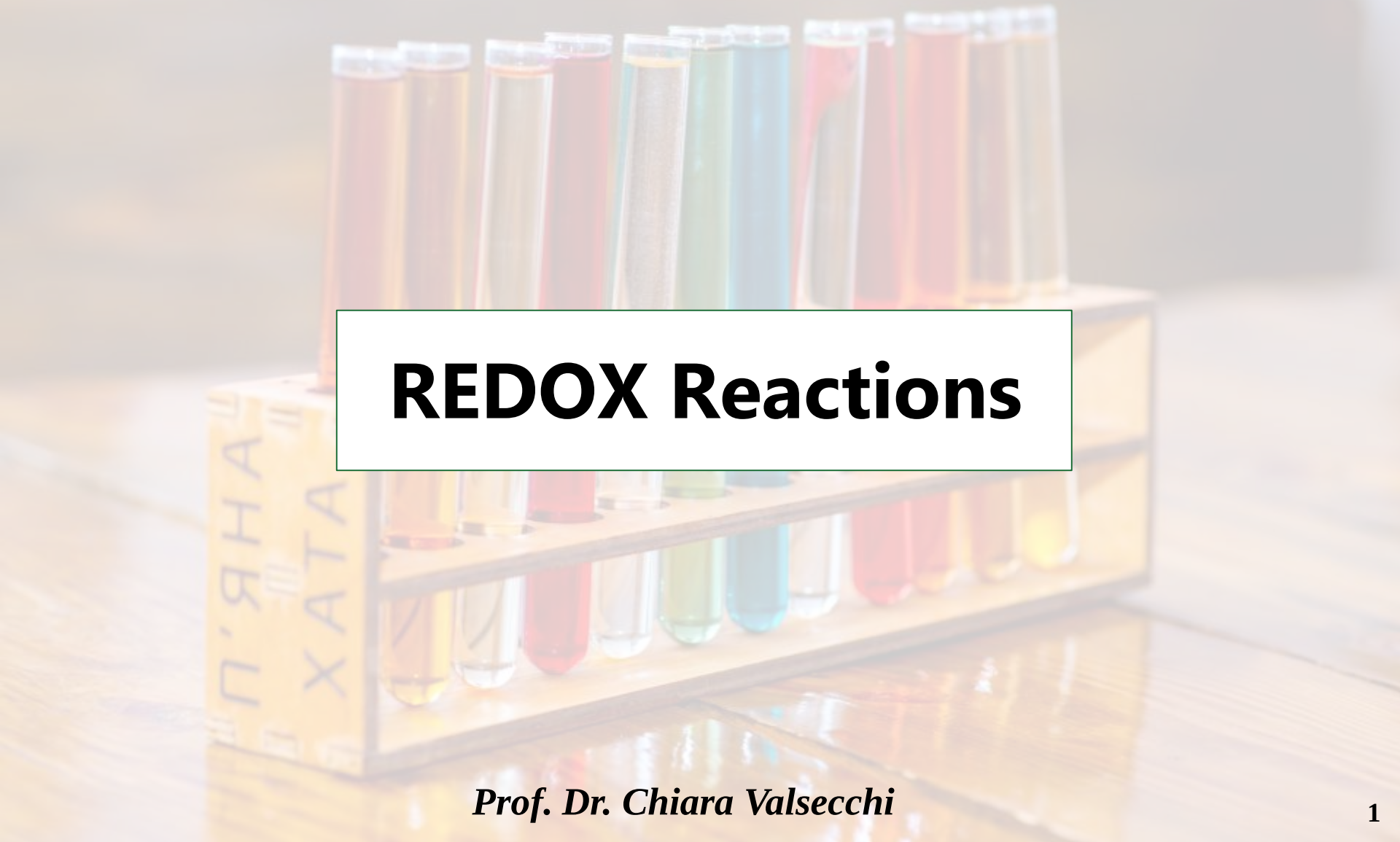


REDOX Reactions

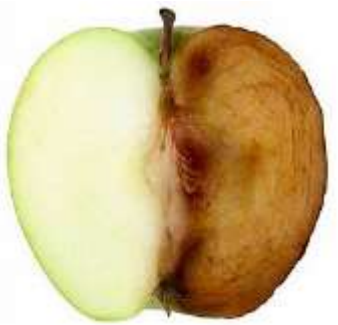
Prof. Dr. Chiara Valsecchi

Class Goals

- What happens in Redox reactions
- *Review:* the Oxidation Number - **Nox**
- How to identify a Redox reaction
- Stoichiometry of a Redox reaction

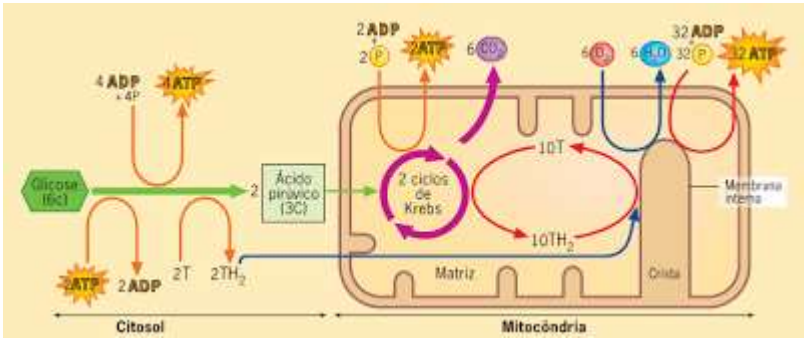
Everyday REDOX

Rust



Food oxidation

Combustion

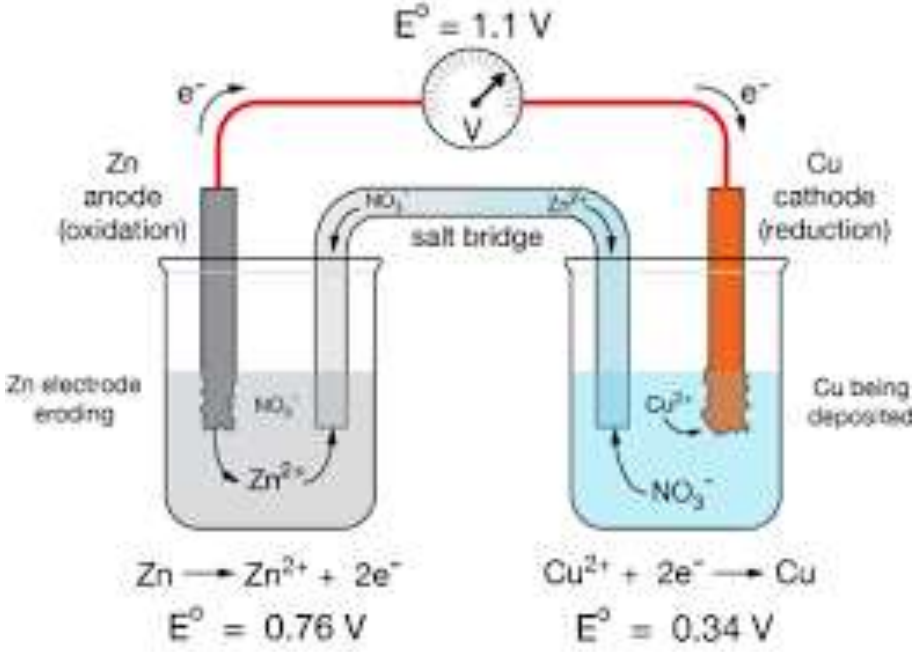


Celular respiration

Everyday REDOX

Traditional/Herbal medicine

Electrochemistry

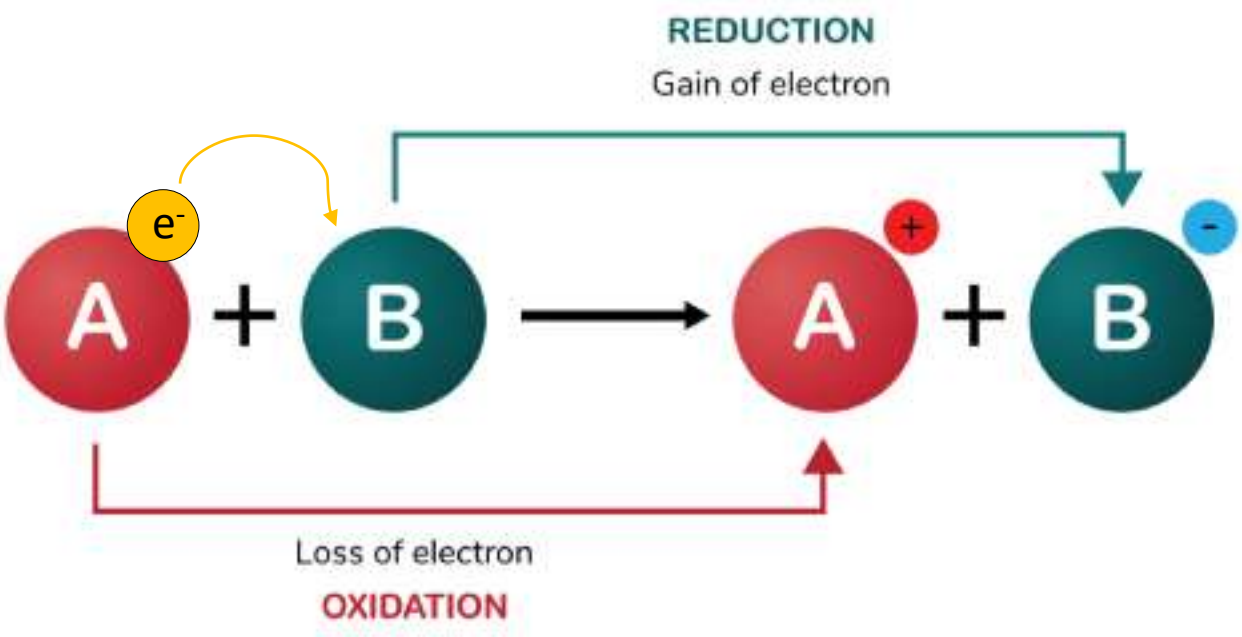


Definitions

A Redox reaction requires transfer of electrons between two molecules.

