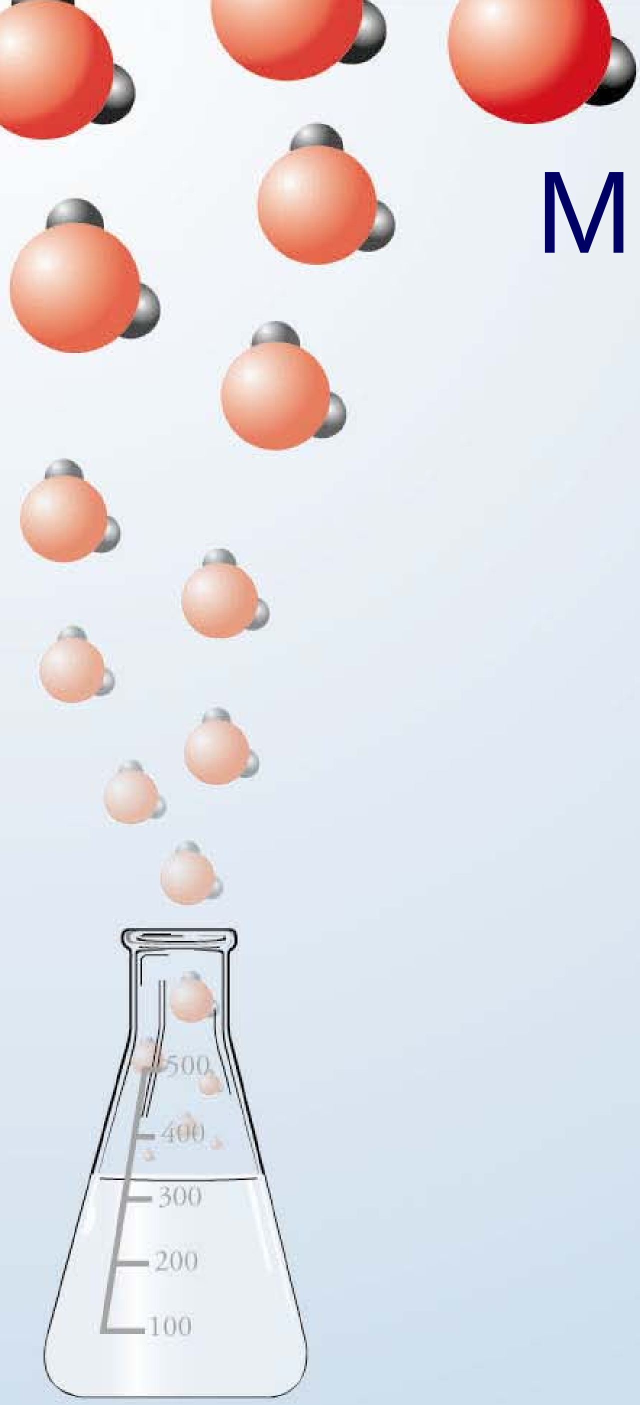
- The definition of reduction was broadened to coincide with the definition of oxidation. According to the modern definition, when something gains electrons, it is *reduced*.

# Reduction

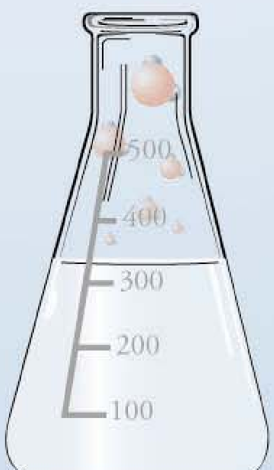
- The loss of electrons (oxidation) by one substance is accompanied by the gain of electrons by another (reduction). ***Reduction*** is any chemical change in which at least one element gains electrons.

# Memory Aid

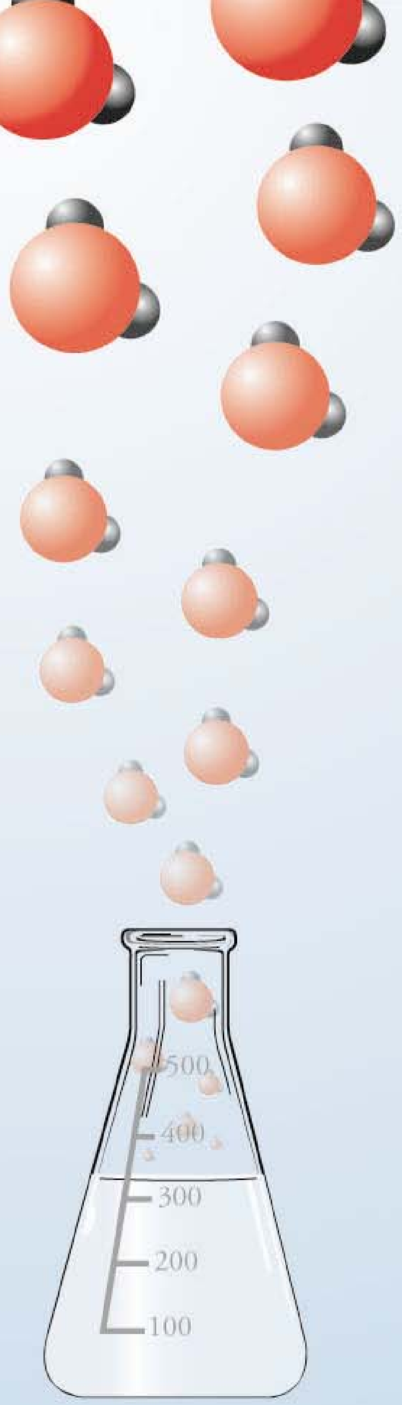

OIL RIG
Oxidation Is Loss
Reduction Is Gain


500
400
300
200
100

# 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

$$2Zn(s) + O_2(g) \rightarrow 2ZnO(s)$$

$$Zn \rightarrow Zn^{2+} + 2e^-$$

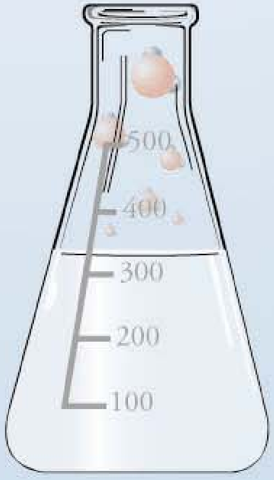
$$O + 2e^- \rightarrow O^{2-}$$

- 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.

