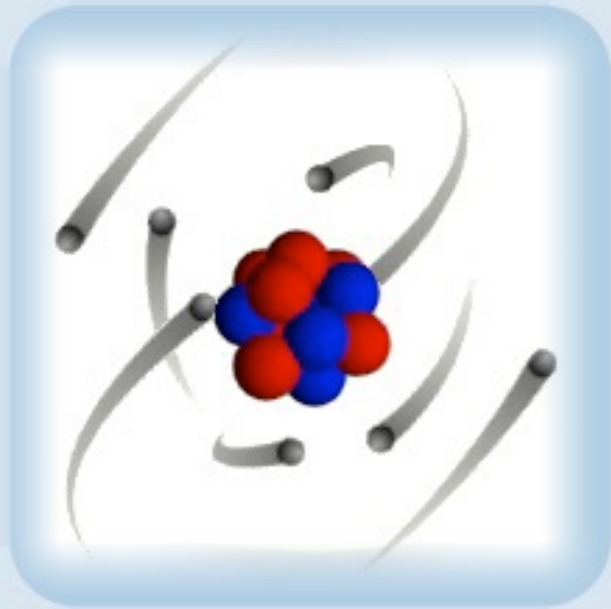


# Chapter 4.5: Electricity & Electrolysis

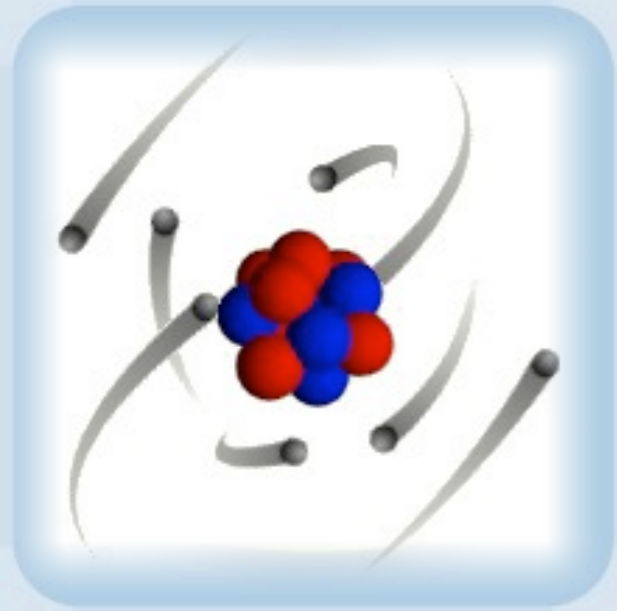


From electrical energy to chemical energy.

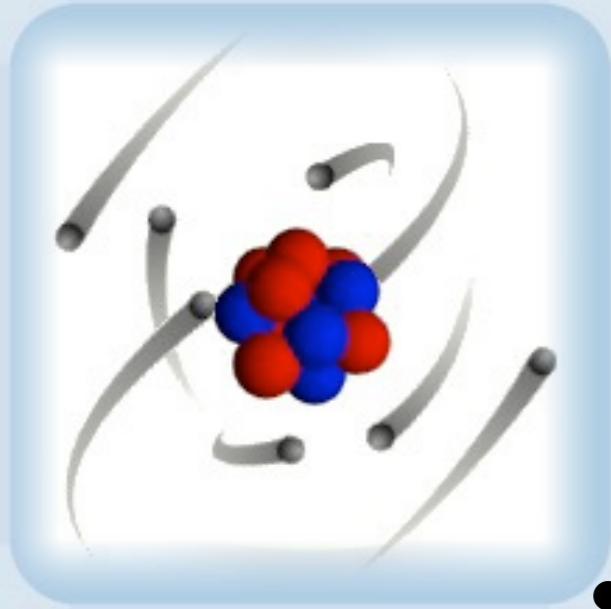


# Electrolysis

Electrolysis (*electro = electricity, lysis = separate*) is the passage of a direct electric current through an ionic compound that is either molten or dissolved in a solvent, resulting in chemical reactions at the electrodes and separation of an ionic compound.

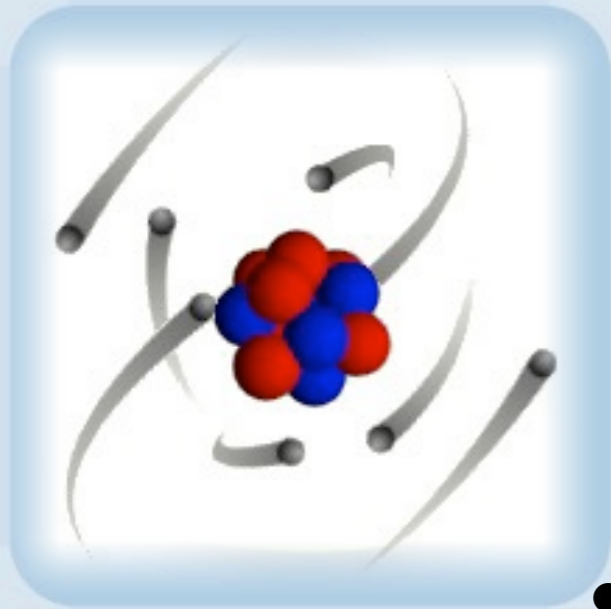


# Electricity



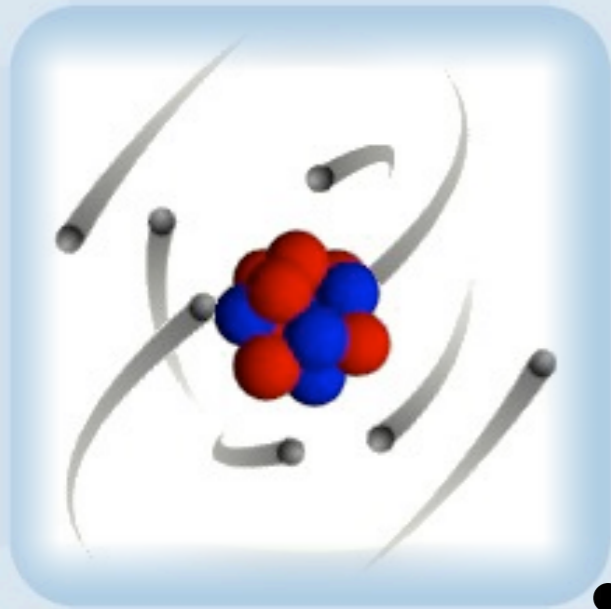
# Electricity

- Electricity is a form of energy produced by a flow of electrons through a conductor.



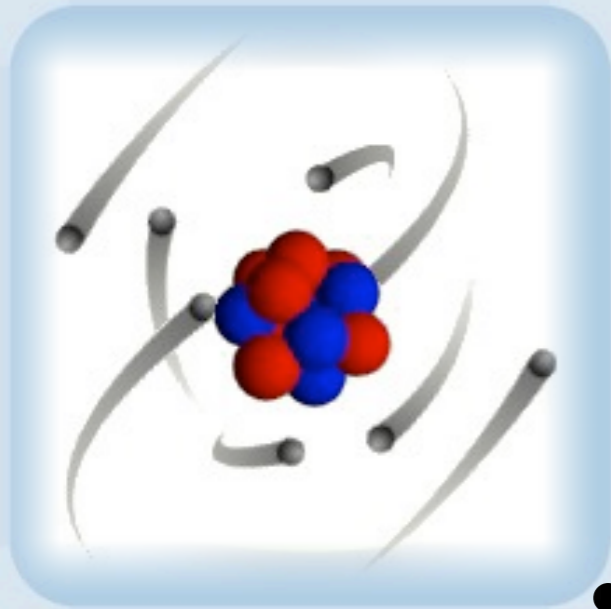
# Electricity

- Electricity is a form of energy produced by a flow of electrons through a conductor.
- A conductor is any substance that allows electrons to flow through it.



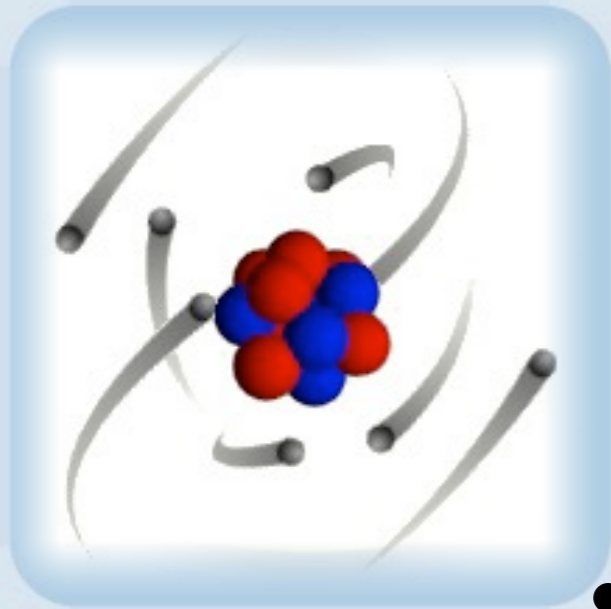
# Electricity

- Electricity is a form of energy produced by a flow of electrons through a conductor.
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- *Conductors* are:
  - a. all metals
  - b. molten (melted) ionic compounds
  - c. electrolytes (ionic solutions)
  - d. graphite (carbon)



# Electricity

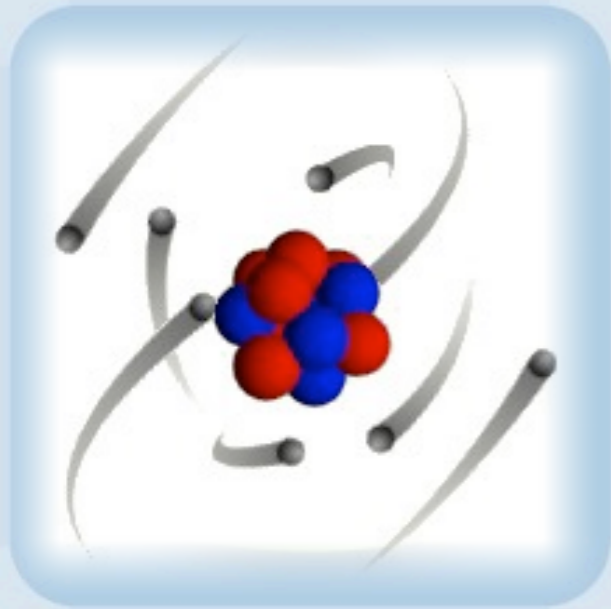
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  - b. molten (melted) ionic compounds
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- Insulators (*Nonconductors*) are:
  - a. nonmetals (except graphite)



# Electricity

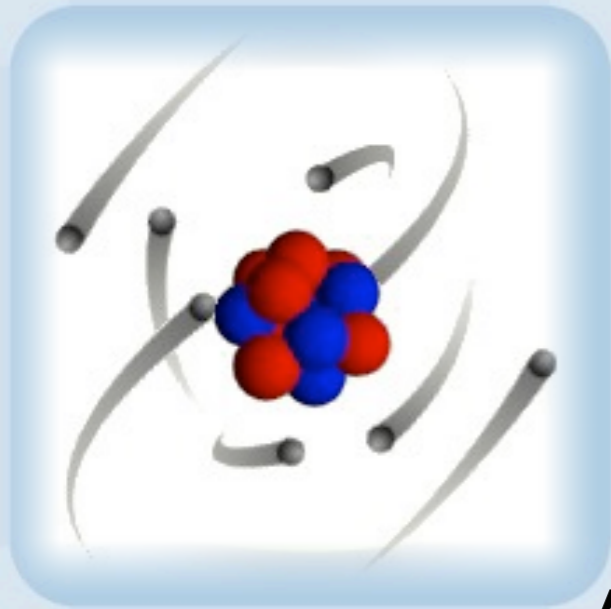
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- A conductor is any substance that allows electrons to flow through it.
- *Conductors* are:
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  - b. molten (melted) ionic compounds
  - c. electrolytes (ionic solutions)
  - d. graphite (carbon)
- *Insulators (Nonconductors)* are:
  - a. nonmetals (except graphite)
  - b. covalent compounds
  - c. solid ionic compounds





# Batteries

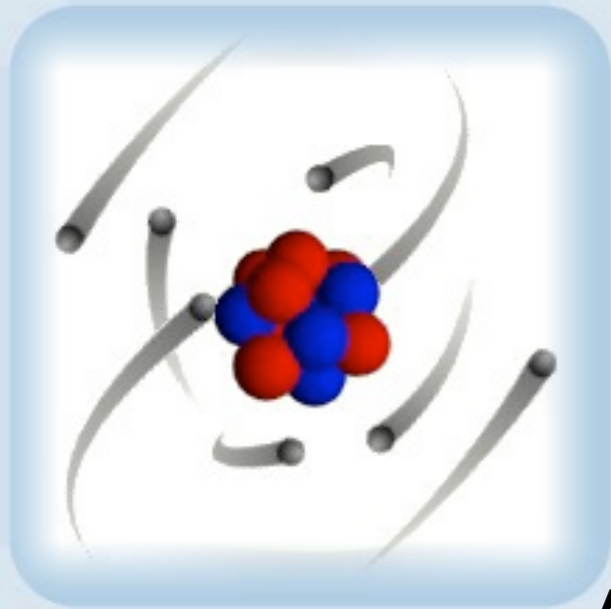




# Batteries



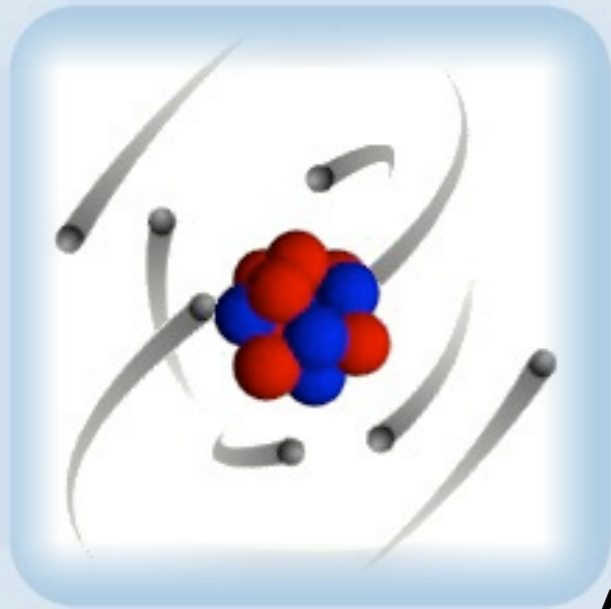
- A battery is an “electron pump” that produces electrical energy (electrons) through a redox reaction.



# Batteries



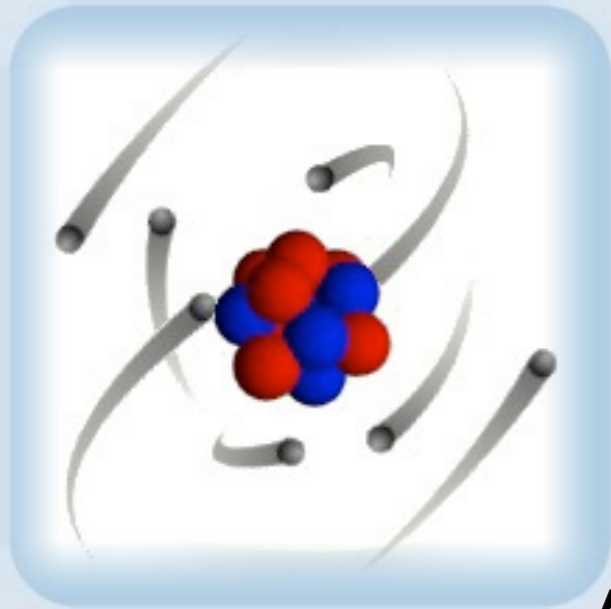
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- In a dry cell battery zinc is oxidized to produce electrons. Manganese ions are reduced when they accept the electrons.



# Batteries



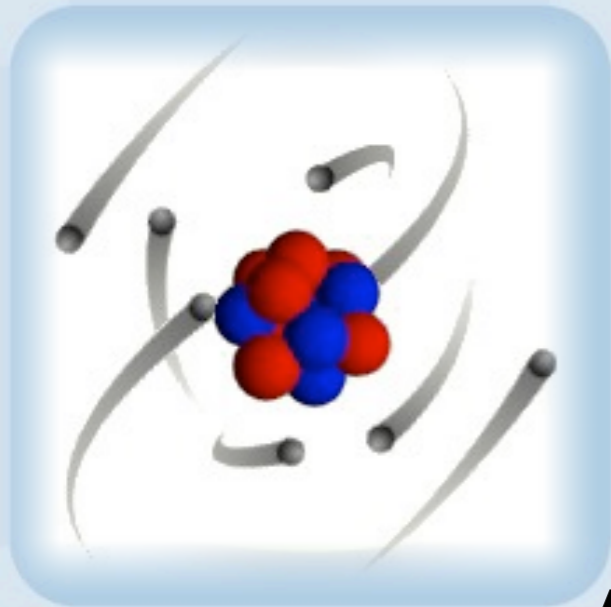
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- The electrons produced by zinc have to travel through a circuit to get to the manganese ions.



# Batteries



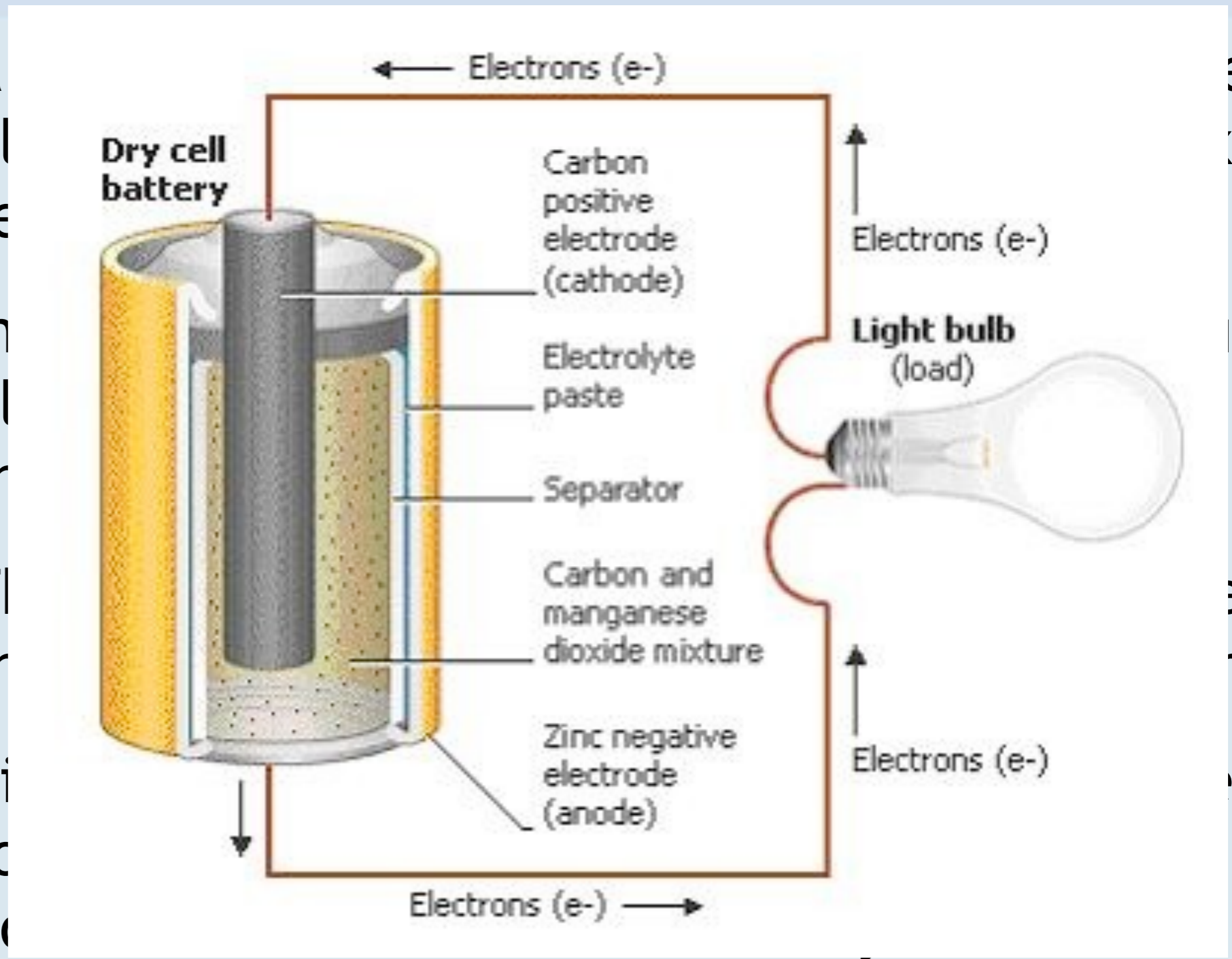
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- In a dry cell battery zinc is oxidized to produce electrons. Manganese ions are reduced when they accept the electrons.
- The electrons produced by zinc have to travel through a circuit to get to the manganese ions.
- Zinc is the negative electrode and a graphite rod leading to the manganese ions is the positive electrode of the battery.



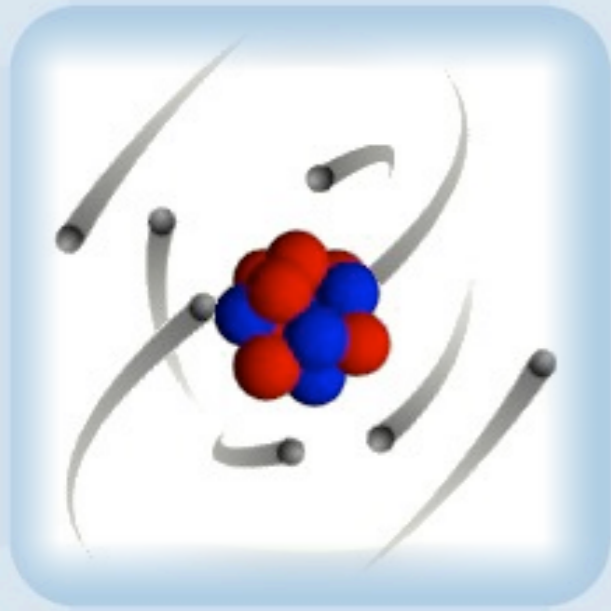
# Batteries



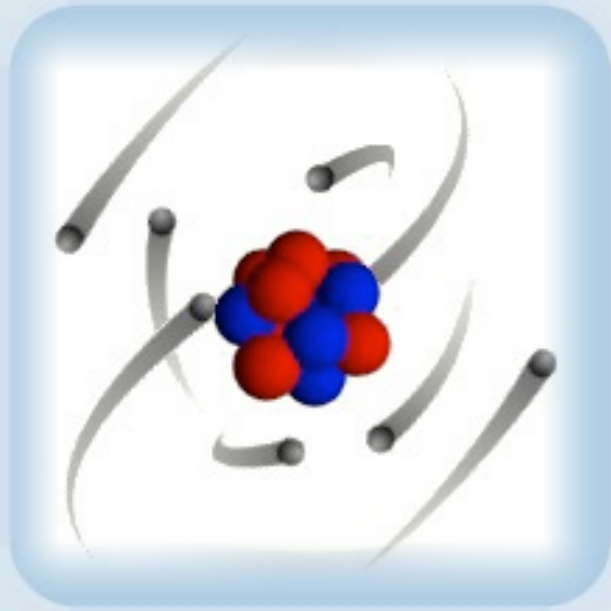
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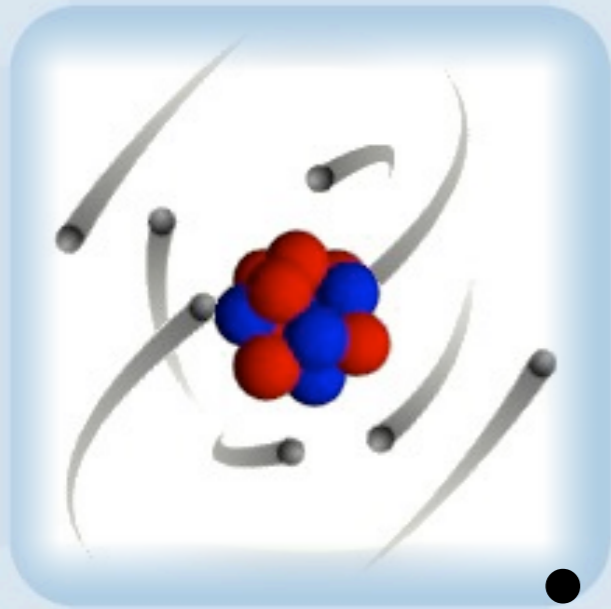


# Electricity: DC and AC



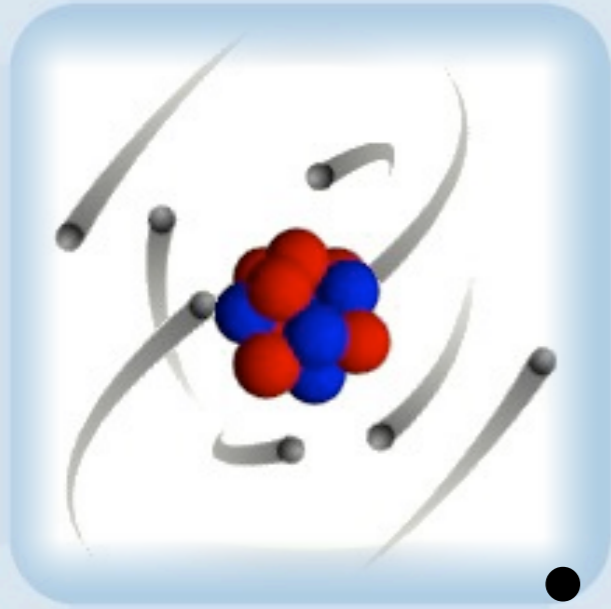
# Electricity: DC and AC





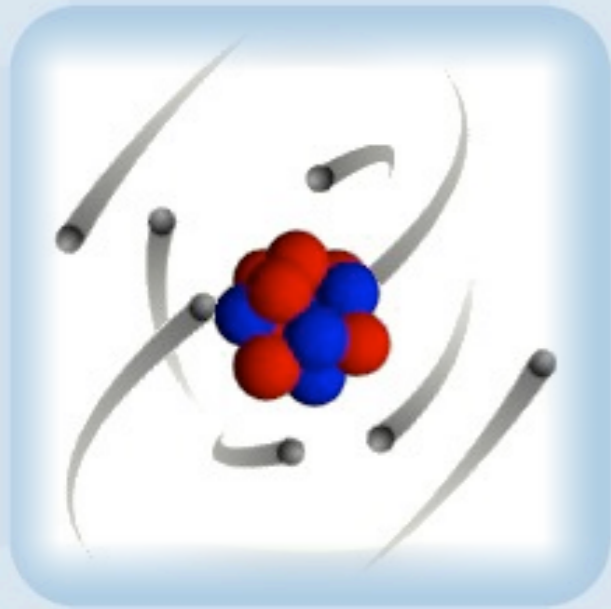
# Electricity: DC and AC

- Batteries produce a *direct current* (DC). The electrons flow from the substance being oxidized (- electrode) to the substance being reduced (+ electrode).

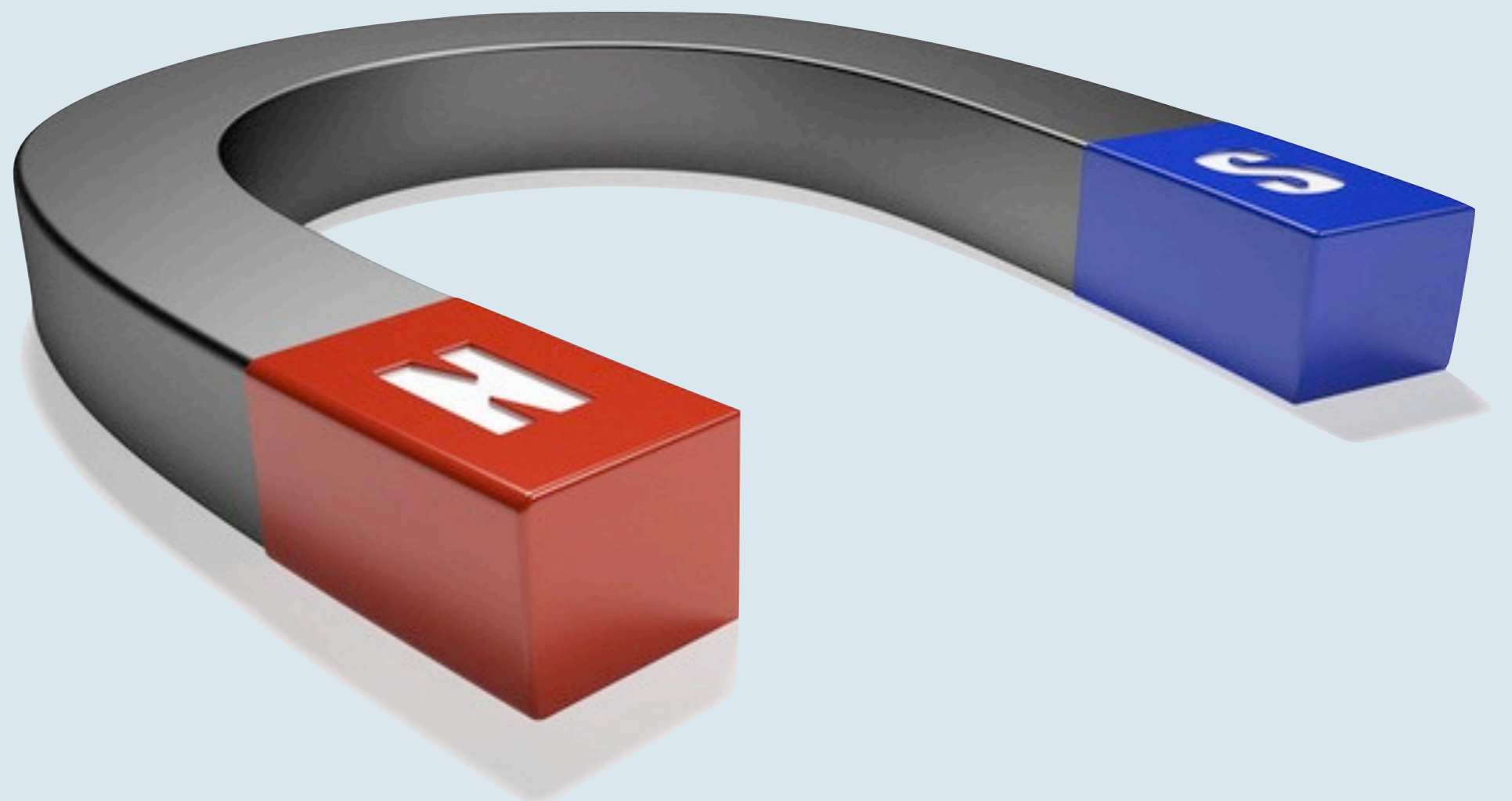


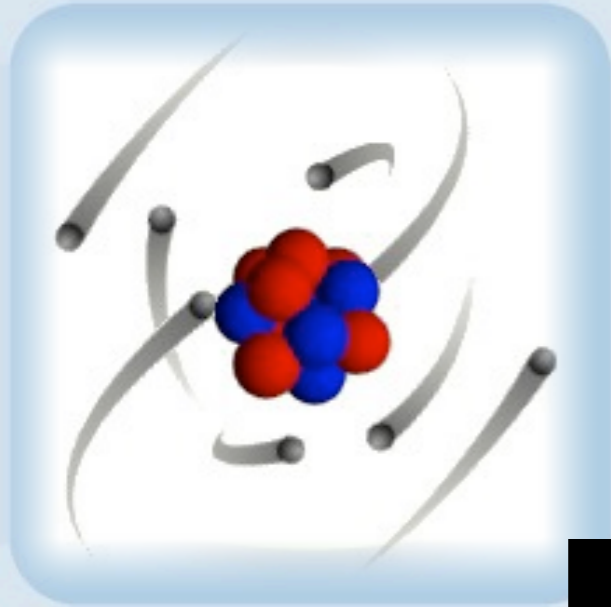
# Electricity: DC and AC

- Batteries produce a *direct current* (DC). The electrons flow from the substance being oxidized (- electrode) to the substance being reduced (+ electrode).
- An electrical generator produce an *alternating current* (AC) in which electrons alternate (move back and forth).  
When you plug an electrical device in at home you are using an AC current in which the electrons alternate 60 times per second.