The Redox reaction is a combined process:

- half reaction is an oxidation: reagent **loses** electrons
- half-reaction is a reduction : reagent **gain** electrons

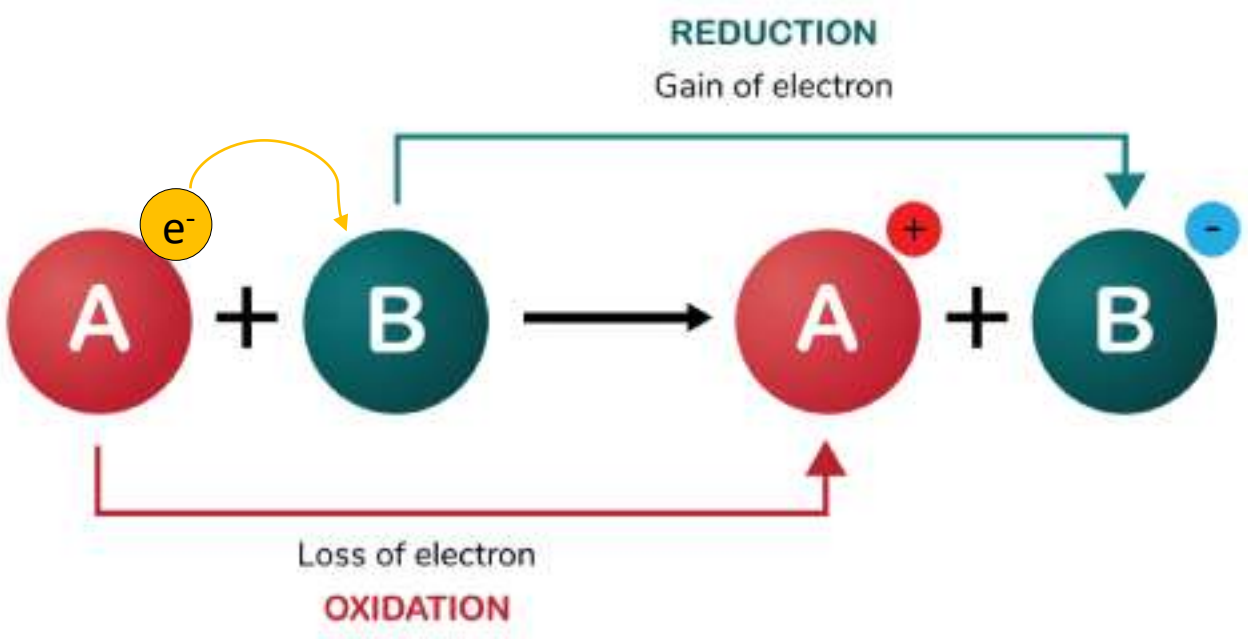


Definitions

Electrons are negatively charged:

oxidation: ELEMENT **loses** electrons ⟶ more POSITIVE

reduction: ELEMENT **gain** electrons ⟶ more NEGATIVE



Oxidation number: Nox

The hypothetical number of electron that an atom can accept/donate in a bond, always considered as ionic bond.

- Based on element electronegativity
- The most electronegative atoms carries a NEGATIVE Nox, all the other have POSITIVE Nox

Elements can have different Nox depending on the type of bond they are involved

Oxidation number: Nox

No ions are present in **covalent compounds** (electrons are shared)

Oxidation Number or State: what will be the charge of an atom if the bond would be ionic ?

Imaginary charge

The most electronegative atom receive the negative charge. All the others are positive

Nox examples

Examples of chlorine containing species	Oxidation state of chlorine
HCl	-1
Cl_2	0
$HClO$	+1
$HClO_2$	+3
ClO_2	+4
$NaClO_3$	+5
$NaClO_4$	+7

Bleach

Examples of nitrogen containing compounds	Oxidation state of nitrogen
NH_3	-3
N_2H_4	-2
N_2	0
N_2O	+1
NO	+2
HNO_2	+3
HNO_3	+5

Toxic in water

Rules

Element	Oxidation state	Exceptions
Group 1	+1	None
Group 2	+2	None
Hydrogen	+1 in compounds containing non-metals	-1 in hydrides (compounds containing a metal) NaH
Fluorine	-1	None
Oxygen	-2	Takes other values when bonded to fluorine. -1 in hydrogen peroxide H_2O_2

Charge Balance: the total Nox sum has to be equal to the total charge of the molecule/ion.

Rules

1. The most electronegative atom gets the negative charge (normally this is oxygen)

2. The weighted sum of the Nox has to be equal to the charge of the molecule/ion

H_2O = neutral molecule

ClO^- = 1 negative charged

Exercises

NO_2	
N_2O_5	
$HClO_3$	
HNO_3	
$Ca(NO_3)_2$	
MnO_4^-	

Exercises

NO_2	N= +4, O = -2
N_2O_5	N = +5, O = -2
$HClO_3$	H=+1, Cl=+5, O = -2
HNO_3	H=+1, N = +5, O = -2
$Ca(NO_3)_2$	Ca=+2, N =+5, O= -2
MnO_4^-	Mn=+7, O= -2

Exercises

$CaCl_2$	
$K_2Cr_2O_7$	
KH	
HCO_3^-	
MgO	

Exercises

$CaCl_2$	Ca = +2, Cl = -1
$K_2Cr_2O_7$	K=+1, Cr=+6, O=-2
KH	K = +1, H= -1
HCO_3^-	H= +1, C=+4, O= -2
H_2O	H= +1, O= -2
MgO	Mg = +2, O = -2

Exercises

Identify the Nox of each element of the following molecules:

C_2H_4O K_2CrO_4 $Na_2(SO_4)_3$ NaClO

N_2O_4 $C_6H_{12}O_6$ CO_2

Exercises

Identify the Nox of each element of the following molecules:

C_2H_4O K_2CrO_4 $Na_2(SO_4)_3$ NaClO

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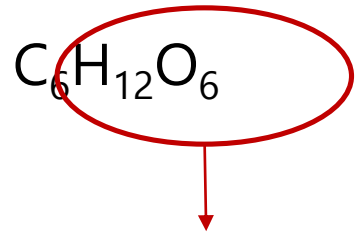

Exercises

Identify the Nox of each element of the following molecules:

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N_2O_4 $C_6H_{12}O_6$ CO_2

Charge balance:

$$\overset{x}{C_6}\overset{+1}{H_{12}}\overset{-2}{O_6}$$

Exercises

Identify the Nox of each element of the following molecules:

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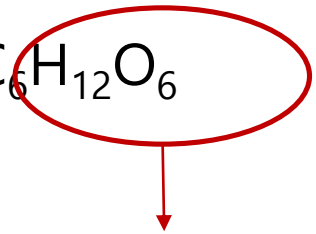

Rules + Charge balance:

$\overset{x}{C_6}\overset{+1}{H_{12}}\overset{-2}{O_6}$

$-2 \cdot 6 + 1 \cdot 12 + x \cdot 6 = 0$

Exercises

Identify the Nox of each element of the following molecules:

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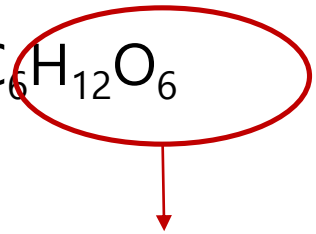


Rules + Charge balance:

$\overset{x}{C_6}\overset{+1}{H_{12}}\overset{-2}{O_6}$

$-2 \cdot 6 + 1 \cdot 12 + x \cdot 6 = 0$

$X = C_{nox} = 0$

Why we need Nox ?

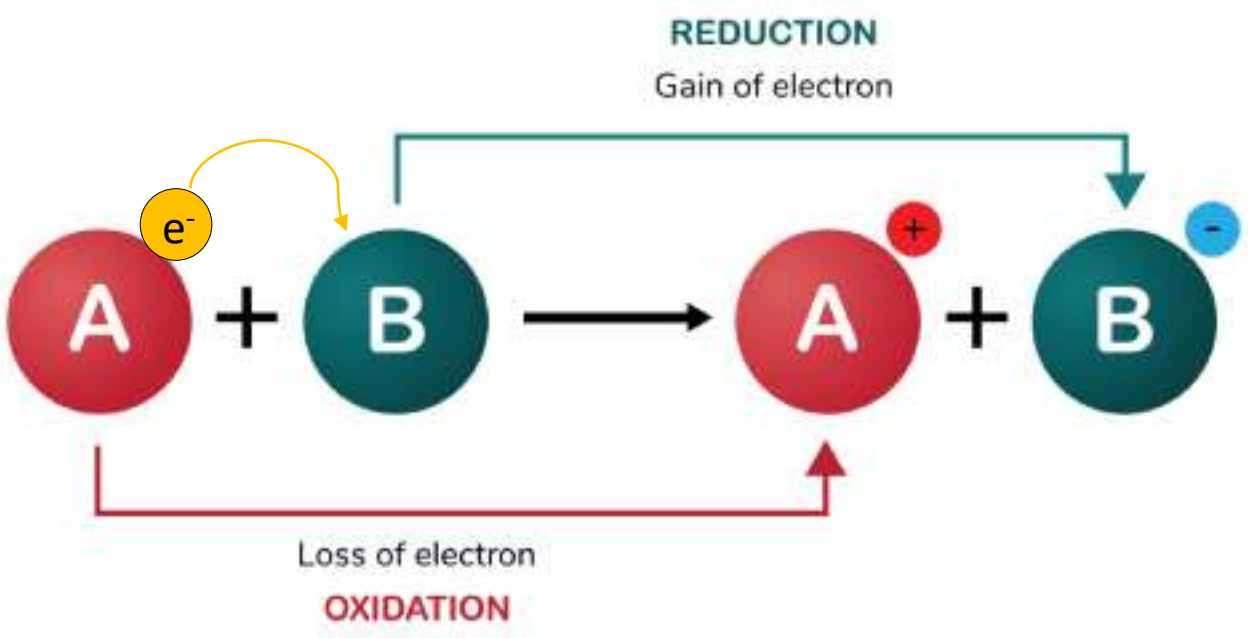
Careful examination of the oxidation numbers of atoms allows us to determine what is oxidized and what is reduced in an oxidation-reduction reaction

Redox reaction

Definitions

Half-reaction oxidation: ELEMENT **loses** electrons: **Nox increase**

Half-reaction reduction: ELEMENT **gain** electrons : **Nox decrease**



Salt formation

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

$$2Na_{(s)} \longrightarrow 2Na^{+} + 2e^{-}$$

$$Cl_2 + 2e^{-} \longrightarrow 2Cl^{-}$$

Salt

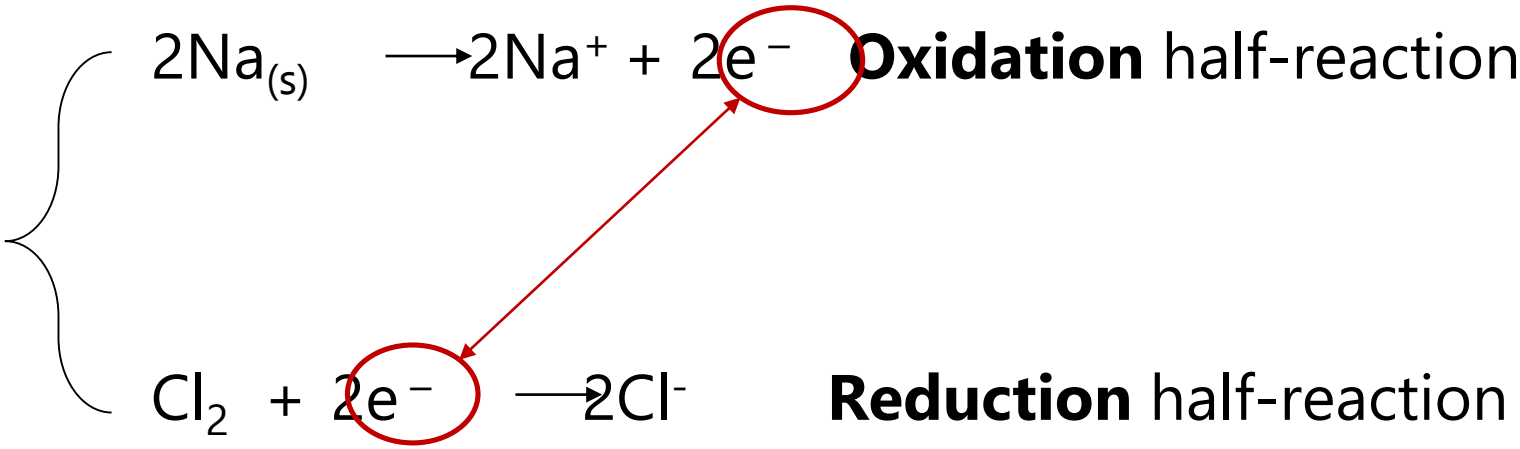
$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