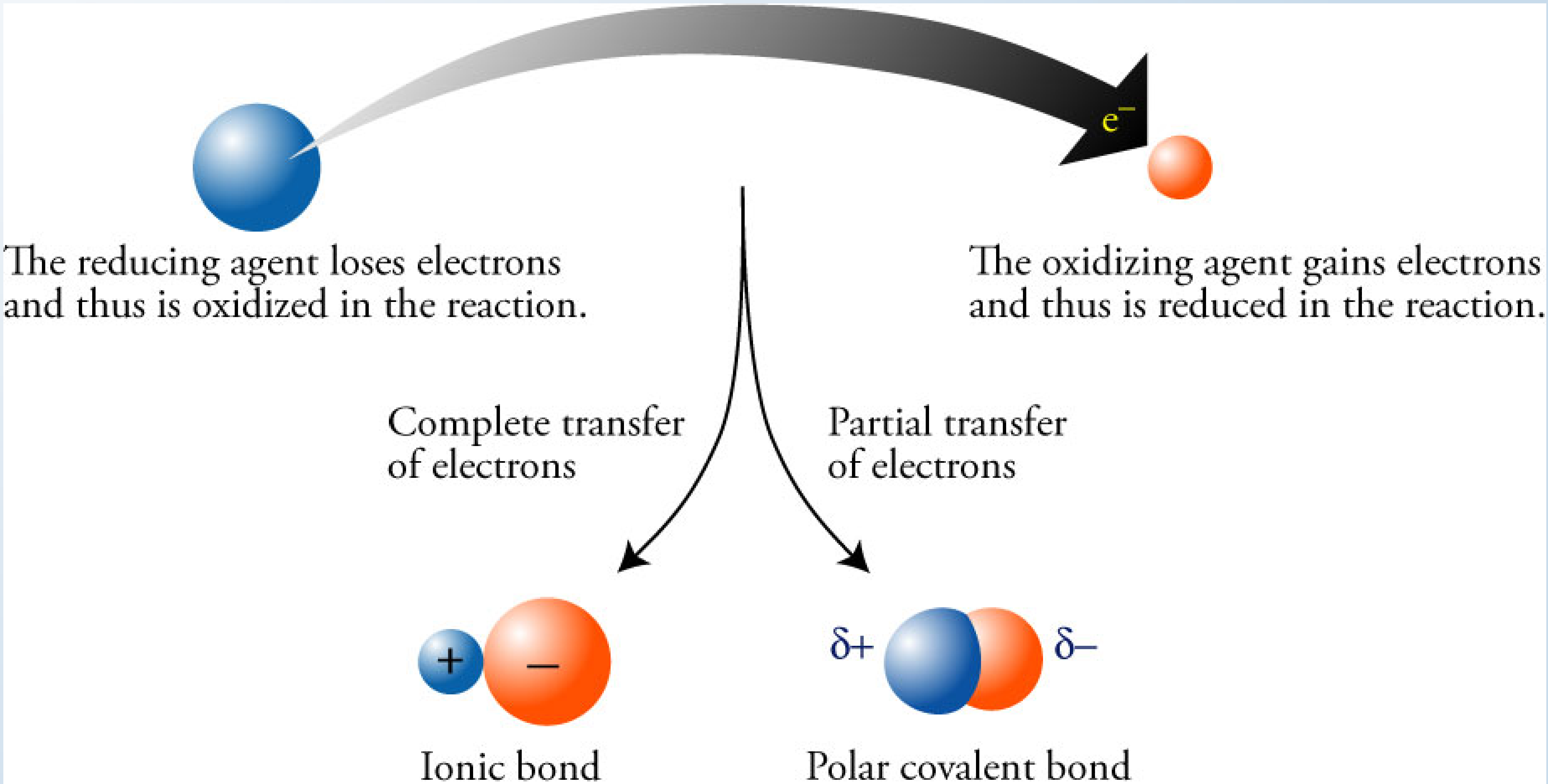
# Partial Loss and Gain of Electrons

$$N_2(g) \quad + \quad O_2(g) \quad \rightarrow \quad 2NO(g)$$

- 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)