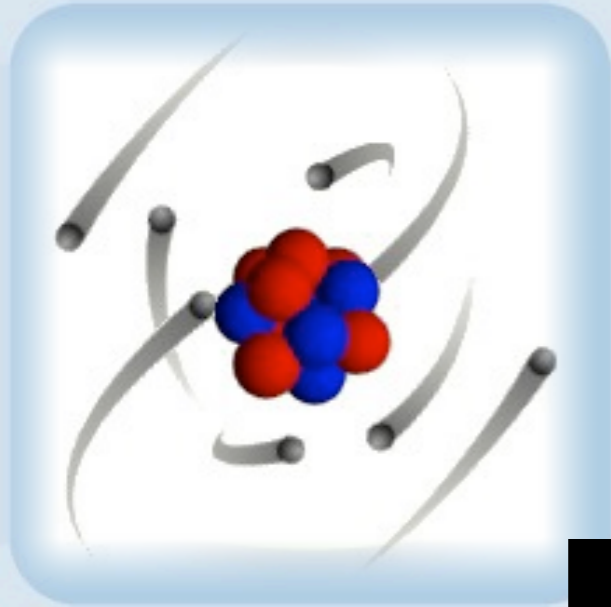


# Magnetic Fields

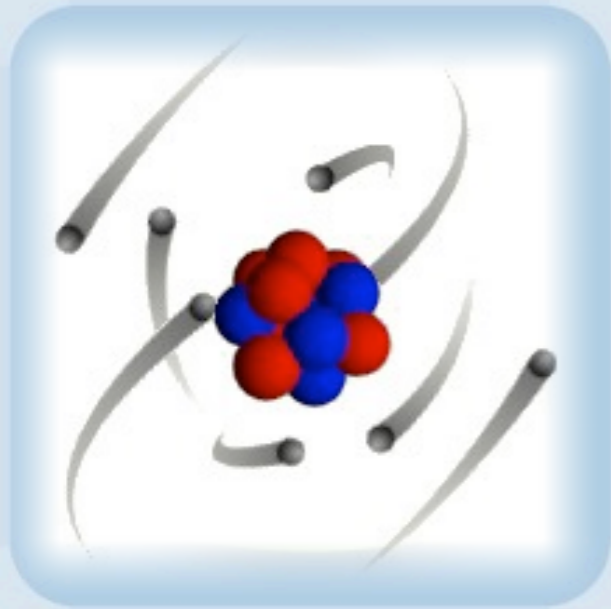




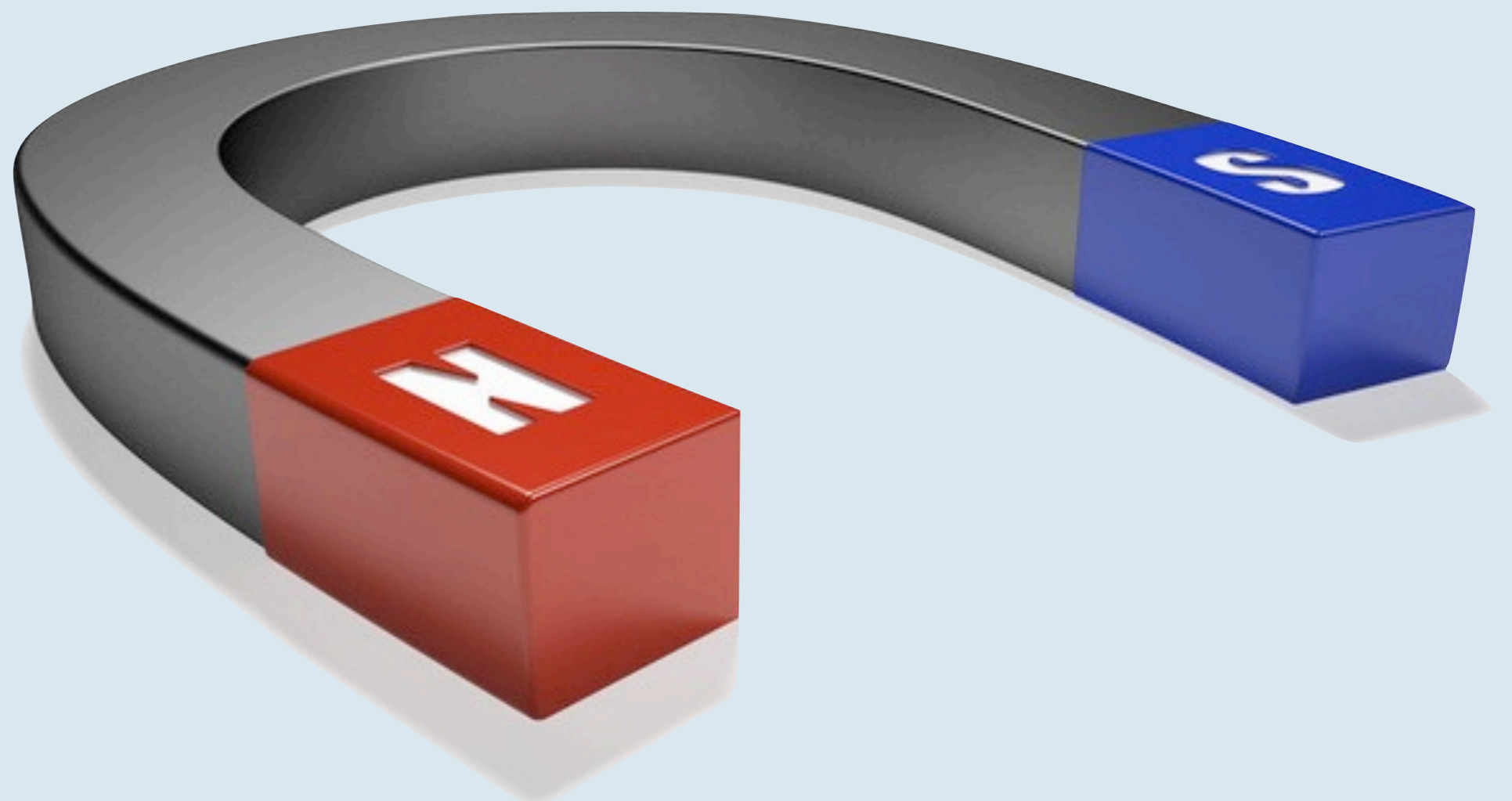
# Magnetic Fields



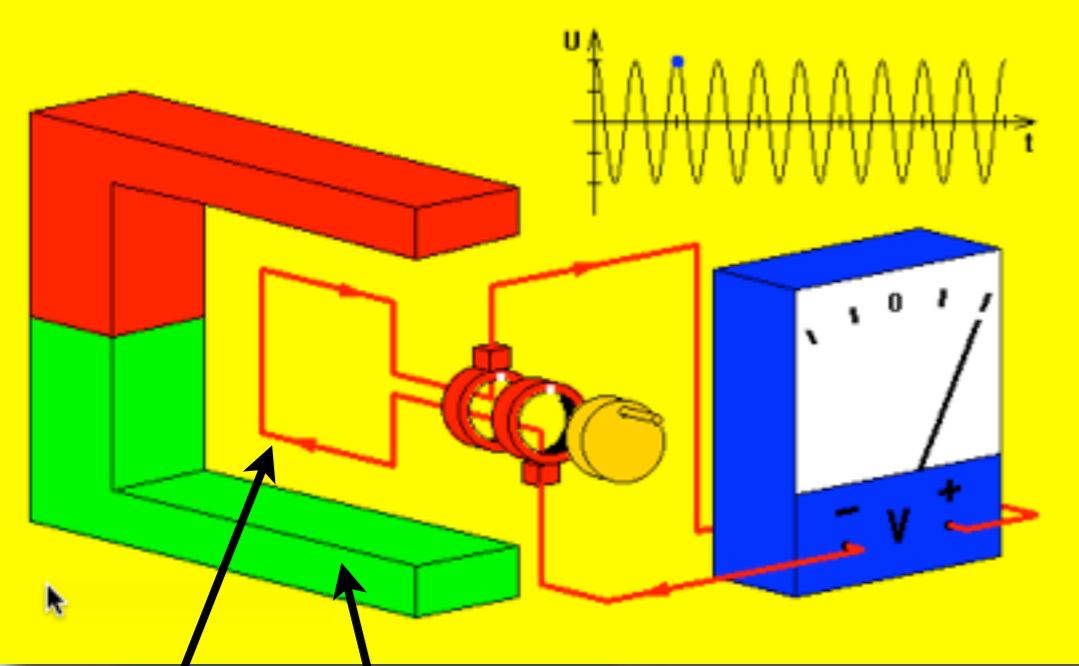
# Magnetic Fields



# Magnetic Fields



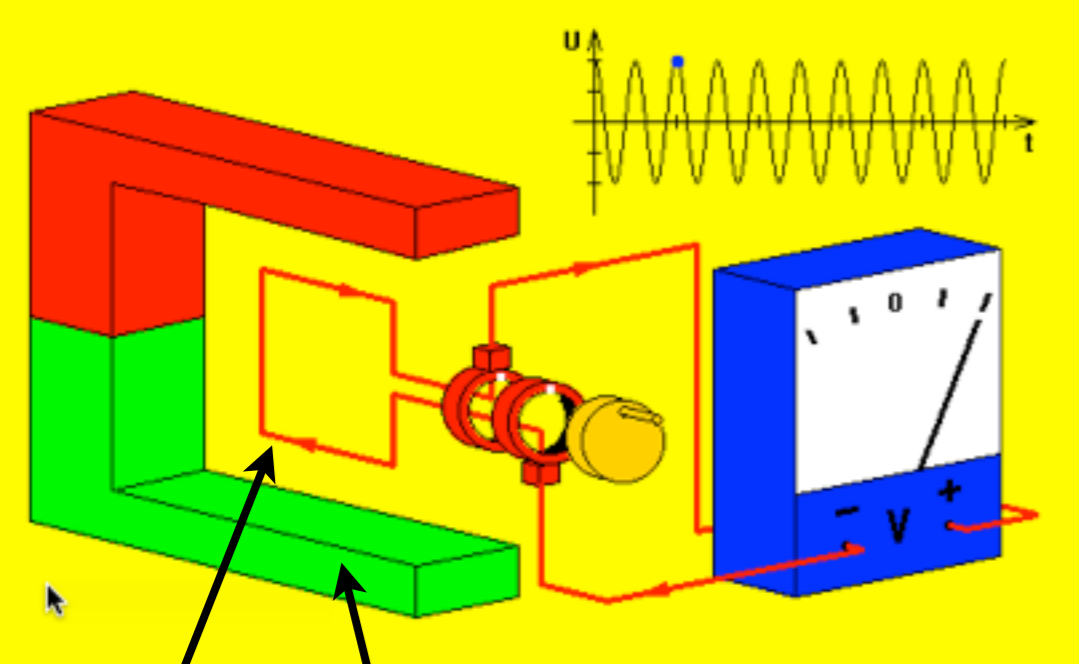
# Electrical Generator



copper coil

magnet

# Electrical Generator

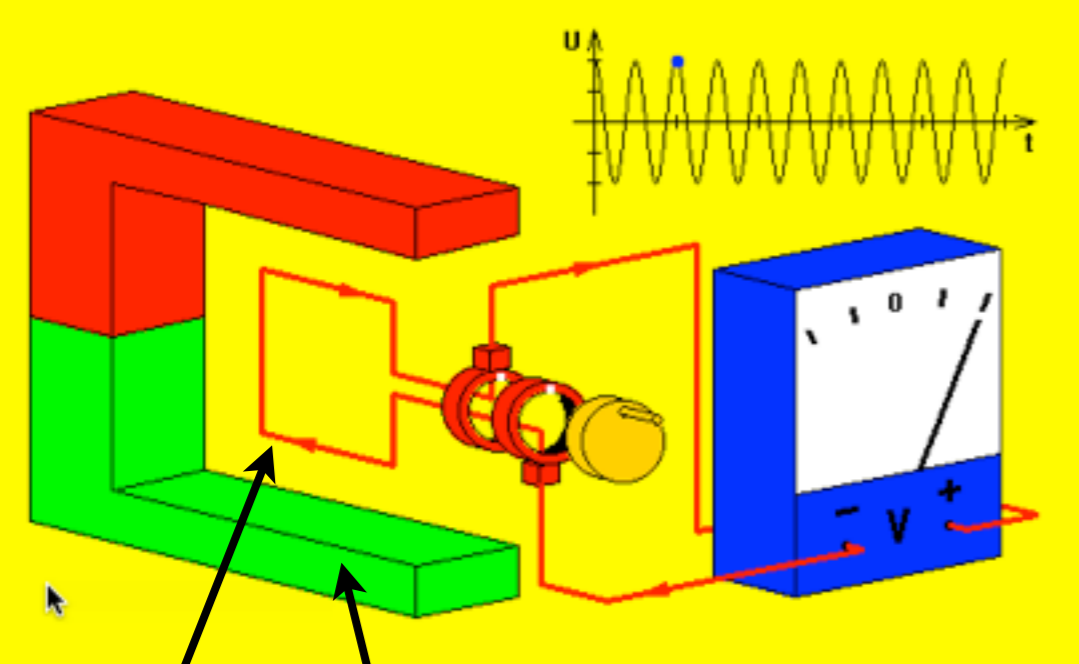


copper coil      magnet

- A copper wire has metallic bonding in which free electrons surround copper ions. These electrons are free to move from ion to ion.

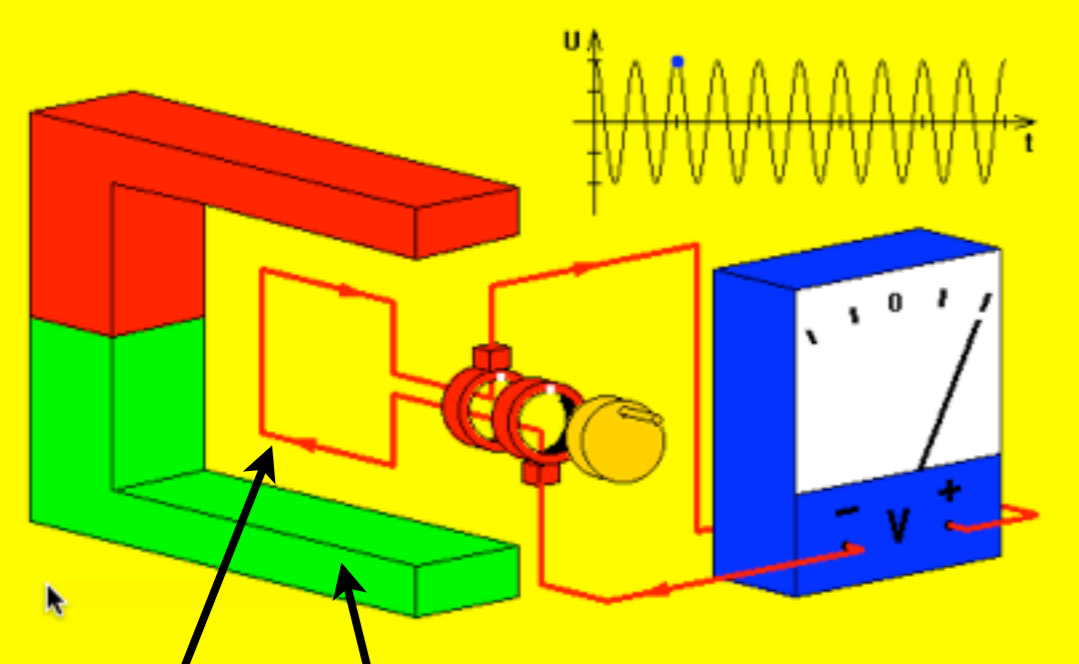


# Electrical Generator



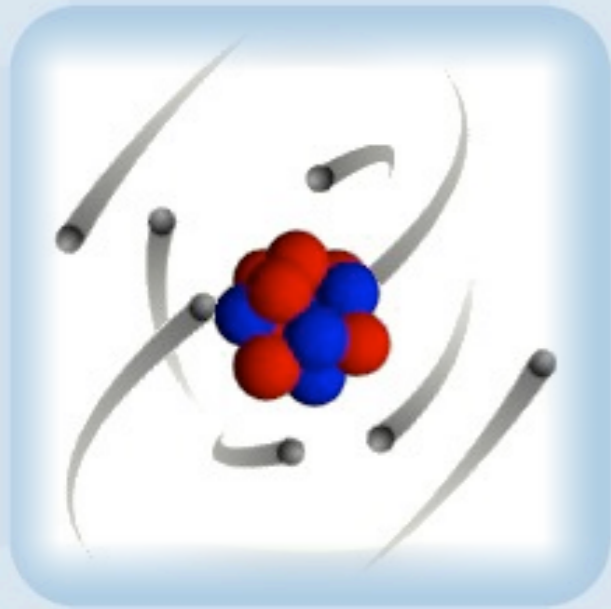
copper coil magnet

- A copper wire has metallic bonding in which free electrons surround copper ions. These electrons are free to move from ion to ion.
- Electrons are influenced by a moving magnetic field. They move in one direction when the north pole of a magnet passes by and in the opposite direction when a south pole passes by.



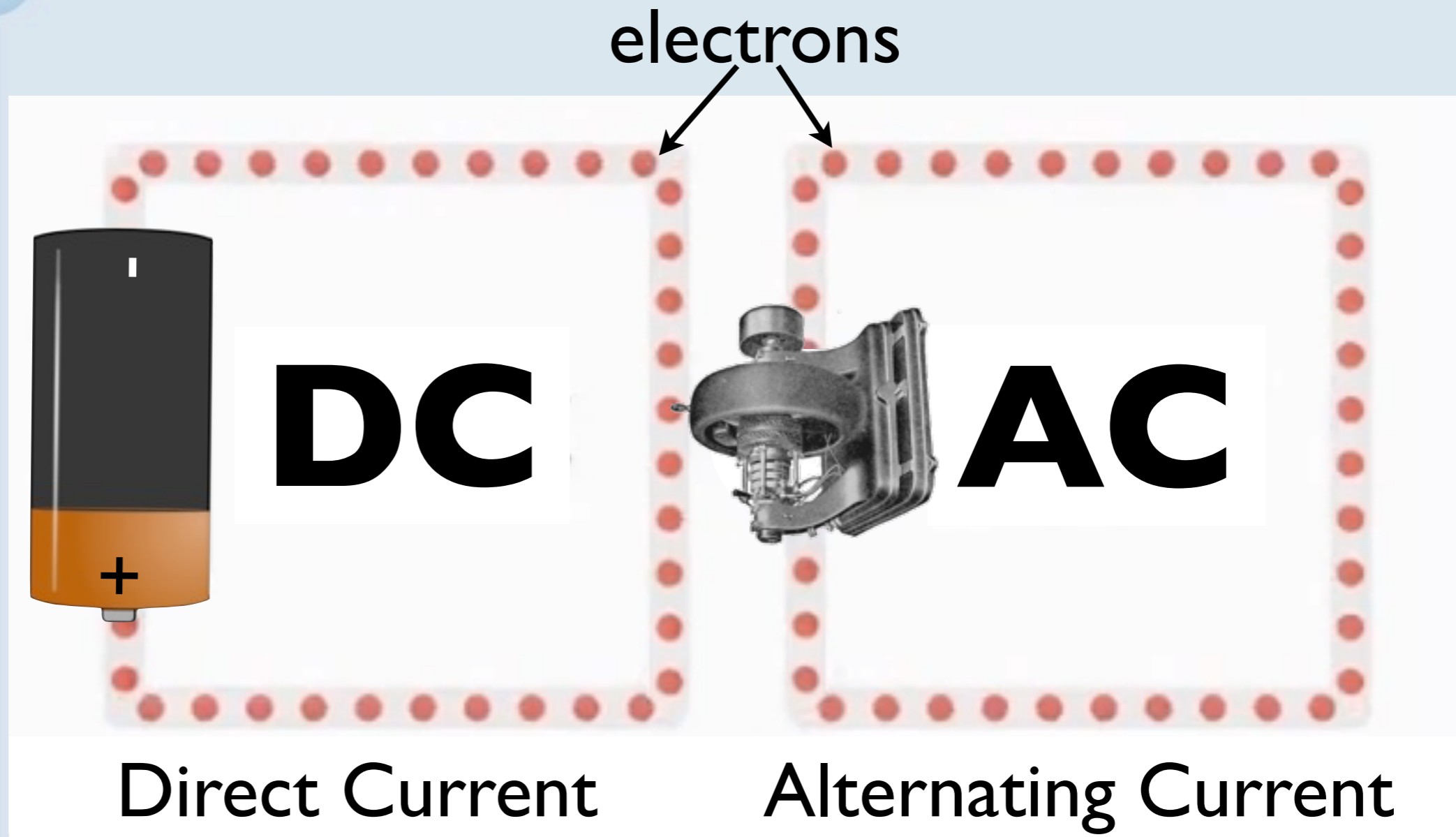
# Electrical Generator

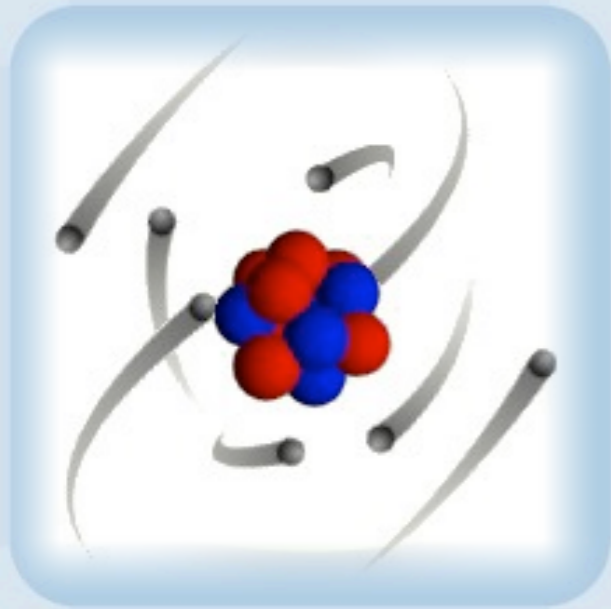
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- Electrons are influenced by a moving magnetic field. They move in one direction when the north pole of a magnet passes by and in the opposite direction when a south pole passes by.
- An alternating current is produced by rotating a coil of wire through a magnetic field causing electrons to move back and forth.



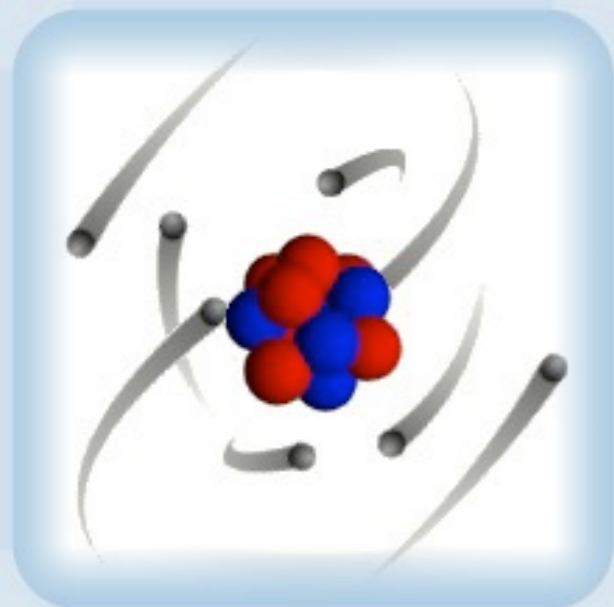
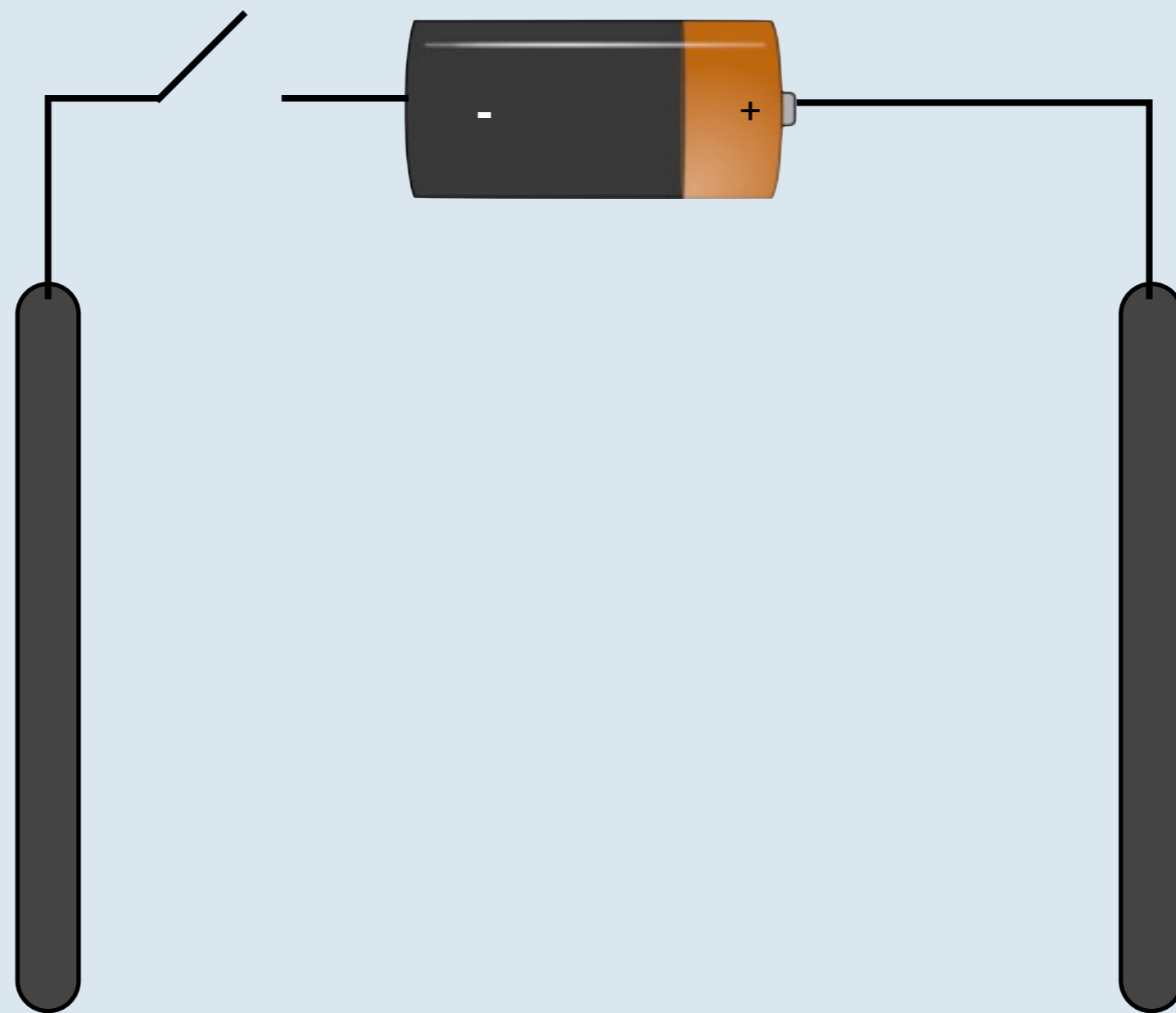
# AC vs. DC

## Motion of electrons

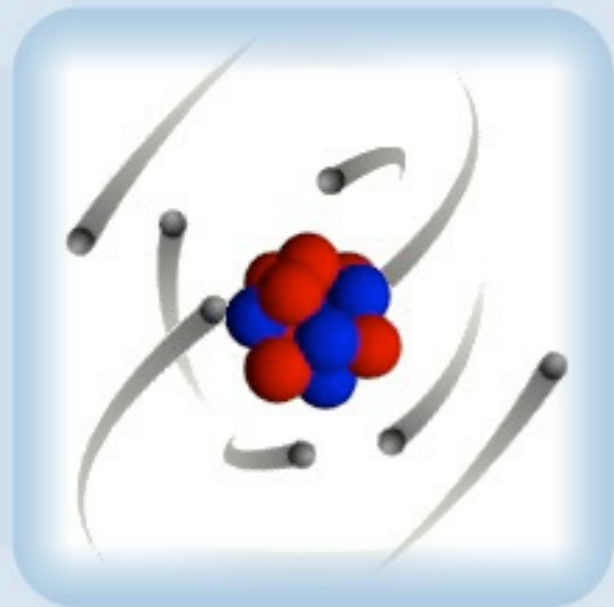
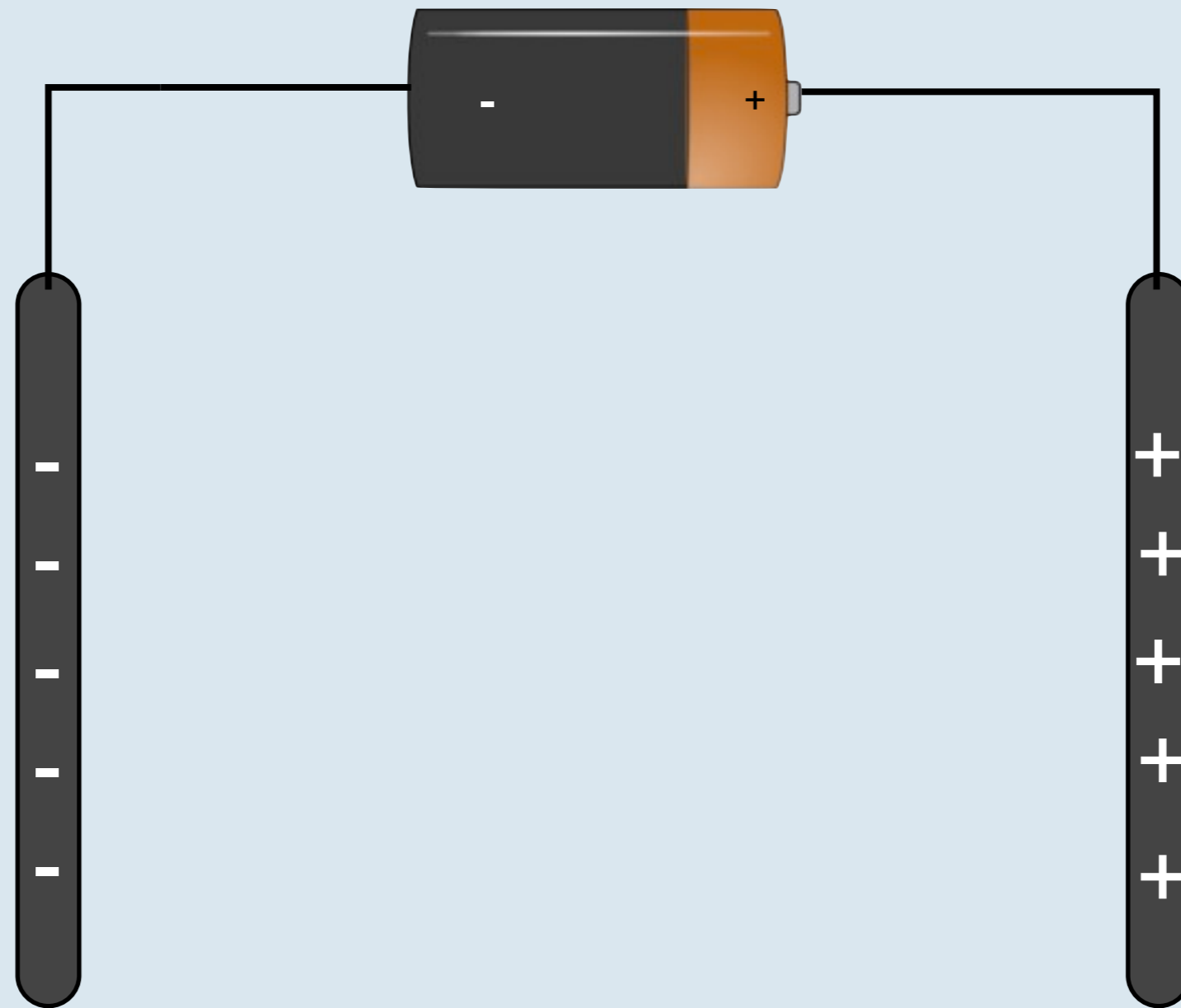




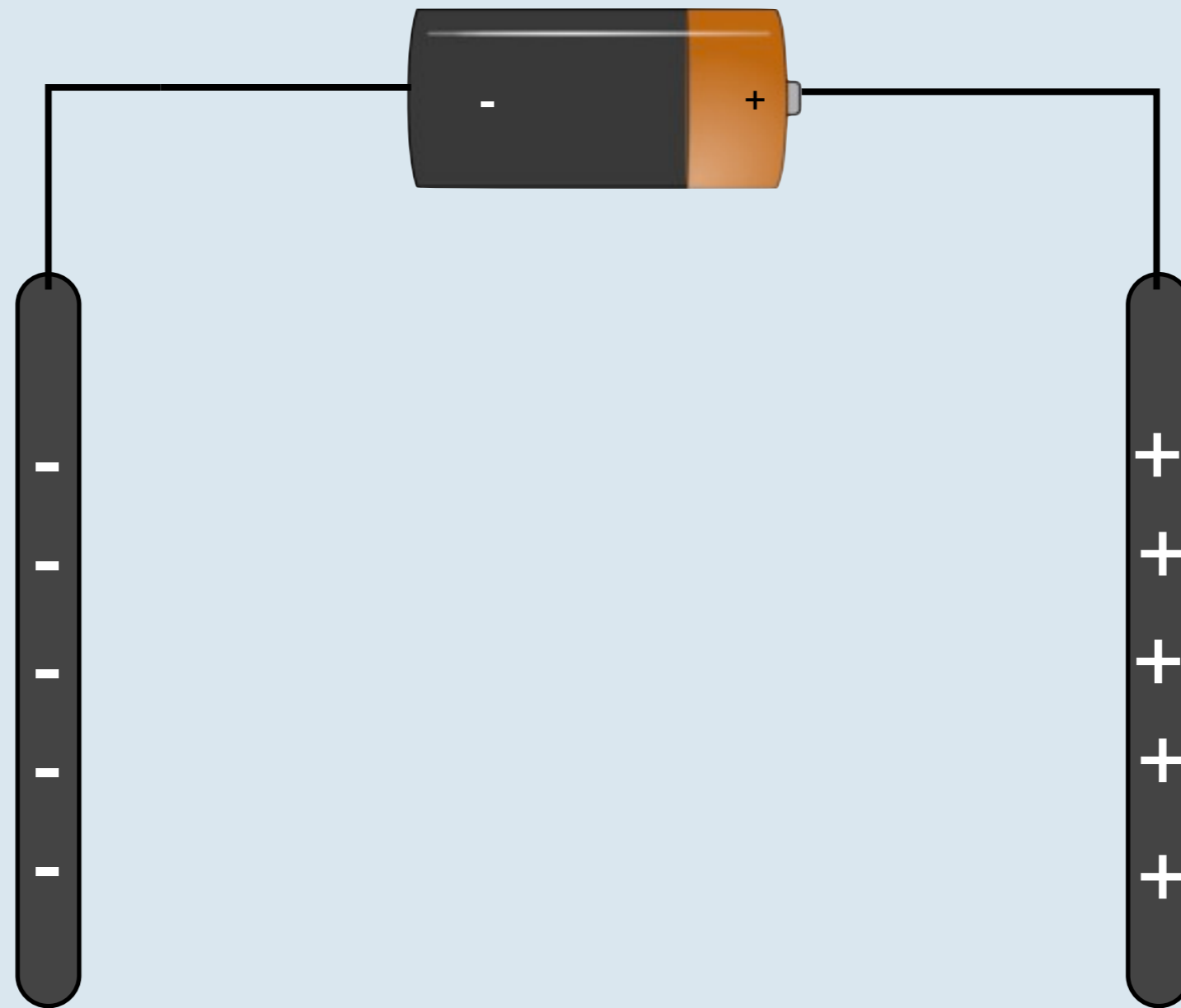
# Electrolysis of Molten Ionic Compounds



When you connect a battery to two graphite electrodes and turn it on, one electrode becomes a cathode (-) while the other becomes an anode (+).

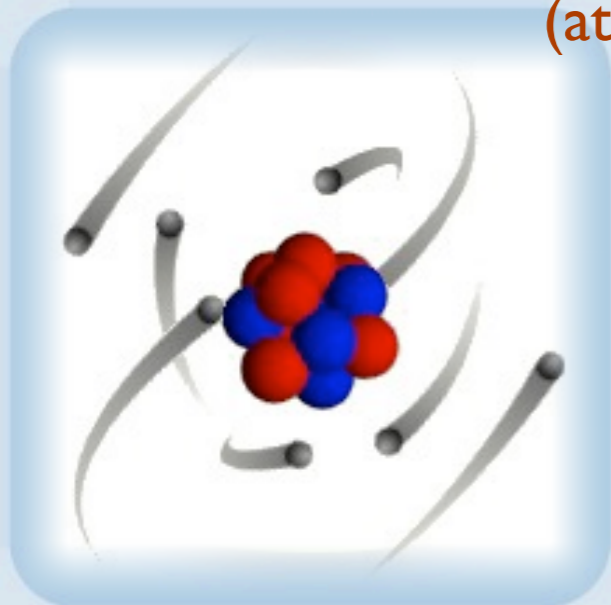


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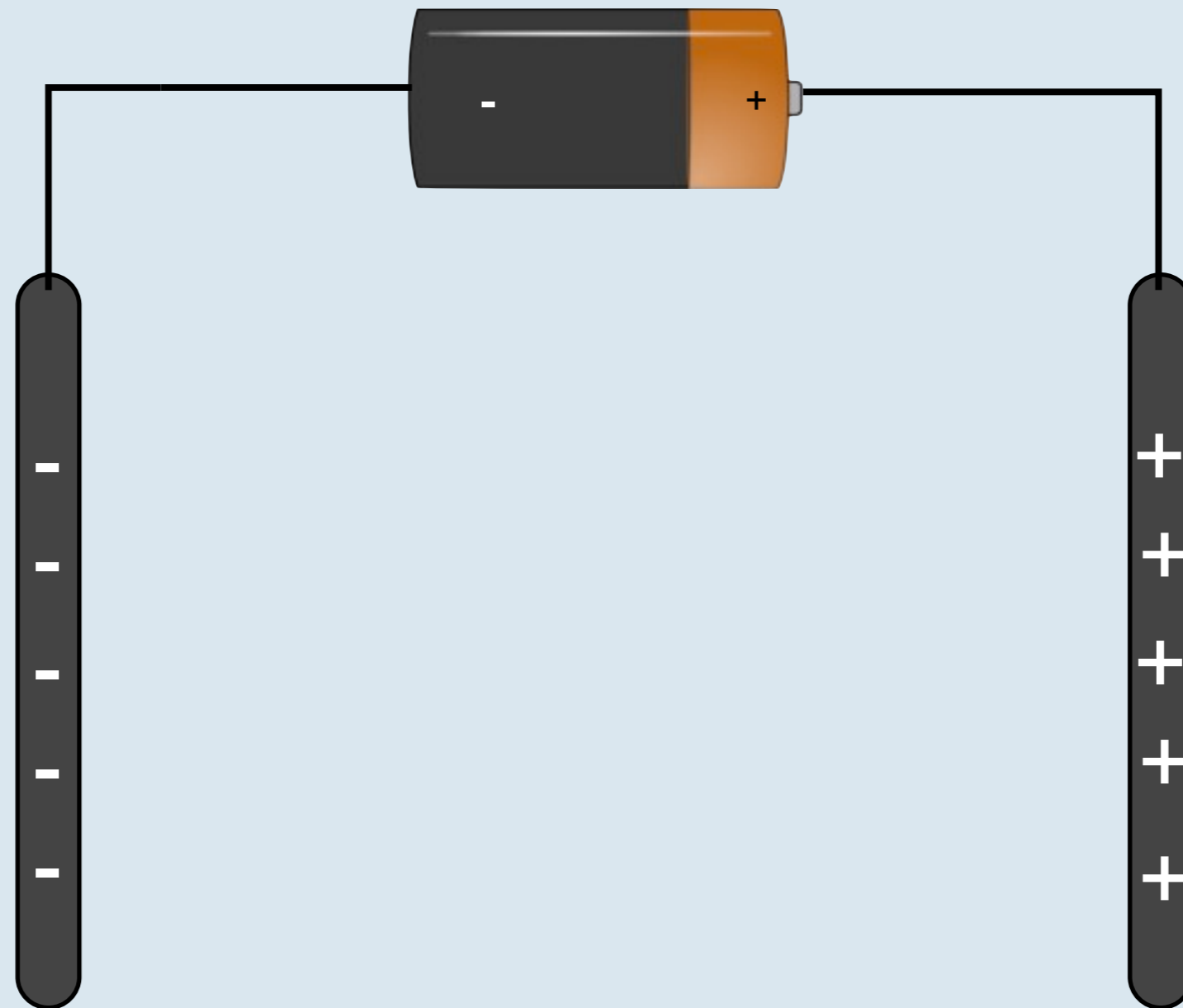


**cathode**

(attracts cations)



When you connect a battery to two graphite electrodes and turn it on, one electrode becomes a cathode (-) while the other becomes an anode (+).

