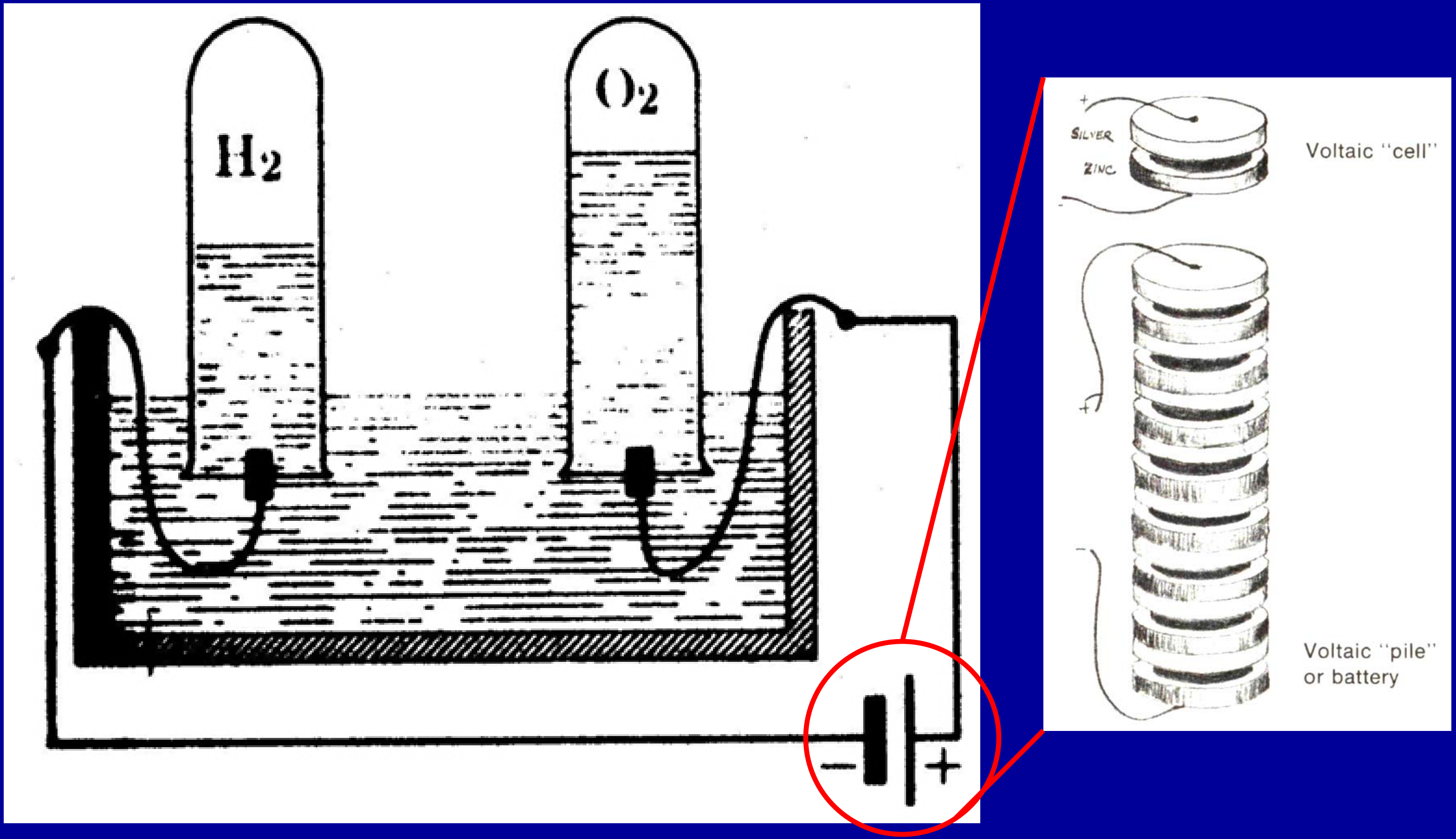
Teaching the HSCE's at differentiated levels

It must be kept in mind that dozens of content expectations does not a curriculum make – and that a curricular framework must therefore be fashioned…