# 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 pervious 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 |

# More Types of Chemical Reactions

- Combination
- Decomposition
- Combustion
- Single Displacement

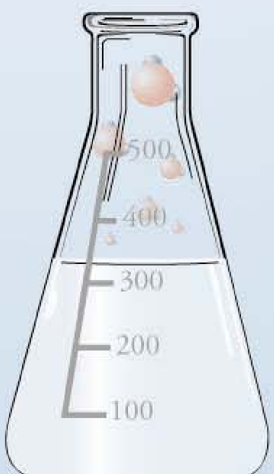
# Combination Reactions

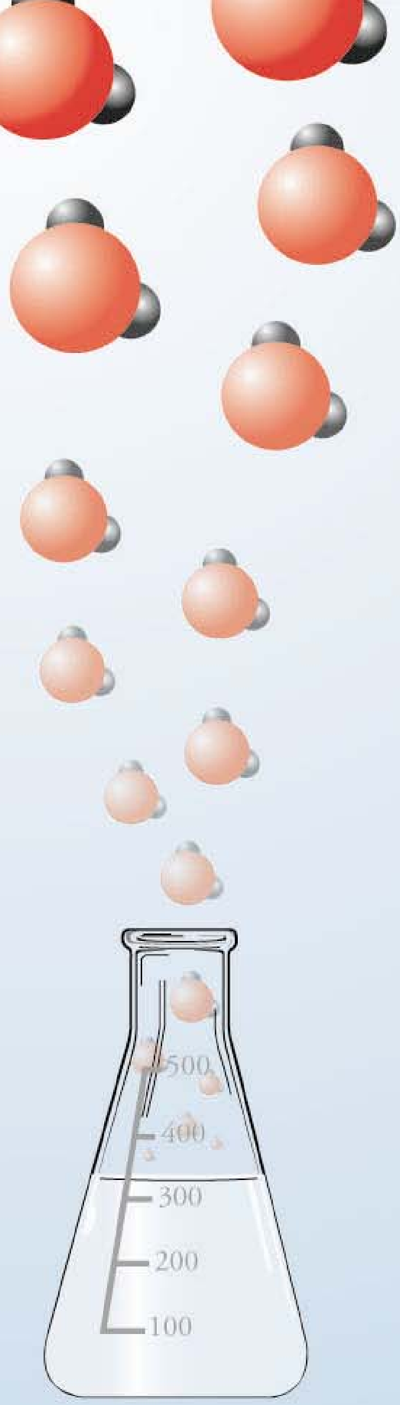
- In ***combination reactions***, two or more elements or compounds combine to form one compound.

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

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

$$MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(s)$$






# Decomposition Reactions

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

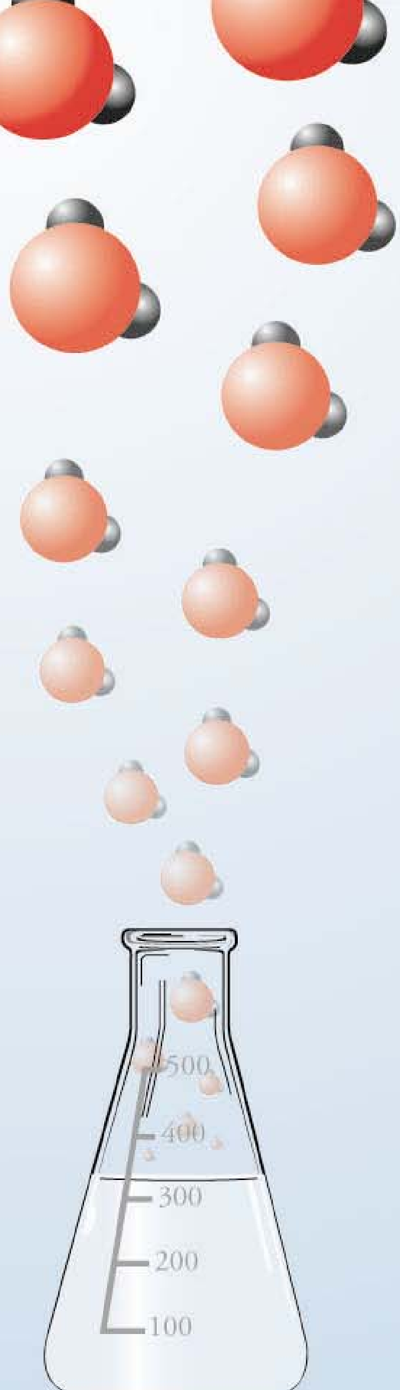
Electric current

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

Electric current

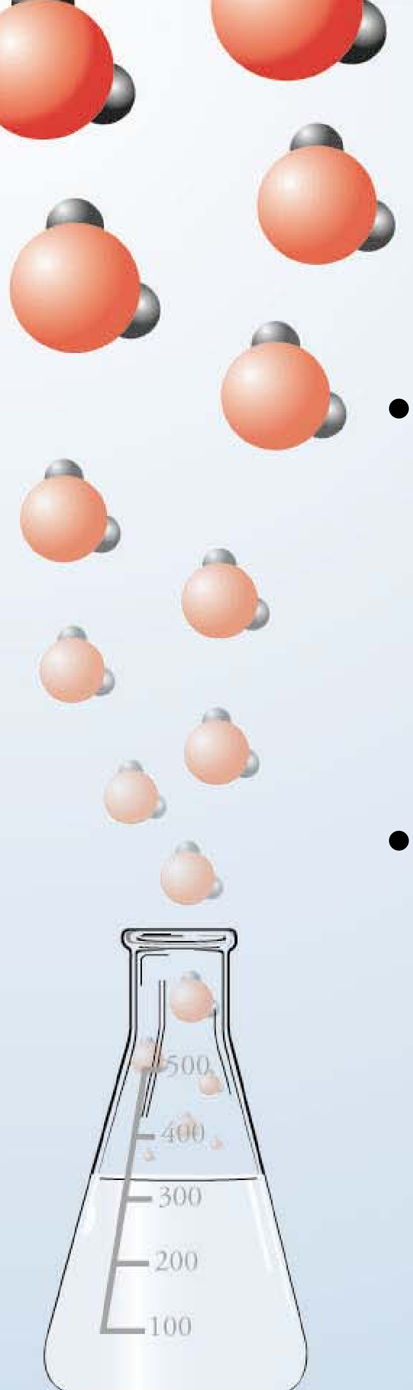
$$2NaCl(l) \rightarrow 2Na(l) + Cl_2(g)$$

# 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, $O_2$, as one of the reactants.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$




# Combustion Products (1)

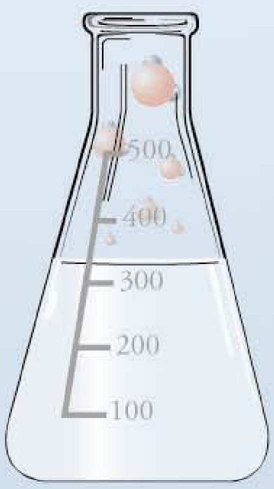
- When any substance that contains carbon is combusted (or burned) completely, the carbon forms carbon dioxide.
- When a substance that contains hydrogen is burned completely, the hydrogen forms water.