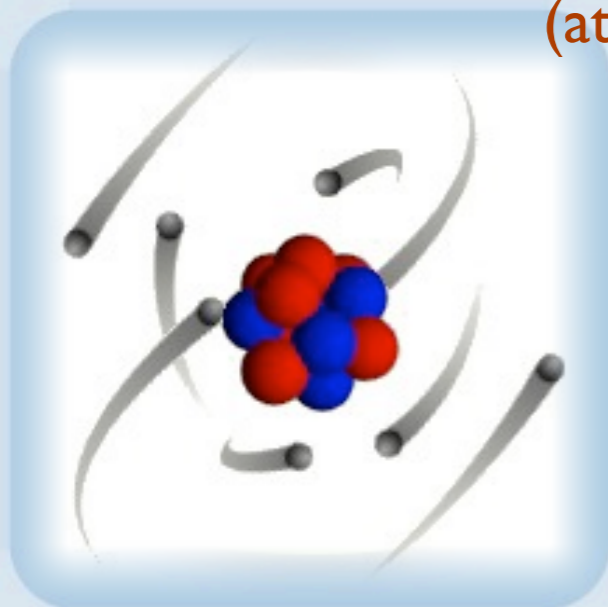


**cathode**

(attracts cations)

**anode**

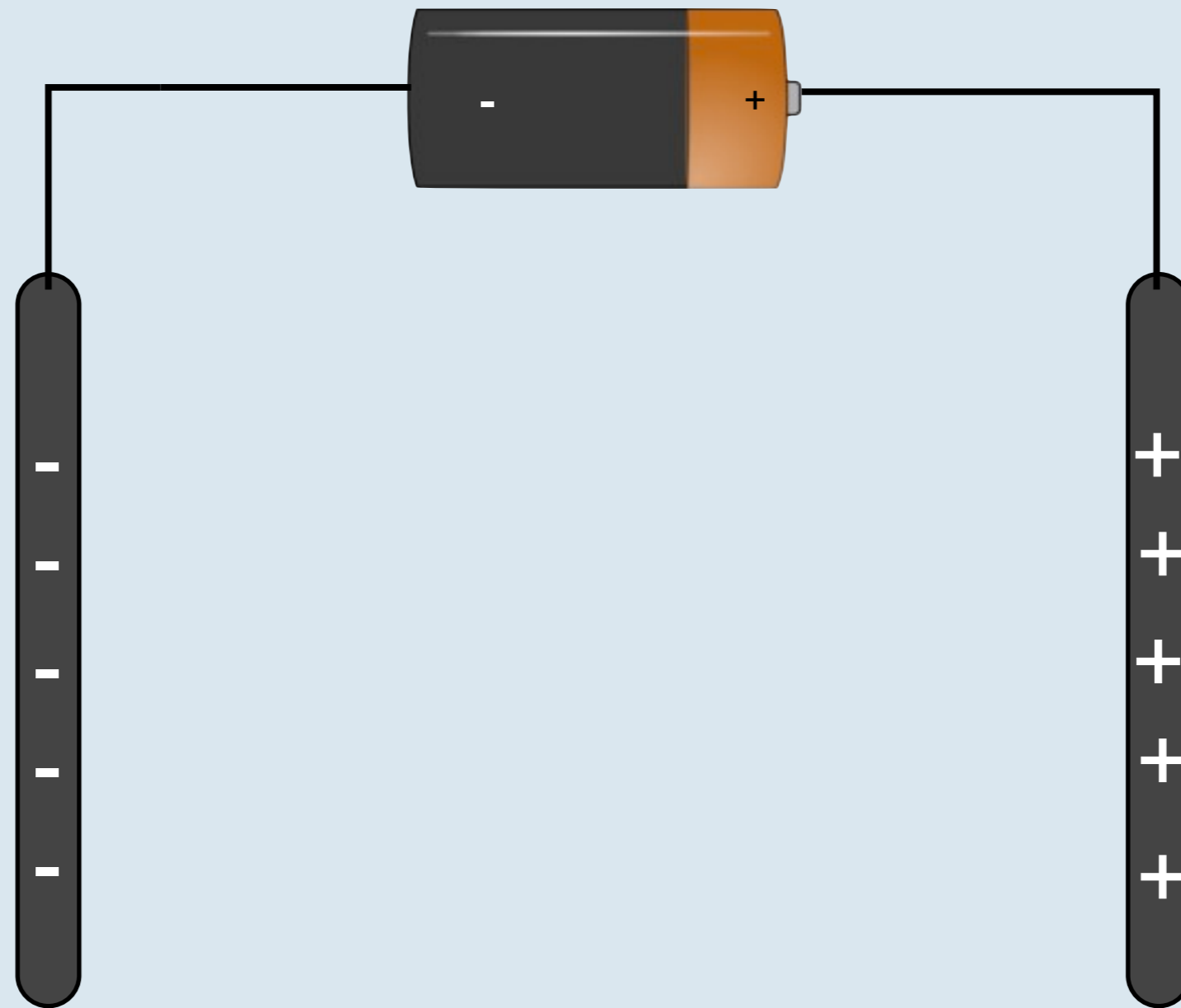
(attracts anions)



When you connect a battery to two graphite electrodes and turn it on, one electrode becomes a cathode (-) while the other becomes an anode (+).

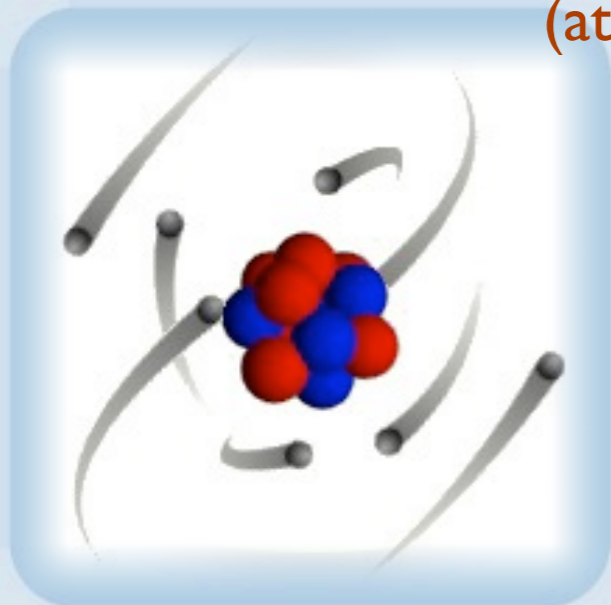


Graphite or platinum are used for electrodes because they are good conductors of electricity and inert.

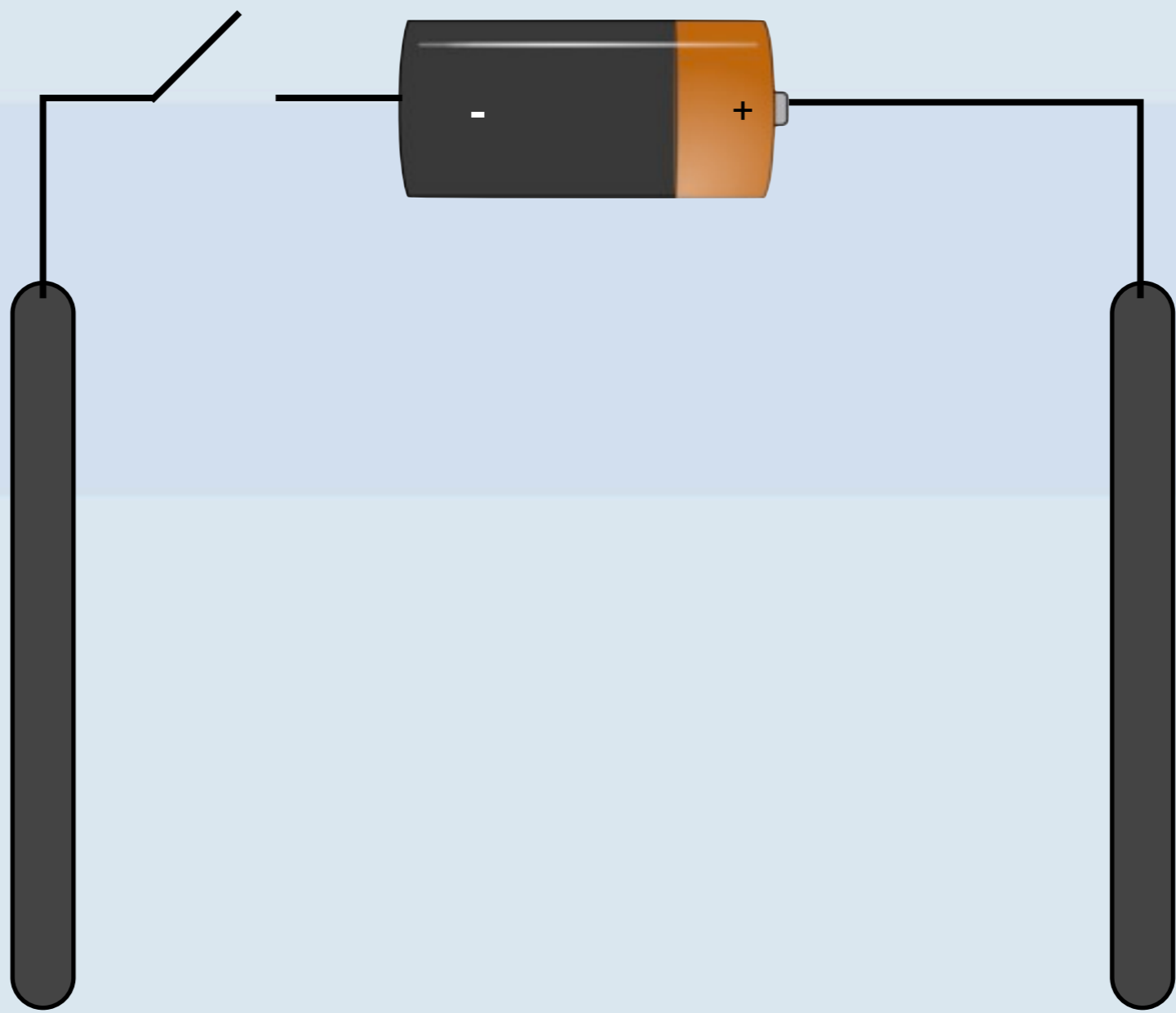
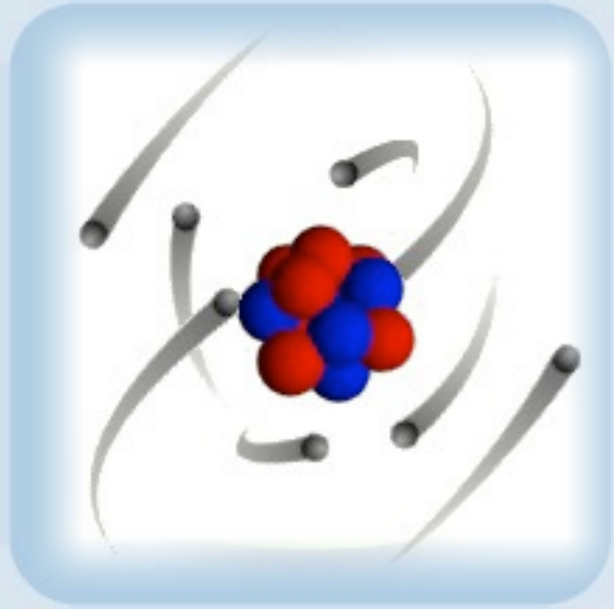


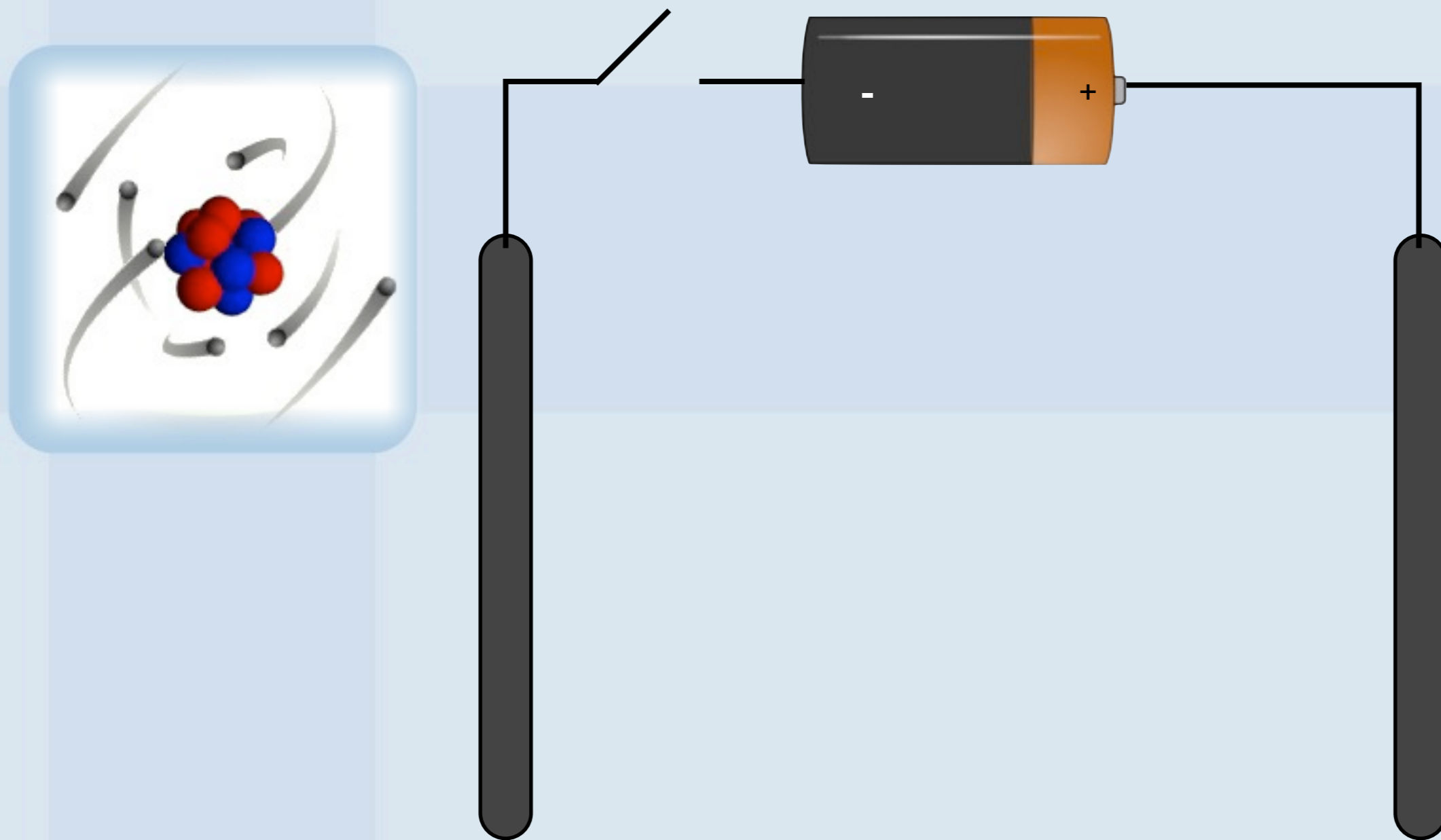
**cathode**  
(attracts cations)

**anode**  
(attracts anions)

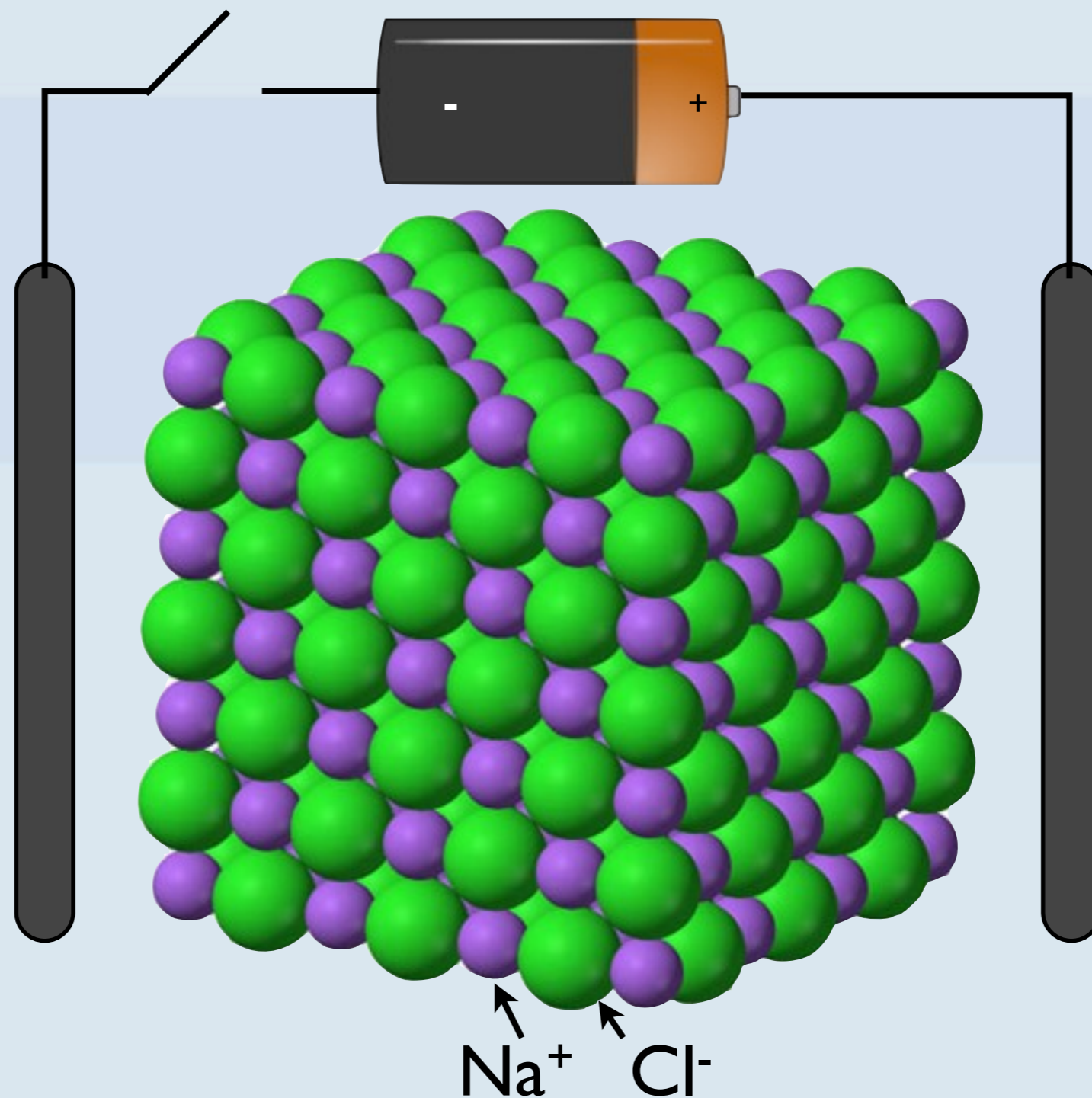
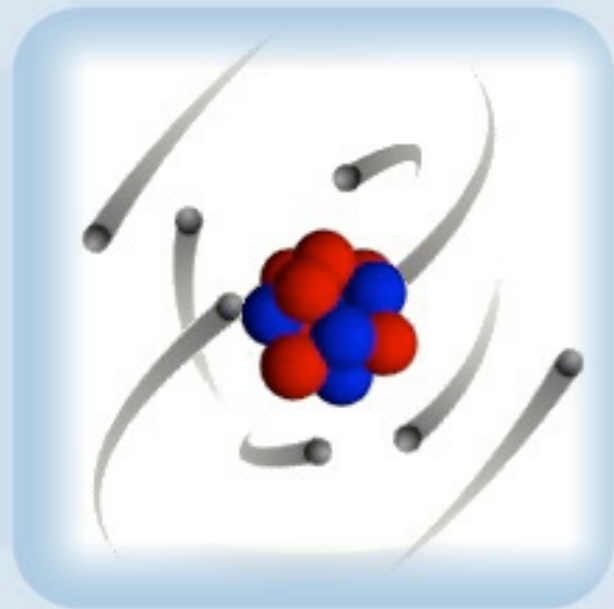


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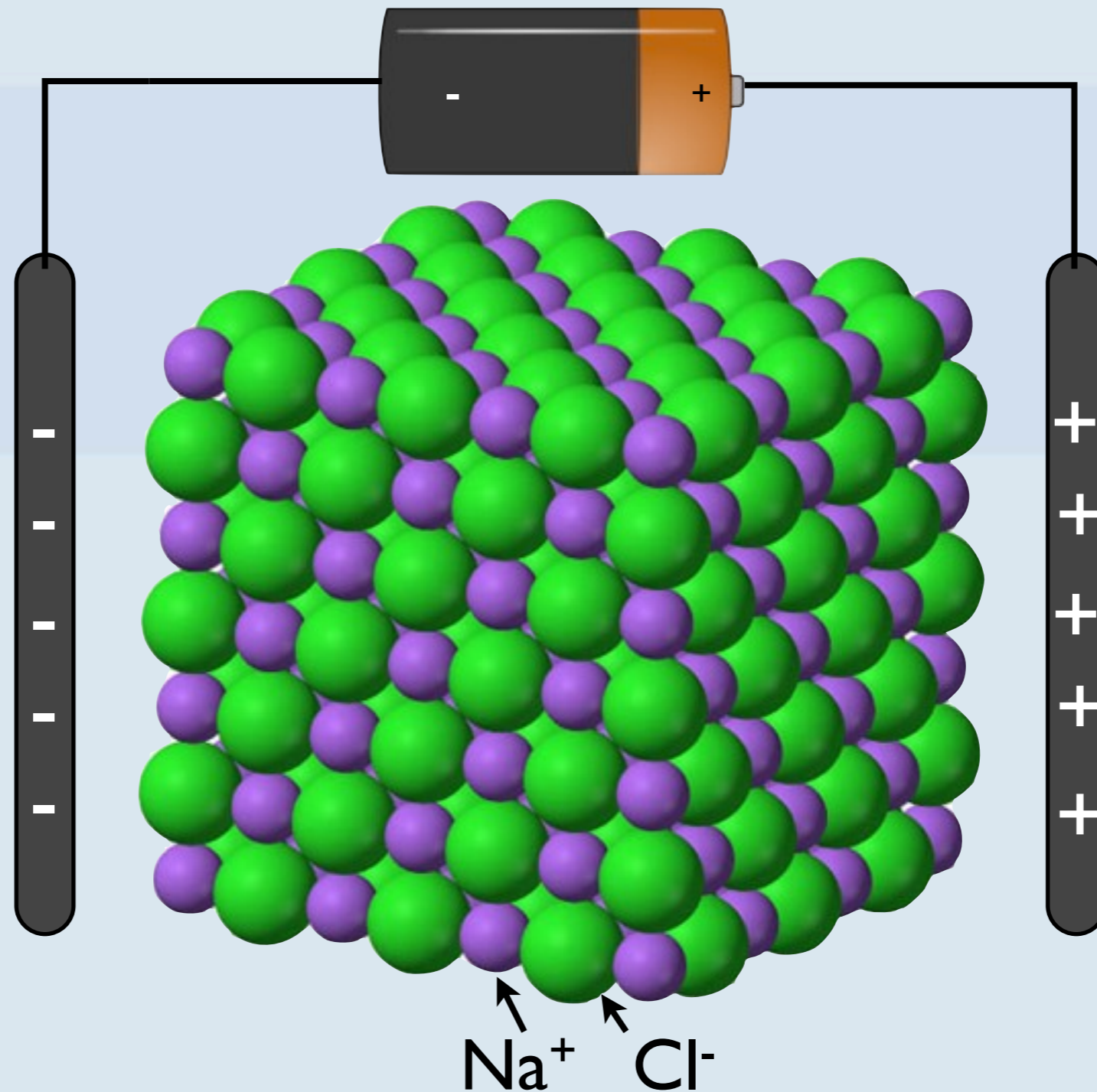
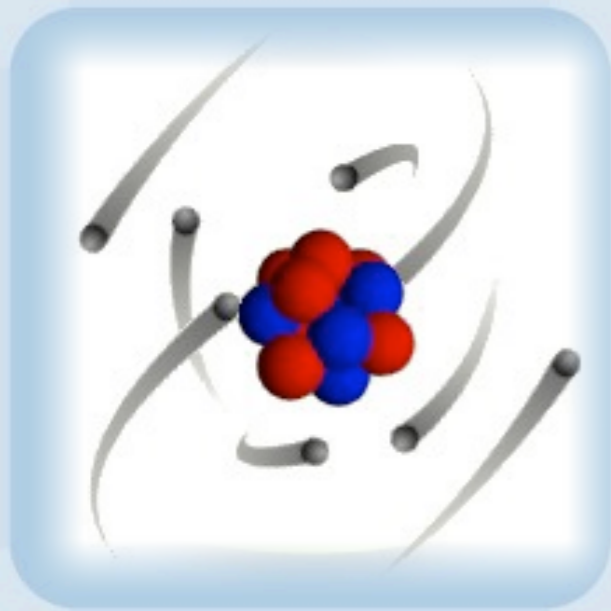




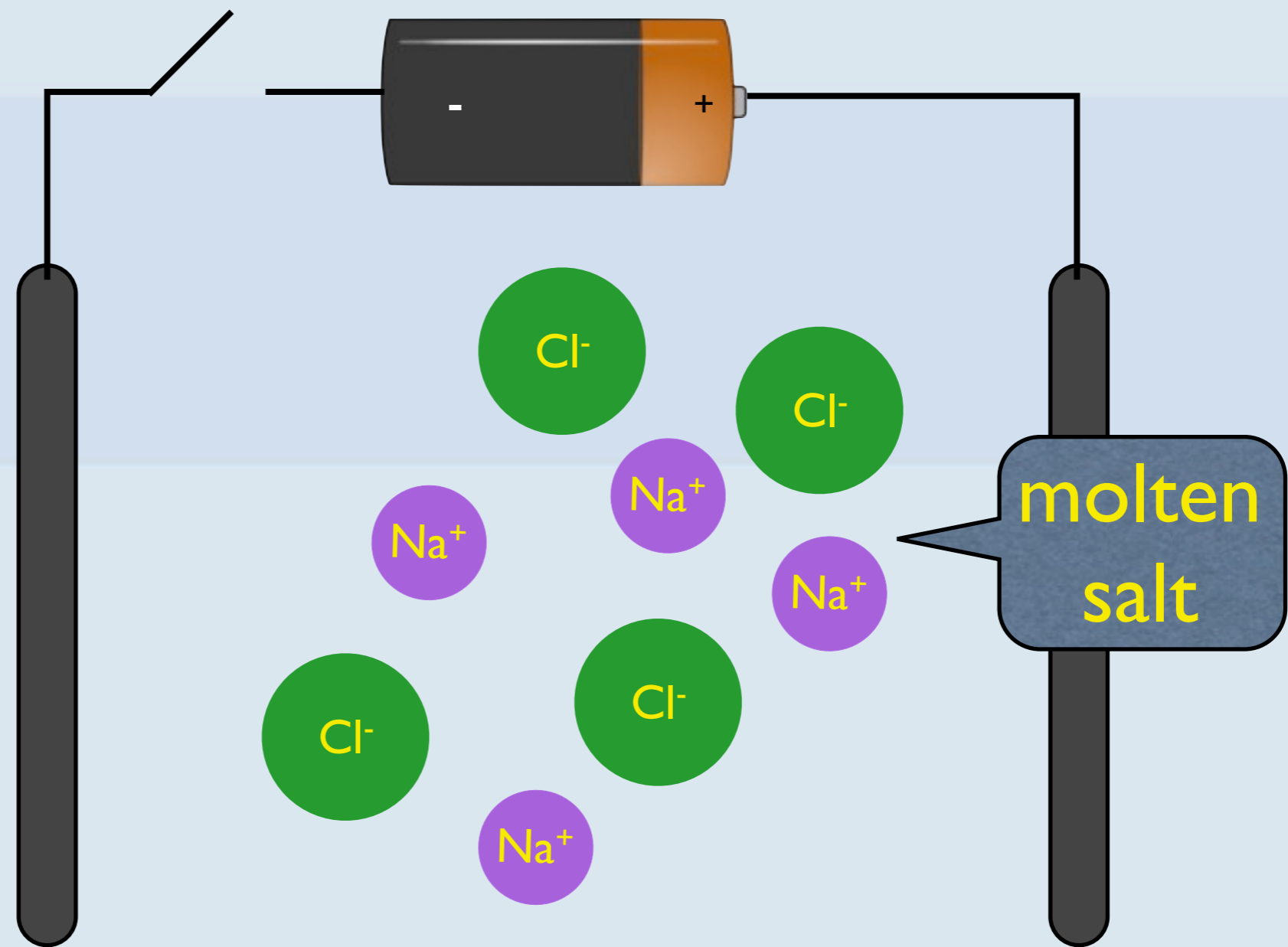
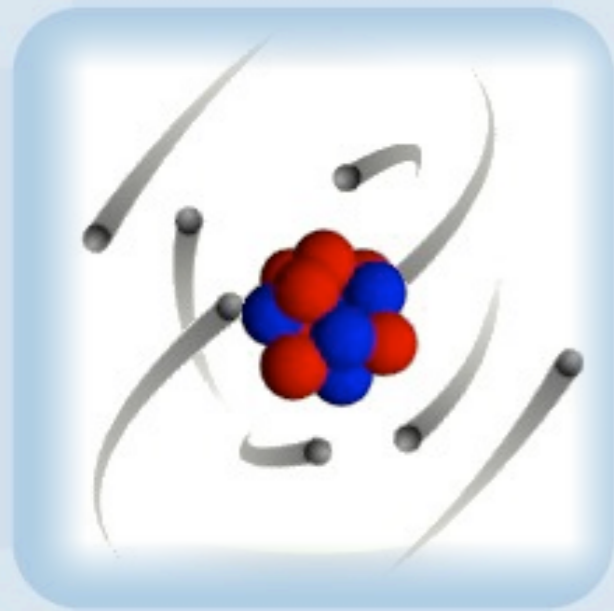
If you were to place solid salt ( $\text{NaCl}_{(s)}$ ) between the electrodes and turn them on nothing would happen. This is because the the ions are locked in place in the crystal lattice and cannot move towards the electrodes.