$2Na_{(s)} \longrightarrow 2Na^+ + 2e^-$ **Oxidation** half-reaction

$Cl_2 + 2e^- \longrightarrow 2Cl^-$ **Reduction** half-reaction

Salt

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



Salt

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

Nox

$2Na^{0} \rightarrow 2Na^{+1} + 2e^-$ **Oxidation** half-reaction

It is oxidized

$Cl^{0}_{2} + 2e^- \rightarrow 2Cl^{-1}$ **Reduction** half-reaction

It is reduced

Salt

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

$2Na^0 \rightarrow 2Na^{+1} + 2e^-$ **Oxidation** half-reaction

It is oxidized: it is the **REDUCING AGENT**

$Cl^0_2 + 2e^- \rightarrow 2Cl^{-1}$ **Reduction** half-reaction

It is reduced: it is the **OXIDIZING AGENT**

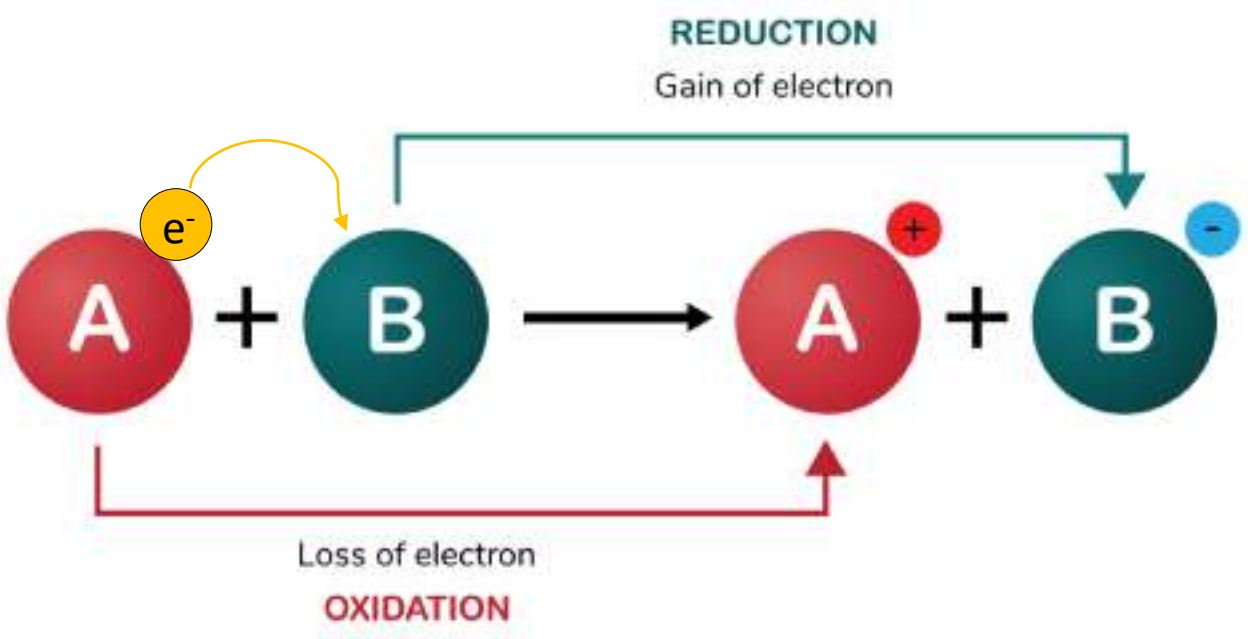
Definitions

Half-reaction oxidation: ELEMENT **loses** electrons: **Nox increase**

It's the REDUCING agent

Half-reaction reduction: ELEMENT **gain** electrons : **Nox decrease**

It's the OXIDIZING agent



Definitions applied

For each of the following reactions find the element oxidized and the element reduced

$$Mg + ZnSO_4 \rightarrow MgSO_4 + Zn$$

$$Cl_2 + KBr \rightarrow KCl + Br_2$$

$$Mg + HNO_3 \rightarrow Mg(NO_3)_2 + NO_2 + H_2O$$

$$HNO_3 + I_2 \rightarrow HIO_3 + NO_2$$

Balancing Redox reaction

There are several basic steps

1. Assign oxidation numbers to the species in the reaction
2. Find the substance oxidized and the substance reduced
3. Write half reactions for the oxidation and reduction
4. Balance the atoms that change in the half reaction
5. Determine the electrons transferred and balance the electrons between the half reactions
6. Check your work. Make sure that both the atoms and charges balance

Balancing Redox reaction

$$\_\_\_\_ Cr^{+6} + \_\_\_\_ S \rightarrow \_\_\_ Cr^{+3} + \_\_\_\_ S^{+4}$$

Balancing Redox reaction

$$\_\_\_\_ Cr^{+6} + \_\_\_\_ S \rightarrow \_\_\_ Cr^{+3} + \_\_\_\_ S^{+4}$$

X 4 $\quad \mathbf{Cr^{+6} + 3\,e^- \rightarrow Cr^{+3}}$

X 3 $\quad \mathbf{S \rightarrow S^{+4} + 4\,e^-}$

$$\_\_4\_\_ Cr^{+6} + \_\_3\_\_ S \rightarrow \_\_4\_ Cr^{+3} + \_\_3\_\_ S^{+4}$$

Balancing Redox reaction

YOU !

$$\_\_\_\_Sn^{2+} + \_\_\_\_Hg^{+2} \rightarrow \_\_\_Sn^{+4} + \_\_\_Hg^{+1}$$

$$\_\_\_\_\_Cu + \_\_\_\_\_Ag^{+1} \rightarrow \_\_\_Cu^{+2} + \_\_\_Ag$$

Rust formation

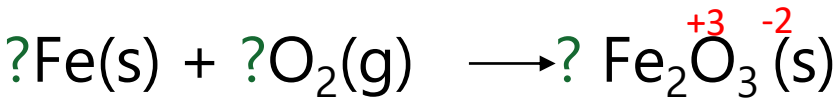
(simplified, no water)

$$?Fe(s) + ?O_2(g) \longrightarrow ?Fe_2O_3(s)$$

Iron Oxide (III)

Rust

(simplified, no water)



Iron Oxide (III)

Rust

(simplified, no water)

$$?Fe(s) + ?O_2(g) \longrightarrow ? \overset{+3}{Fe_2}\overset{-2}{O_3}(s)$$

Iron Oxide (III)

$$Fe^0 \longrightarrow Fe^{3+} + 3e^-$$

$$O_2^0 + 4e^- \longrightarrow 2\,O^{2-}$$

Rust

(simplified, no water)

$$?Fe(s) + ?O_2(g) \longrightarrow ? \overset{+3}{Fe_2}\overset{-2}{O_3}(s)$$

Iron Oxide (III)

$$Fe^0 \longrightarrow Fe^{3+} + 3e^-$$

Oxidation half-reaction

Reducing agent !

$$O_2^0 + 4e^- \longrightarrow 2\ O^{2-}$$

Reduction half-reaction

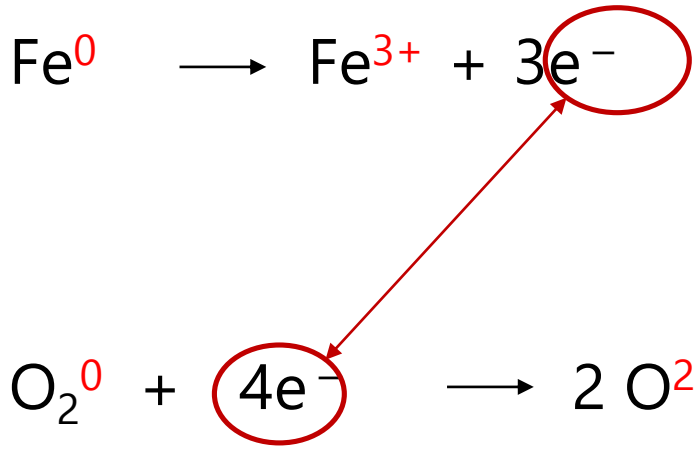
Oxidizing agent !

Rust

(simplified, no water)

$$?Fe(s) + ?O_2(g) \longrightarrow ? \overset{+3}{Fe_2}\overset{-2}{O_3}(s)$$

Iron Oxide (III)



Oxidation half-reaction

Reducing agent !

Reduction half-reaction

Oxidizing agent !

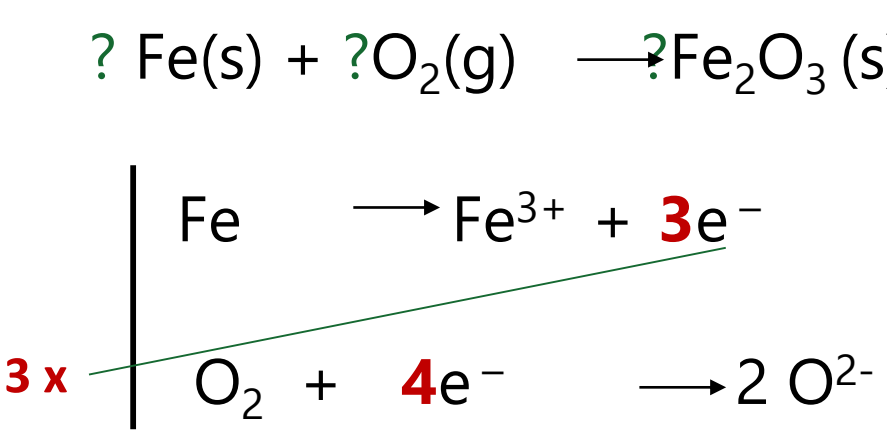
Redox Balance

$? \; Fe(s) + ? O_2(g) \longrightarrow ? Fe_2O_3(s)$ (Simplified)