$$2C_6H_{14}(g) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(l)$$

# 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.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$



# Combustion Products (3)

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

$$CH_3SH(g) + 3O_2(g)$$

$$\rightarrow CO_2(g) + 2H_2O(l) + SO_2(g)$$

# Single Displacement

Pure element displaces element in compound

$$Zn(s) + CuSO_4(aq) \longrightarrow ZnSO_4(aq) + Cu(s)$$

$$Cd(s) + H_2SO_4(aq) \longrightarrow CdSO_4(aq) + H_2(s)$$

$$Cl_2(g) + 2NaI(aq) \longrightarrow 2NaCl(aq) + I_2(s)$$

# Single Displacement Reaction

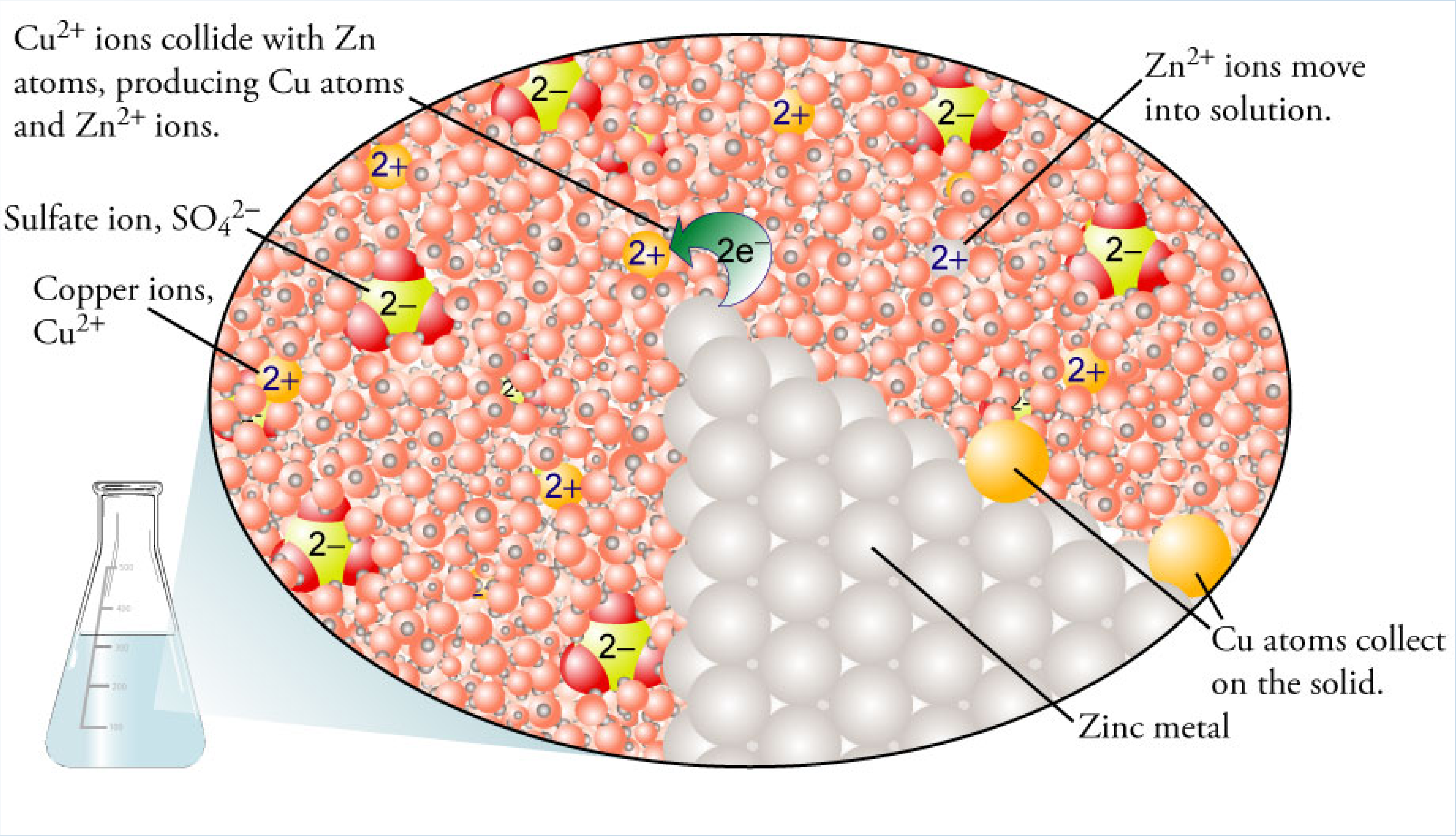
$$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$$