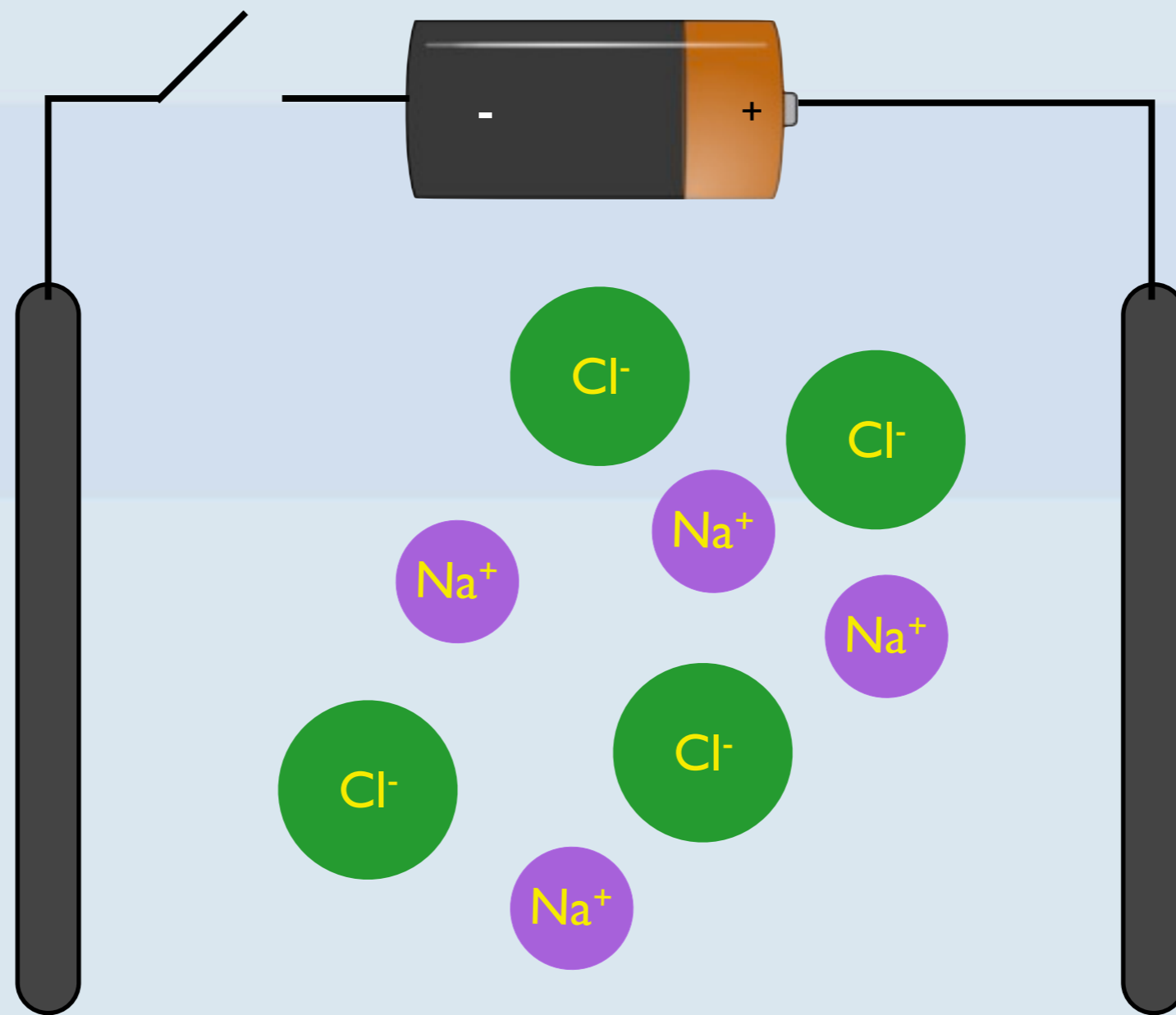
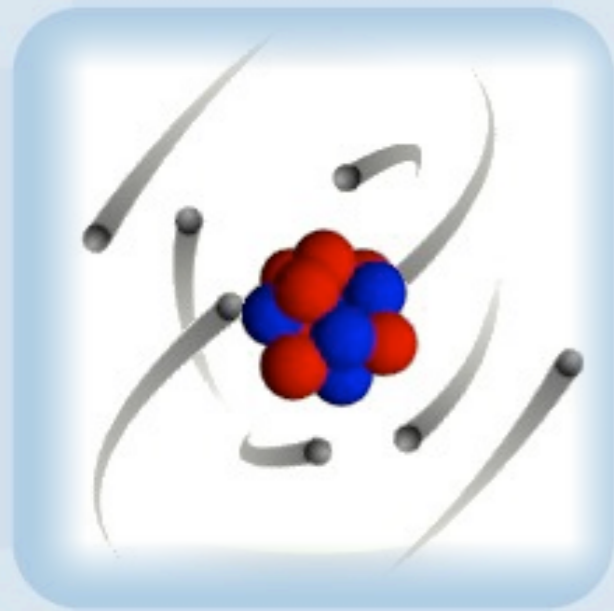
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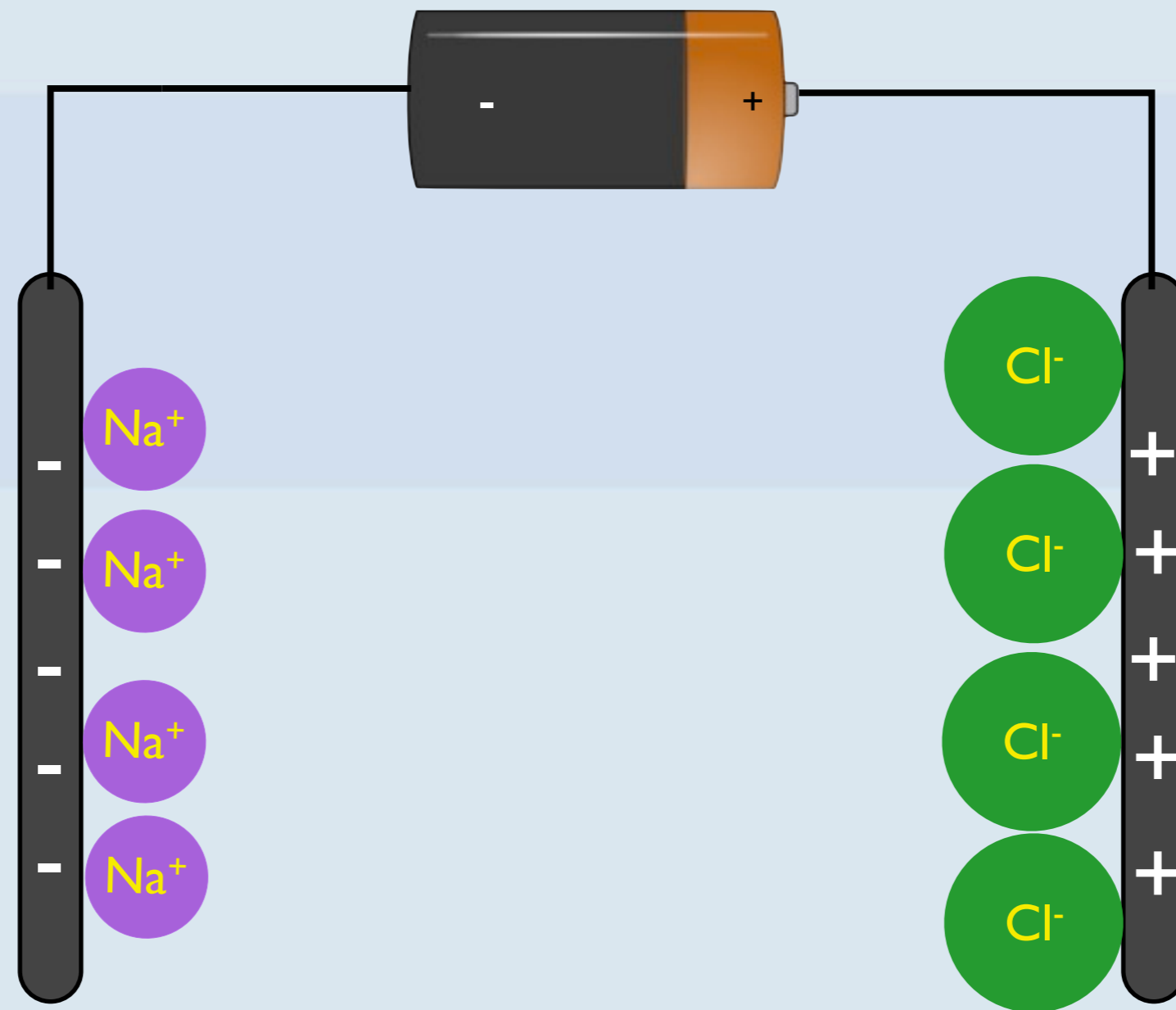
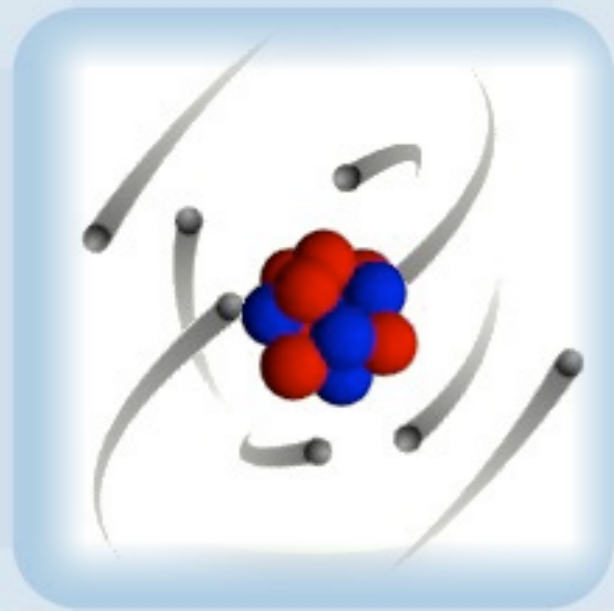
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When you heat salt to  $801^\circ\text{C}$ , it melts into a liquid.  
The ions are now free to move.

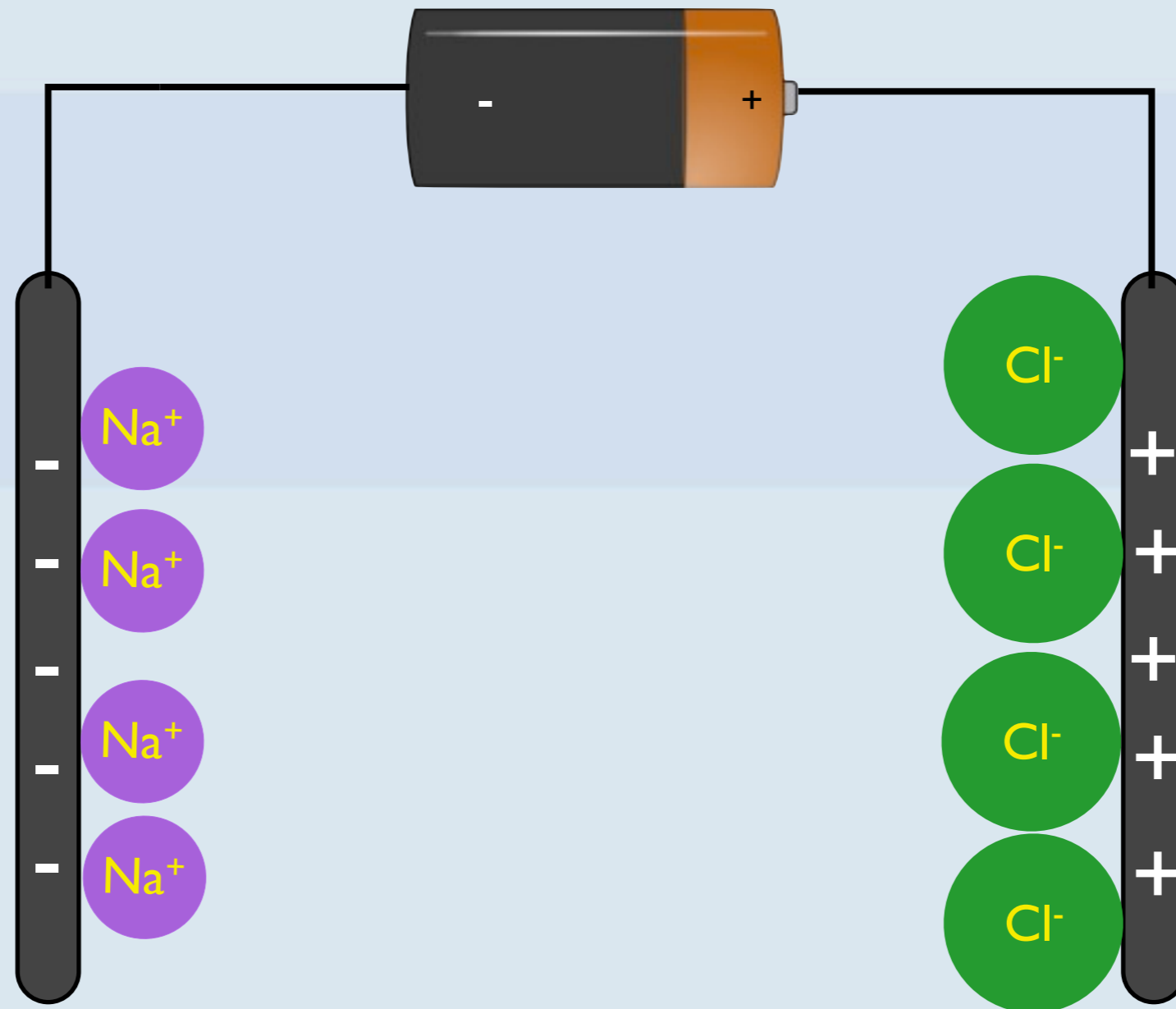
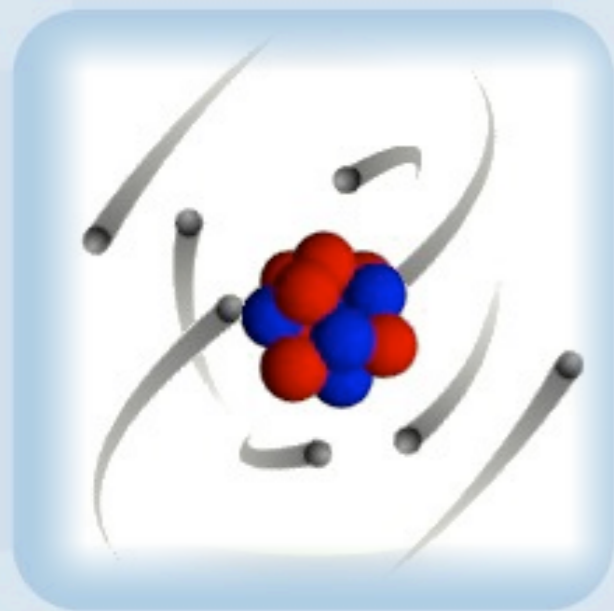


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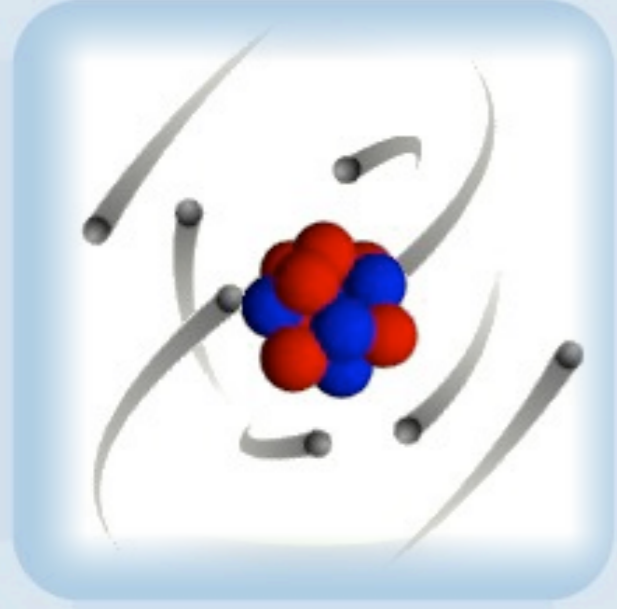


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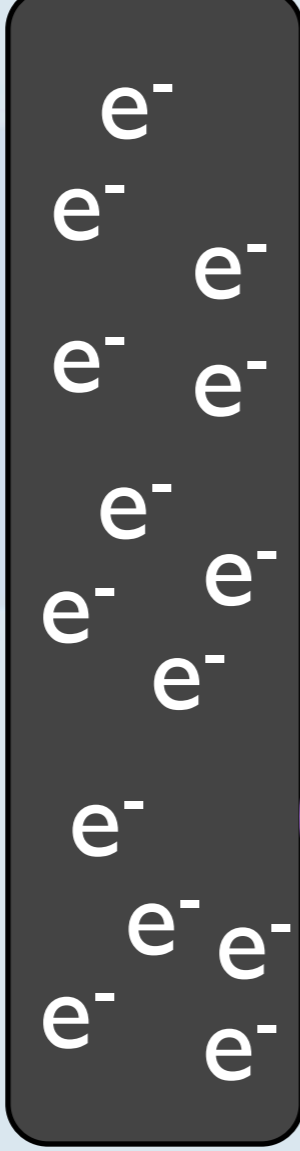
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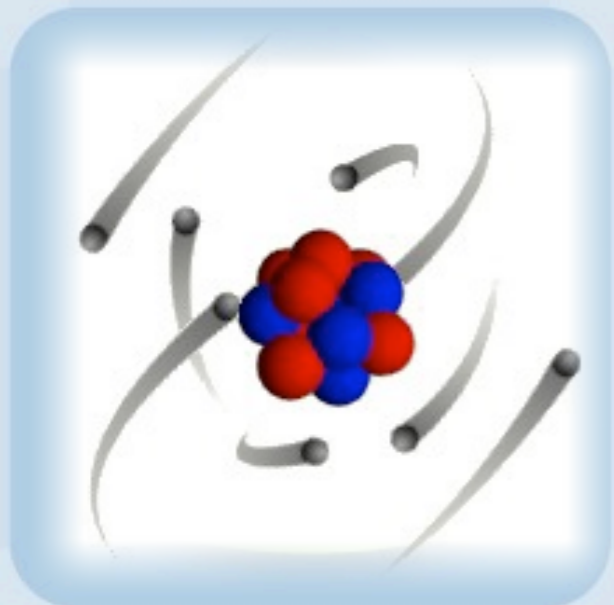
The sodium cations are attracted to the cathode (-).

The chloride anions are attracted to the anode (+).

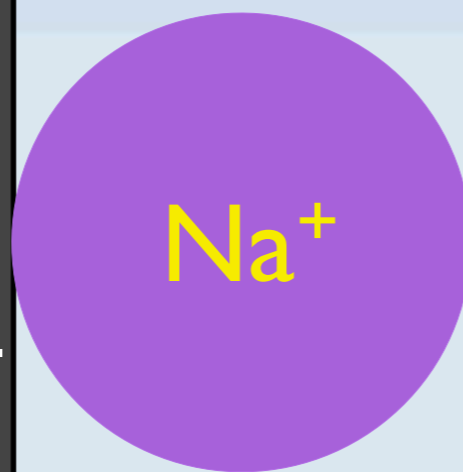


*cathode*

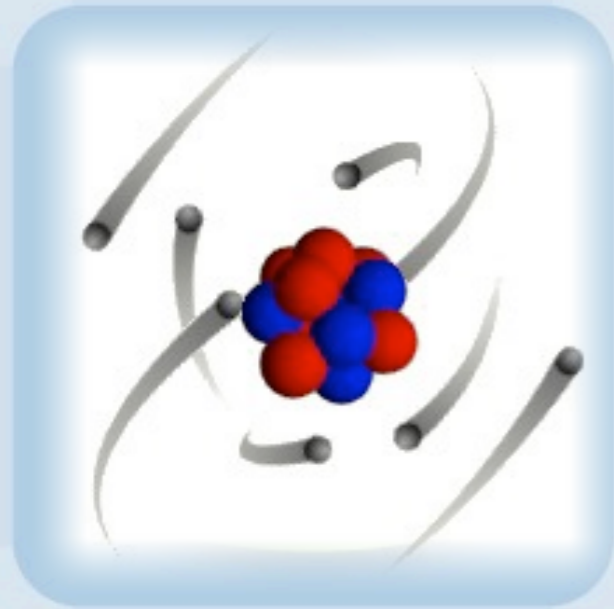




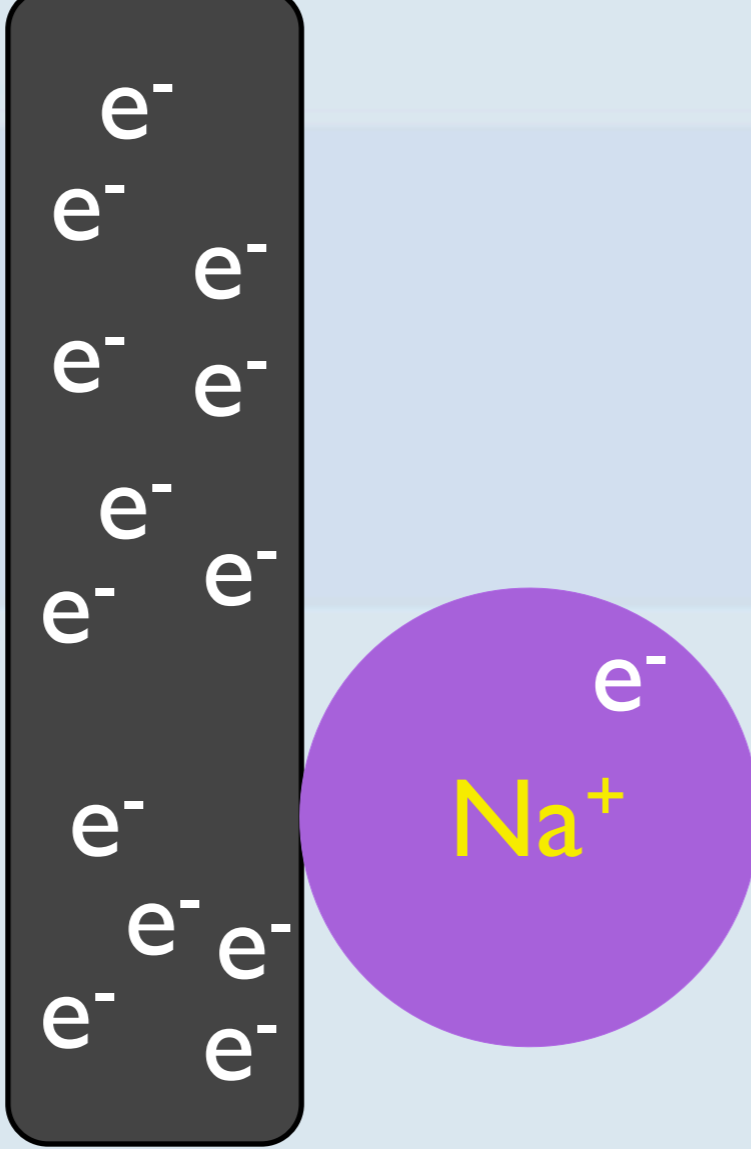
cathode



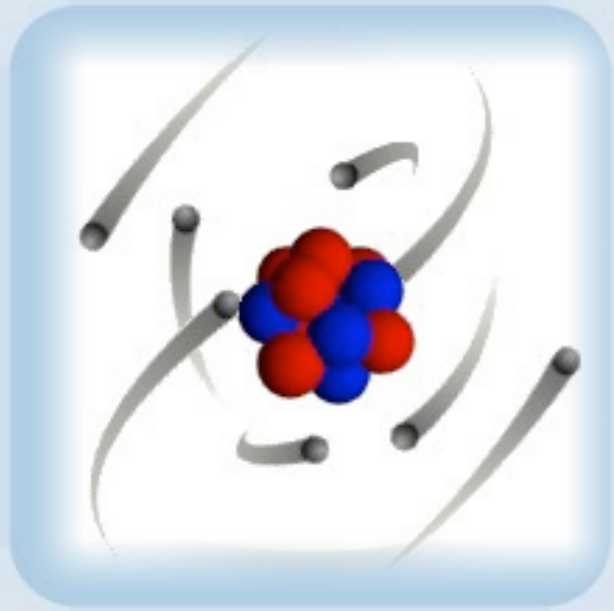
At the cathode a sodium ion is reduced when it gains an electron from the cathode.



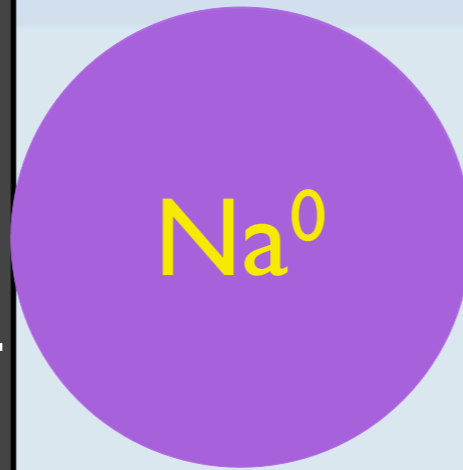
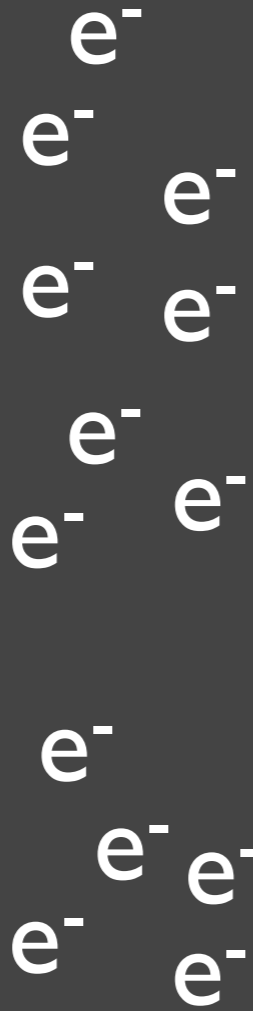
*cathode*



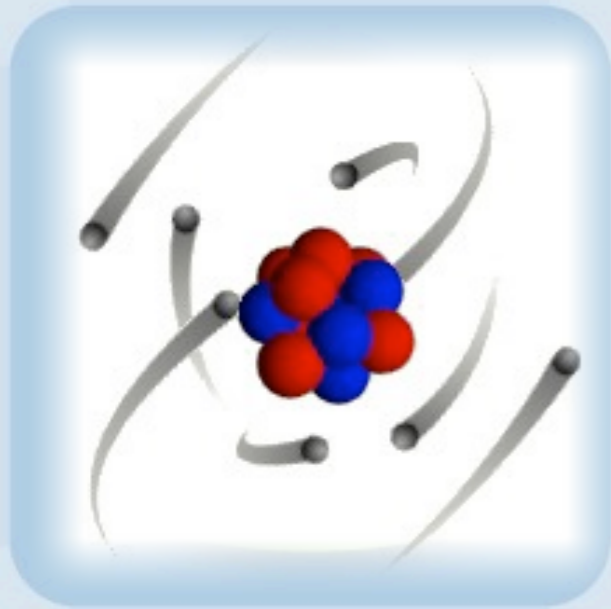
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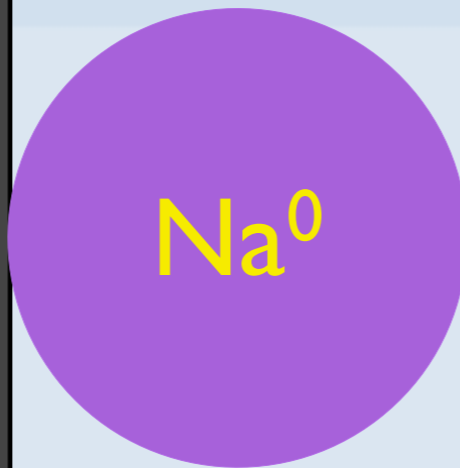
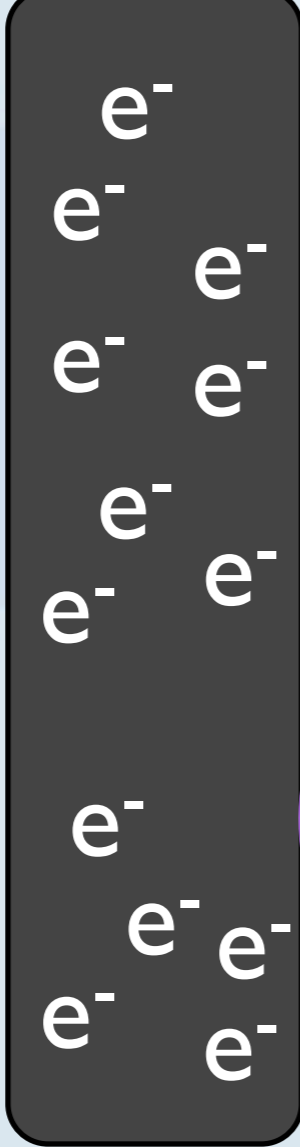
*cathode*



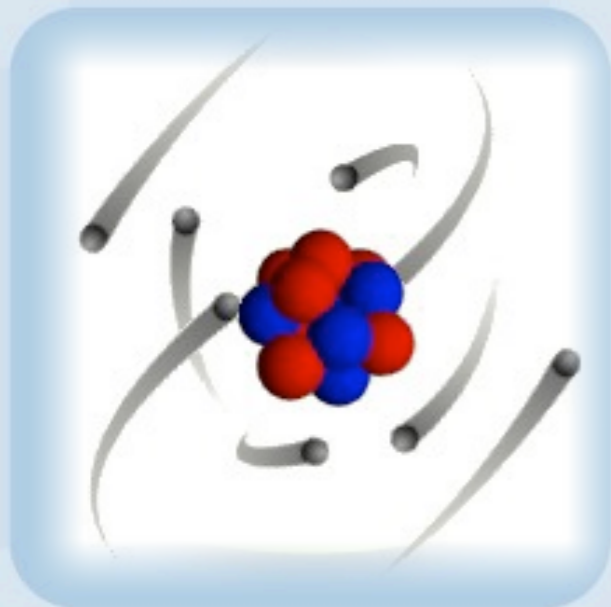
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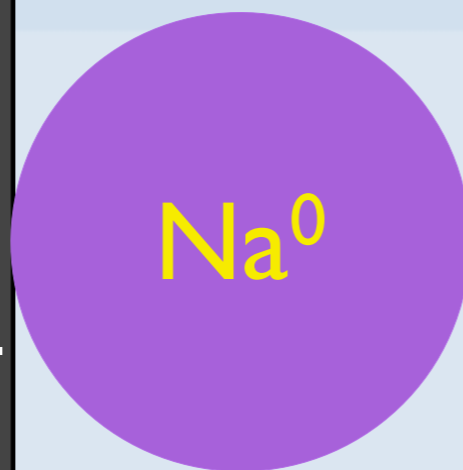
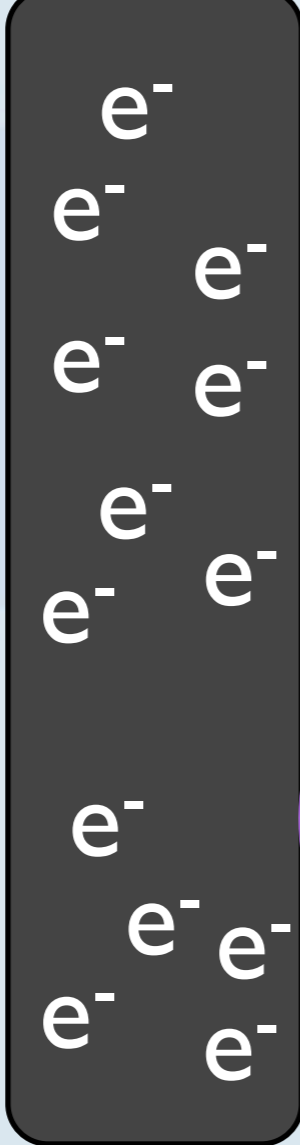
*cathode*



At the cathode a sodium ion is reduced when it gains an electron from the cathode.

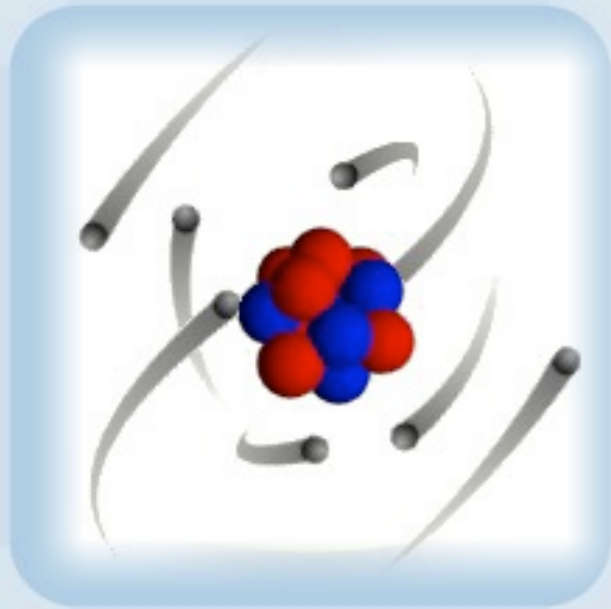


*cathode*

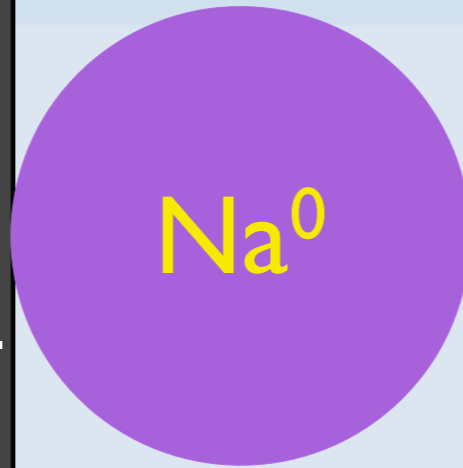
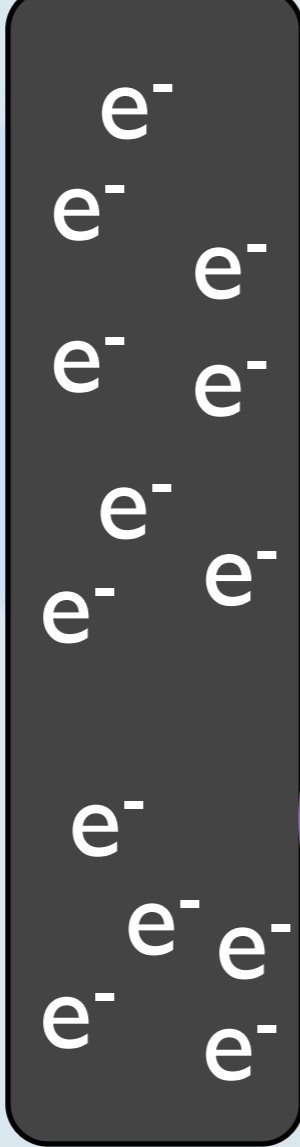


At the cathode a sodium ion is reduced when it gains an electron from the cathode.





*cathode*

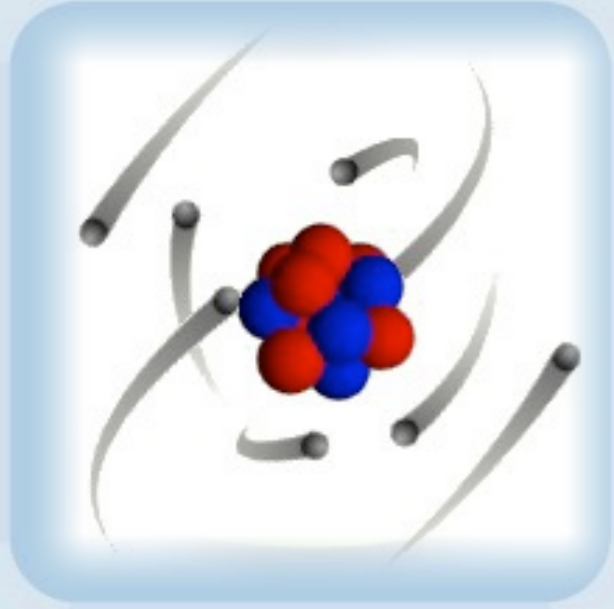


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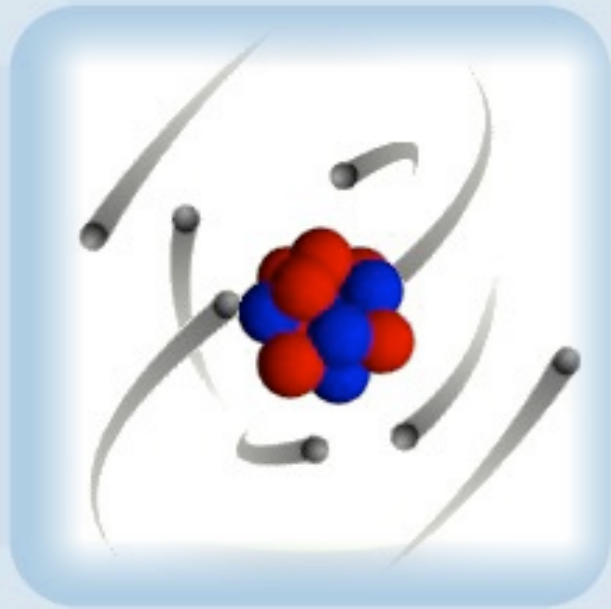


Sodium atoms build up on the cathode as more sodium ions are reduced to sodium atoms.