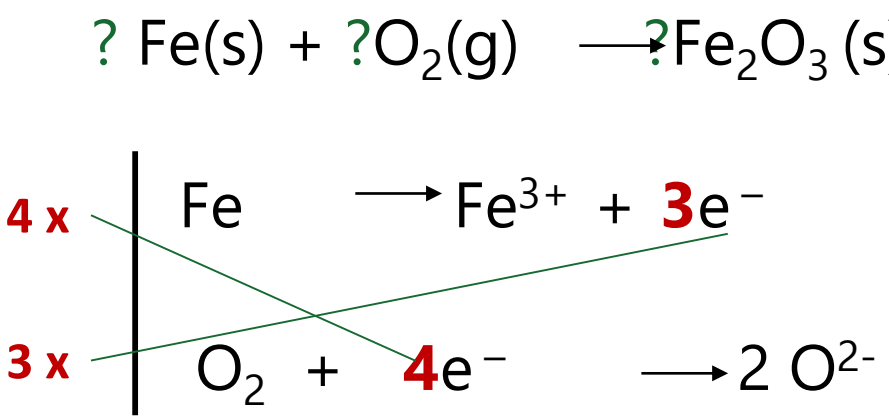
$$Fe \longrightarrow Fe^{3+} + \mathbf{3}e^-$$

$$O_2 + \mathbf{4}e^- \longrightarrow 2\, O^{2-}$$

Redox Balance

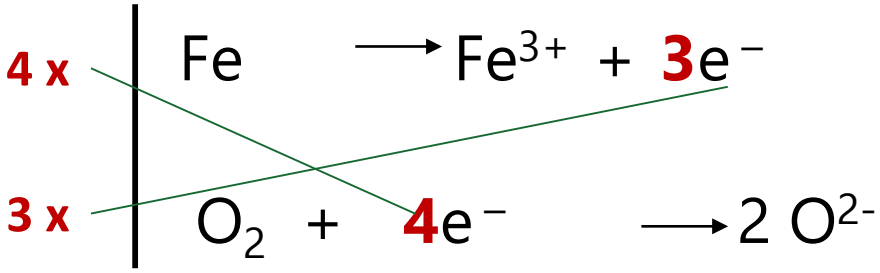


Redox Balance



Redox Balance

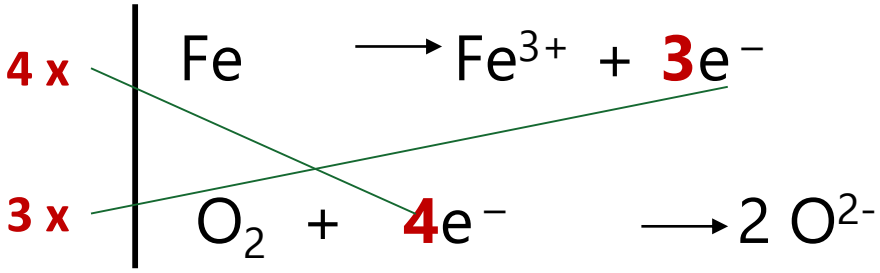
$? \; Fe(s) + ? O_2(g) \longrightarrow ? Fe_2O_3(s)$ (Simplified)



$$4\,Fe^0 + 3\,O_2^0 + 12e^- \longrightarrow 4Fe^{3+} + 6\,O^{2-} + 12e^-$$

Redox Balance

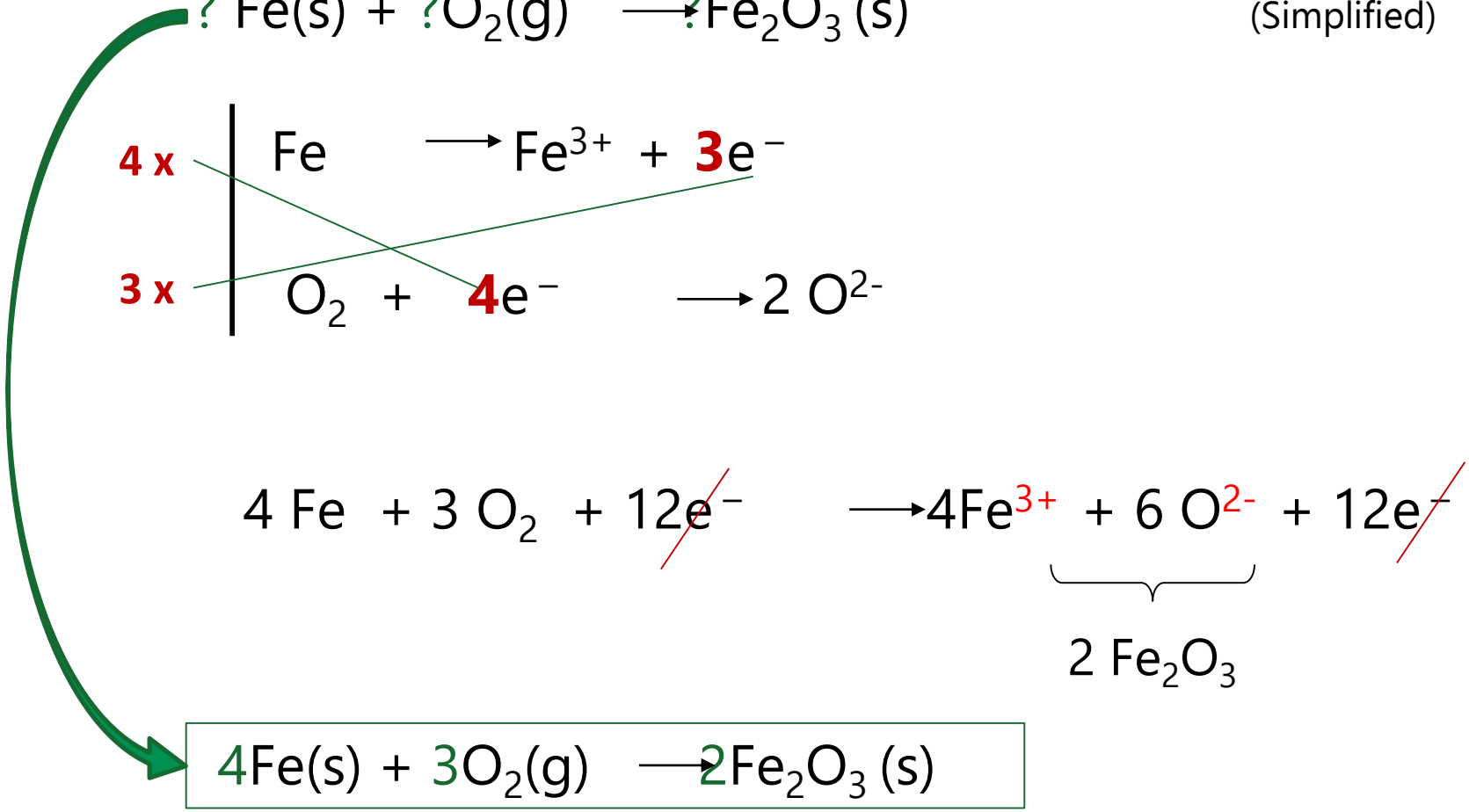
$? \; Fe(s) + ? O_2(g) \longrightarrow ? Fe_2O_3(s)$ (Simplified)



$$4\,Fe + 3\,O_2 + 12e^- \longrightarrow 4Fe^{3+} + 6\,O^{2-} + 12e^-$$

$4Fe^{3+} + 6\,O^{2-} = 2\,Fe_2O_3$

Redox Balance



Redox Balance, 一点点难

$Ag(s) + H_2S(g) + O_2(g) \rightarrow Ag_2S(s) + H_2O\ (g)$

Silver staining

Redox Balance, 一点点难

$$Ag(s) + H_2S(g) + O_2(g) \rightarrow Ag_2S(s) + H_2O\,(g)$$

x 4 | $Ag^0 \rightarrow Ag^{+1} + e^-$

$O_2^0 + 4e^- \rightarrow 2O^{2-}$

$$4Ag + O_2 + 4e^- \rightarrow 4Ag^{+1} + 2O^{2-} + 4e^-$$

$$4Ag + O_2 + H_2S \rightarrow 2Ag_2S + 2H_2O$$

$$4Ag + O_2 + 2H_2S \rightarrow 2Ag_2S + 2H_2O$$

Put the ions into the molecules in the reaction

Balance atoms (H last)

Combustion，更难

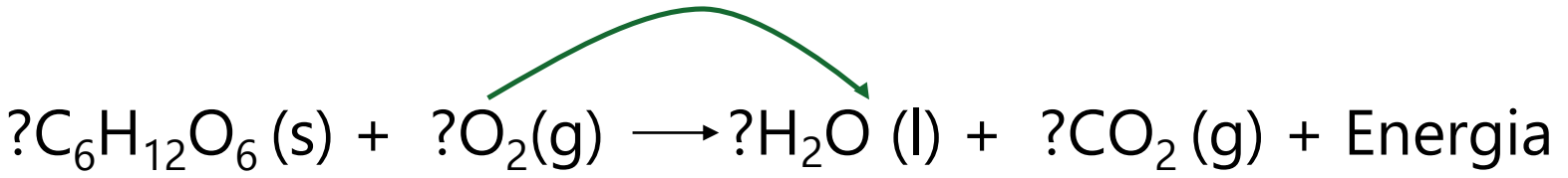
Celular respiration:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

Glucose

Combustion

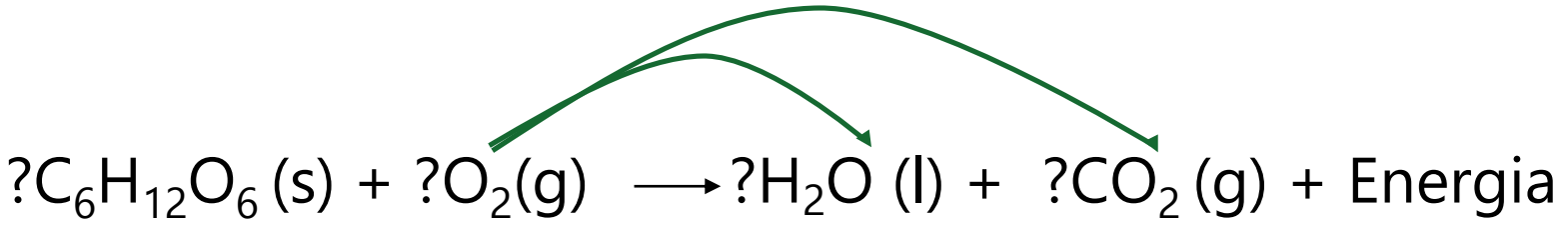
Celular respiration:



Glucose

Combustion

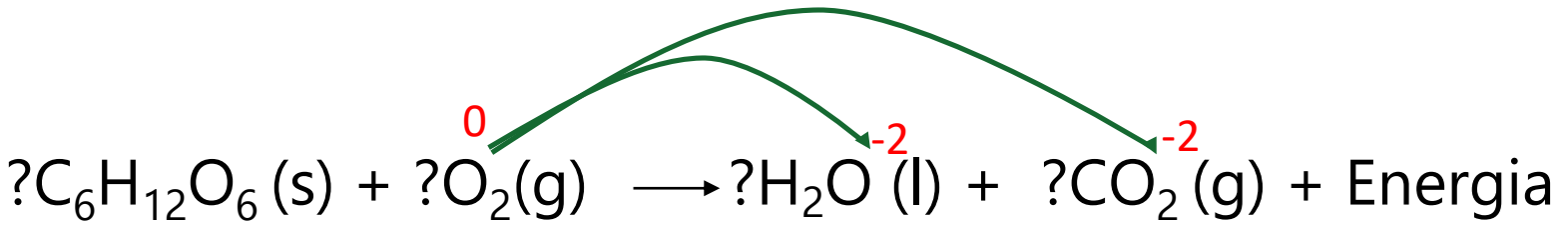
Celular respiration:



Glucose

Combustion

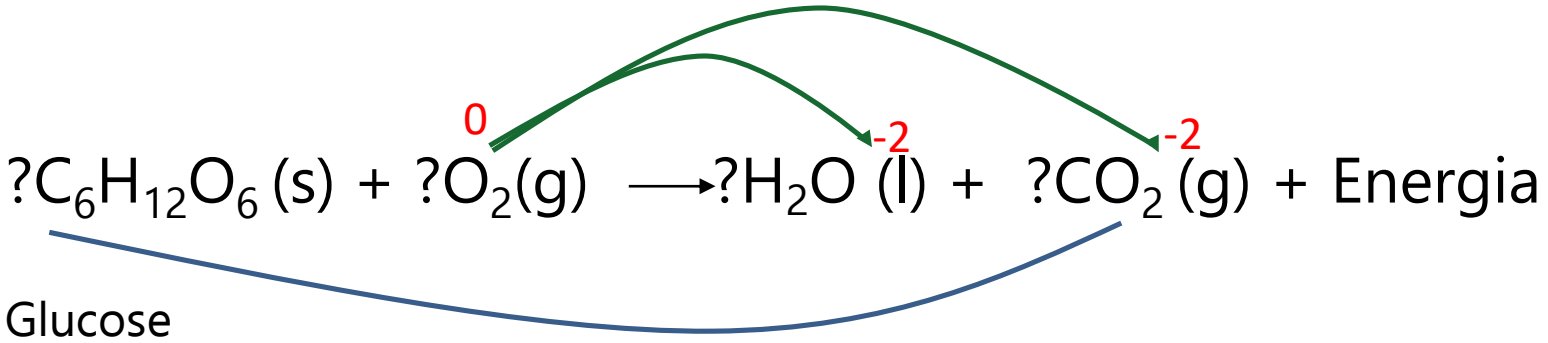
Celular respiration:



Glucose

Combustion

Celular respiration:

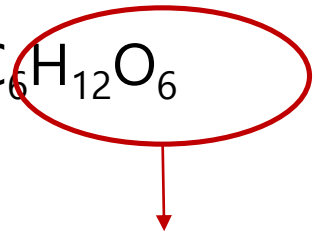


Exercises

Identify the Nox of each element of the following molecules:

C_2H_4O K_2CrO_4 $Na_2(SO_4)_3$ $NaClO$

N_2O_4 $C_6H_{12}O_6$ CO_2



Rules + Charge balance:

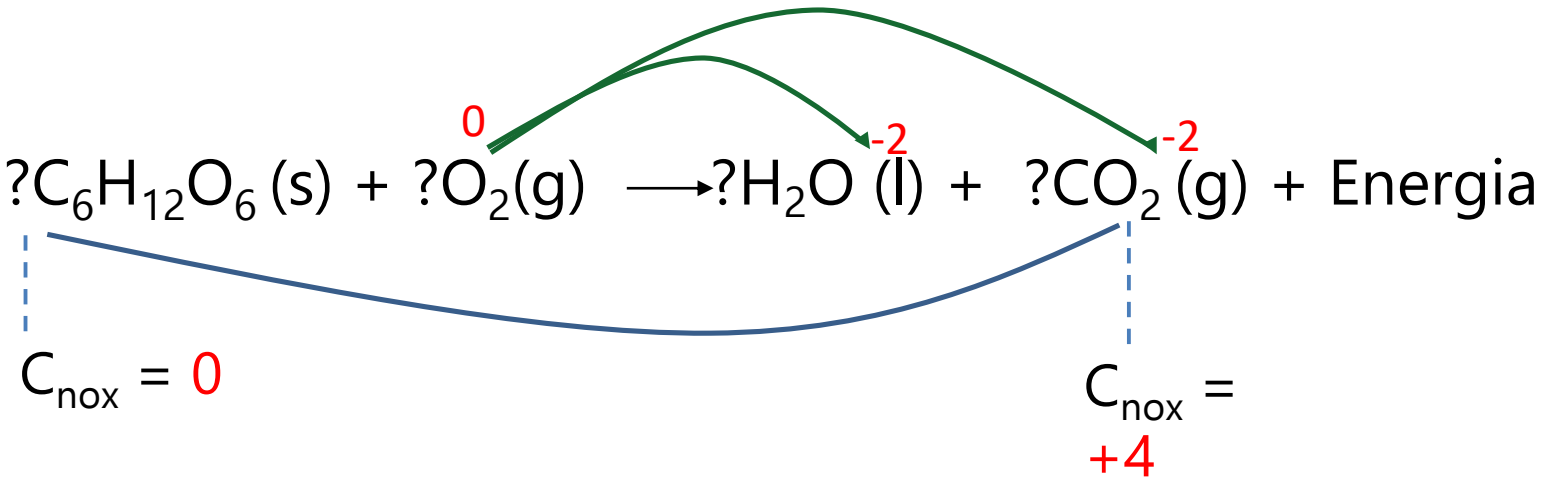
$\overset{x}{C_6}\overset{+1}{H_{12}}\overset{-2}{O_6}$

$-2 \cdot 6 + 1 \cdot 12 + x \cdot 6 = 0$

$X = C_{nox} = 0$

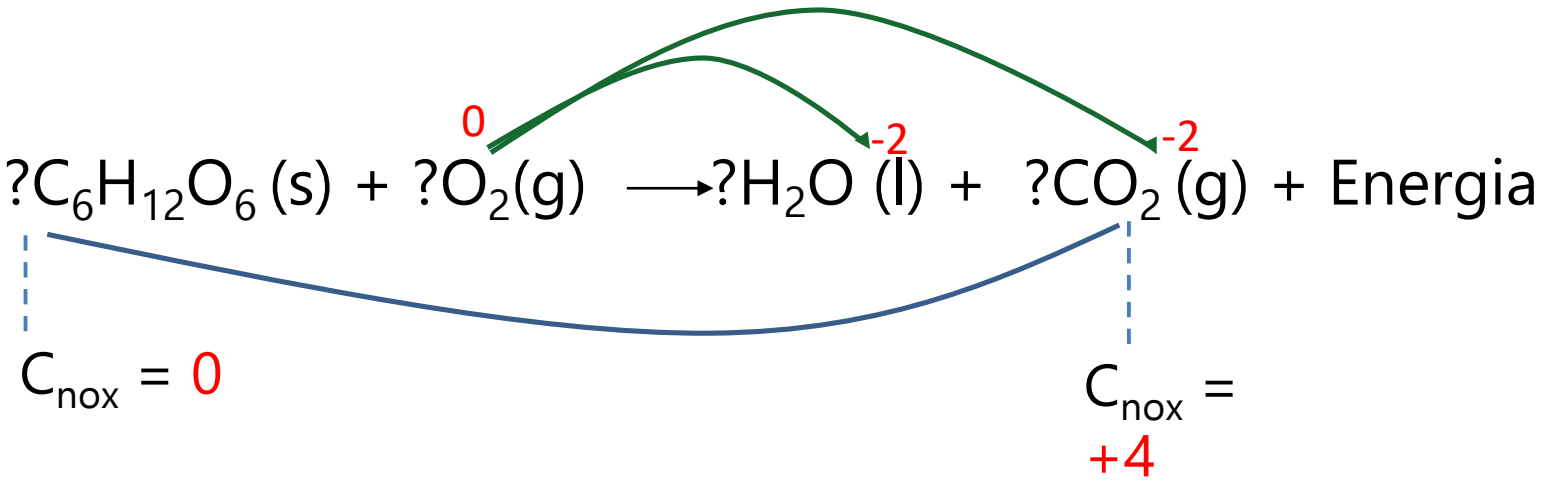
Combustion

Celular respiration:



Combustion

Celular respiration:



Glucose suffers oxidation: it is the reducing agent

Oxygen suffers reduction: it is the oxidizing agent

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} \longrightarrow \overset{+4}{CO_2} + \ldots.$$

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} \longrightarrow \overset{+4}{CO_2} + \ldots.$$

Step 1. balance atoms except O, H

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} \longrightarrow 6\overset{+4}{C}O_2 + \ldots.$$

Step 1. balance atoms except O, H

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} \longrightarrow 6\overset{+4}{CO_2}$$

Step 1. balance atoms except O, H

Step 2. Balance O by adding water

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} + 6H_2O \longrightarrow 6\overset{+4}{C}O_2$$

Step 1. balance atoms except O, H

Step 2. Balance O by adding water

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} + 6H_2O \longrightarrow 6\overset{+4}{C}O_2$$

Step 1. balance atoms except O, H

Step 2. Balance O by adding water

Step 3. Balance H by adding H^+

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} + 6H_2O \longrightarrow 6\overset{+4}{C}O_2 + 24H^+$$

Step 1. balance atoms except O, H

Step 2. Balance O by adding water

Step 3. Balance H by adding H^+

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\overset{0}{C_6H_{12}O_6} + 6H_2O \longrightarrow 6\overset{+4}{C}O_2 + 24H^+ + 24e^-$$

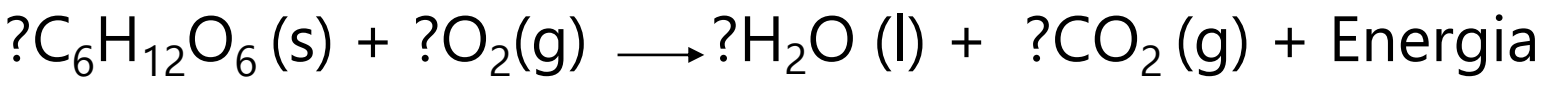
Step 1. balance atoms except O, H

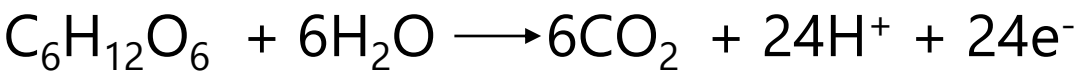
Step 2. Balance O by adding water

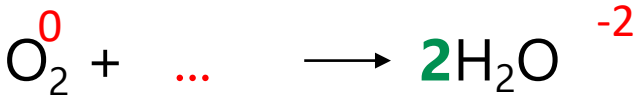
Step 3. Balance H by adding H^+

Step 4. Balance e^- to check charges

Stochiometry:







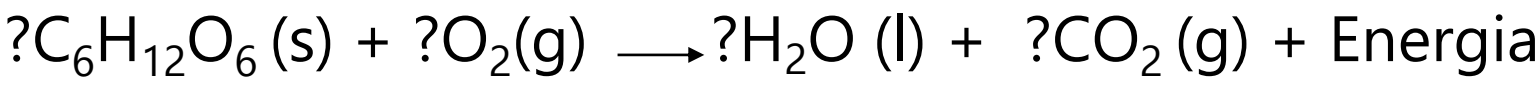
Step 1. balance atoms except O, H

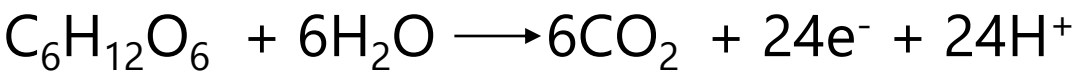
Step 2. Balance O by adding water

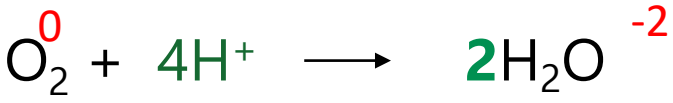
Step 3. Balance H by adding H^+

Step 4. Balance e^- to check charges

Stochiometry:







Step 1. balance atoms except O, H

Step 2. Balance O by adding water

Step 3. Balance H by adding H^+

Step 4. Balance e^- to check charges

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+$$

$$O_2^{0} + 4H^+ + 4e^- \longrightarrow 2H_2O^{-2}$$

Step 1. balance atoms except O, H

Step 2. Balance O by adding water

Step 3. Balance H by adding H^+

Step 4. Balance e^- to check charges

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$\left|\begin{array}{l} C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+ \\ \\ O_2 + 4H^+ + 4e^- \longrightarrow \mathbf{2}H_2O \end{array}\right.$$

Step 5. Balance e^- between half-reactions

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+$$

$$6x \quad O_2 + 4H^+ + 4e^- \longrightarrow \mathbf{2}H_2O$$

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+$$

$$6x \quad O_2 + 4H^+ + 4e^- \longrightarrow \mathbf{2}H_2O$$

$$C_6H_{12}O_6 + 6H_2O + 6O_2 + 24H^+ + 24e^- \longrightarrow 6CO_2 + 24e^- + 24H^+ + 12H_2O$$

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+$$

$$6x \quad O_2 + 4H^+ + 4e^- \longrightarrow \mathbf{2}H_2O$$

$$C_6H_{12}O_6 + 6H_2O + 6O_2 + \cancel{24}H^+ + \cancel{24}e^- \longrightarrow 6CO_2 + \cancel{24}e^- + \cancel{24}H^+ + 12H_2O$$

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+$$

$$6x \quad O_2 + 4H^+ + 4e^- \longrightarrow \mathbf{2}H_2O$$

$$C_6H_{12}O_6 + 6H_2O + 6O_2 + 24H^+ + 24e^- \longrightarrow 6CO_2 + 24e^- + 24H^+ + 12H_2O$$

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+$$

$$6x \quad O_2 + 4H^+ + 4e^- \longrightarrow \mathbf{2}H_2O$$

$$C_6H_{12}O_6 + 6H_2O + 6O_2 + 24H^+ + 24e^- \longrightarrow 6CO_2 + 24e^- + 24H^+ + 12H_2O$$

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Stochiometry:

$$?C_6H_{12}O_6\,(s) + ?O_2(g) \longrightarrow ?H_2O\,(l) + ?CO_2\,(g) + \text{Energia}$$

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^- + 24H^+$$

$$6x \quad O_2 + 4H^+ + 4e^- \longrightarrow \mathbf{2}H_2O$$

$$C_6H_{12}O_6 + 6H_2O + 6O_2 + 24H^+ + 24e^- \longrightarrow 6CO_2 + 24e^- + 24H^+ + 12H_2O$$

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Balanced !

Stochiometry 2

$$H_2O_2 + NO \rightarrow N_2O_3 + H_20$$

Exercises

$Ag(s) + H_2S(g) + O_2(g) \rightarrow Ag_2S(s) + H_2O\,(g)$

Silver staining

$C_2H_4O + K_2CrO_4 + H_2SO_4 \rightarrow C_2H_4O_2(g) + Cr_2(SO_4)_3 + K_2SO_4$

Breathanalyzer

$Cl_2(g) + NaOH\,(aq) \rightarrow NaCl\,(aq) + NaClO\,(aq) + H_2O\,(g)$

Bleach production

$N_2H_4\,(g) + N_2O_4\,(g) \rightarrow N_2(g) + H_2O\,(g)$

Rocket Fuel

Electrochemistry

The study of the interchange of chemical and electrical energy

Battery uses energy from oxidation-reduction reaction to produce energy

Involves two types of processes:

- Production of an electric current from a chemical reaction
- Use of electric current to produce a chemical change

How batteries work ?

Separate oxidizing agent (electron acceptor) from reducing agent (electron donor)

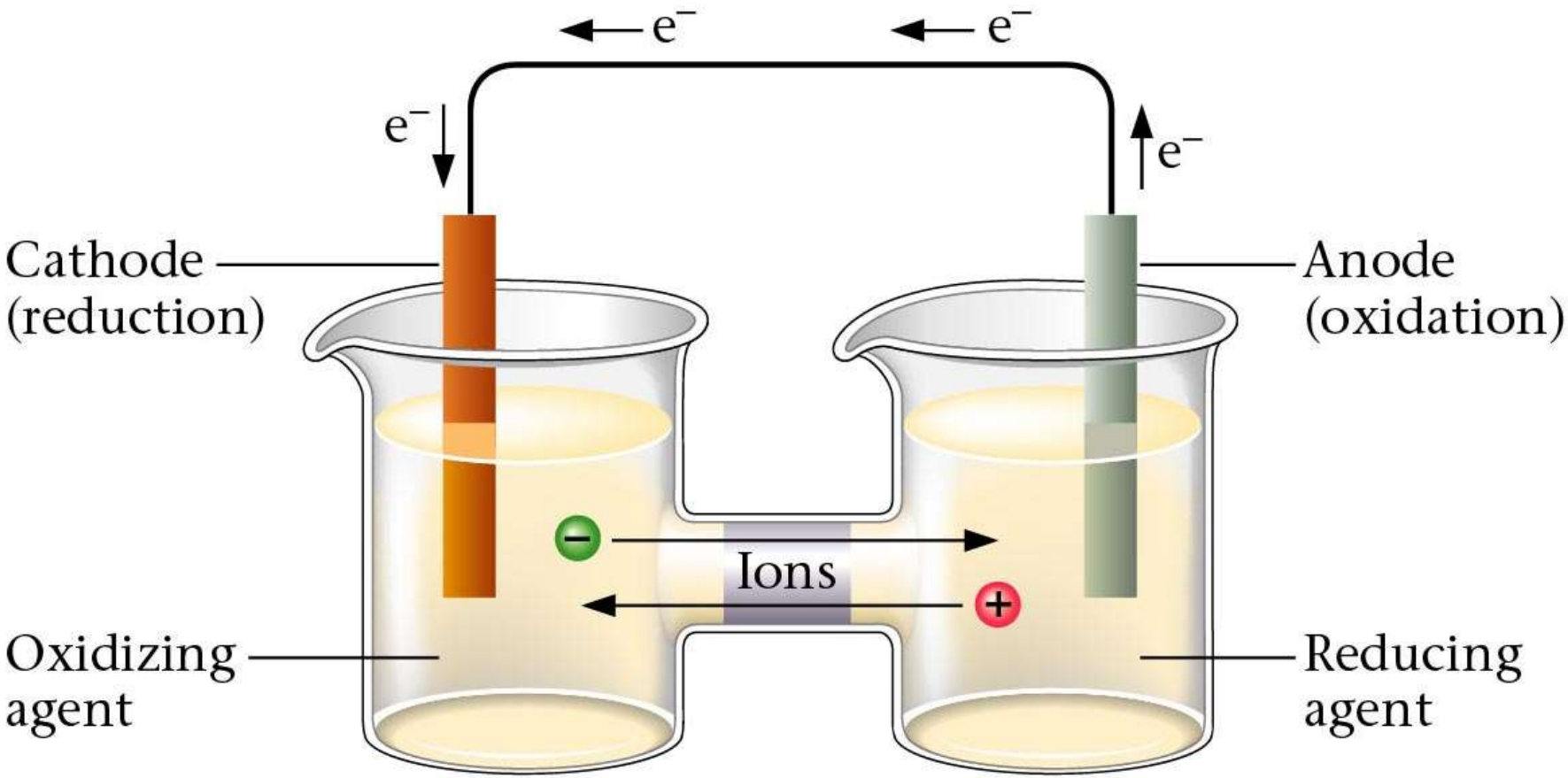
Electron transfer must occur through a wire

Current produced in wire by electron flow can be directed through a device to produce useful work

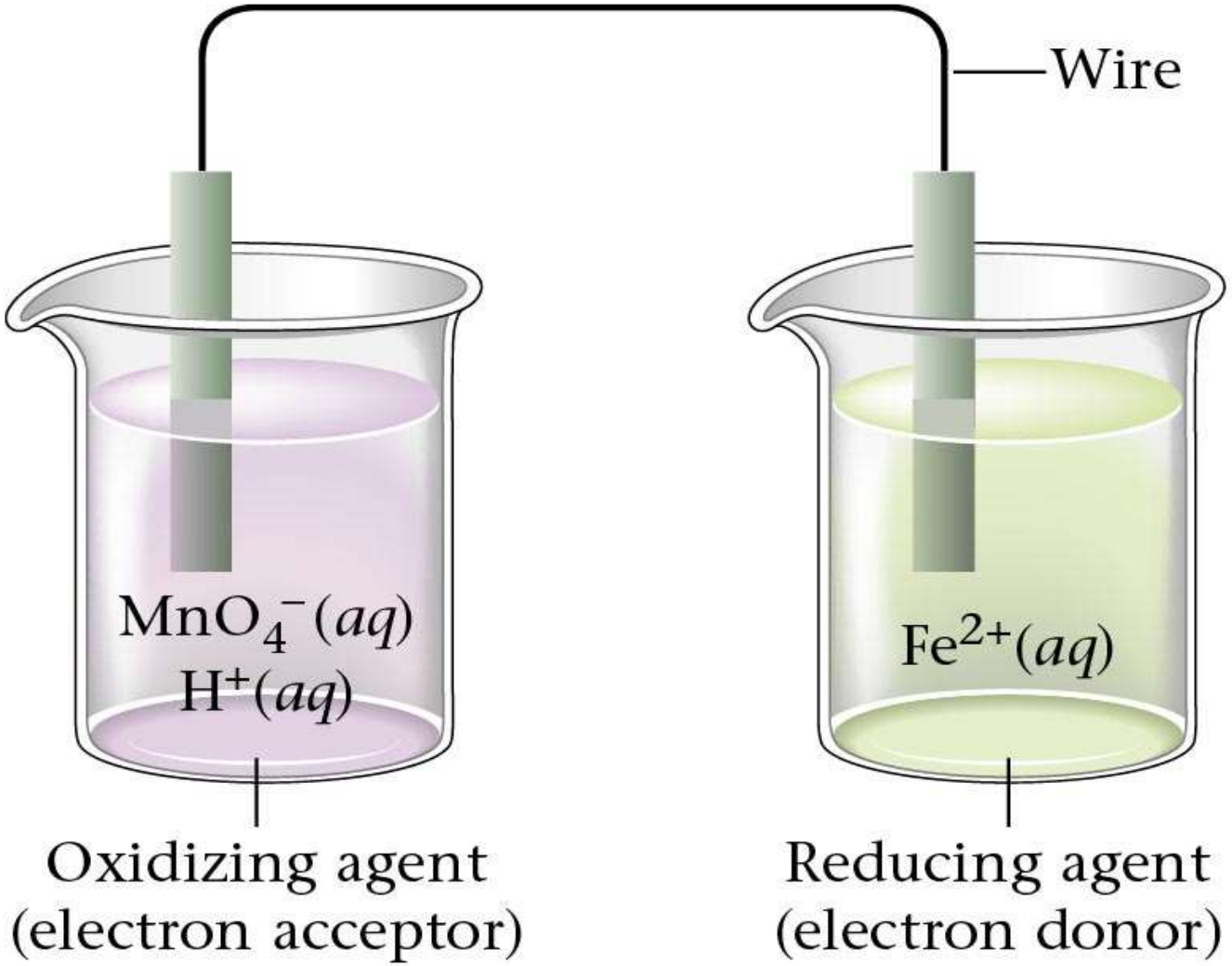
Anode = electrode where oxidation occurs