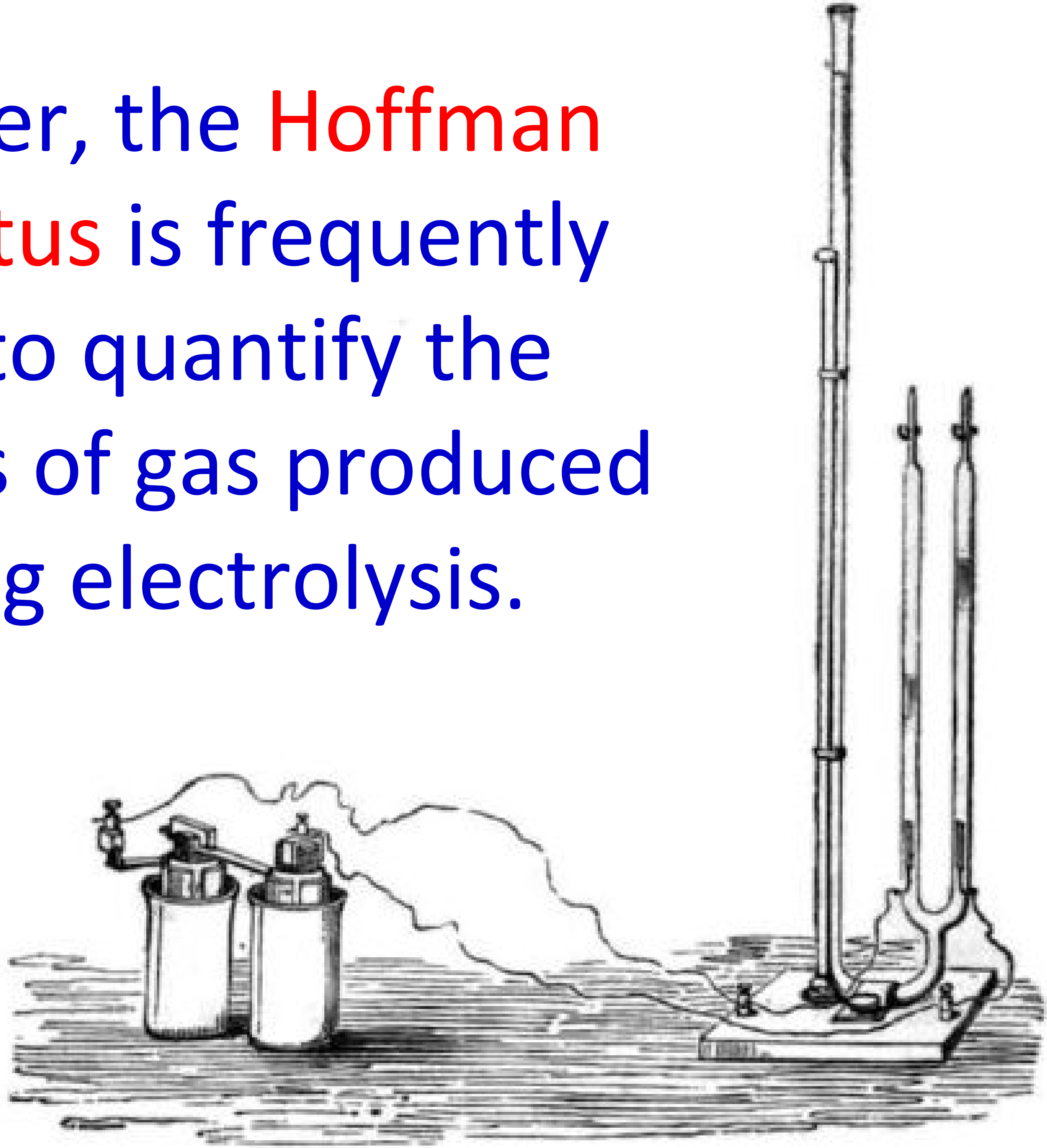
One difficulty in implementing the HSCE's is trying to make chemistry *accessible* to those who (for whatever reason) have a difficult time grasping more abstract concepts – while, at the same time, sufficiently challenging those more adept at such matters.