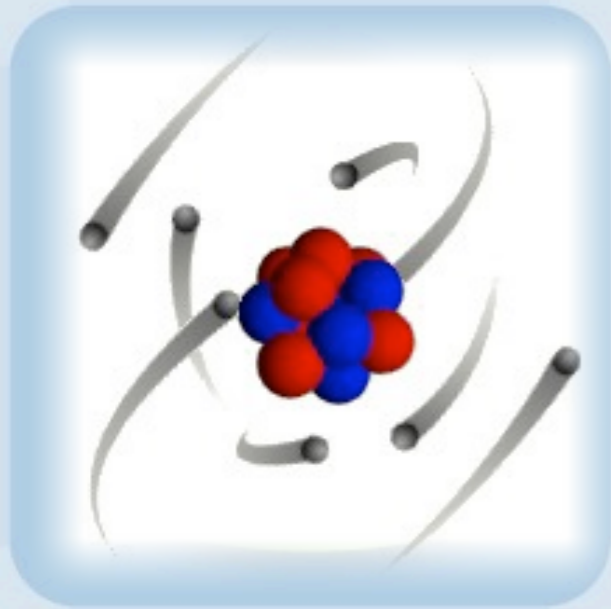




*anode*

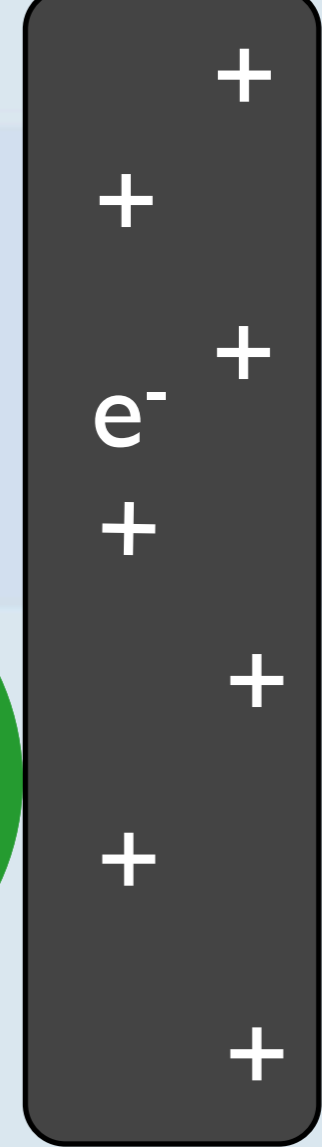
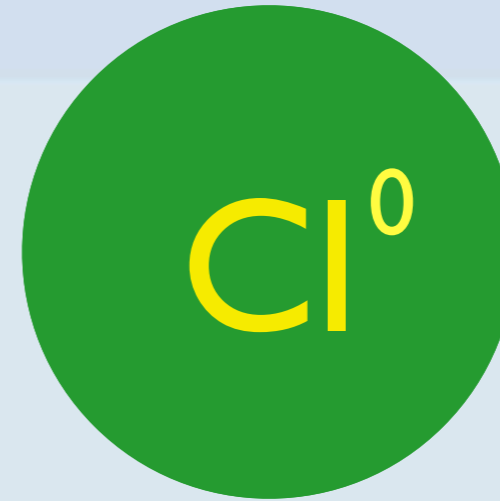
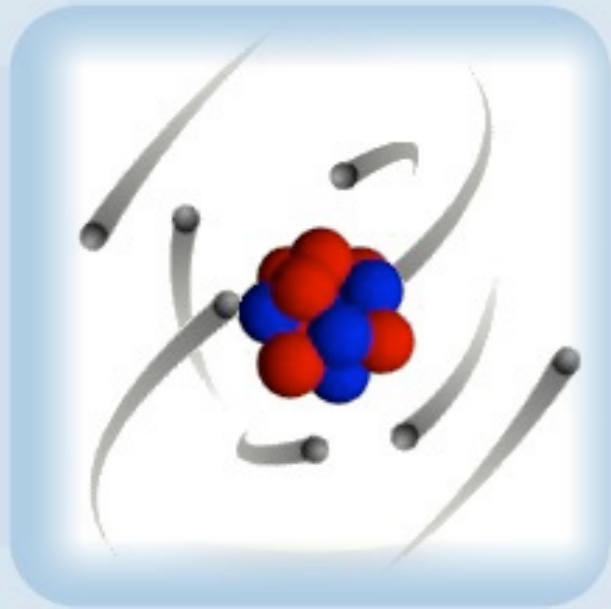


At the anode, a chloride ion is oxidized when it loses an electron to the anode.



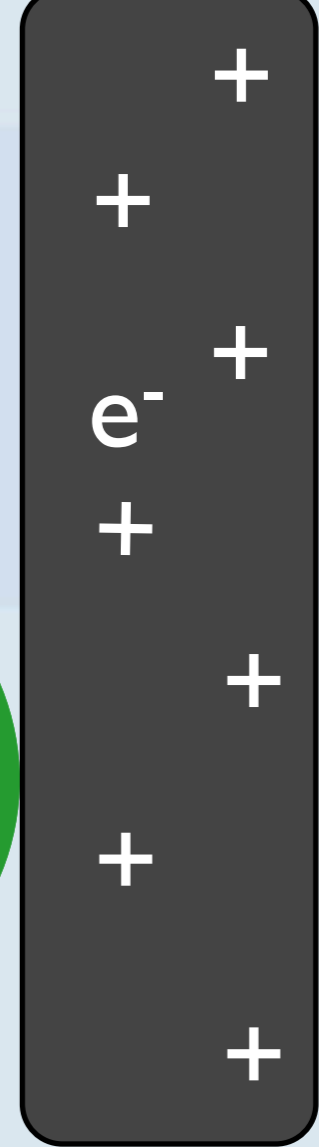
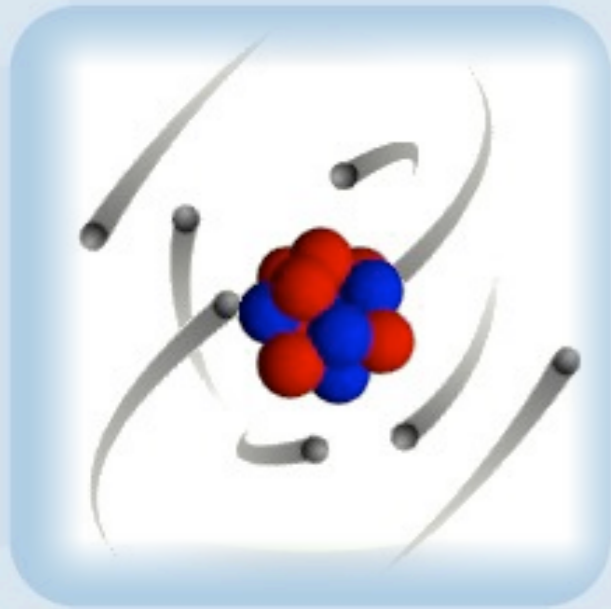
*anode*

At the anode, a chloride ion is oxidized when it loses an electron to the anode.



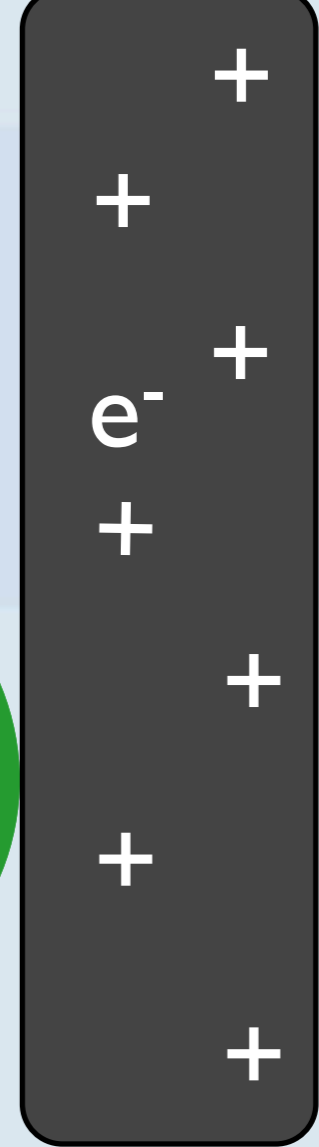
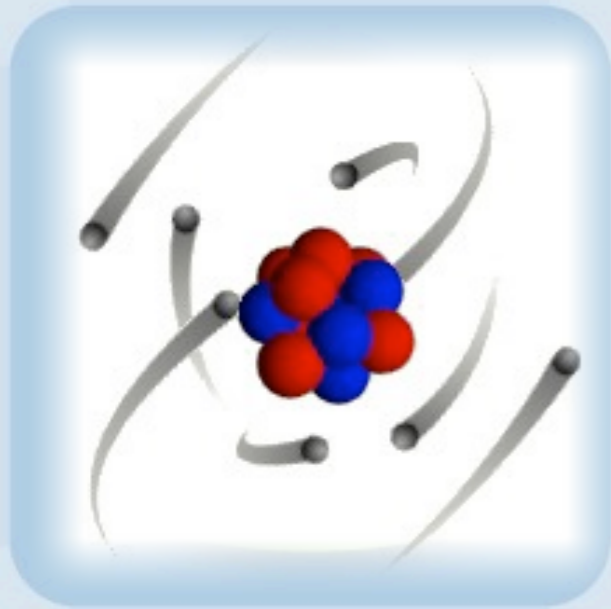
*anode*

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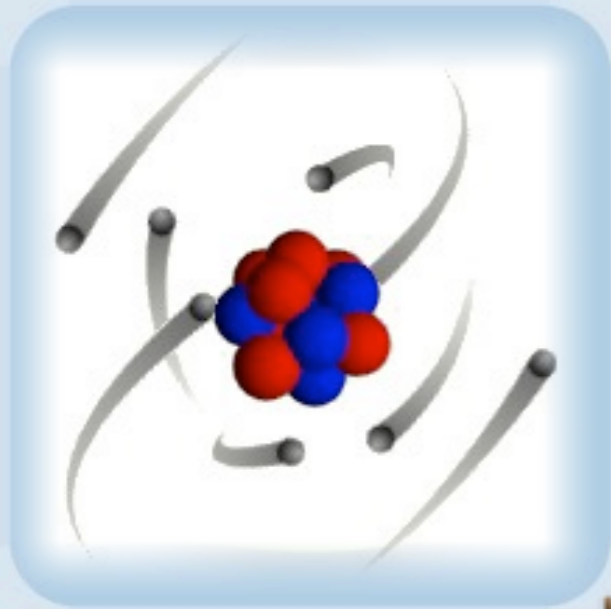


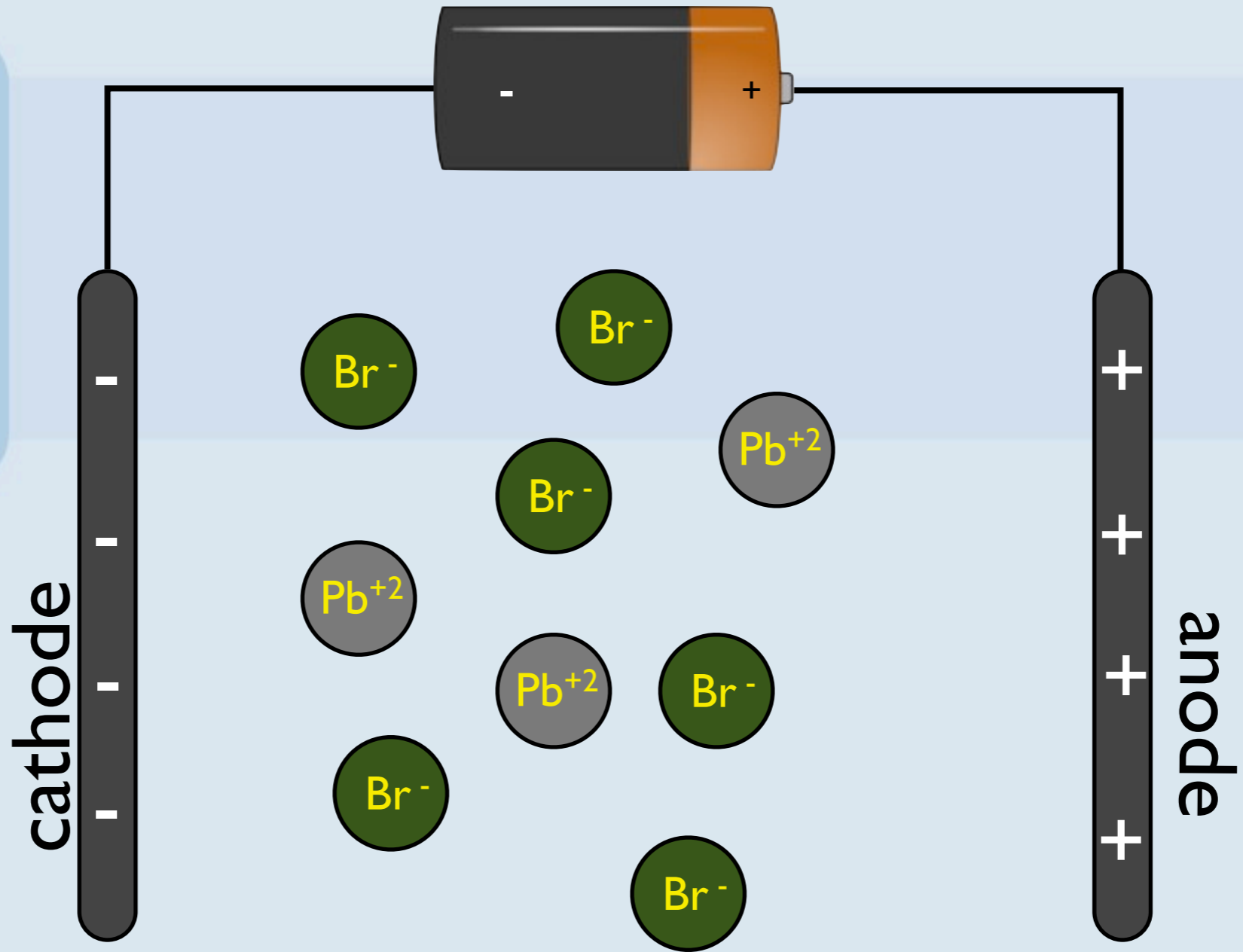
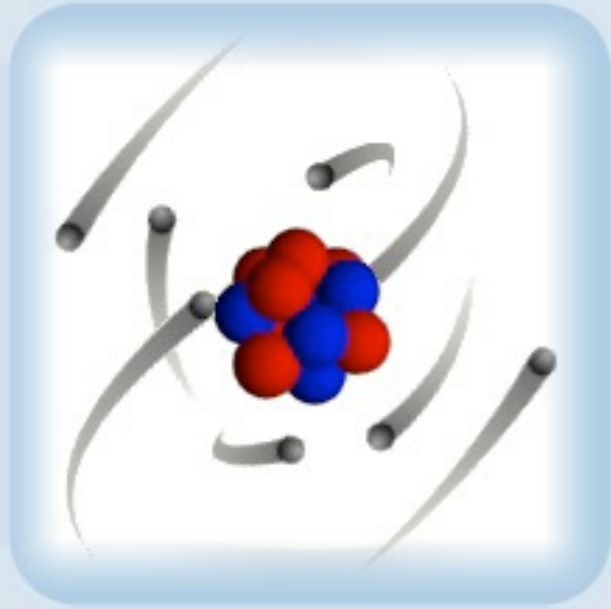
At the anode, a chloride ion is oxidized when it loses an electron to the anode.



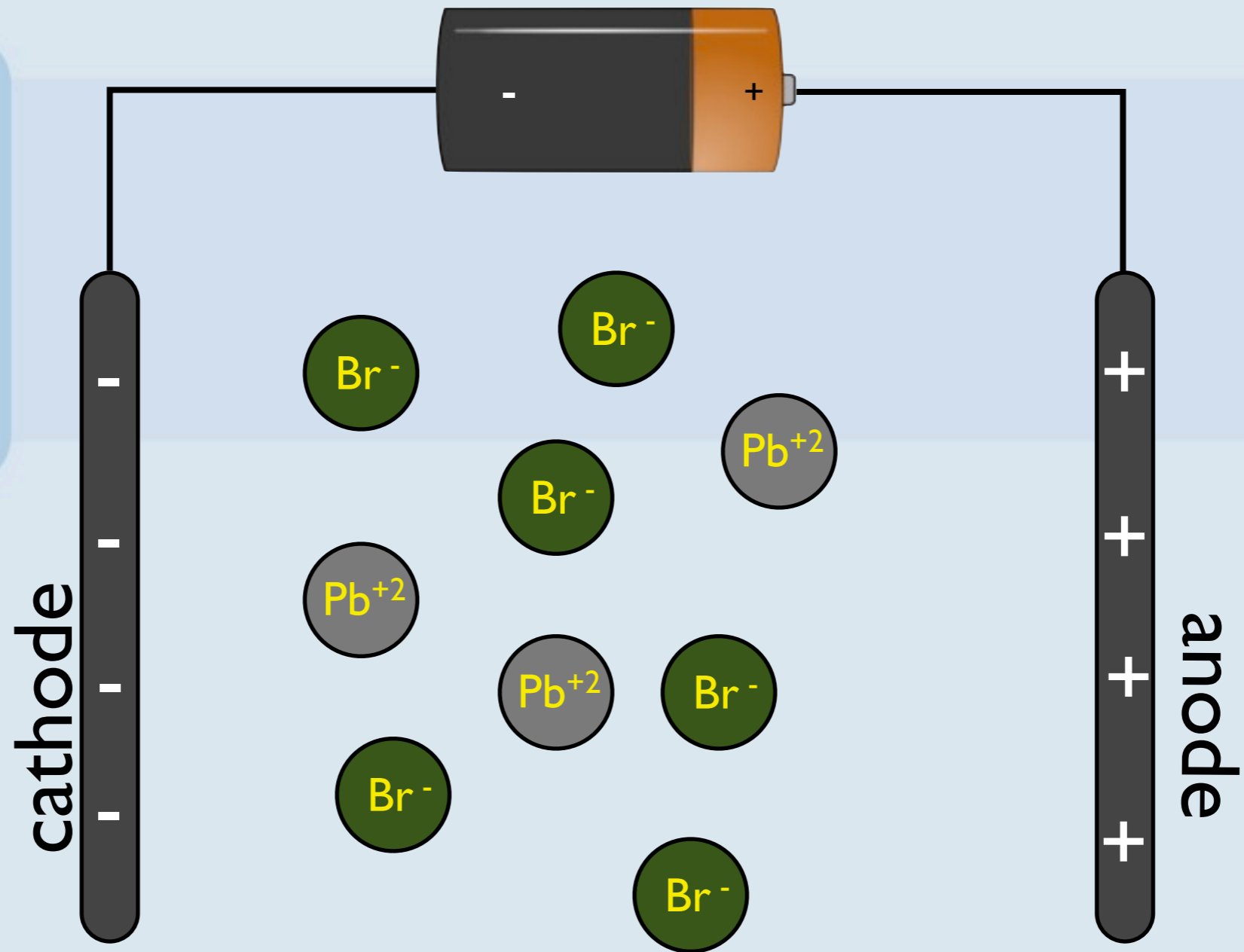
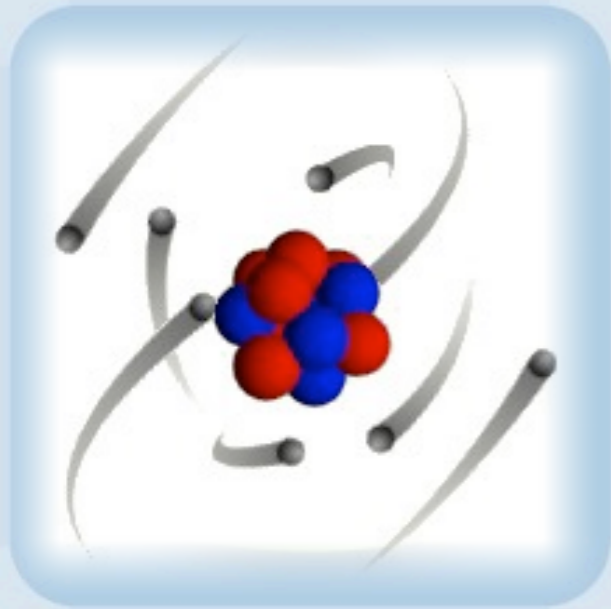
Chlorine gas ( $\text{Cl}_{2(g)}$ ) forms at the anode as chloride ions gain electrons and become chloride atoms.

# Electrolysis

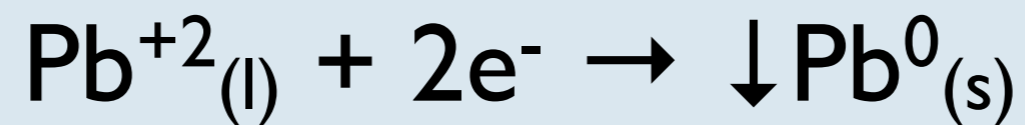


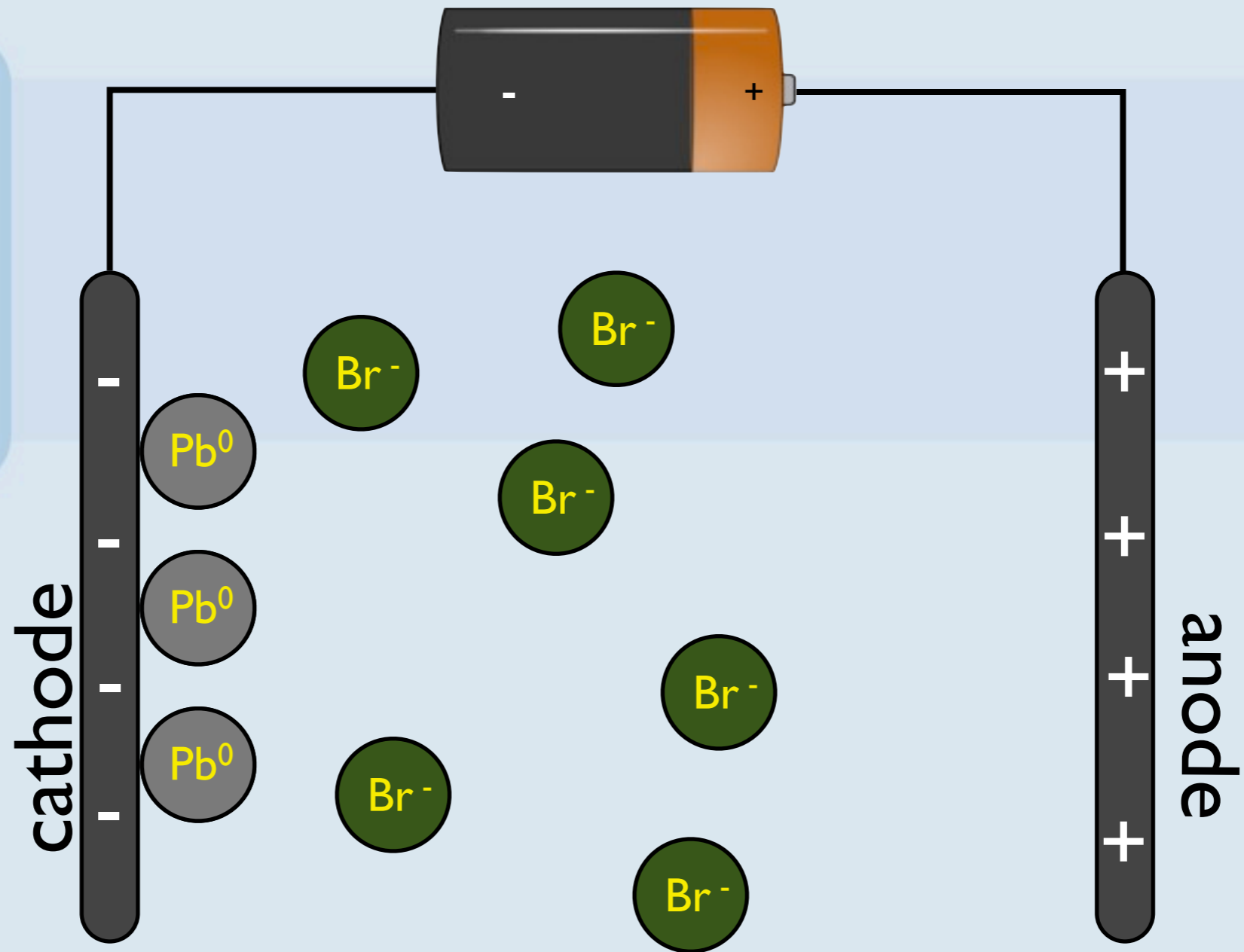
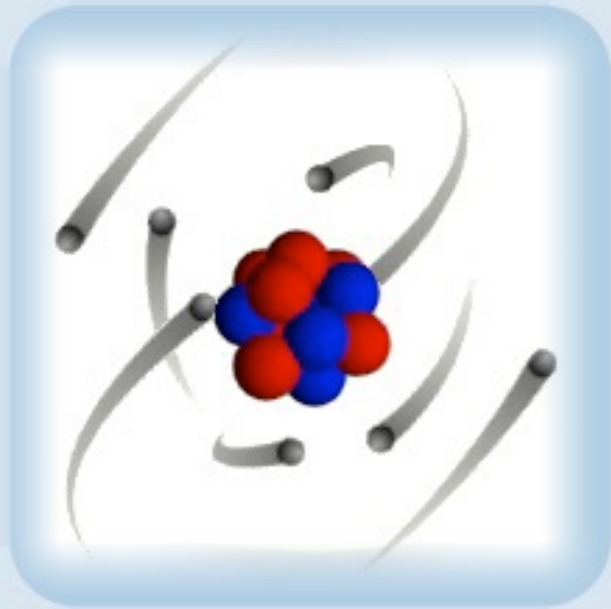




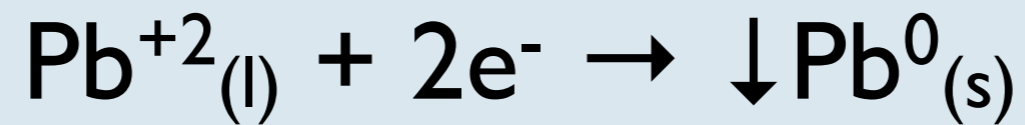


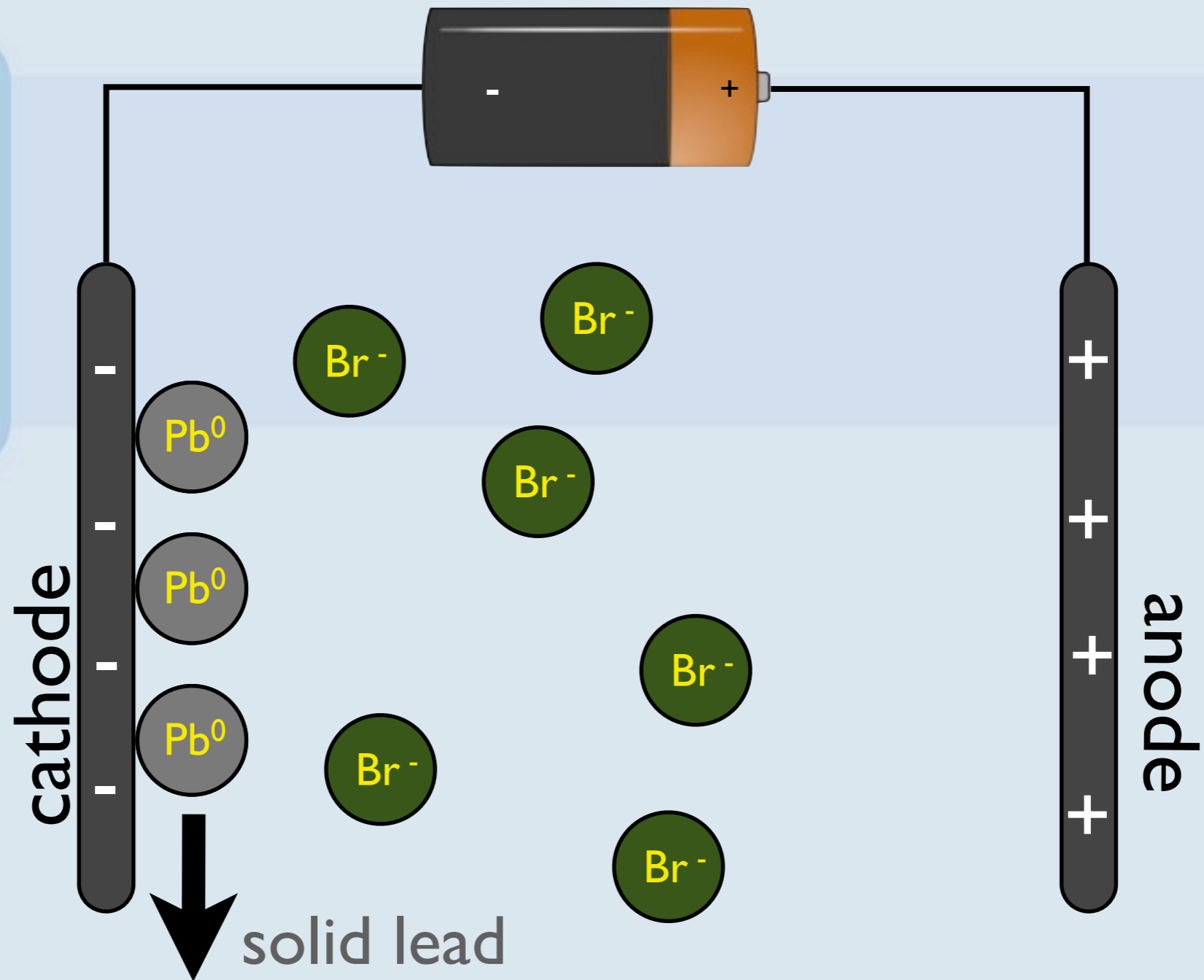
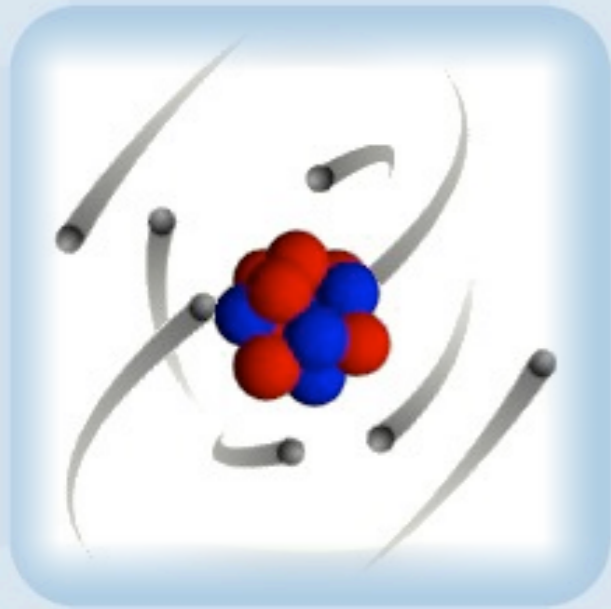
At the cathode lead ions are reduced to lead atoms:



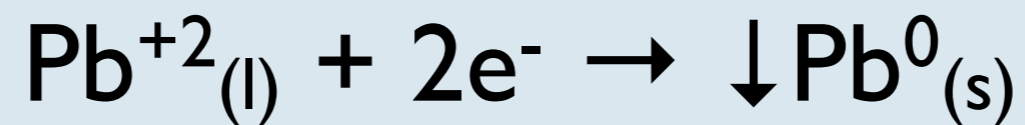


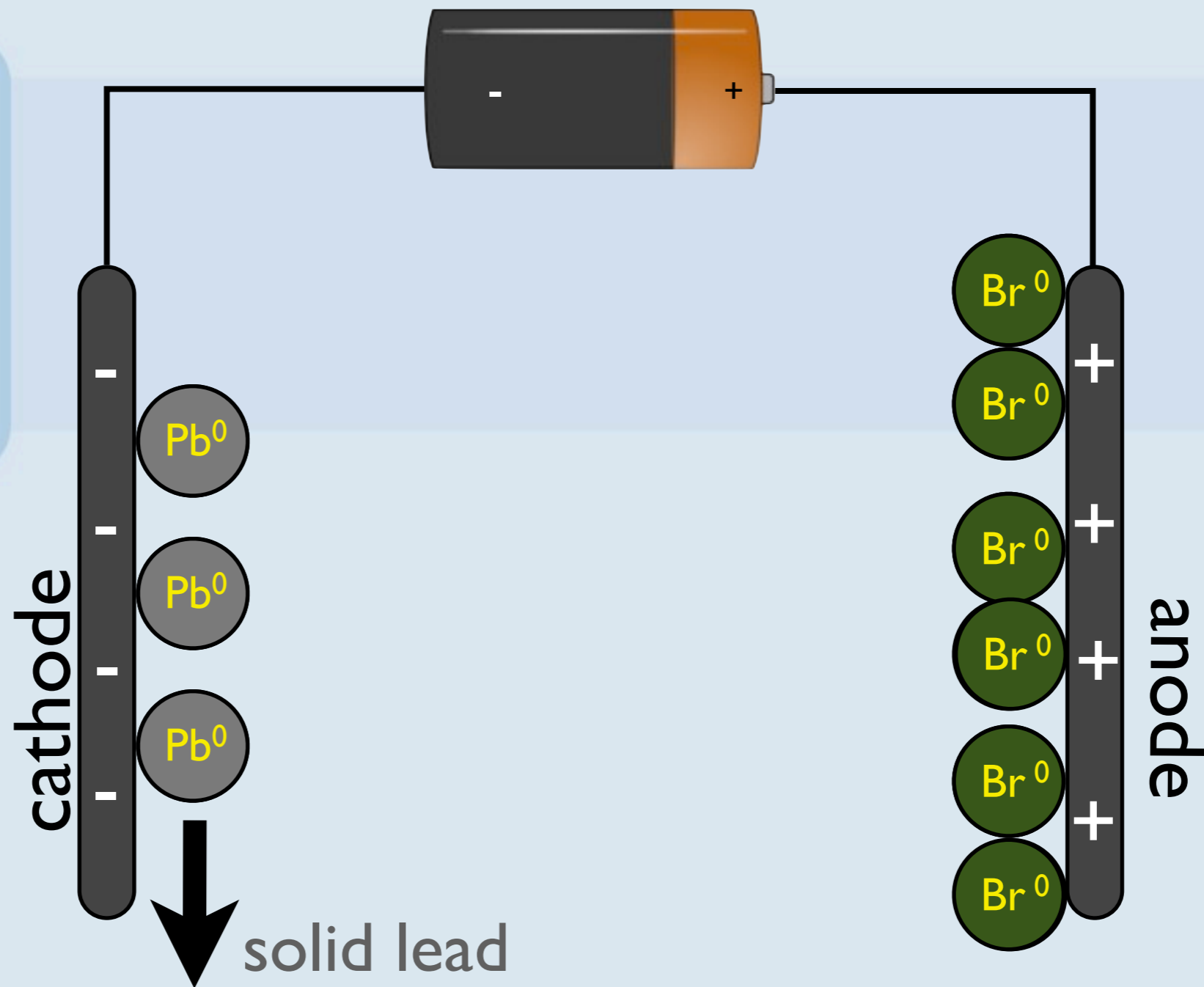
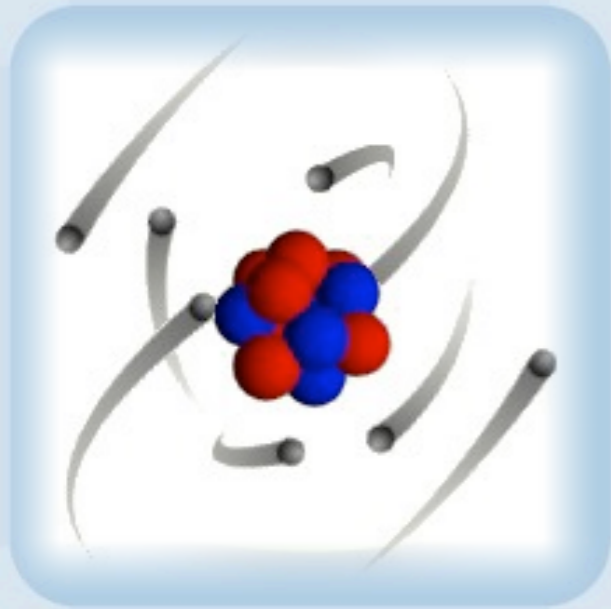
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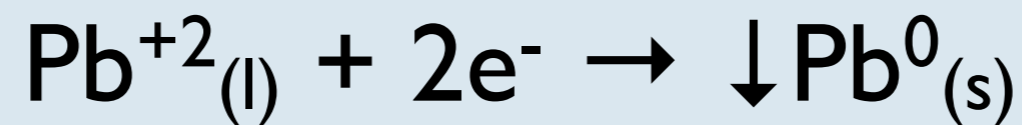