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

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

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

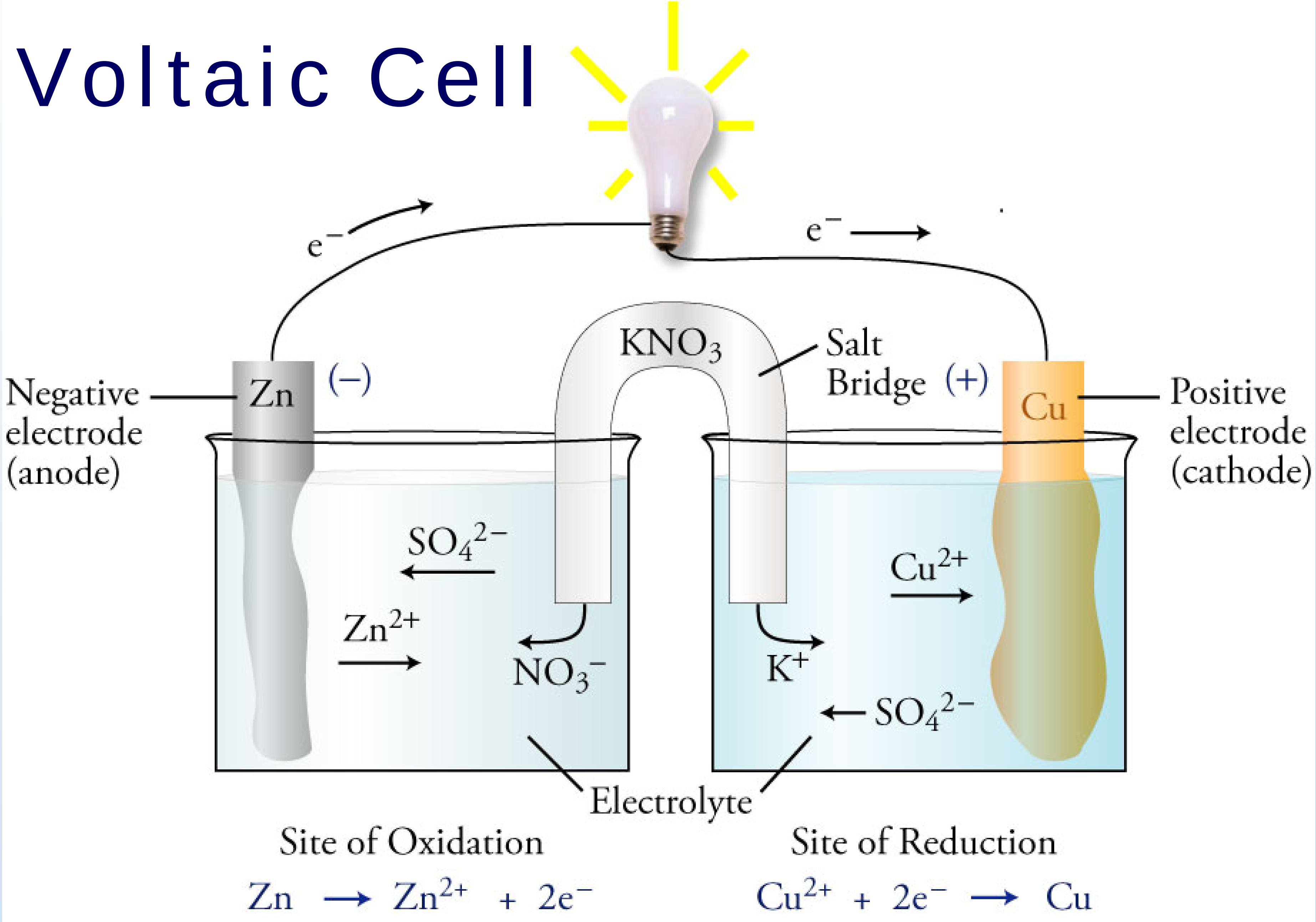
# Single Displacement Reaction Example



# Voltaic Cell

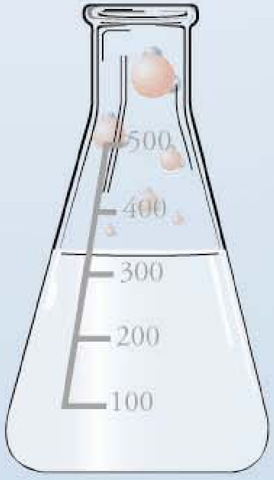
- The system in which two half-reactions for a redox reaction are separated allowing the electrons transferred in the reaction to be passed between them through a wire is called ***voltaic cell.***

# Voltaic Cell



# Electrodes

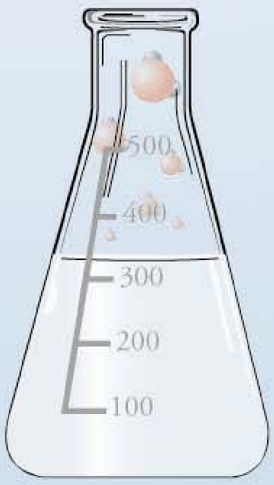
- The electrical conductors placed in the half-cells are called ***electrodes***.
- They can be ***active electrodes***, which participate in the reaction, or ***passive electrodes***, which transfer the electrons into or out of a half-cell but do not participate in the reaction.



# 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.

# 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***.

# Leclanché Cell or Dry Cell

Anode oxidation:

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

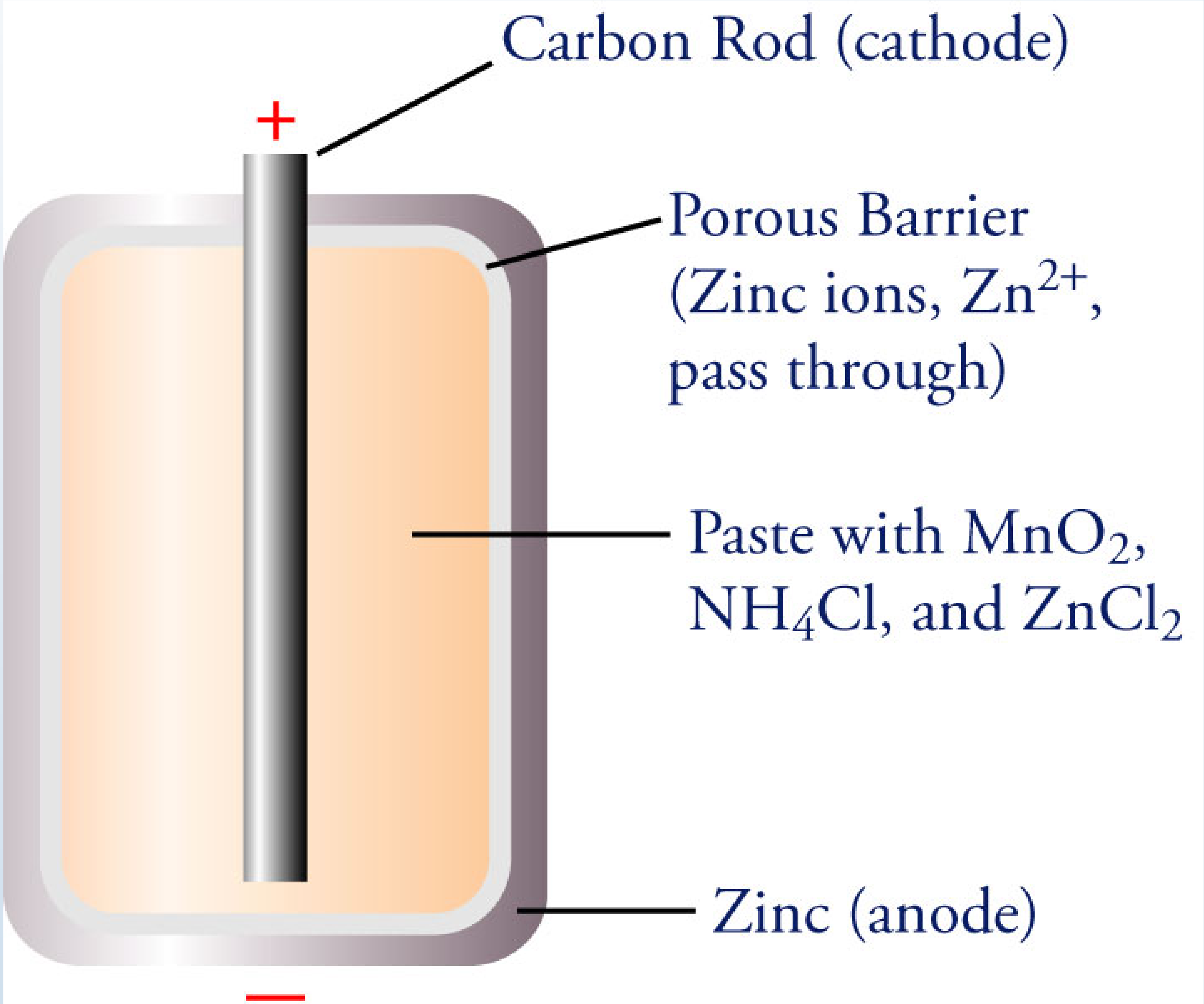
Cathode reduction:

$$2MnO_2(s) + 2NH_4^+(aq) + 2e^- \rightarrow Mn_2O_3(s) + 2NH_3(aq) + H_2O(l)$$

Overall reaction:

$$Zn(s) + 2MnO_2(s) + 2NH_4^+(aq) \rightarrow Zn^{2+}(aq) + Mn_2O_3(s) + 2NH_3(aq) + H_2O(l)$$

# Dry Cell Image



# Alkaline Batteries

Anode oxidation:

$$Zn(s) + 2OH^{-}(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^{-}$$

Cathode reduction:

$$2MnO_2(s) + H_2O(l) + 2e^{-} \rightarrow Mn_2O_3(s) + 2OH^{-}(aq)$$

Overall reaction:

$$Zn(s) + 2MnO_2(s) \rightarrow ZnO(s) + Mn_2O_3(s)$$

# 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.

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

# 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***.

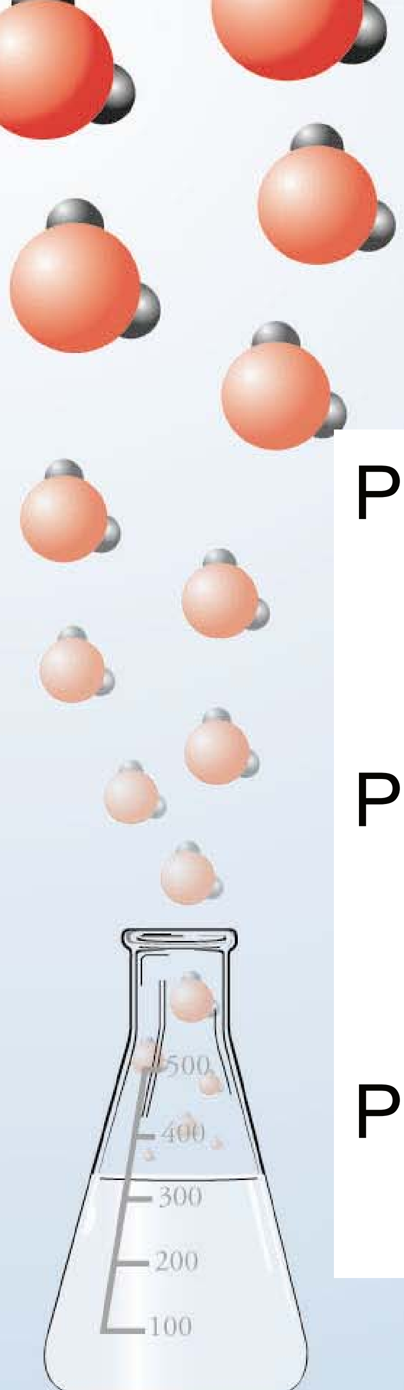
# Nickel-Cadmium Battery

$$Cd(s) + 2OH^-(aq) \rightleftharpoons Cd(OH)_2(s) + 2e^-$$

$$NiO(OH)(s) + H_2O(l) + e^- \rightleftharpoons Ni(OH)_2(s) + OH^-(aq)$$

$$Cd(s) + 2NiO(OH)(s) + 2H_2O(l) \rightleftharpoons Cd(OH)_2(s) + 2Ni(OH)_2(s)$$

# Lead Acid Battery




$$\mathrm{Pb}(s) + \mathrm{HSO_4^-}(aq) + \mathrm{H_2O(l)} \rightleftharpoons \mathrm{PbSO_4}(s) + \mathrm{H_3O^+}(aq) + 2e^-$$