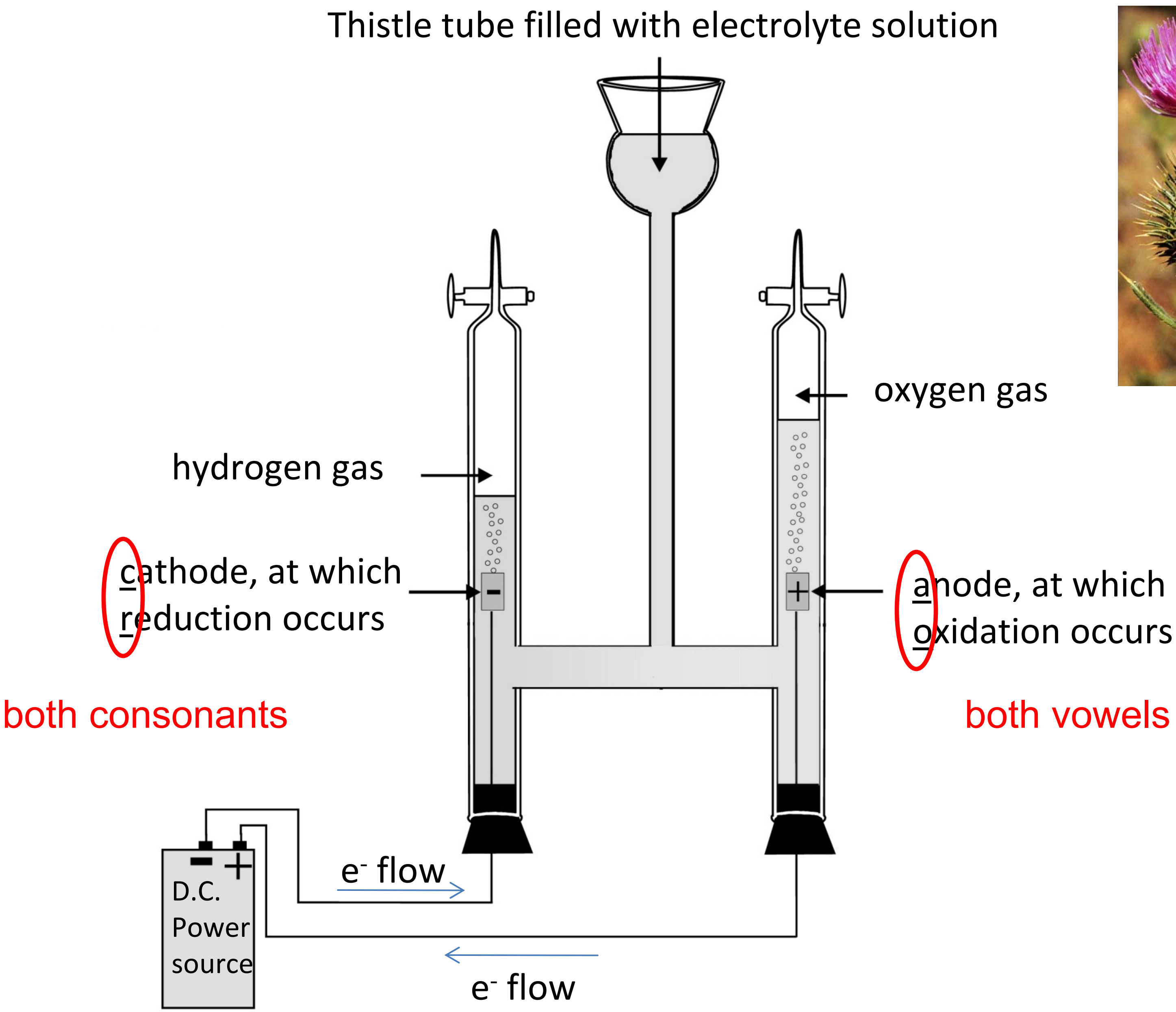
A good example of such an instructional dilemma involves the electrical decomposition of water or *electrolysis*, first performed by the Englishmen William Nicholson and Anthony Carlisle in 1800, about one year following Volta's "pile" .



The electrolysis of water requires minimal equipment…

However, the Hoffman apparatus is frequently used to quantify the amounts of gas produced during electrolysis.