Cathode = electrode where reduction occurs

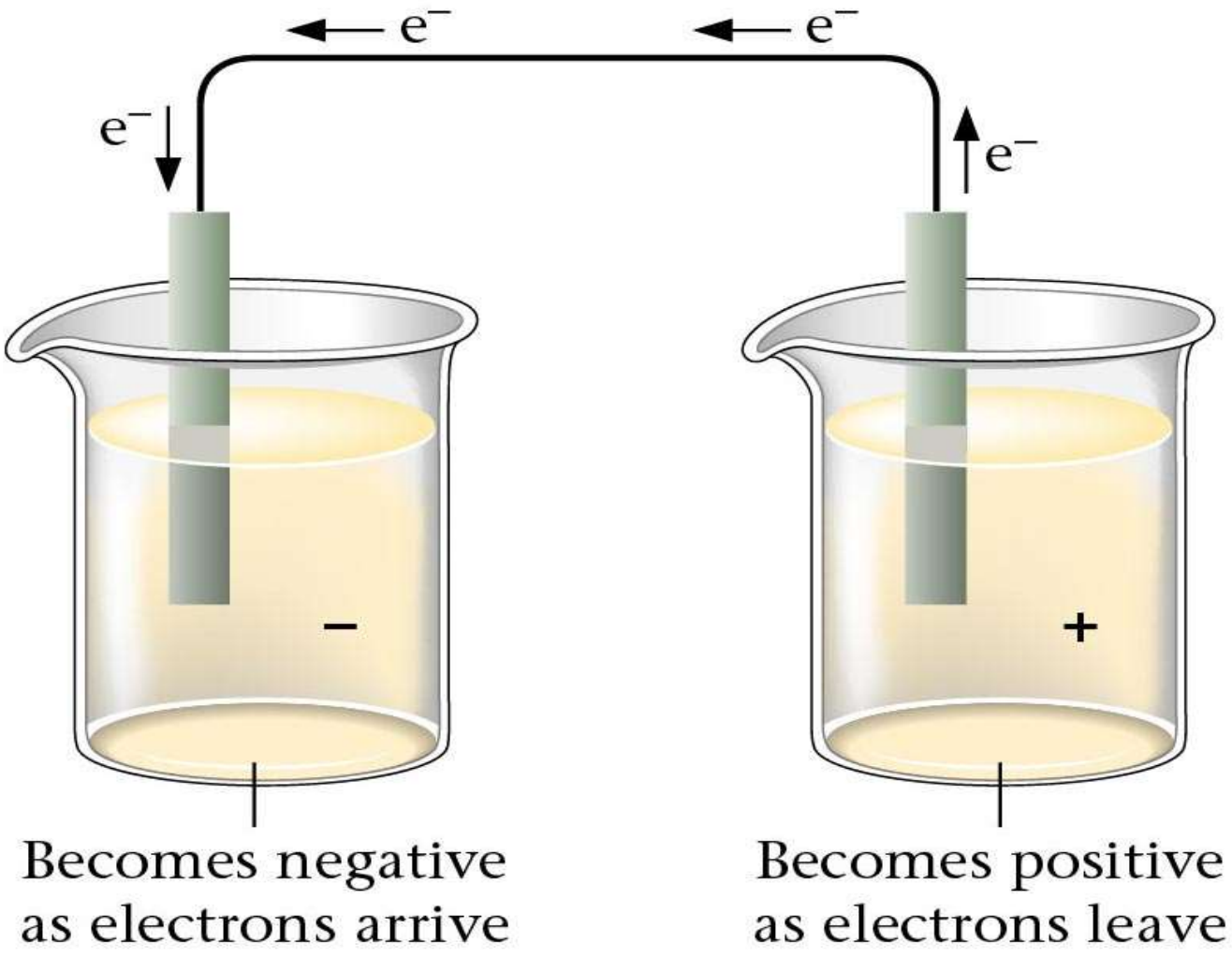
Schematics of a battery



Schematics of a battery

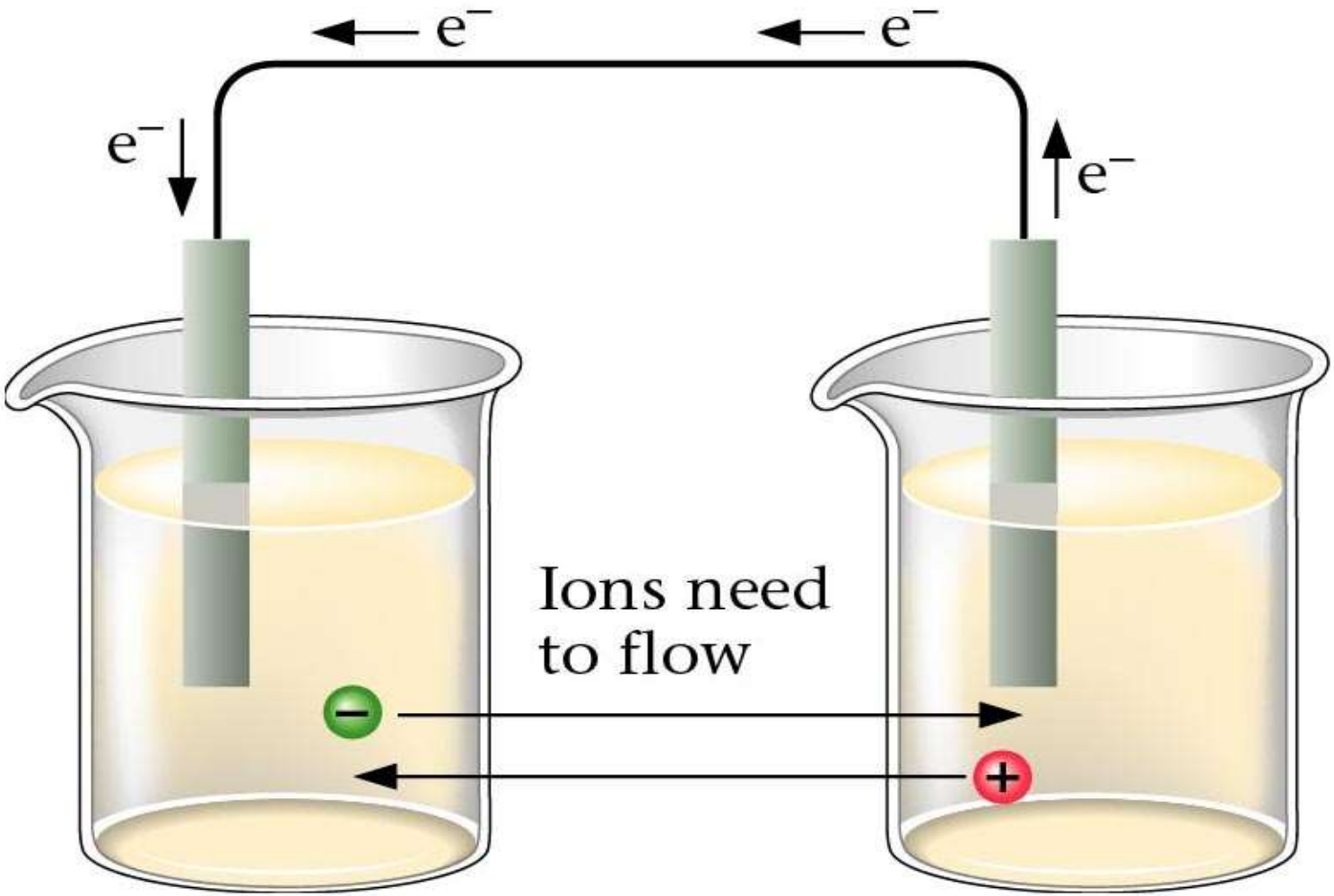


Schematics of a battery



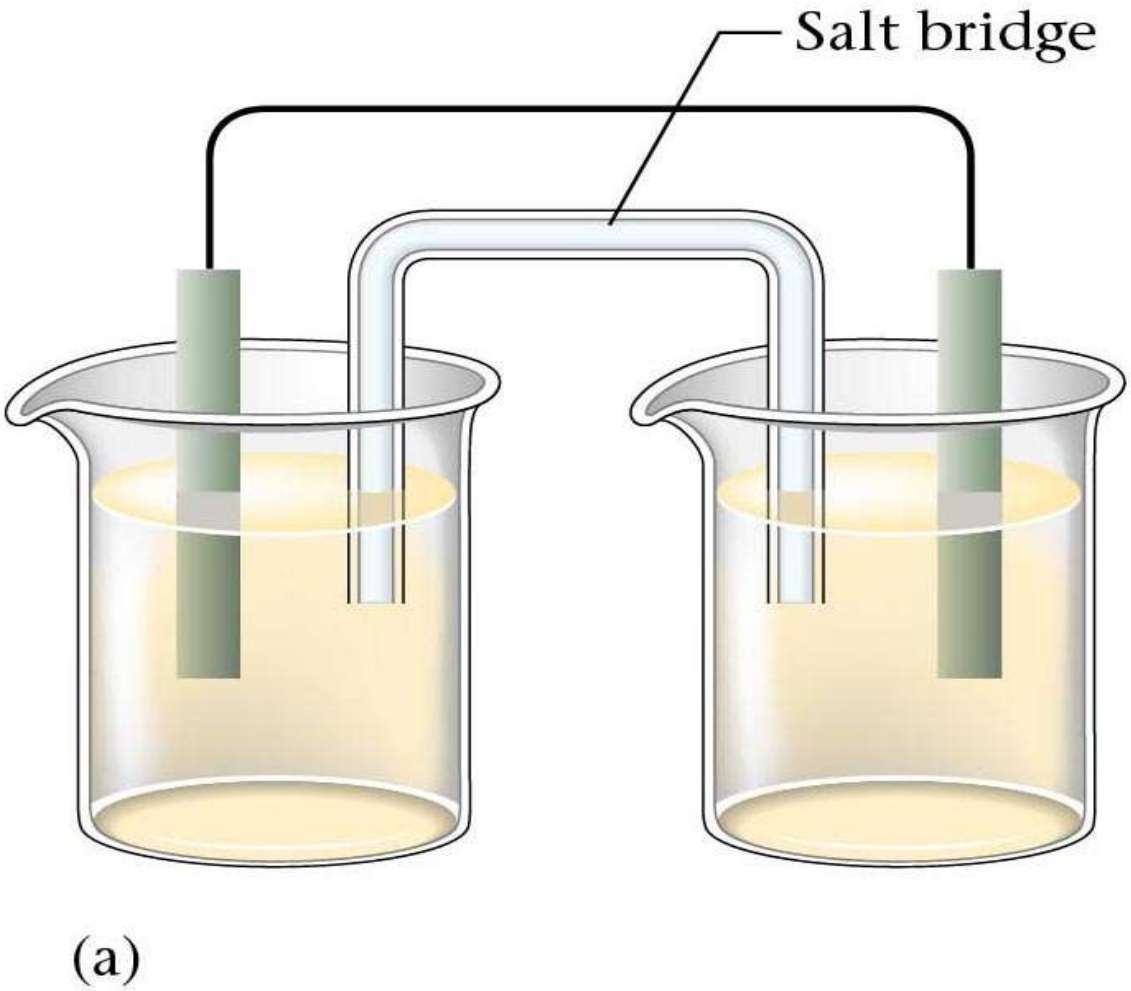
Schematics of a battery

Ion flow through the salt bridge keeps the charge neutral.