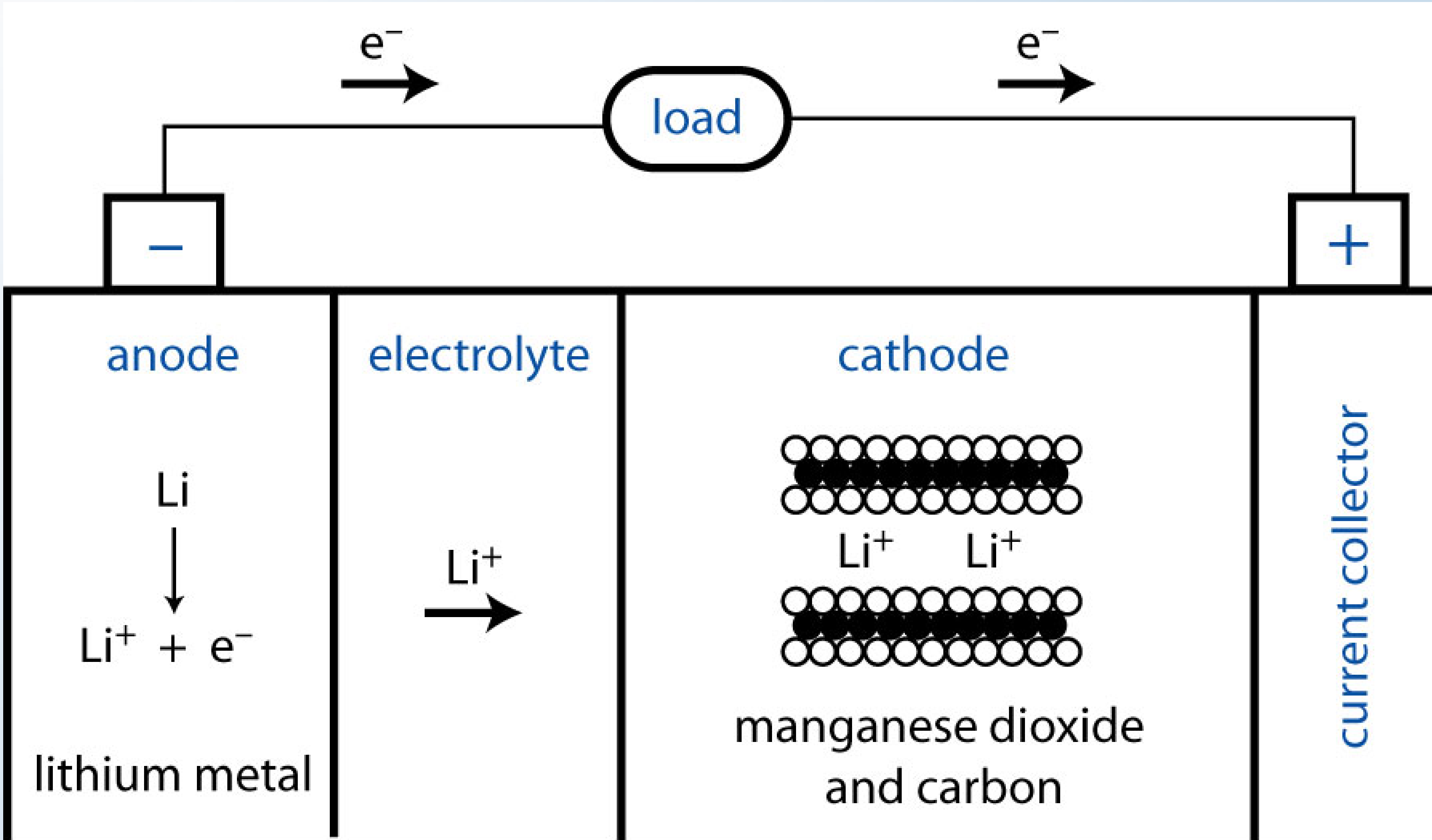
$$\mathrm{PbO_2}(s) + \mathrm{HSO_4^-}(aq) + 3\mathrm{H_3O^+}(aq) + 2e^- \rightleftharpoons \mathrm{PbSO_4}(s) + 5\mathrm{H_2O(l)}$$

$$\mathrm{Pb}(s) + \mathrm{PbO_2}(s) + 2\mathrm{HSO_4^-}(aq) + 2\mathrm{H_3O^+}(aq) \rightleftharpoons 2\mathrm{PbSO_4}(s) + 4\mathrm{H_2O(l)}$$

# 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




$$nLi \longrightarrow nLi^+ + ne^- \qquad MnO_2 + nLi^+ + ne^- \longrightarrow Li_nMnO_2$$

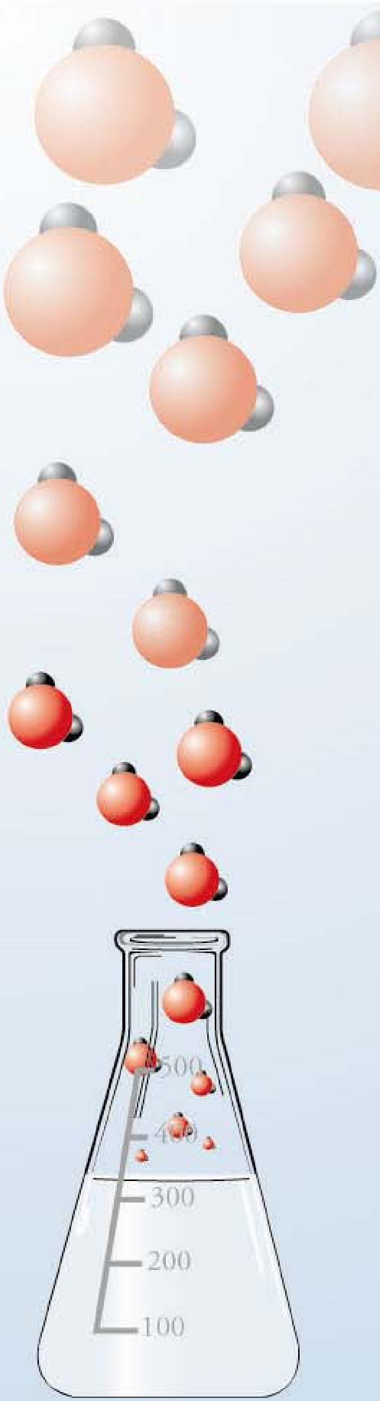
$$Li + MnO_2 \longrightarrow Li_nMnO_2$$