Thistle tube filled with electrolyte solution
oxygen gas
hydrogen gas
cathode, at which
reduction occurs
anode, at which
oxidation occurs
both consonants
both vowels
D.C.
Power
source
e⁻ flow
e⁻ flow

For the more basic level of chemistry, our goal is to use the electrolysis of water to get across concepts relating to oxidation-reduction or *redox* chemistry:

Overall chemical change:

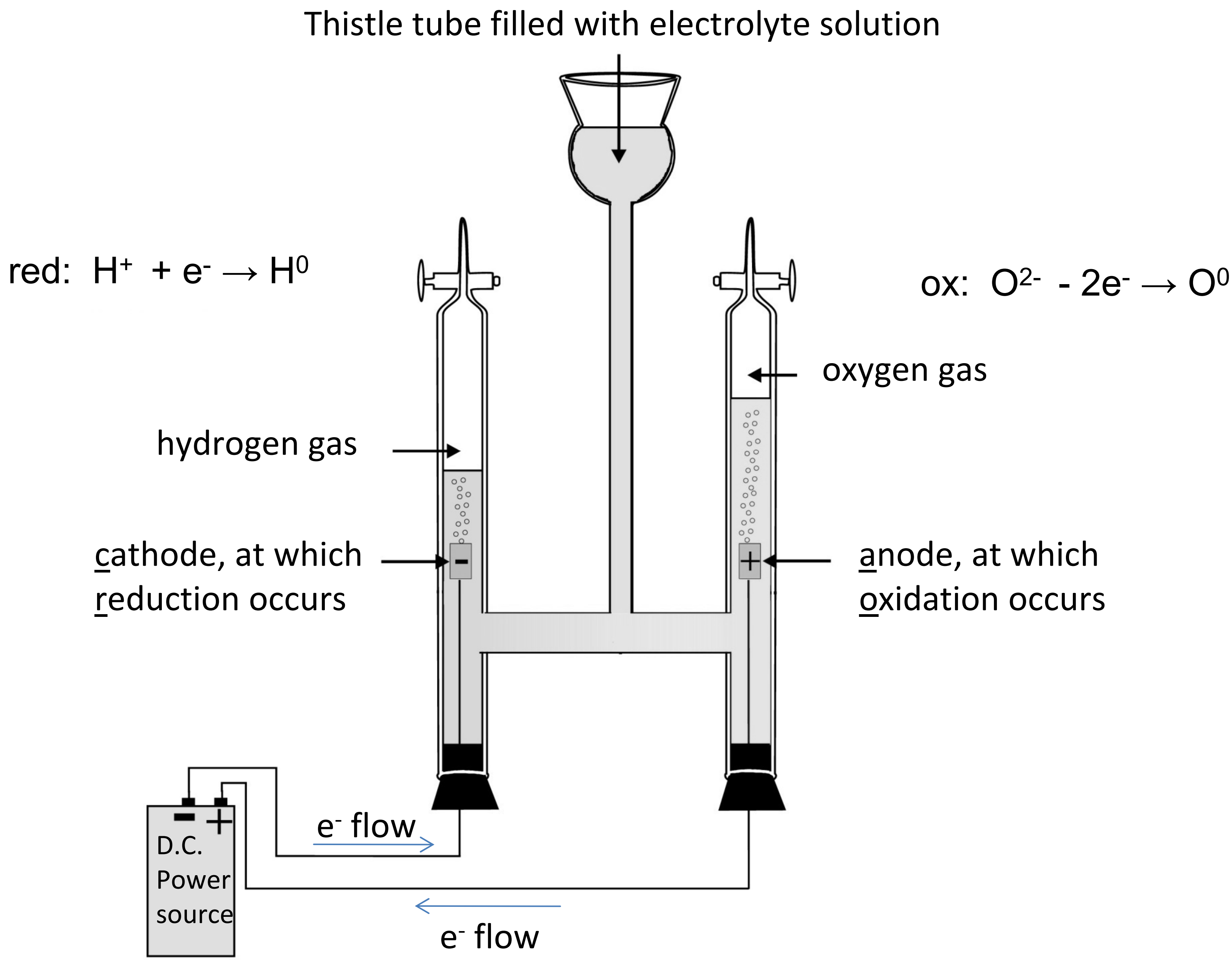
$$2H_2O \rightarrow 2H_2 + O_2$$