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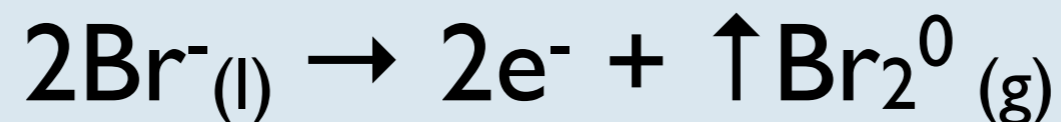


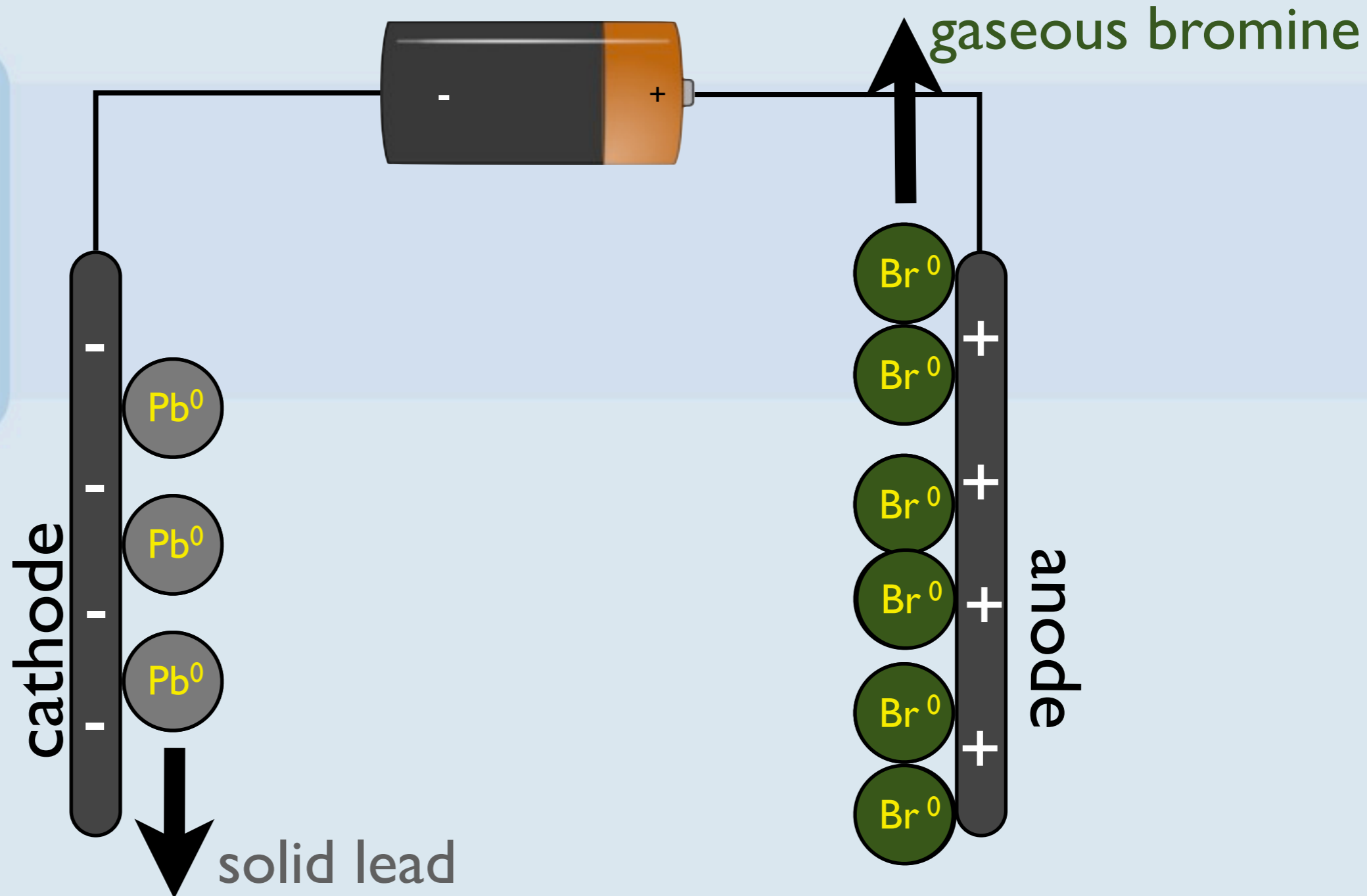
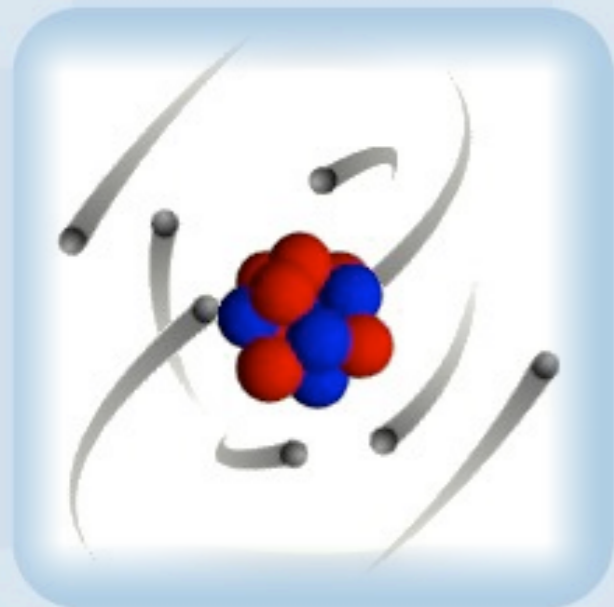


At the cathode lead ions are reduced to lead atoms:

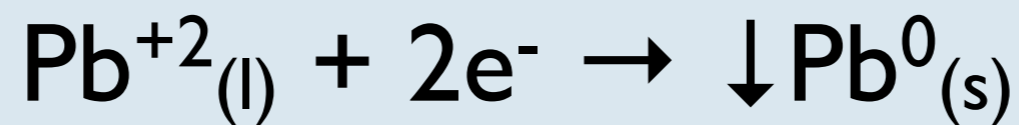


At the anode bromide ions are oxidized to bromine atoms:

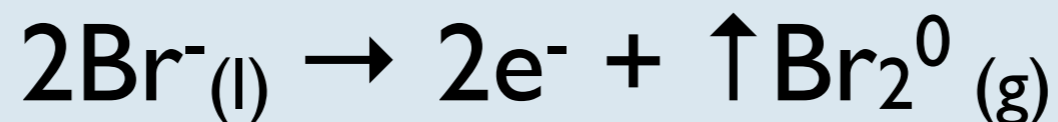




At the cathode lead ions are reduced to lead atoms:



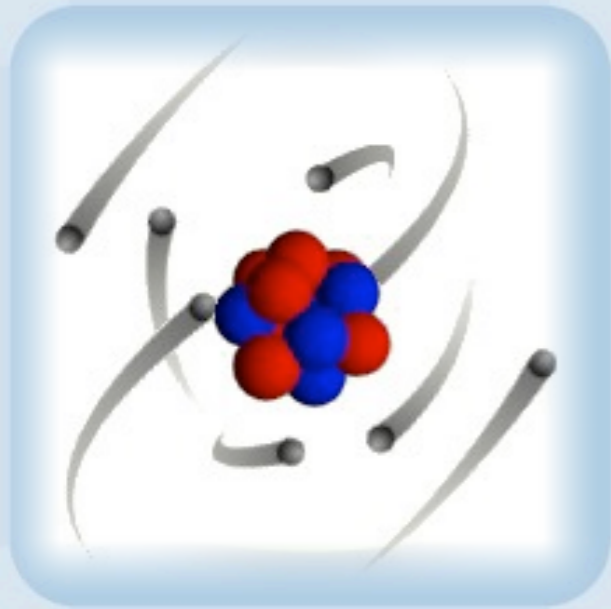
At the anode bromide ions are oxidized to bromine atoms:





# Summing it up!

- Ionic compounds must be in a molten state for electrolysis to occur.
- The metallic cation is always attracted to the cathode (- electrode) where it is reduced to a metallic atom.  
Metallic atoms form a solid (except Hg).
- The nonmetallic anion is always attracted to the anode (+ electrode) where it is oxidized and becomes a nonmetallic atom.  
Nonmetallic atoms usually form gases.



# Electrolysis of Ionic Solutions



# Electrolysis of Solutions





# Electrolysis of Solutions

- When you dissolve an ionic substance in water it dissociates into metallic cations and nonmetallic anions.



# Electrolysis of Solutions

- When you dissolve an ionic substance in water it dissociates into metallic cations and nonmetallic anions.
- Salt is dissolved in water:  
$$\text{NaCl}_{(s)} \rightarrow \text{Na}^+_{(aq)} + \text{Cl}^-_{(aq)}$$



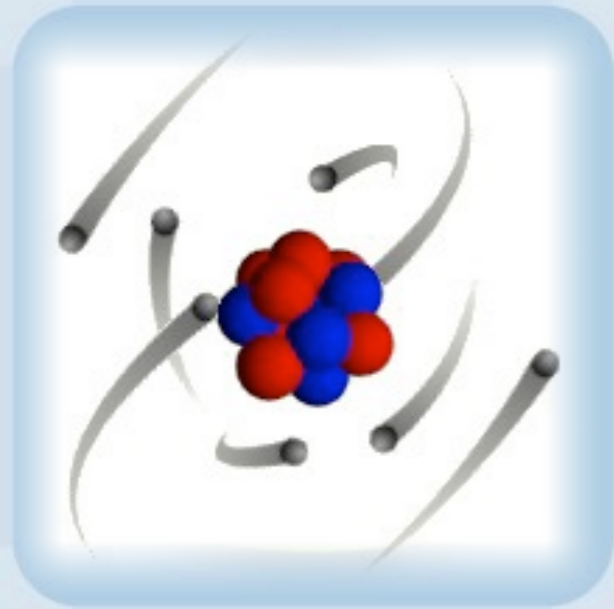
# Electrolysis of Solutions

- When you dissolve an ionic substance in water it dissociates into metallic cations and nonmetallic anions.
- Salt is dissolved in water:  
$$\text{NaCl}_{(s)} \rightarrow \text{Na}^+_{(aq)} + \text{Cl}^-_{(aq)}$$
- Like its molten state, ions in solution are free to move and will be attracted to an oppositely charged electrode.

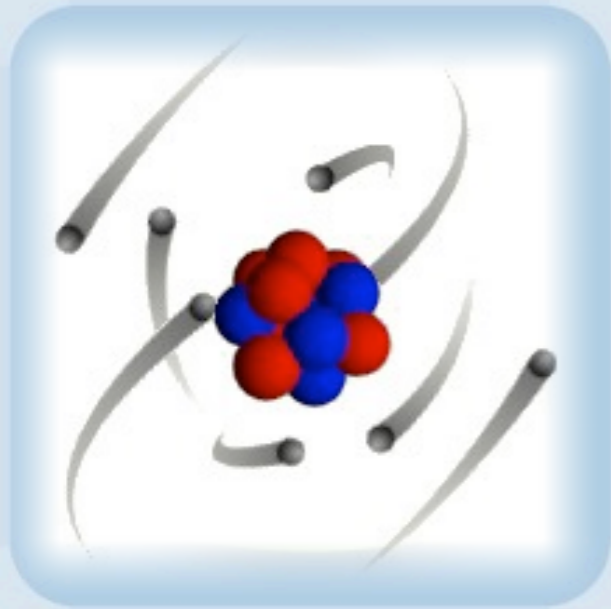


# Electrolysis of Solutions



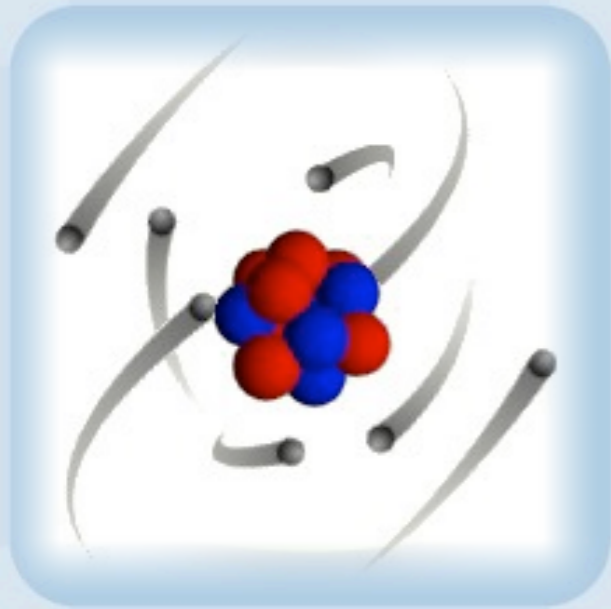


# Electrolysis of Solutions



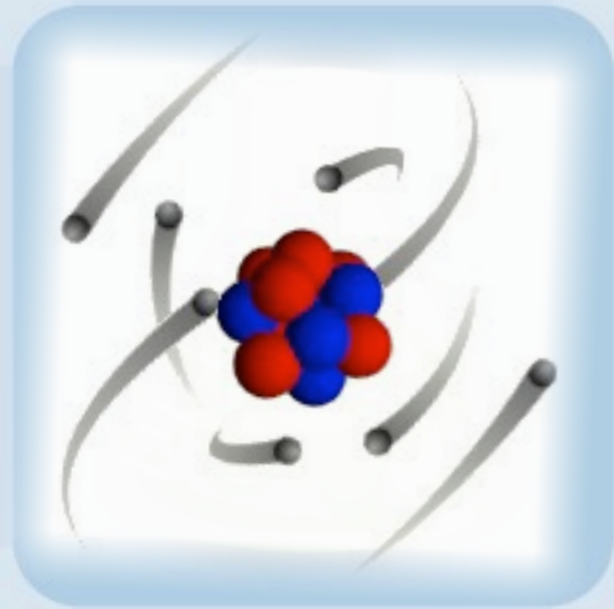
# Electrolysis of Solutions

- The advantage of using solutions instead of melting a compound is the cost.  
It cost much less to dissolve an ionic compound in water than paying for the energy in heating an ionic compound to its melting point.



# Electrolysis of Solutions

- The advantage of using solutions instead of melting a compound is the cost.  
It cost much less to dissolve an ionic compound in water than paying for the energy in heating an ionic compound to its melting point.
- The disadvantage is that  $H^+$  ions and  $OH^-$  ions in water can interfere with the production of ionic elements in a compound.



# ionization of water





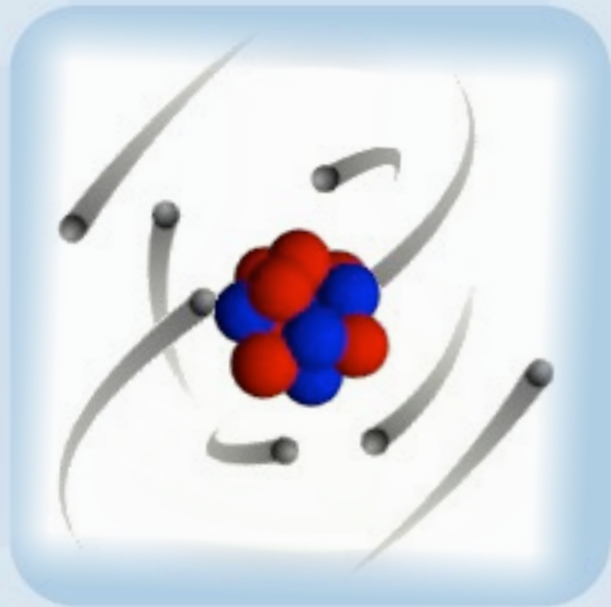
# Ionization of water

- In pure water a very, very small number of water molecules break into hydrogen and hydroxide ions.



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- The ionization of water:  
$$\text{H}_2\text{O}_{(l)} \rightarrow \text{H}^+_{(aq)} + \text{OH}^-_{(aq)}$$
- The hydrogen ions and hydroxide ions can interfere with the redox reaction of the solute in the solution.

# Metallic ions

Li	Lithium
K	Potassium
Ba	Barium
Sr	Strontium
Ca	Calcium
Na	Sodium
Mg	Magnesium
Al	Aluminum
Mn	Manganese
Zn	Zinc
Cr	Chromium
Fe	Iron
Cd	Cadmium
Co	Cobalt
Ni	Nickel
Sn	Tin
Pb	Lead
H	Hydrogen
Sb	Antimony
As	Arsenic
Bi	Bismuth
Cu	Copper
Hg	Mercury
Ag	Silver
Pt	Platinum
Au	Gold

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Cu	Copper
Hg	Mercury
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Au	Gold

# Metallic ions

- Metallic ions more active than hydrogen on the activity series will not accept electrons at the cathode (- electrode). If they are present hydrogen is reduced instead of the metallic ion.

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# Metallic ions

- Metallic ions more active than hydrogen on the activity series will not accept electrons at the cathode (- electrode). If they are present hydrogen is reduced instead of the metallic ion.
- Most metallic ions in solution will not be reduced in electrolysis . Instead hydrogen reduced to form H<sub>2(g)</sub>.  

$$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$$

# Metallic ions

Li	Lithium
K	Potassium
Ba	Barium
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Ca	Calcium
Na	Sodium
Mg	Magnesium
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Mn	Manganese
Zn	Zinc
Cr	Chromium
Fe	Iron
Cd	Cadmium
Co	Cobalt
Ni	Nickel
Sn	Tin
Pb	Lead

Will not reduce.

H	Hydrogen
Sb	Antimony
As	Arsenic
Bi	Bismuth
Cu	Copper
Hg	Mercury
Ag	Silver
Pt	Platinum
Au	Gold

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# Nonmetallic ions

*Fluoride*

*Chloride*

*Bromide*

*Iodide*

*Hydroxide*

*Sulfide*

*Oxide*

*Nitride*

*Sulfate*

*Sulfide*

*Nitrate*

*Nitrite*

*Phosphate*



Fluoride  
Chloride  
Bromide  
Iodide  
Hydroxide  
Sulfide  
Oxide  
Nitride  
Sulfate  
Sulfide  
Nitrate  
Nitrite  
Phosphate

# Nonmetallic ions

- Halogen ions ( $F^-_{(aq)}$ ,  $Cl^-_{(aq)}$ ,  $I^-_{(aq)}$ ...) will oxidize at the anode instead of hydroxide ions ( $OH^-_{(aq)}$ ).

Fluoride  
Chloride  
Bromide  
Iodide  
Hydroxide  
Sulfide  
Oxide  
Nitride  
Sulfate  
Sulfide  
Nitrate  
Nitrite  
Phosphate

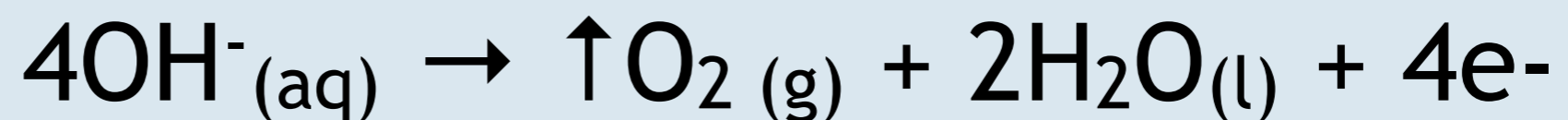
# Nonmetallic ions

- Halogen ions ( $F^-_{(aq)}$ ,  $Cl^-_{(aq)}$ ,  $I^-_{(aq)}$ ...) will oxidize at the anode instead of hydroxide ions ( $OH^-_{(aq)}$ ).
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Fluoride  
Chloride  
Bromide  
Iodide  
Hydroxide  
Sulfide  
Oxide  
Nitride  
Sulfate  
Sulfide  
Nitrate  
Nitrite  
Phosphate

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- When hydroxide is oxidized it forms oxygen gas ( $O_2$ ).



Fluoride

Chloride

Bromide

Iodide

Hydroxide

Sulfide

Oxide

Nitride

Sulfate

Sulfide

Nitrate

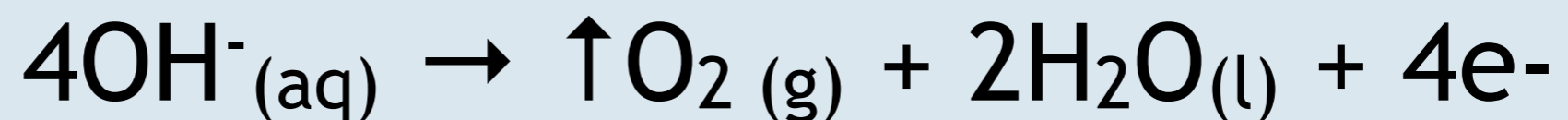
Nitrite

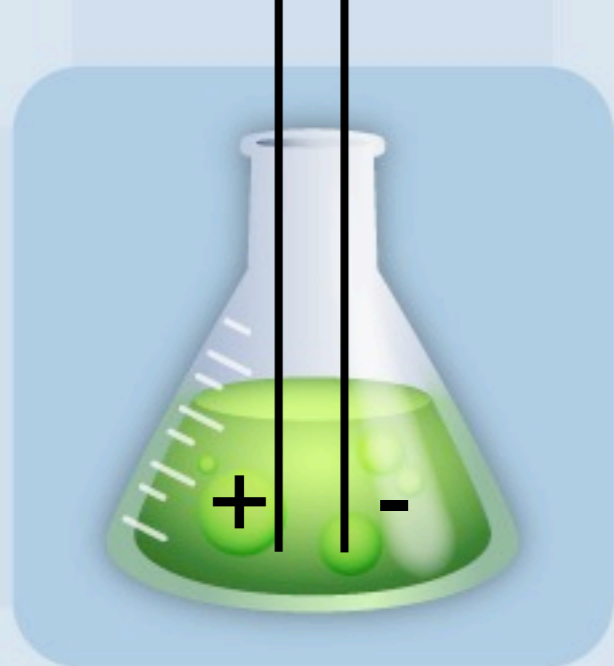
Phosphate

Will not oxidize.

# Nonmetallic ions

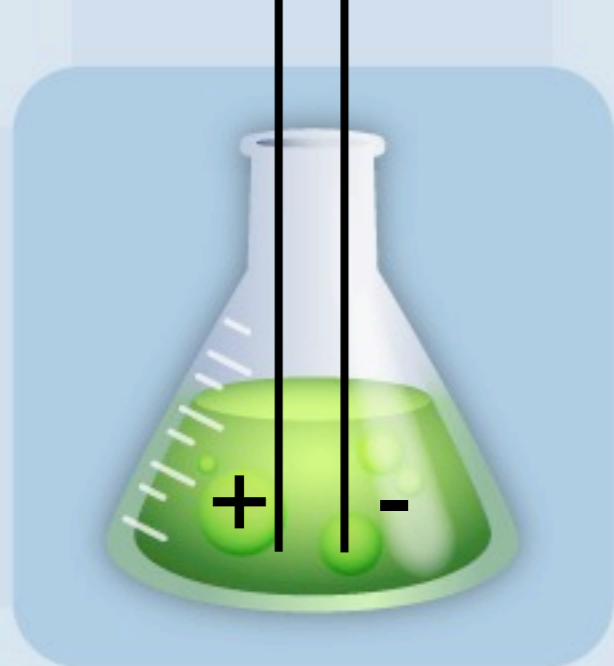
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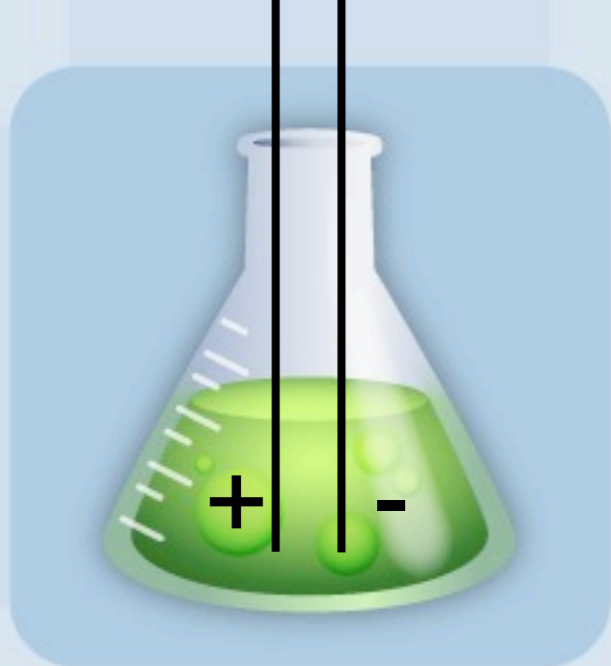
**What forms in these electrolysis reactions involving solutions?**

<b>Solution</b>	<b>Forms at cathode</b>	<b>Forms at anode</b>
$\text{NaCl}_{(\text{aq})}$		
$\text{CuSO}_4_{(\text{aq})}$		
$\text{AgNO}_3_{(\text{aq})}$		
$\text{FeBr}_2_{(\text{aq})}$		
$\text{MgF}_2_{(\text{aq})}$		



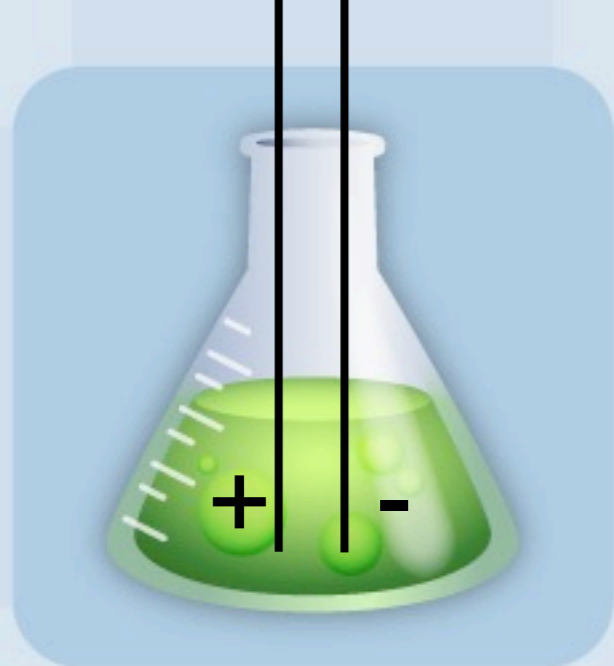
**What forms in these electrolysis reactions involving solutions?**

<b>Solution</b>	<b>Forms at cathode</b>	<b>Forms at anode</b>
$\text{NaCl}_{(\text{aq})}$	hydrogen gas	chlorine gas
$\text{CuSO}_4(\text{aq})$		
$\text{AgNO}_3 (\text{aq})$		
$\text{FeBr}_2 (\text{aq})$		
$\text{MgF}_2(\text{aq})$		



**What forms in these electrolysis reactions involving solutions?**

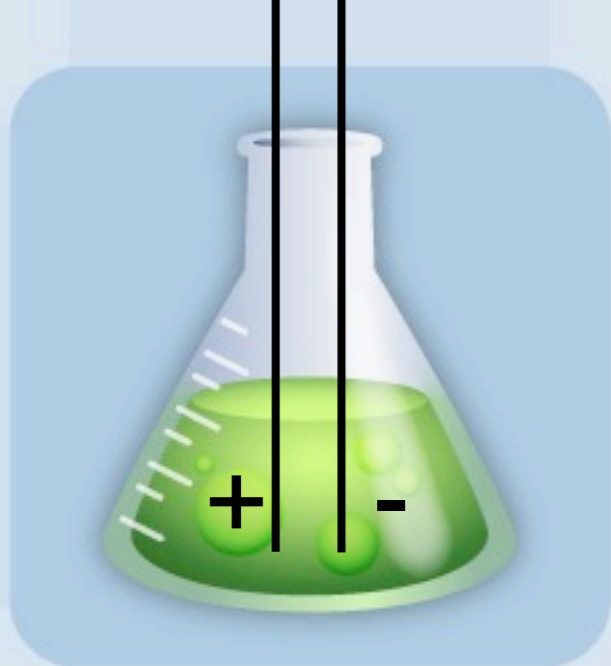
<b>Solution</b>	<b>Forms at cathode</b>	<b>Forms at anode</b>
$\text{NaCl}_{(\text{aq})}$	hydrogen gas	chlorine gas
$\text{CuSO}_{4(\text{aq})}$	copper atoms	oxygen gas
$\text{AgNO}_3 (\text{aq})$		
$\text{FeBr}_2 (\text{aq})$		
$\text{MgF}_{2(\text{aq})}$		



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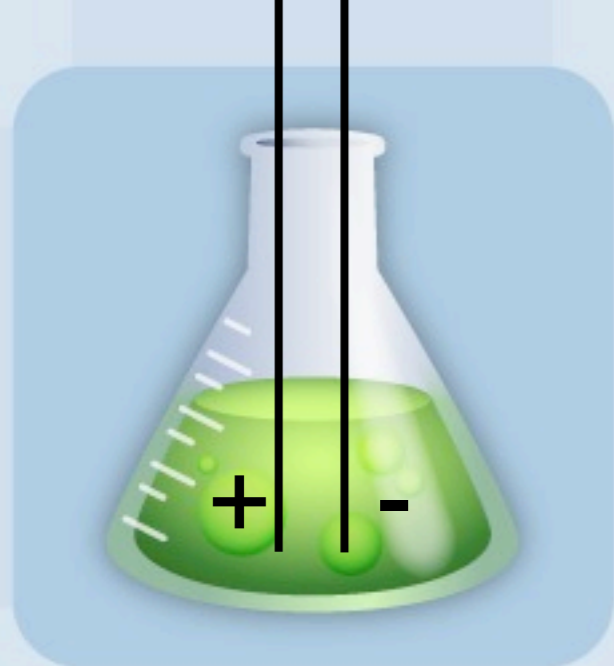
<b>Solution</b>	<b>Forms at cathode</b>	<b>Forms at anode</b>
$\text{NaCl}_{(\text{aq})}$	hydrogen gas	chlorine gas
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$\text{AgNO}_3_{(\text{aq})}$	silver atoms	oxygen gas
$\text{FeBr}_2_{(\text{aq})}$		
$\text{MgF}_2_{(\text{aq})}$		





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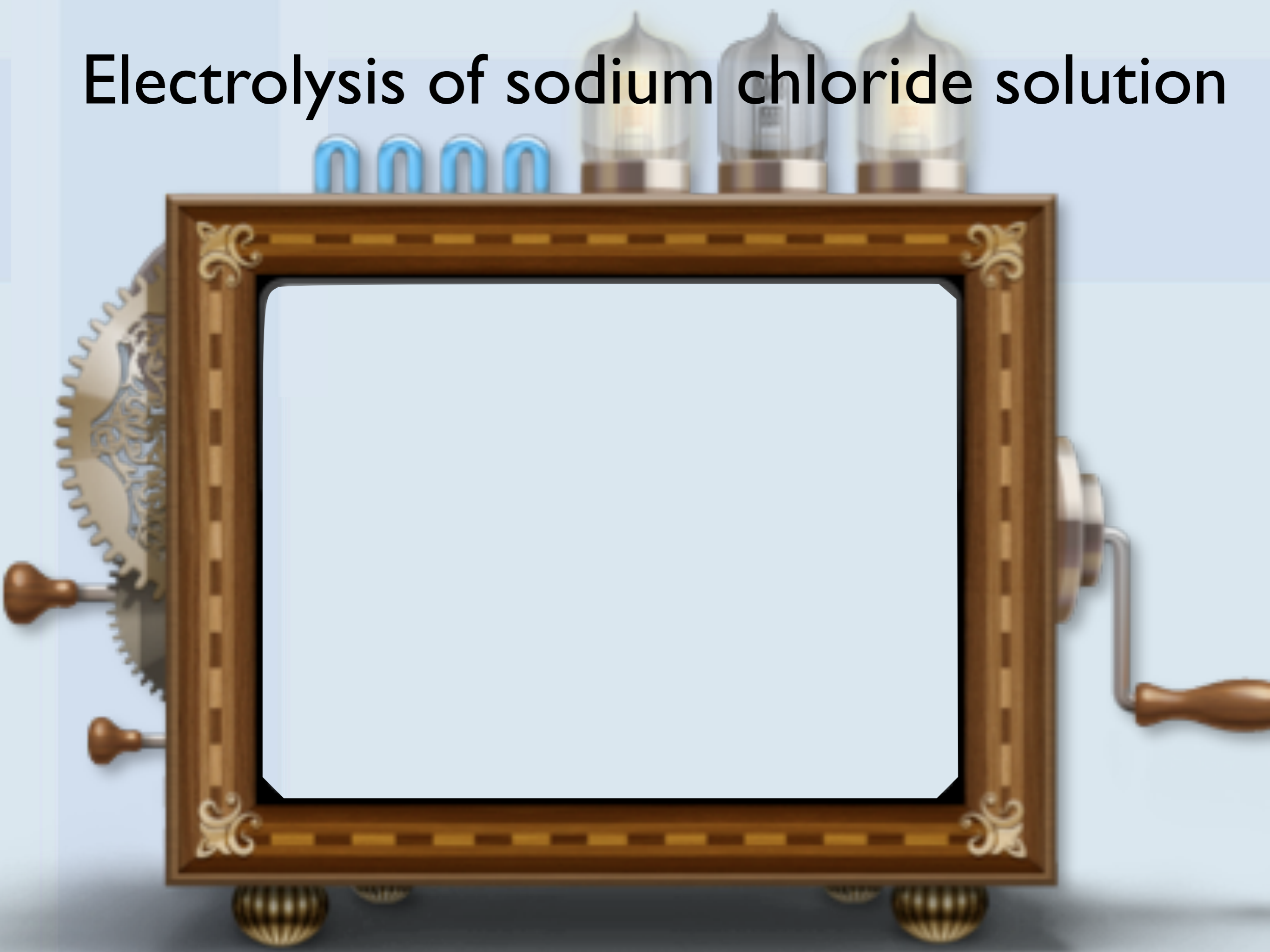
<b>Solution</b>	<b>Forms at cathode</b>	<b>Forms at anode</b>
$\text{NaCl}_{(\text{aq})}$	hydrogen gas	chlorine gas
$\text{CuSO}_4_{(\text{aq})}$	copper atoms	oxygen gas
$\text{AgNO}_3_{(\text{aq})}$	silver atoms	oxygen gas
$\text{FeBr}_2_{(\text{aq})}$	hydrogen gas	bromine liquid
$\text{MgF}_2_{(\text{aq})}$		