# 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.

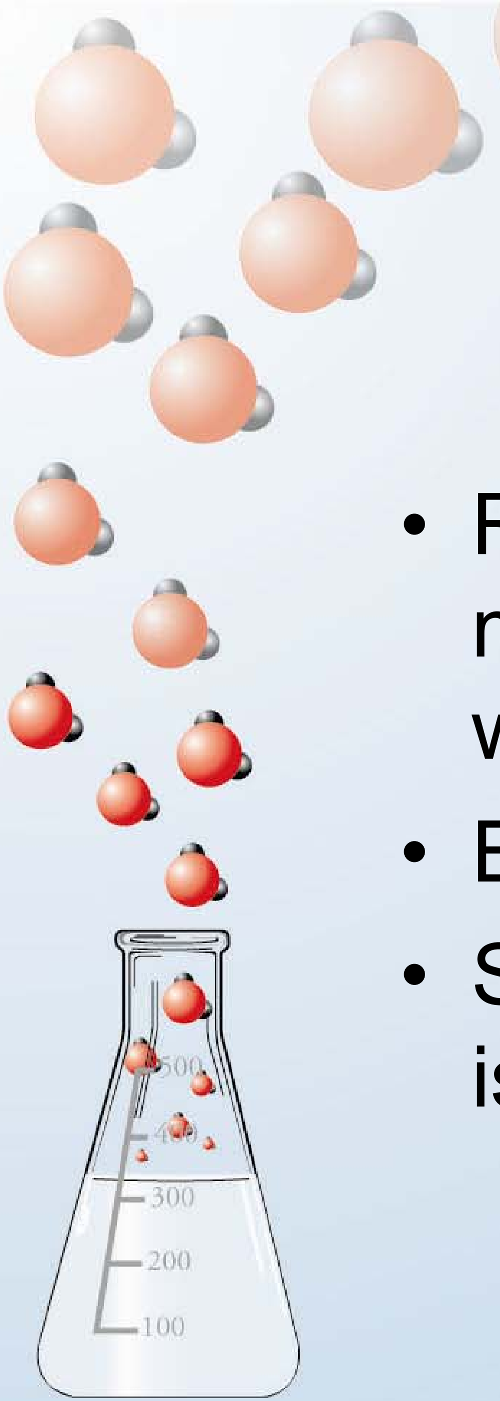
# Problems with Lithium-Metal Batteries

- 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



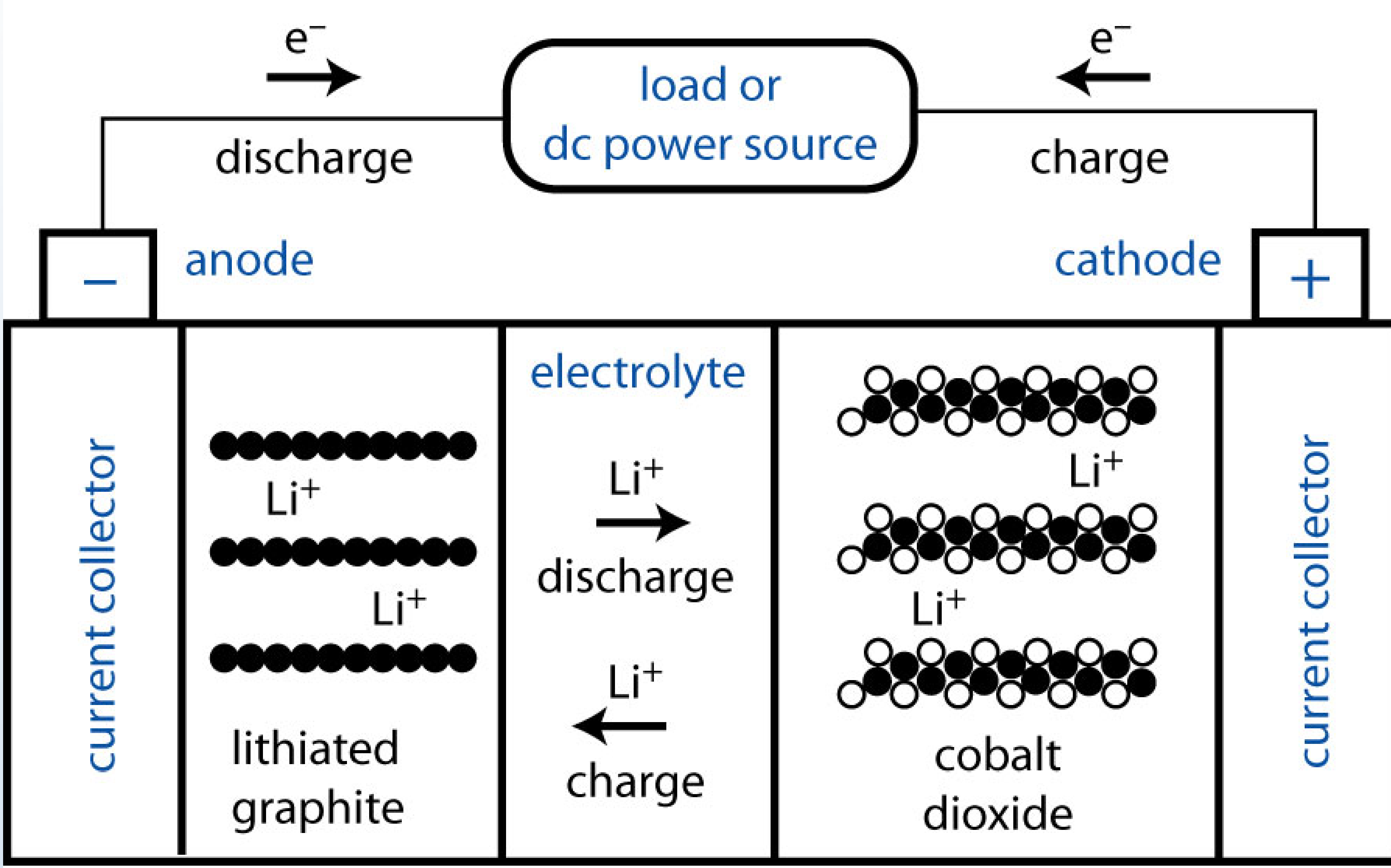

# Limitations of Lithium-Ion Batteries

- 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




$$Li_nC_6 \longrightarrow nLi^+ + 6C + ne^- \qquad CoO_2 + nLi^+ + ne^- \longrightarrow Li_nCoO_2$$

$$Li_nC_6 + CoO_2 \longrightarrow 6C + Li_nCoO_2$$

# 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.