$$2H_2^{1+}O^{2-} \rightarrow 2H_2^{0} + O_2^{0}$$

$$\text{red:} \quad H^{1+} + e^{-} \rightarrow H^{0}$$

$$\text{ox:} \quad O^{2-} - 2e^{-} \rightarrow O^{0}$$

Overall reaction: $2H_2O \rightarrow 2H_2 + O_2$

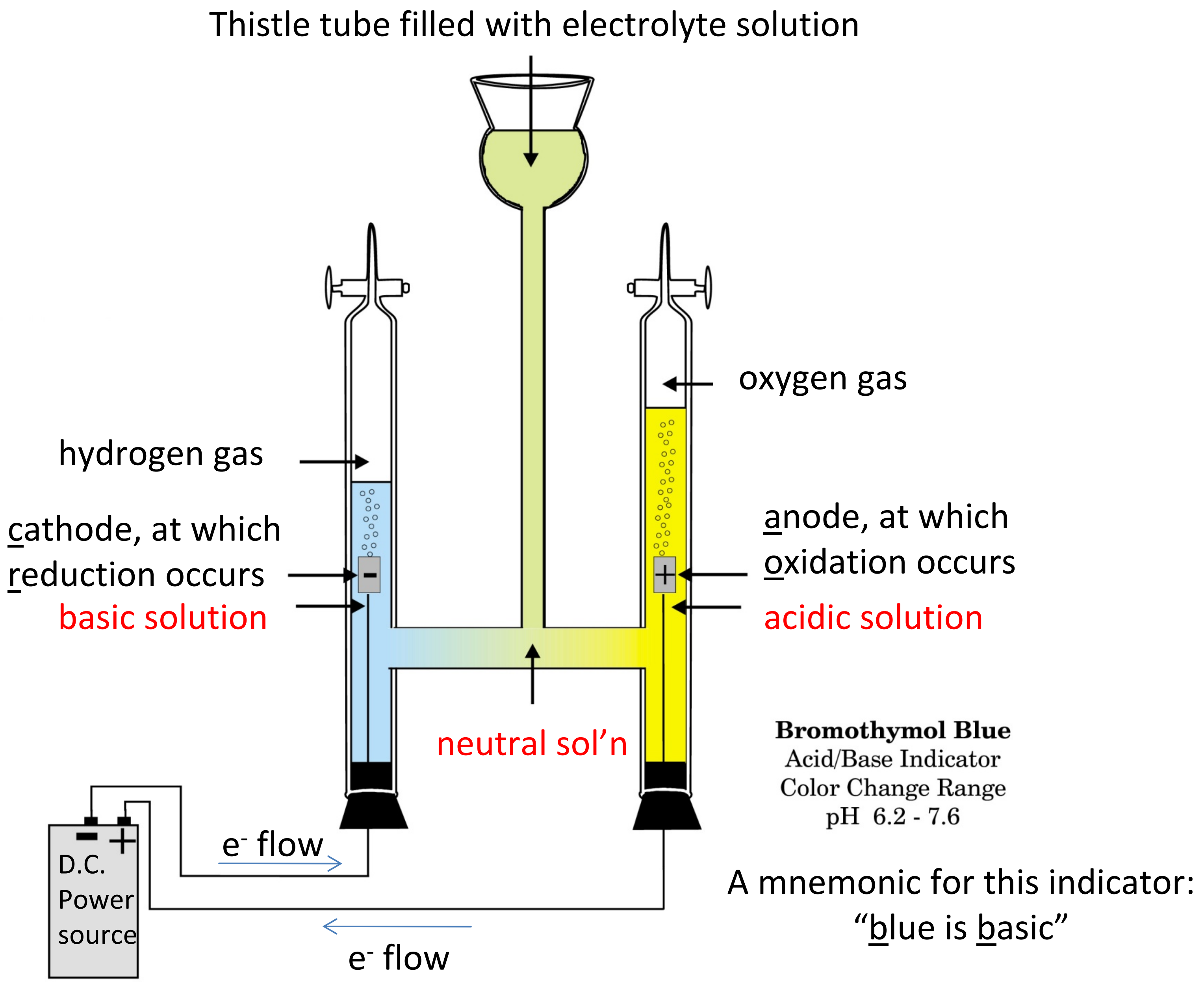


However, a bit of thought suggests that the decomposition of water is not quite so straightforward…

If water molecules simply "fell apart" into hydrogen and oxygen gases, as the overall equation suggests, then the gases should evolve as a *mixture*.