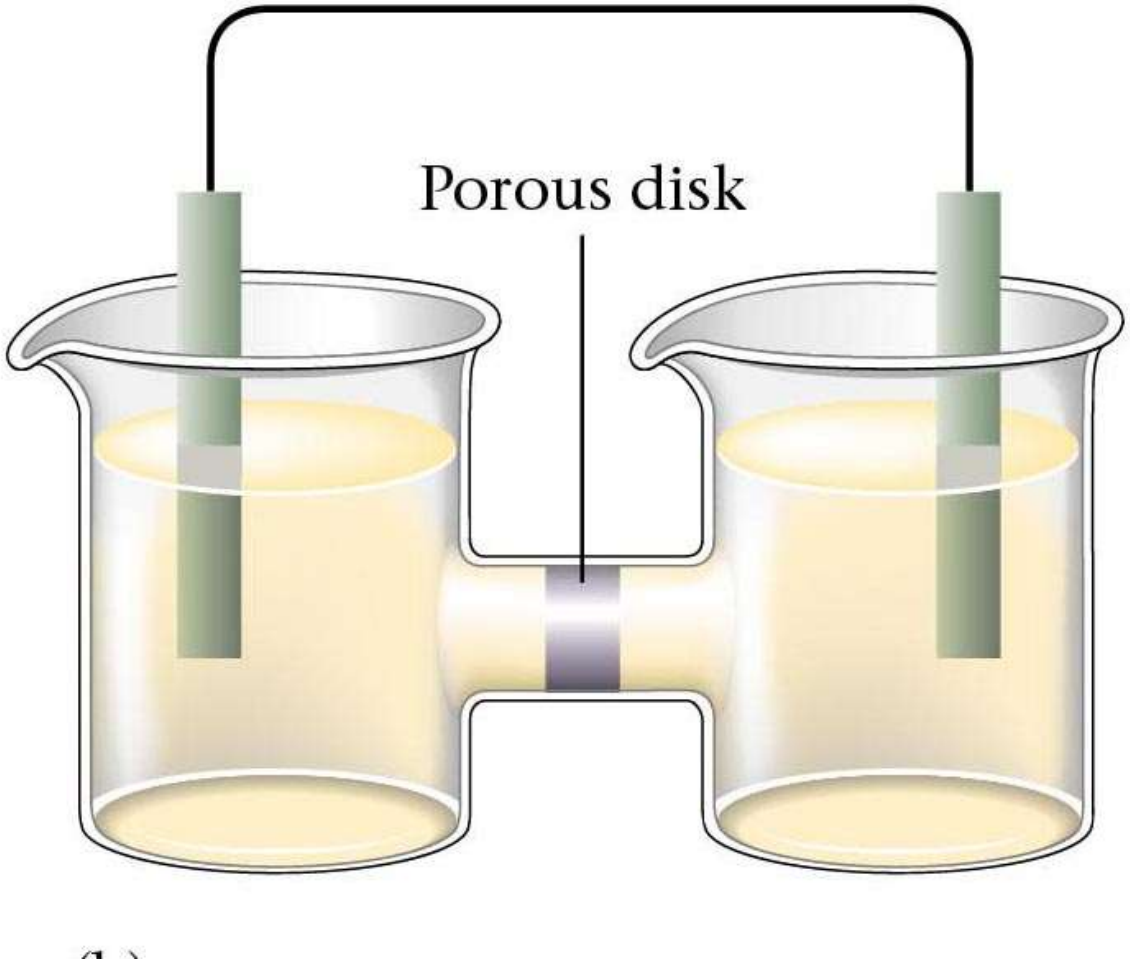
Schematics of a battery

Ion flow through the salt bridge keeps the charge neutral.

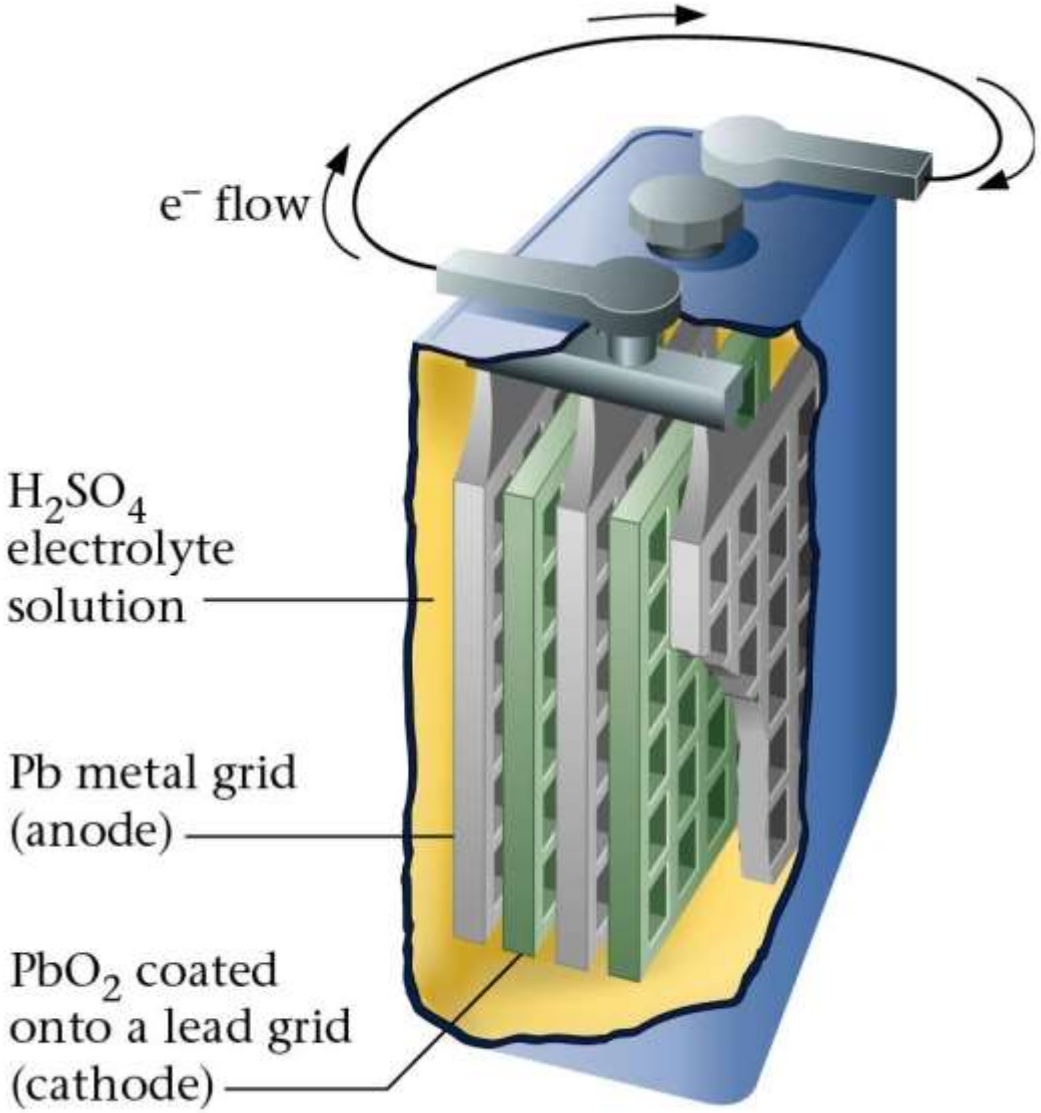


Schematics of a battery

Or Ions can flow through porous disk keeps the charge neutral.

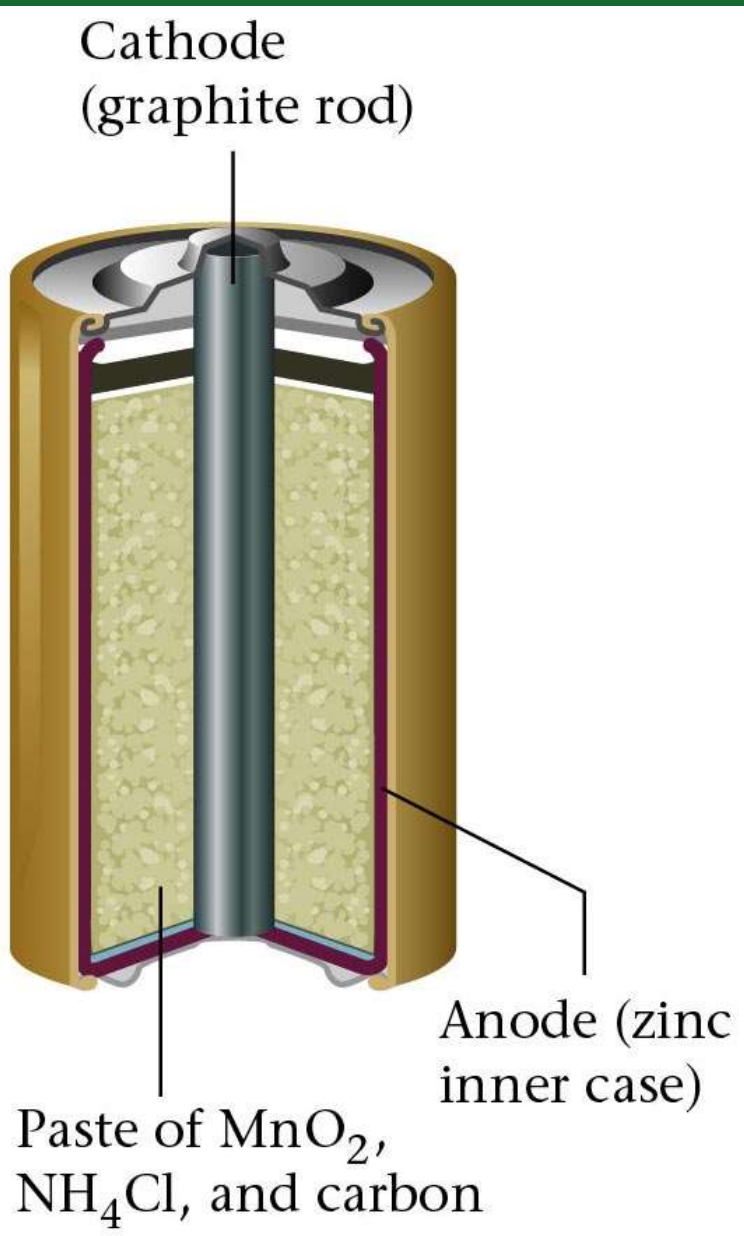


lead battery in cars



A common dry cell battery.

AAA



A mercury battery