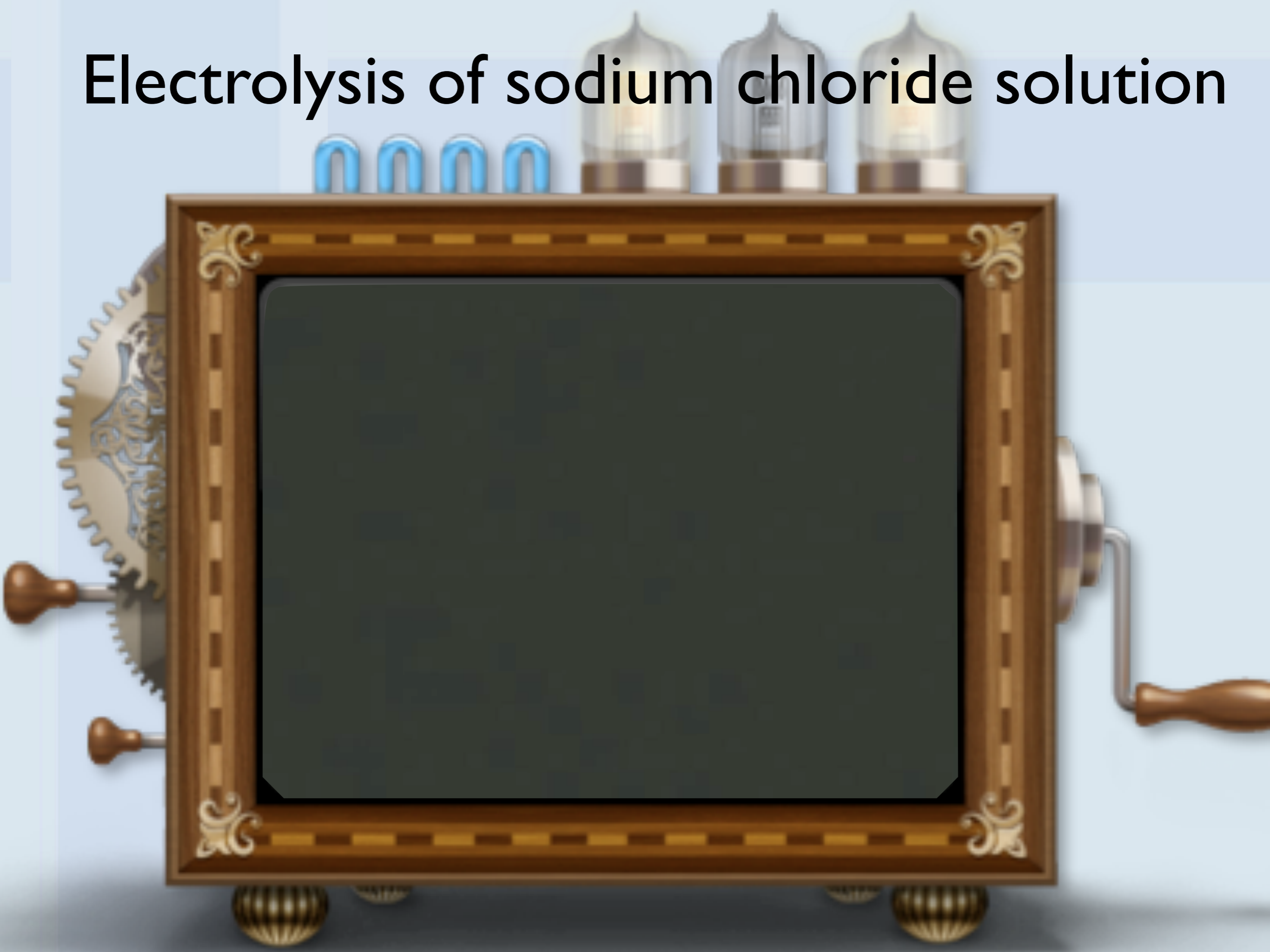
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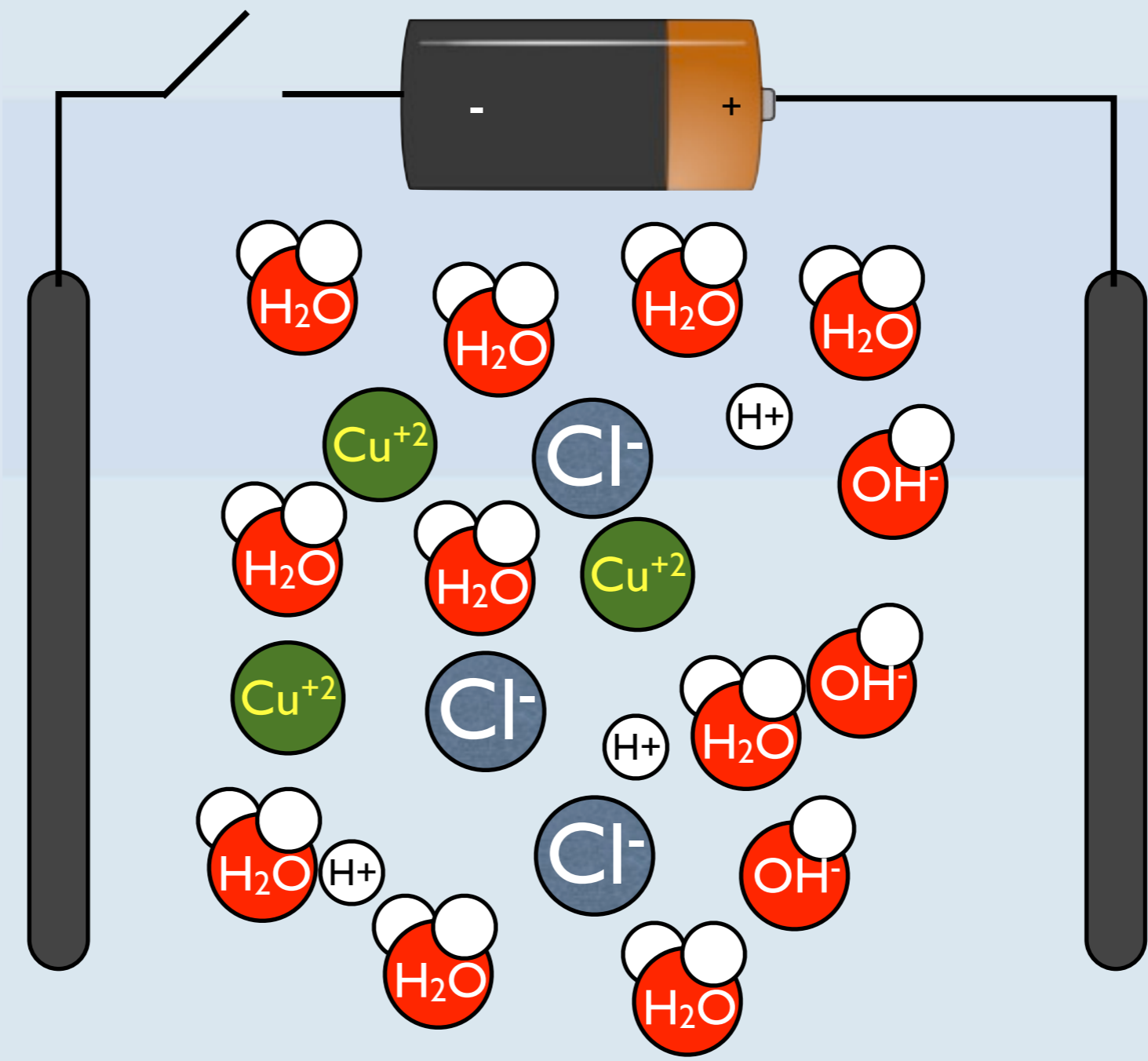
<b>Solution</b>	<b>Forms at cathode</b>	<b>Forms at anode</b>
$\text{NaCl}_{(\text{aq})}$	hydrogen gas	chlorine gas
$\text{CuSO}_{4(\text{aq})}$	copper atoms	oxygen gas
$\text{AgNO}_3 (\text{aq})$	silver atoms	oxygen gas
$\text{FeBr}_2 (\text{aq})$	hydrogen gas	bromine liquid
$\text{MgF}_{2(\text{aq})}$	hydrogen gas	fluorine gas

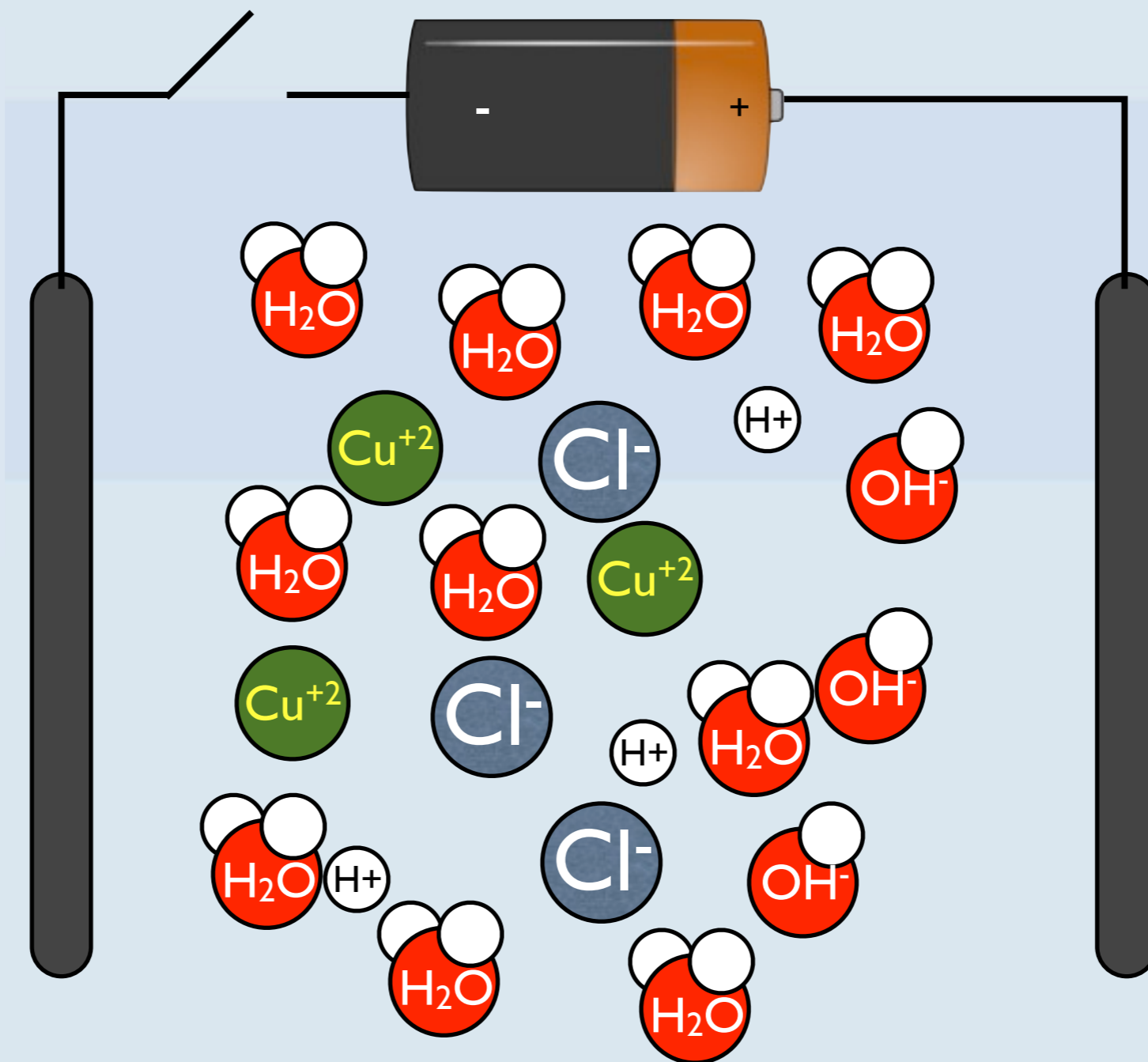
# Electrolysis of sodium chloride solution



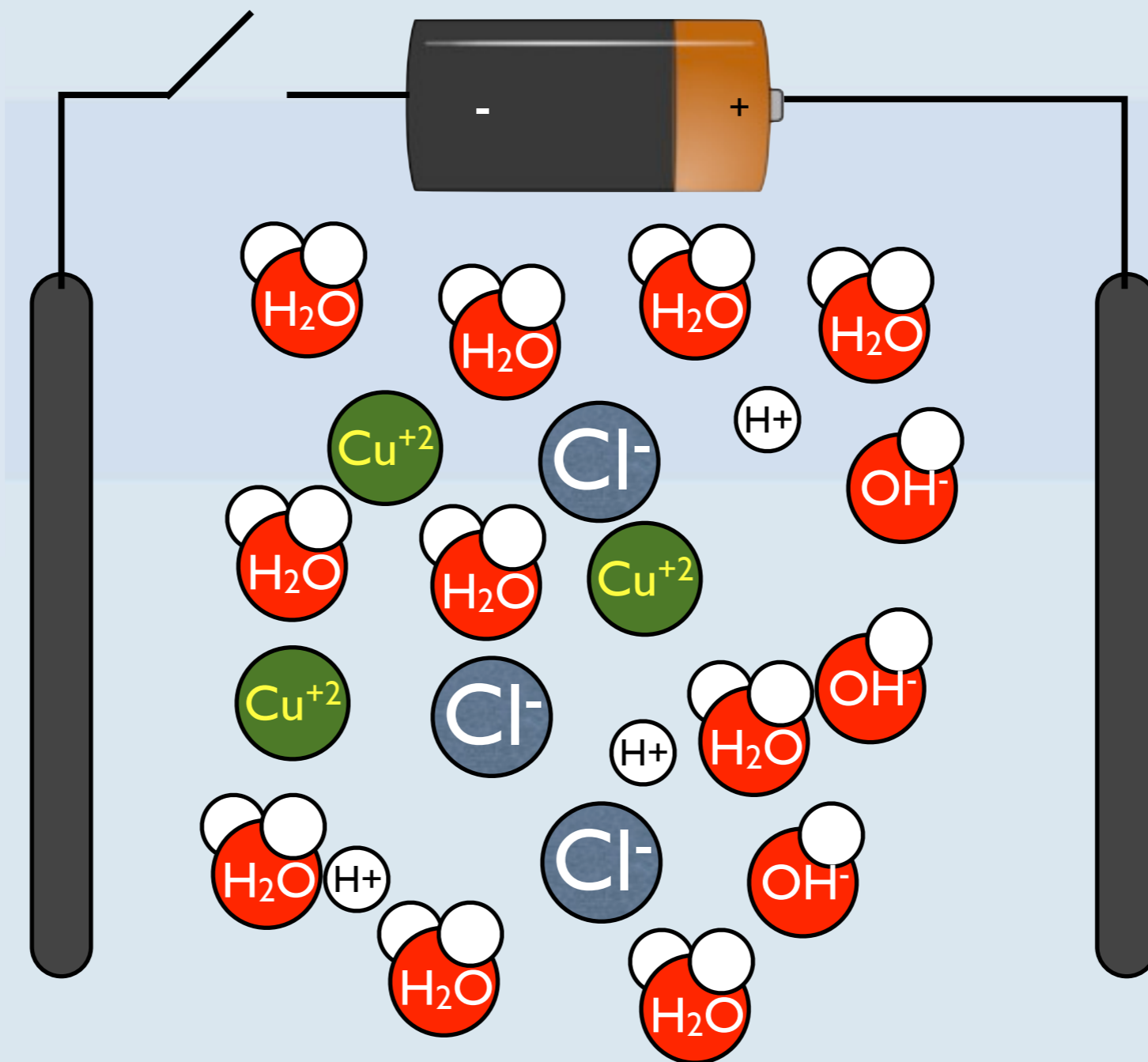
# Electrolysis of sodium chloride solution





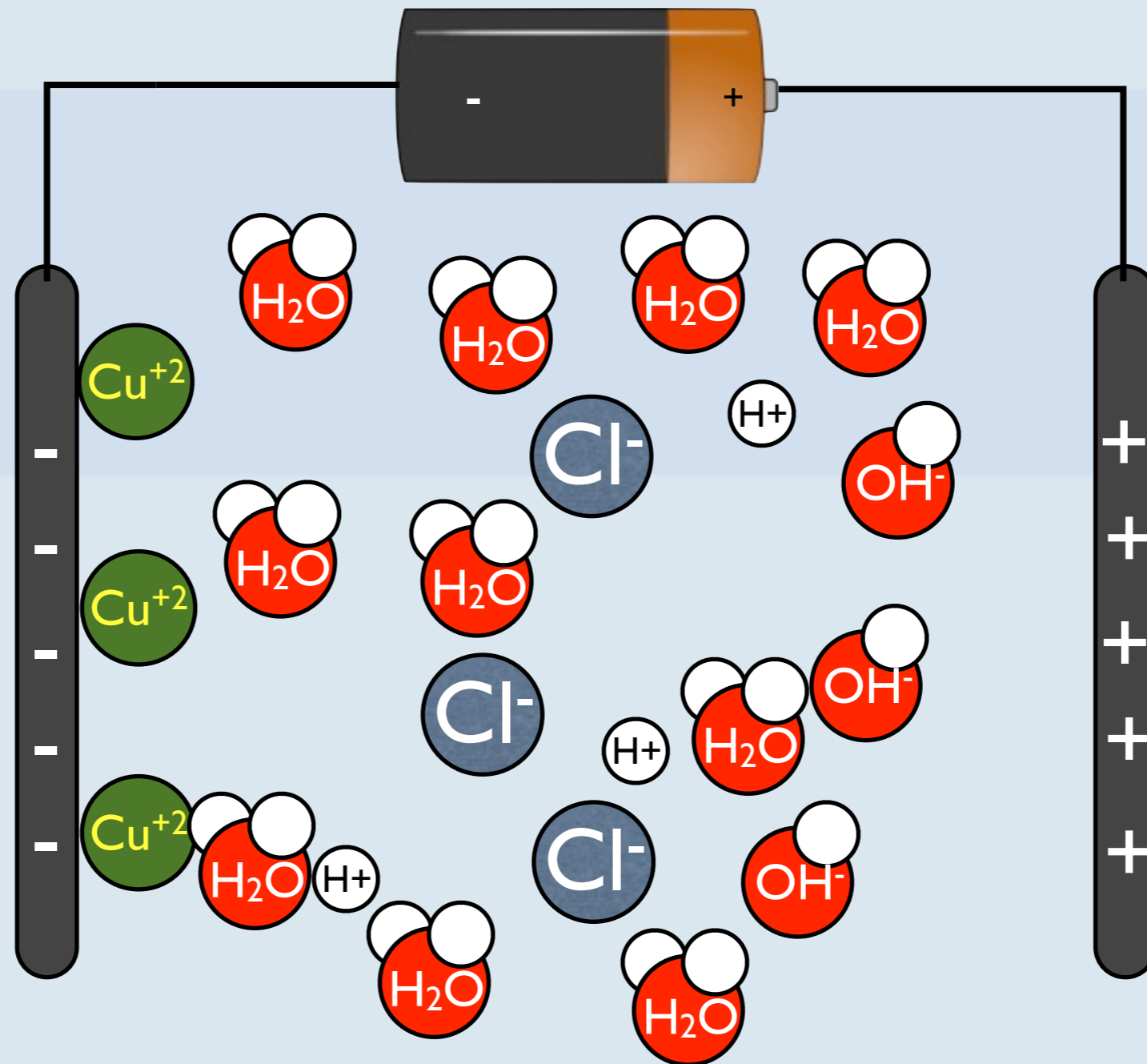


What do you predict would happen if you dissolve copper(II) chloride in water and place electrodes in the solution?



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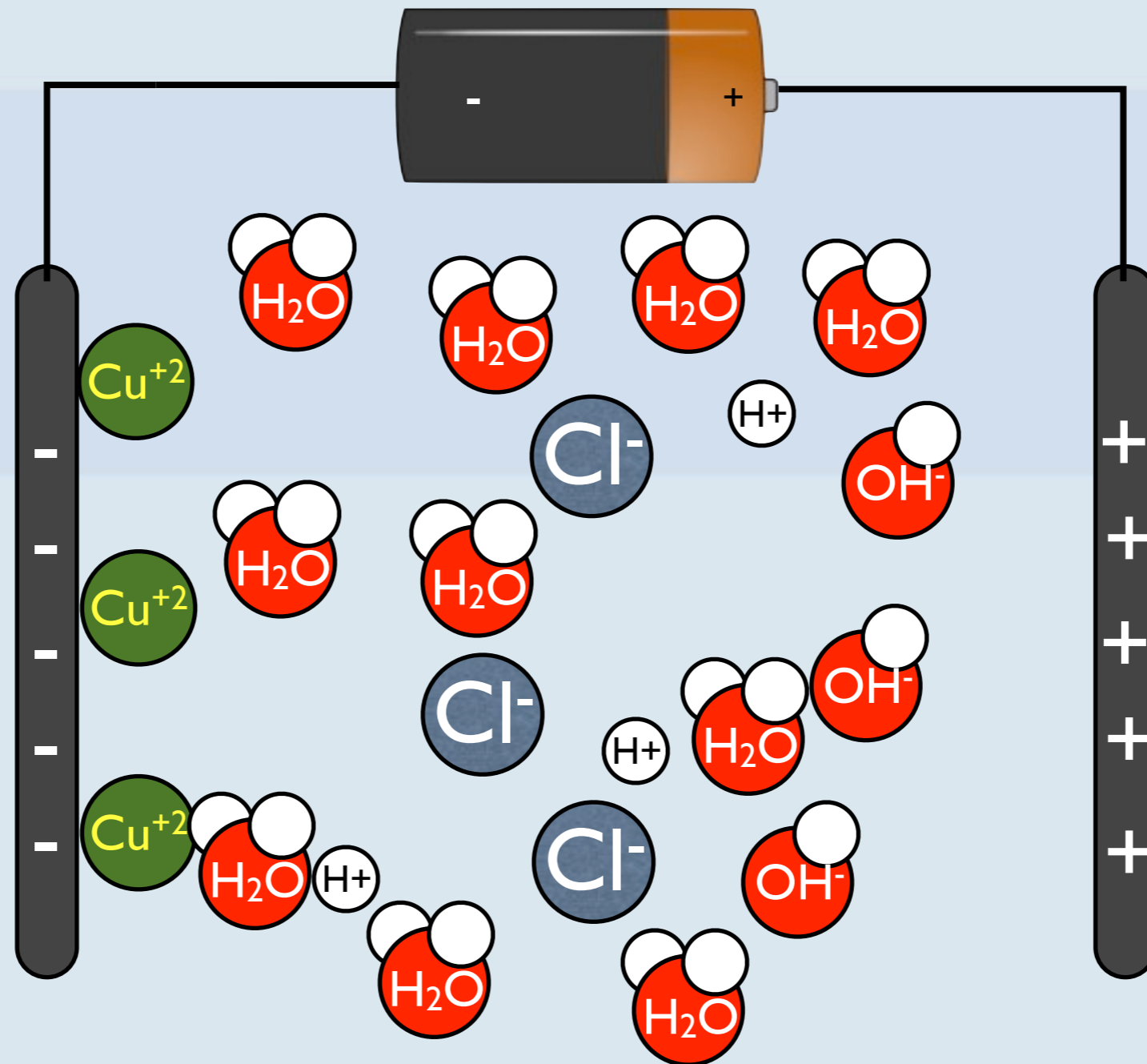
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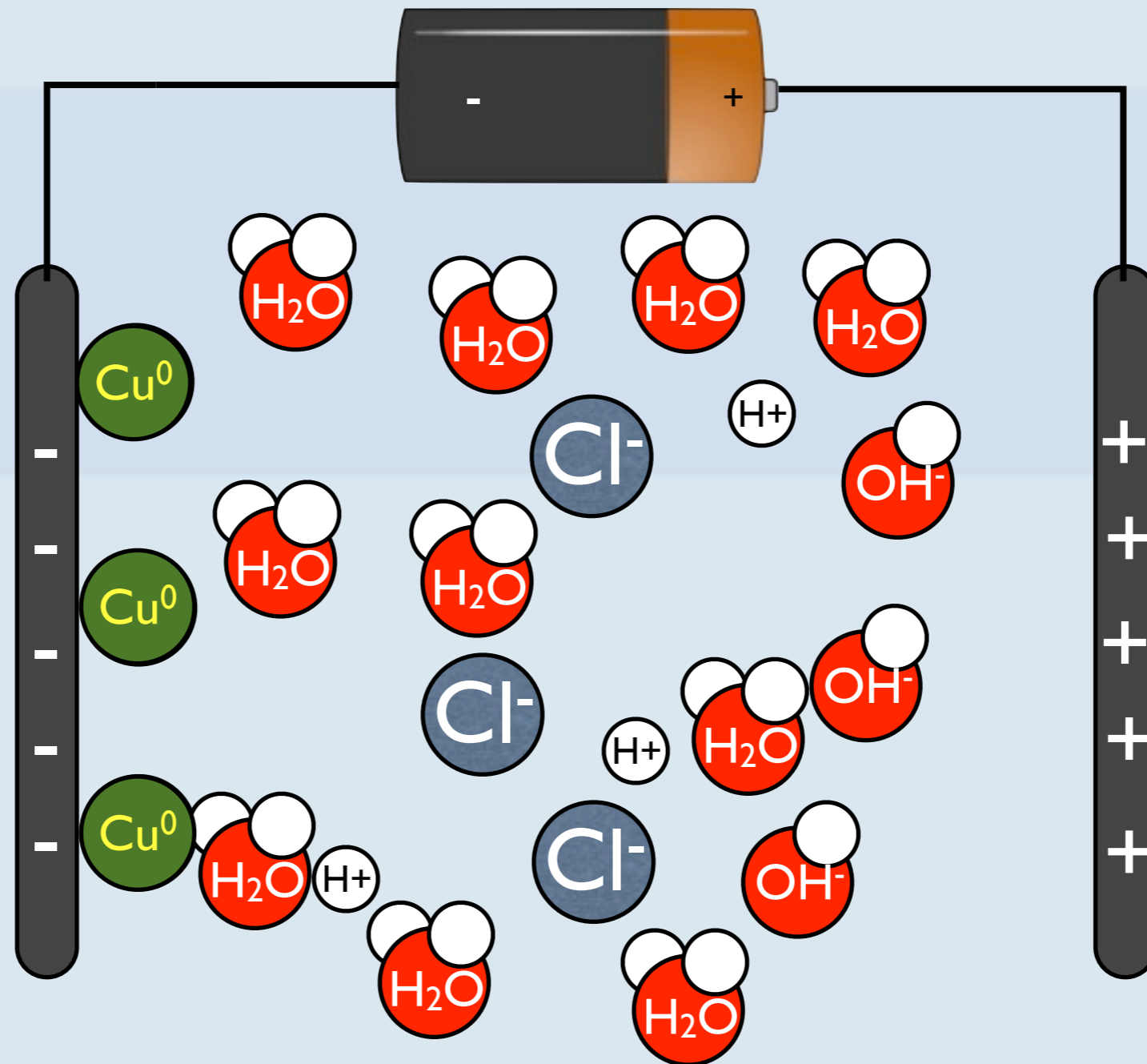




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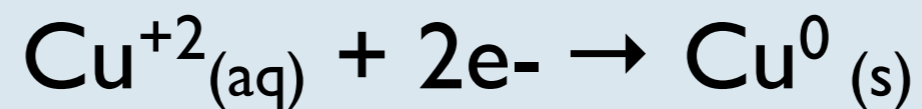
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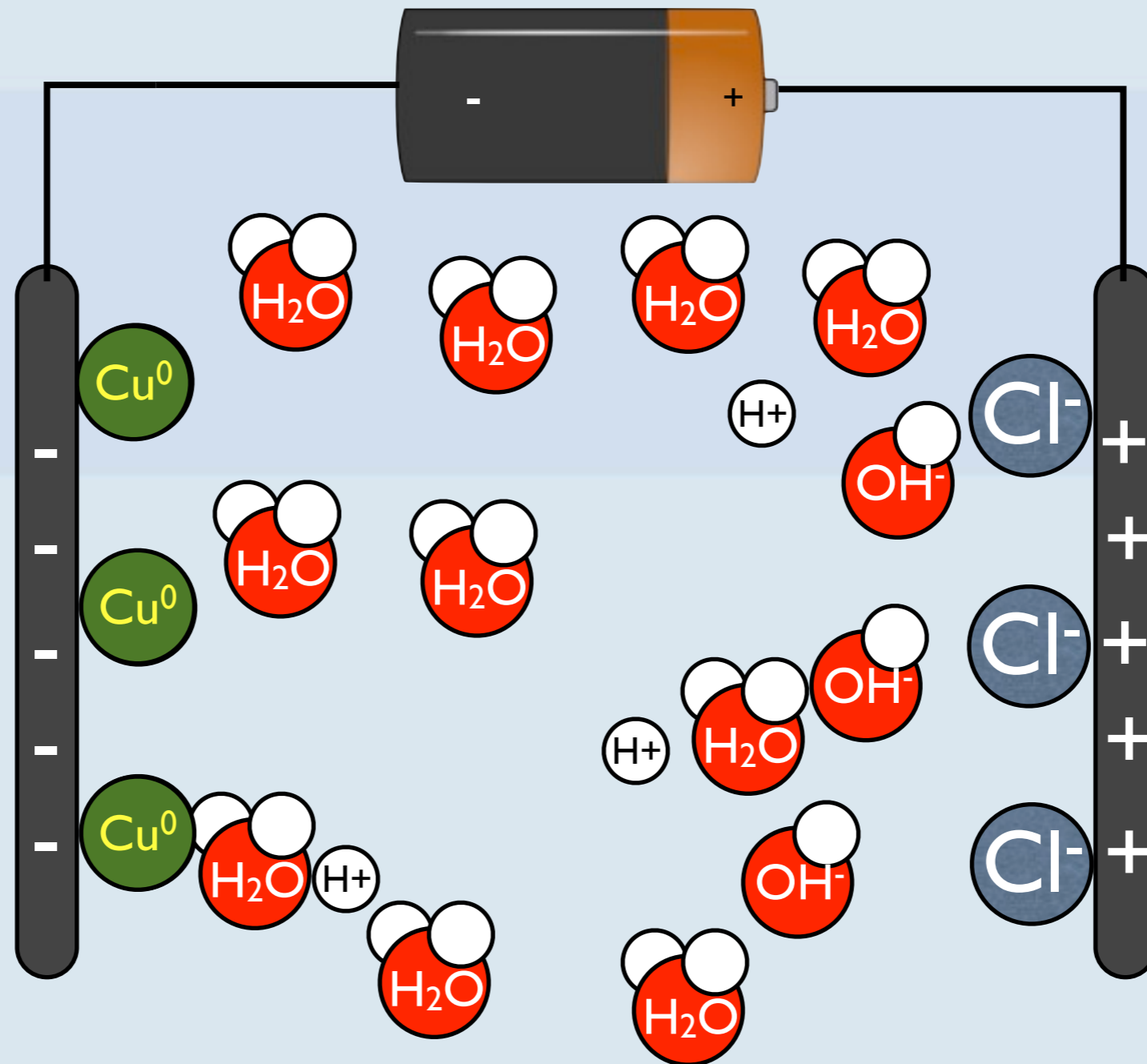




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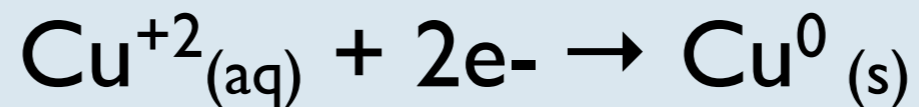
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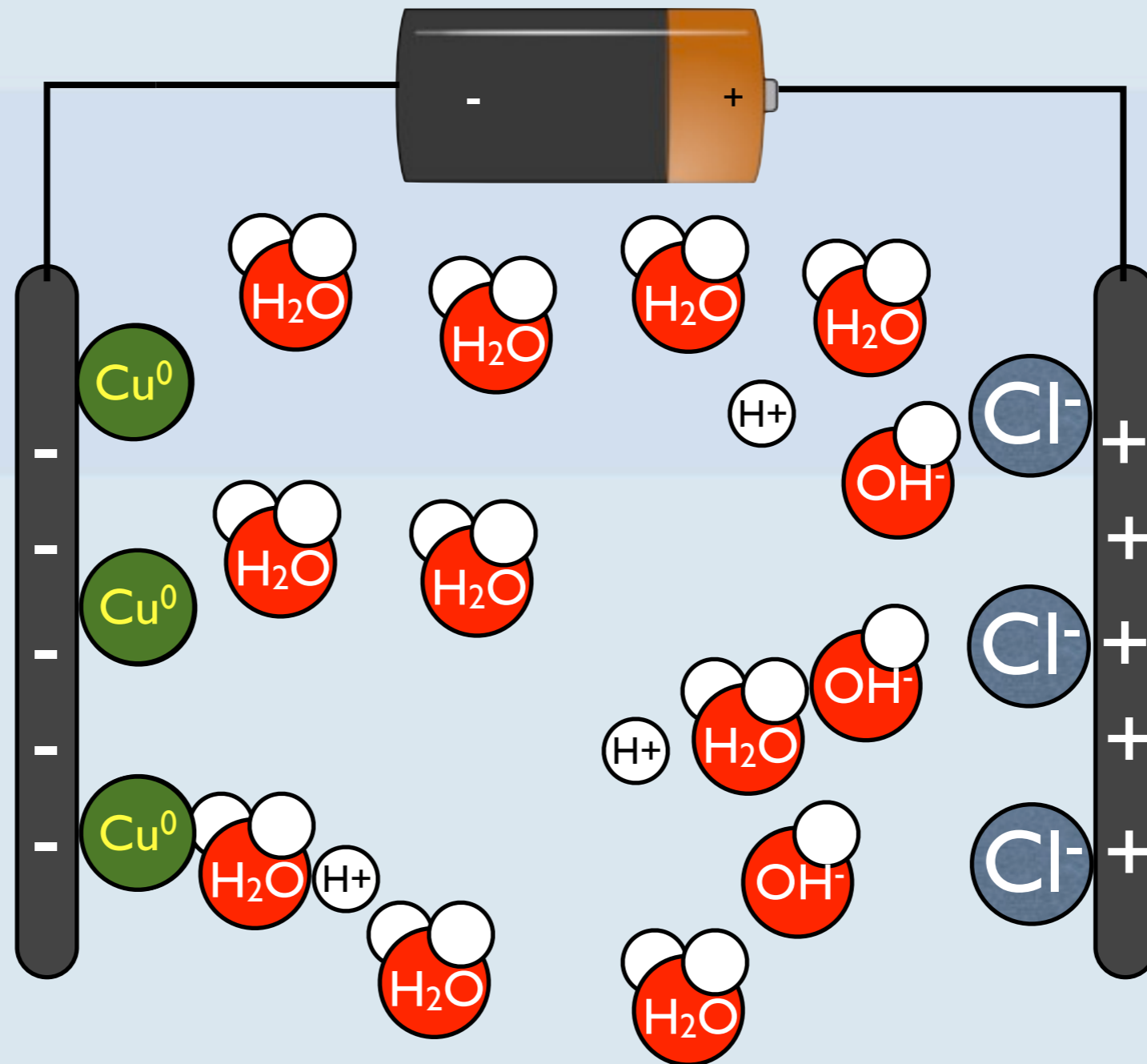


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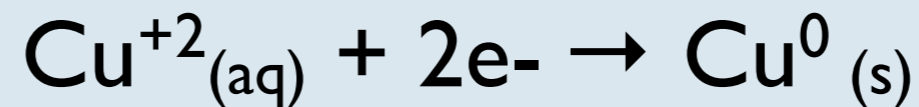