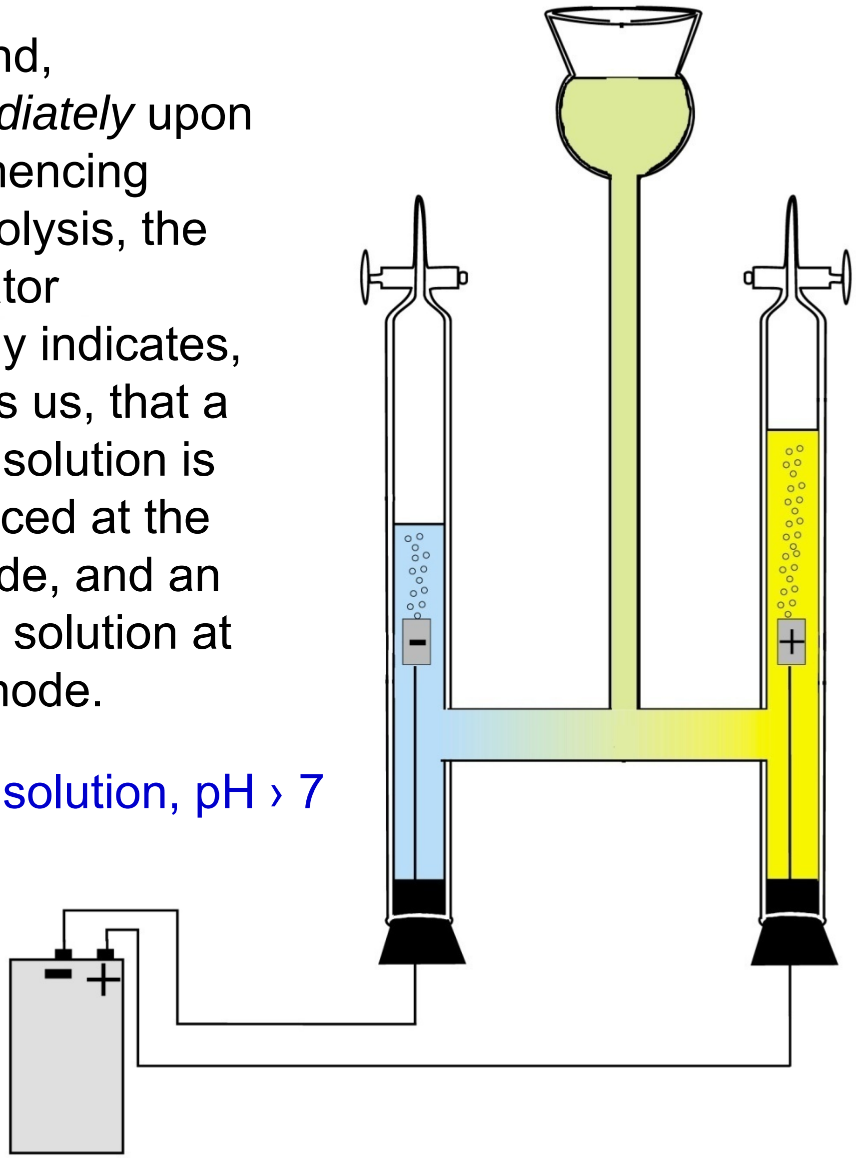
Instead, each gas appears at its own electrode!

Furthermore, the addition of bromothymol blue as an *acid/base indicator* reveals acid/base chemistry occurring at the electrodes.