*Chloride ions are oxidized into chlorine atoms.*



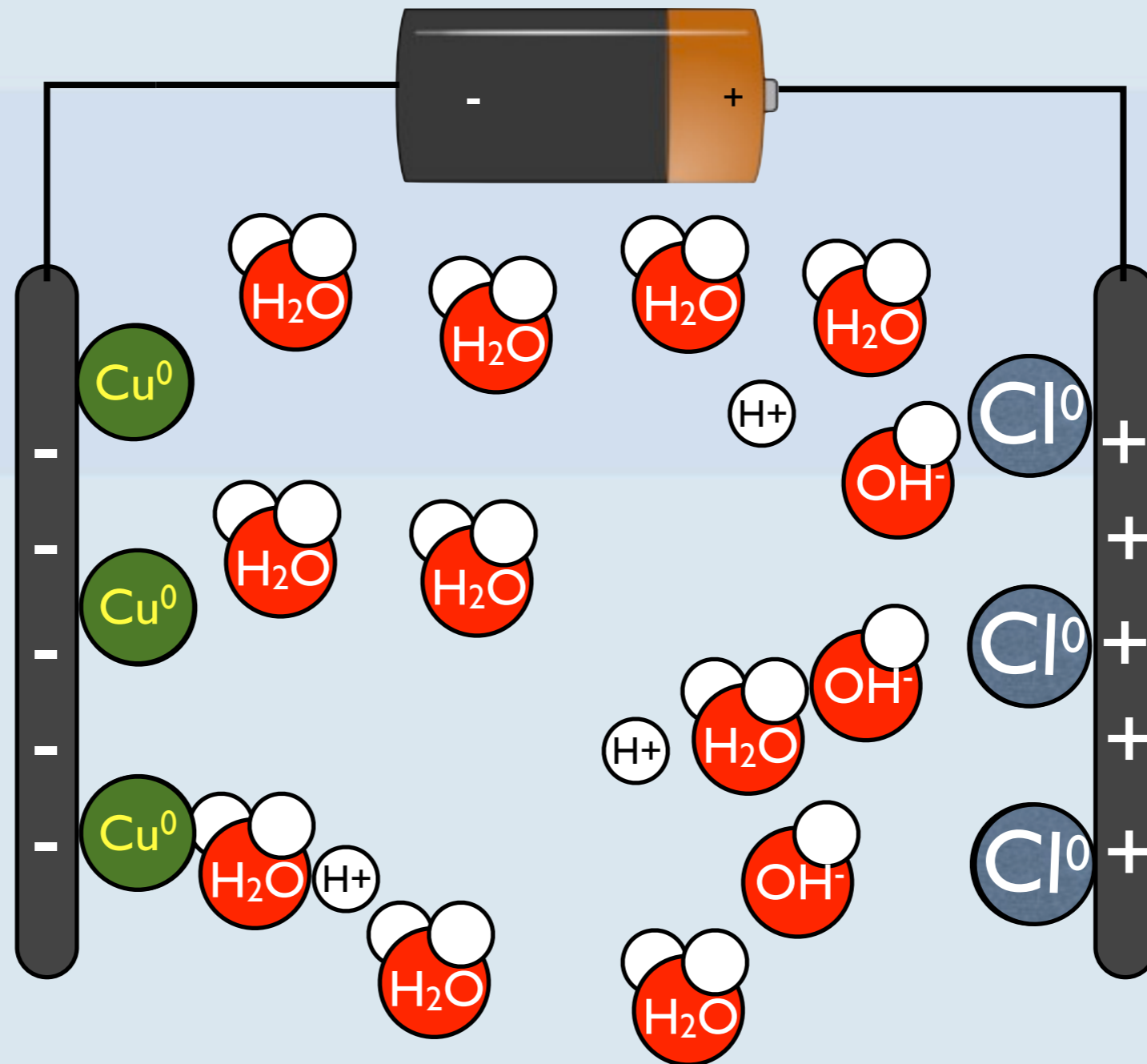
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# Electroplating



# Electroplating

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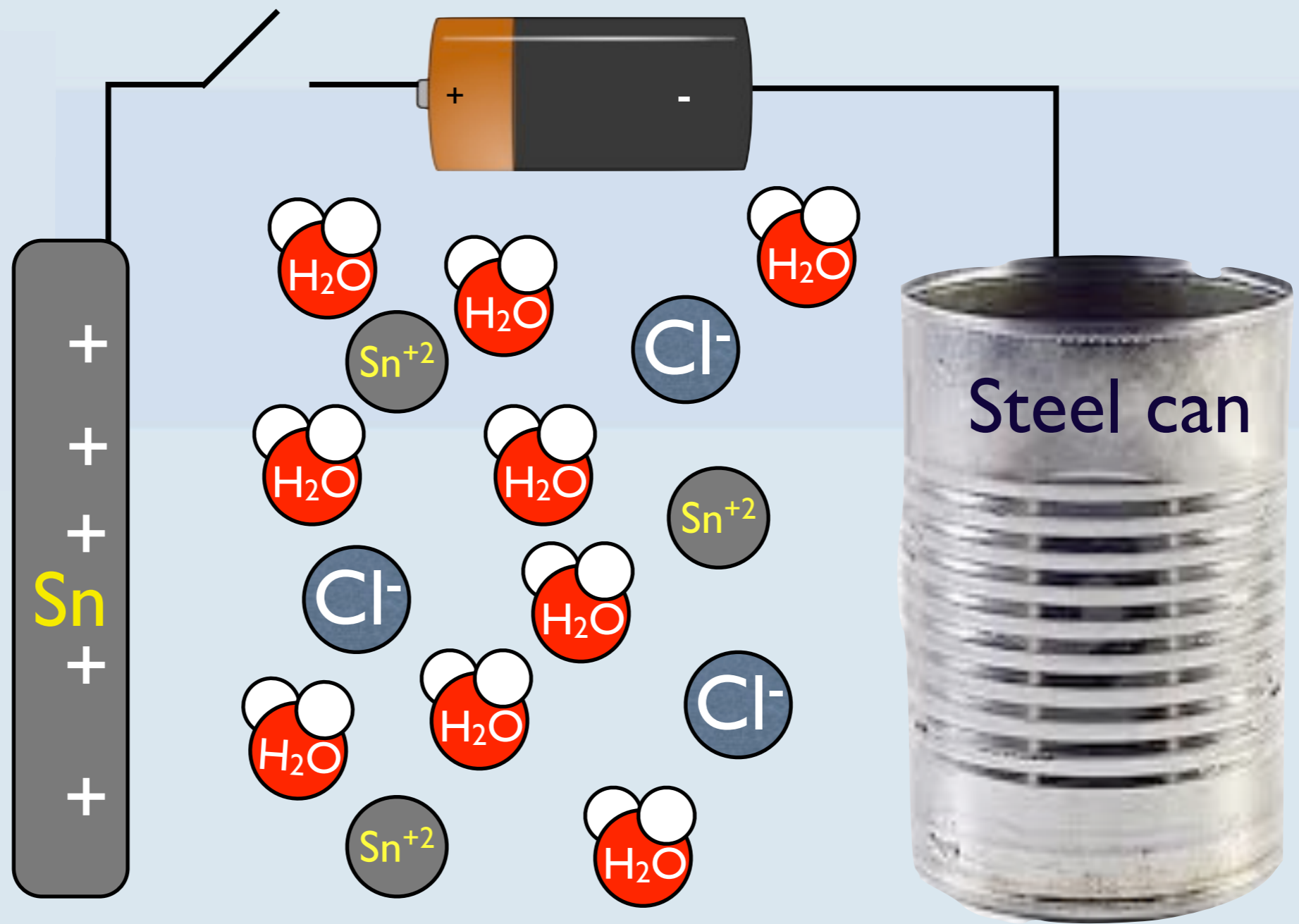




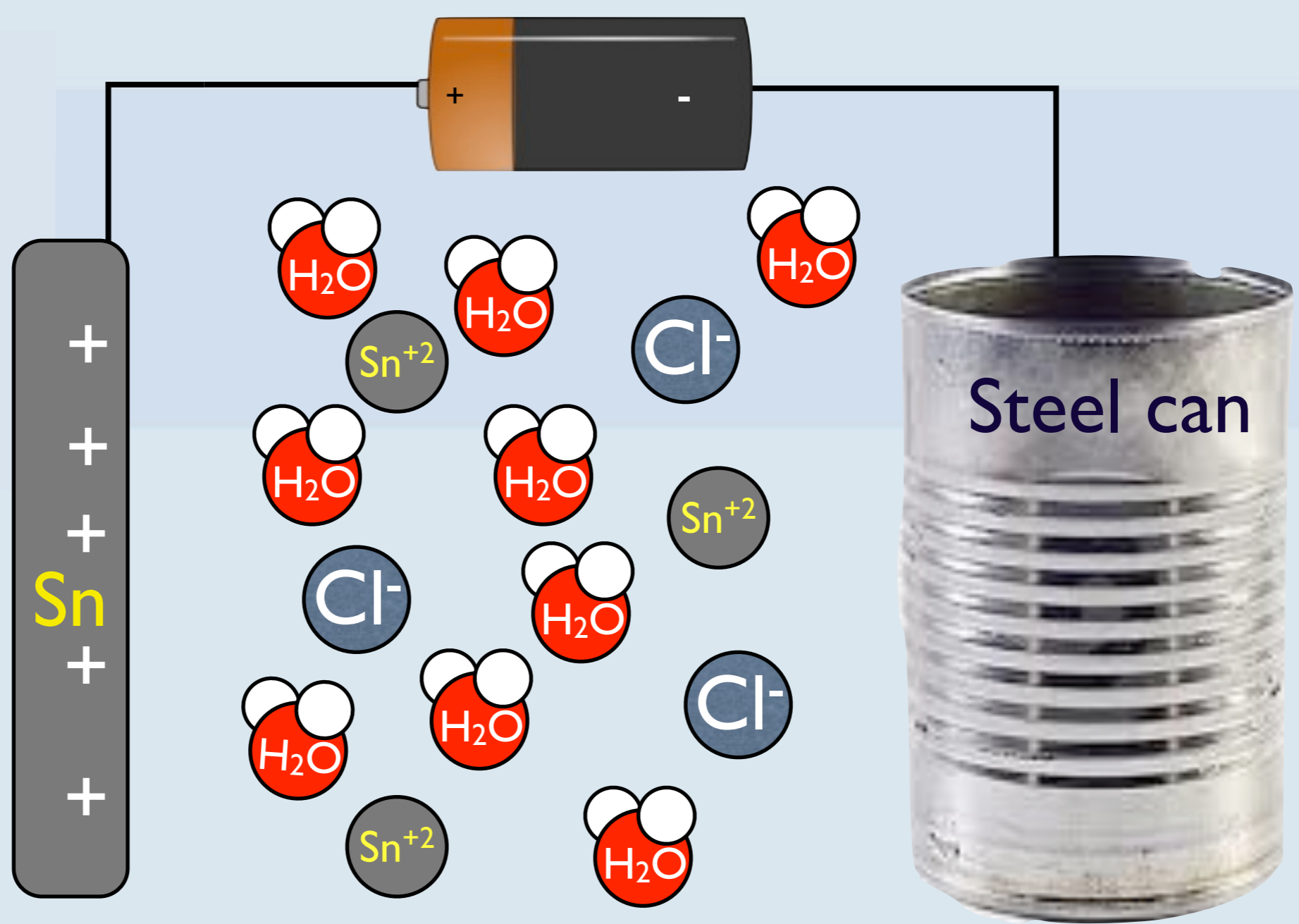
# Electroplating

- Electroplating is covering the surface of one metal with a thin layer of another metal.
- In electroplating, the anode(+) is the metal used to plate another metal while the cathode (-) the the metal being plated.
- The solution contains the metal ion of the metal being used to plate.

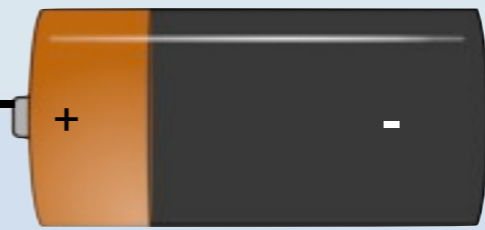
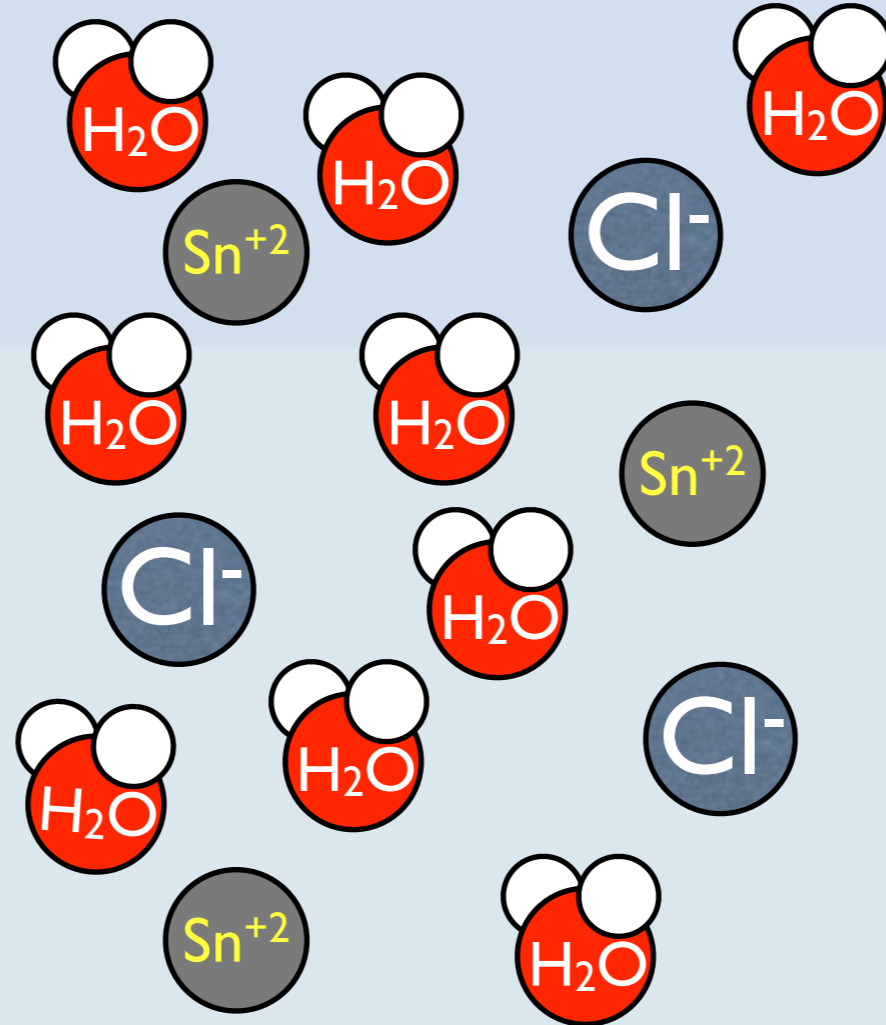
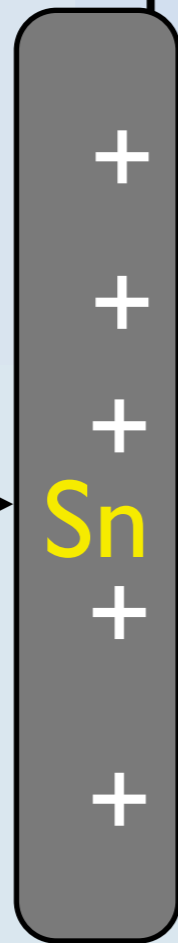
Text



Text



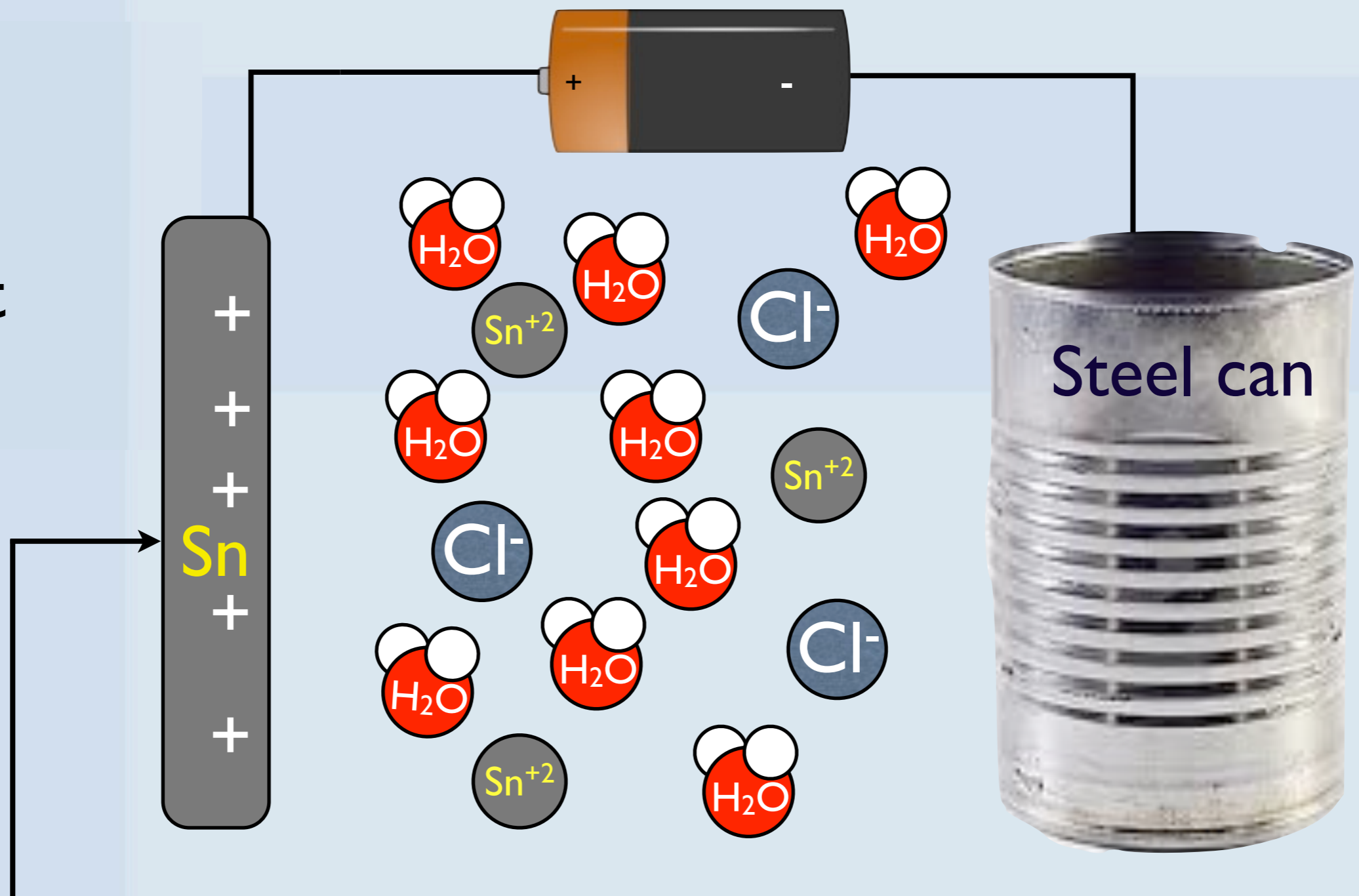
Text



Tin anode:

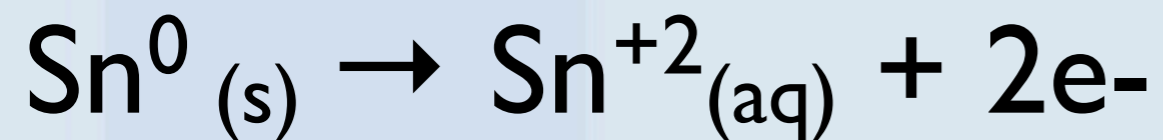
Tin atoms are oxidized into tin(II) ions. *These ions go into solution.*

Text

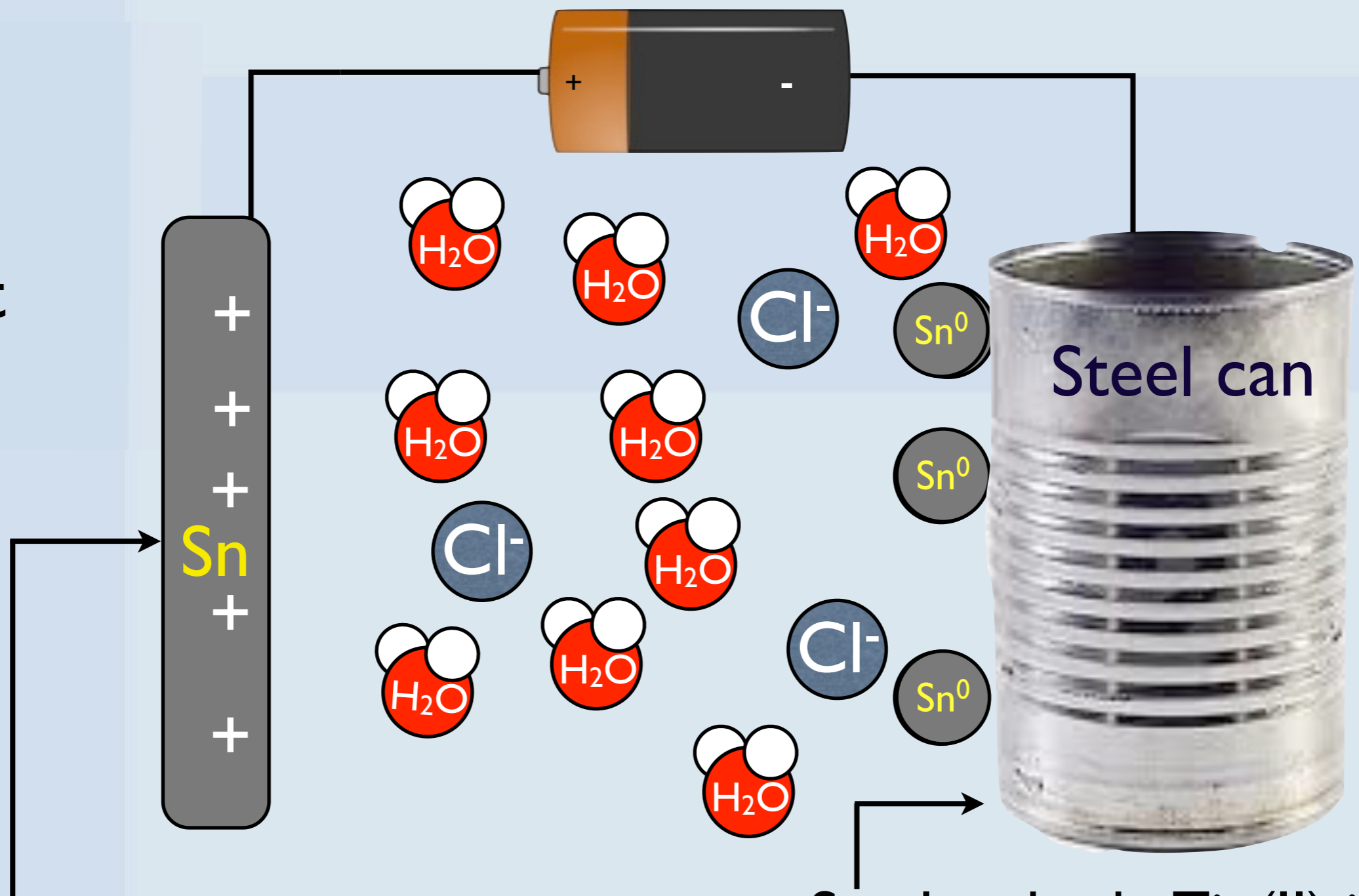


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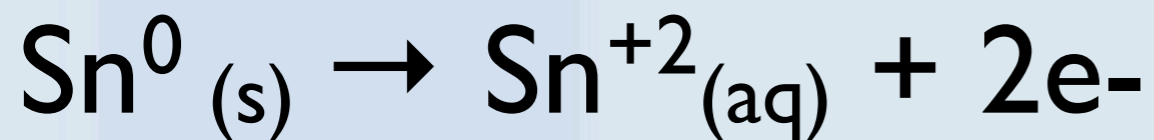


Text



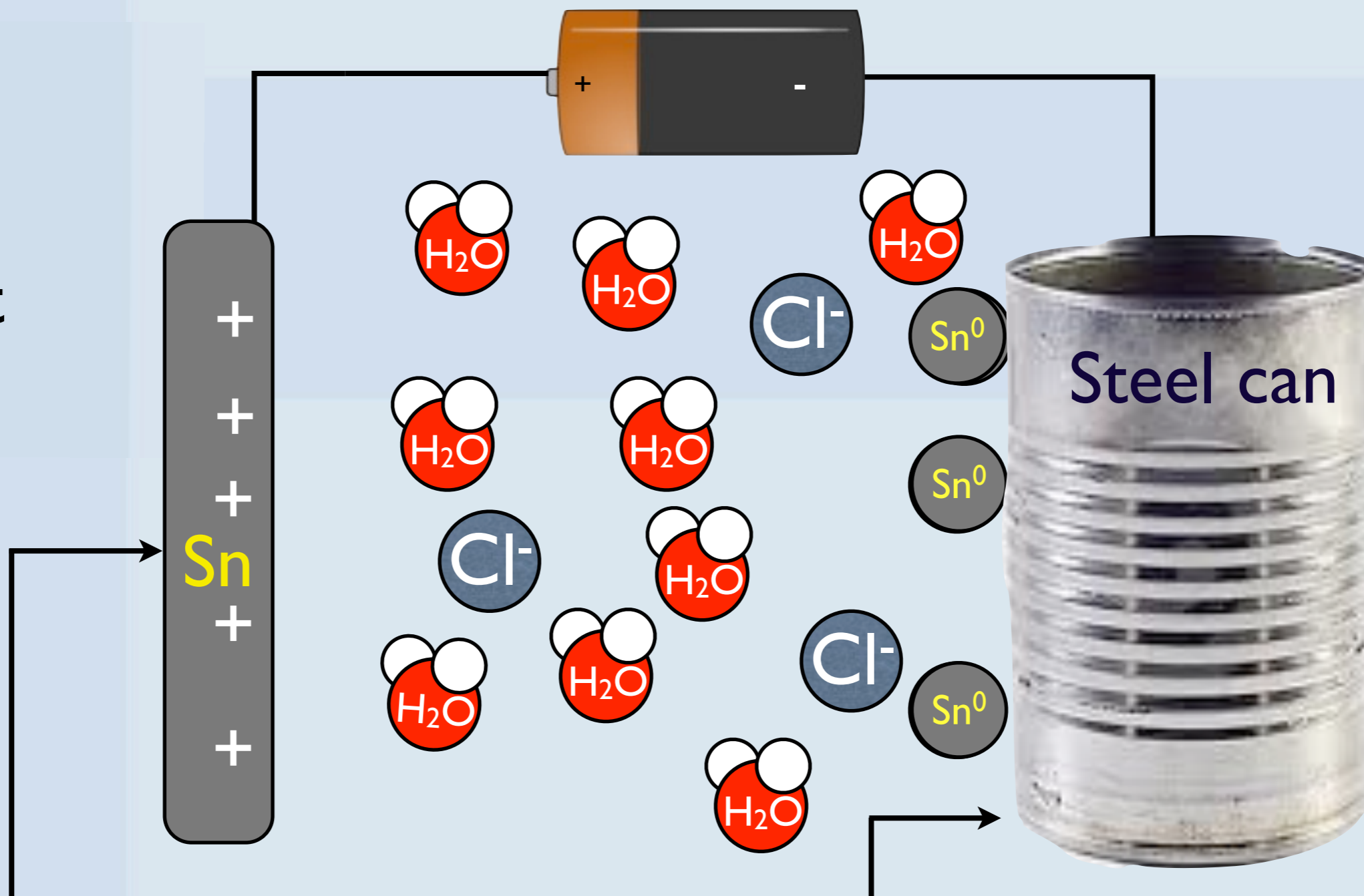
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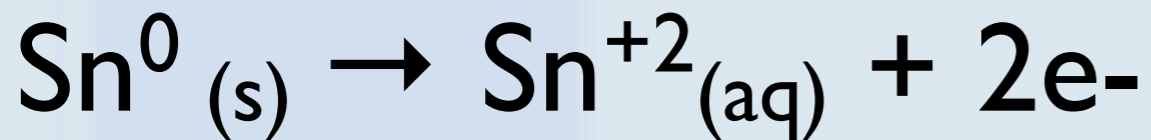
Steel cathode: Tin(II) ions are reduced into tin atoms on the surface of the steel. These atoms form solid tin on the surface of steel.

Text



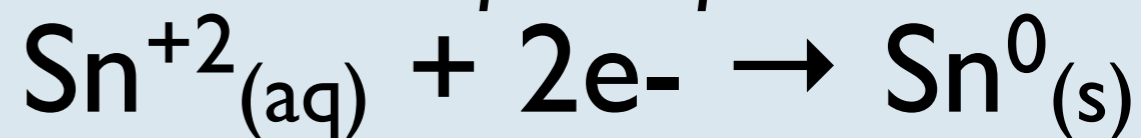
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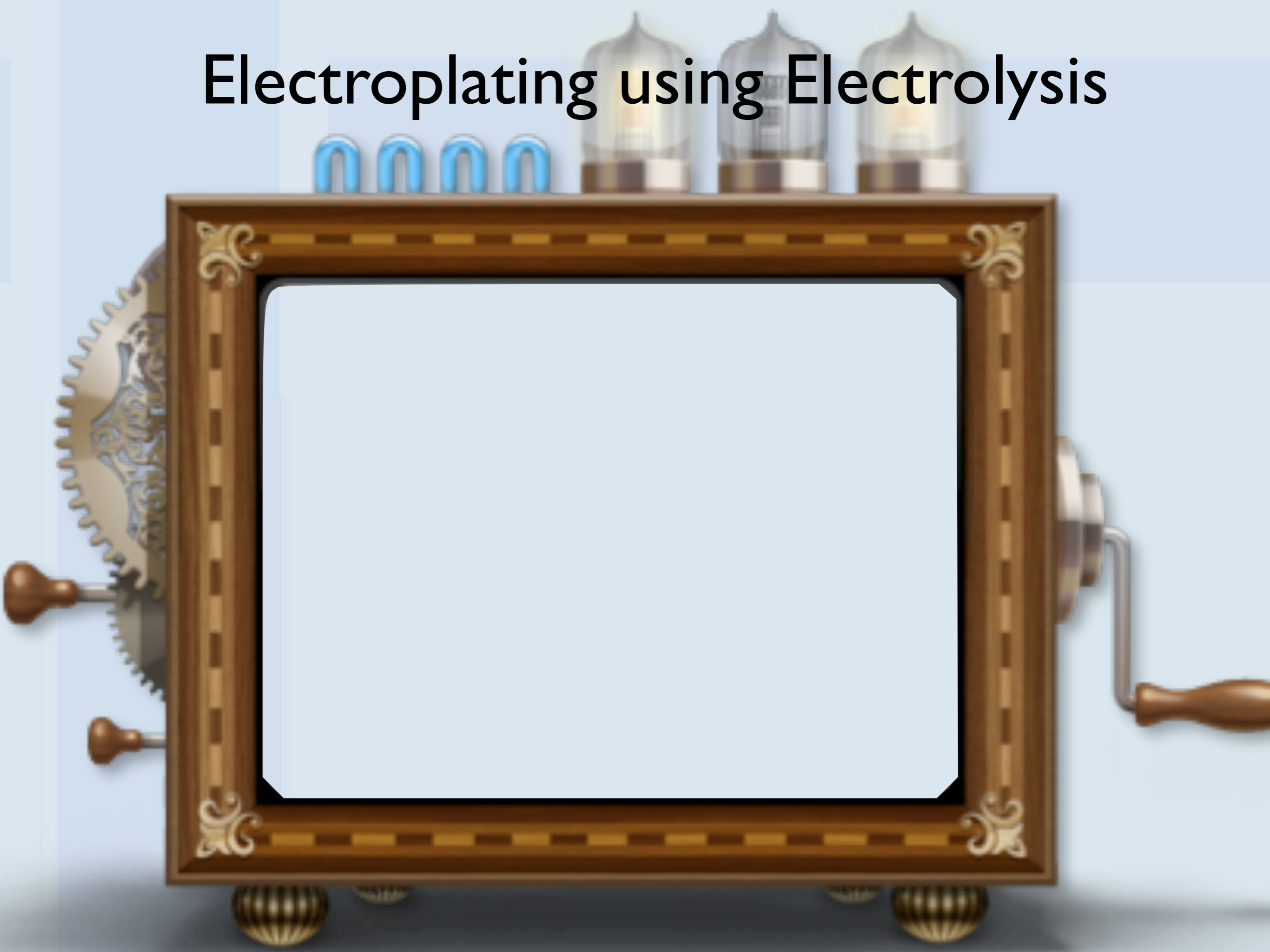


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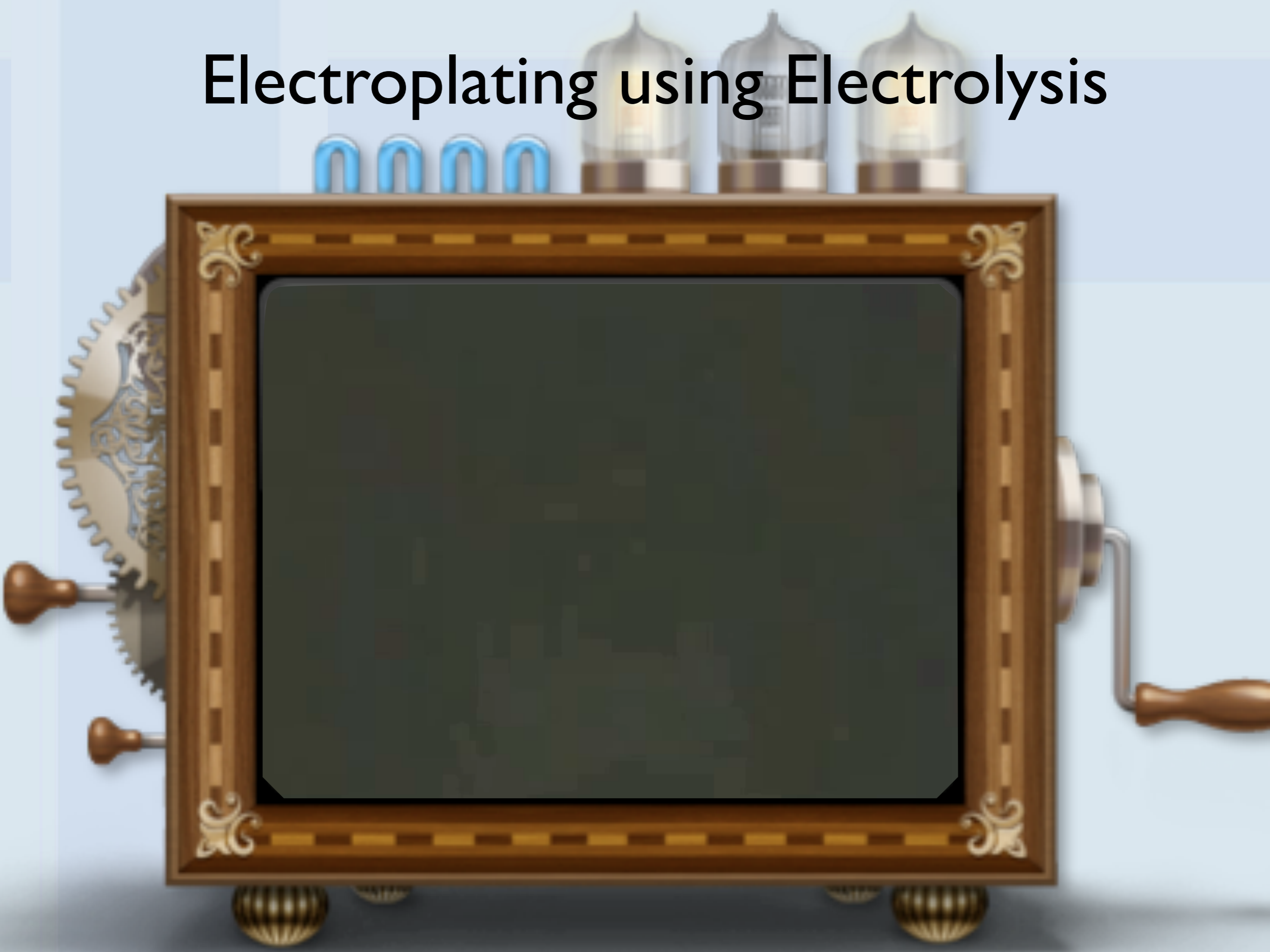


# Electroplating using Electrolysis





# Electroplating using Electrolysis





**Any  
Questions?**