Thistle tube filled with electrolyte solution
oxygen gas
hydrogen gas
cathode, at which reduction occurs
basic solution
anode, at which oxidation occurs
acidic solution
neutral sol'n
Bromothymol Blue
Acid/Base Indicator
Color Change Range
pH 6.2 - 7.6
D.C. Power source
e- flow
e- flow
A mnemonic for this indicator:
"blue is basic"

First, it must be kept in mind that water is the substance undergoing chemical change within this apparatus – the electrolyte only serving to conduct electrical impulse through the system.

Second, *immediately* upon commencing electrolysis, the indicator literally indicates, or tells us, that a basic solution is produced at the cathode, and an acidic solution at the anode.



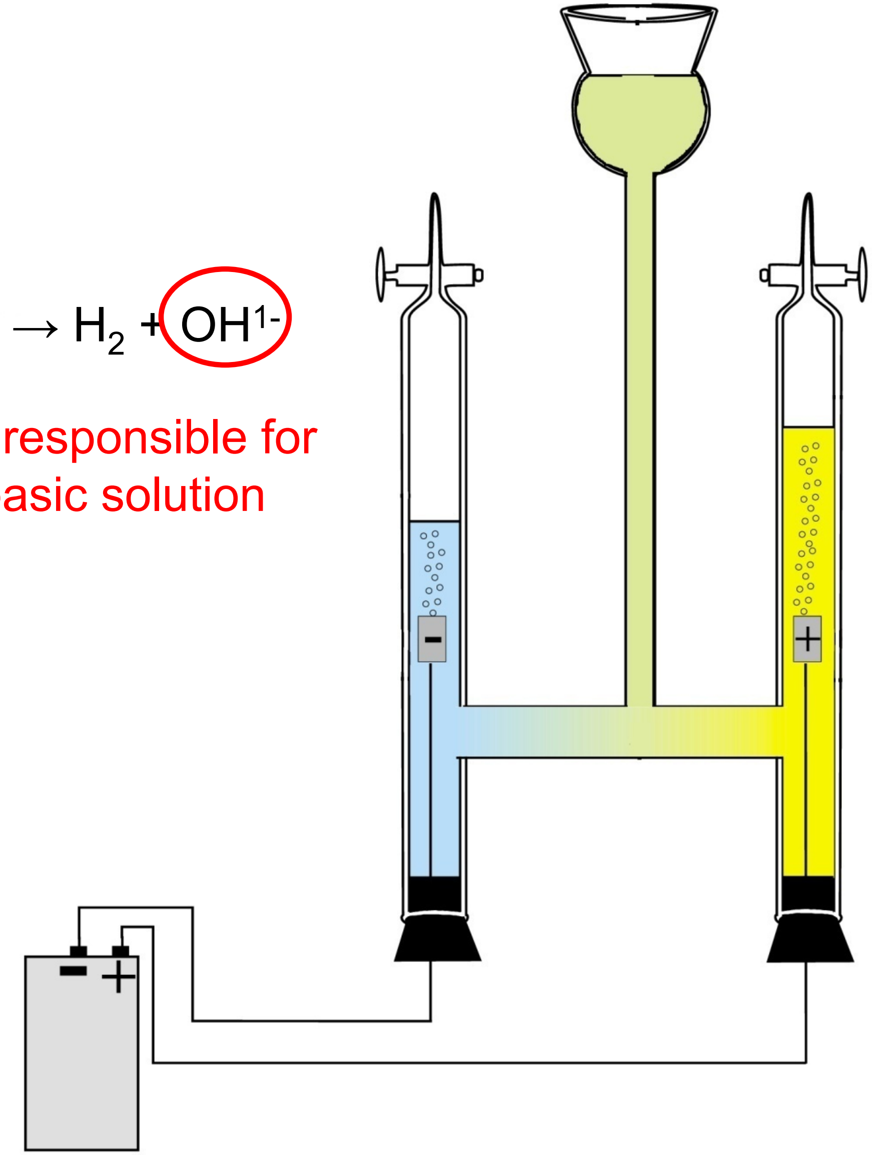
basic solution, pH › 7

acidic solution, pH ‹ 7

These facts can be used to begin to sketch out the chemical process of change occurring at each electrode:

$H_2O \rightarrow H_2 + OH^{1-}$

ion responsible for basic solution



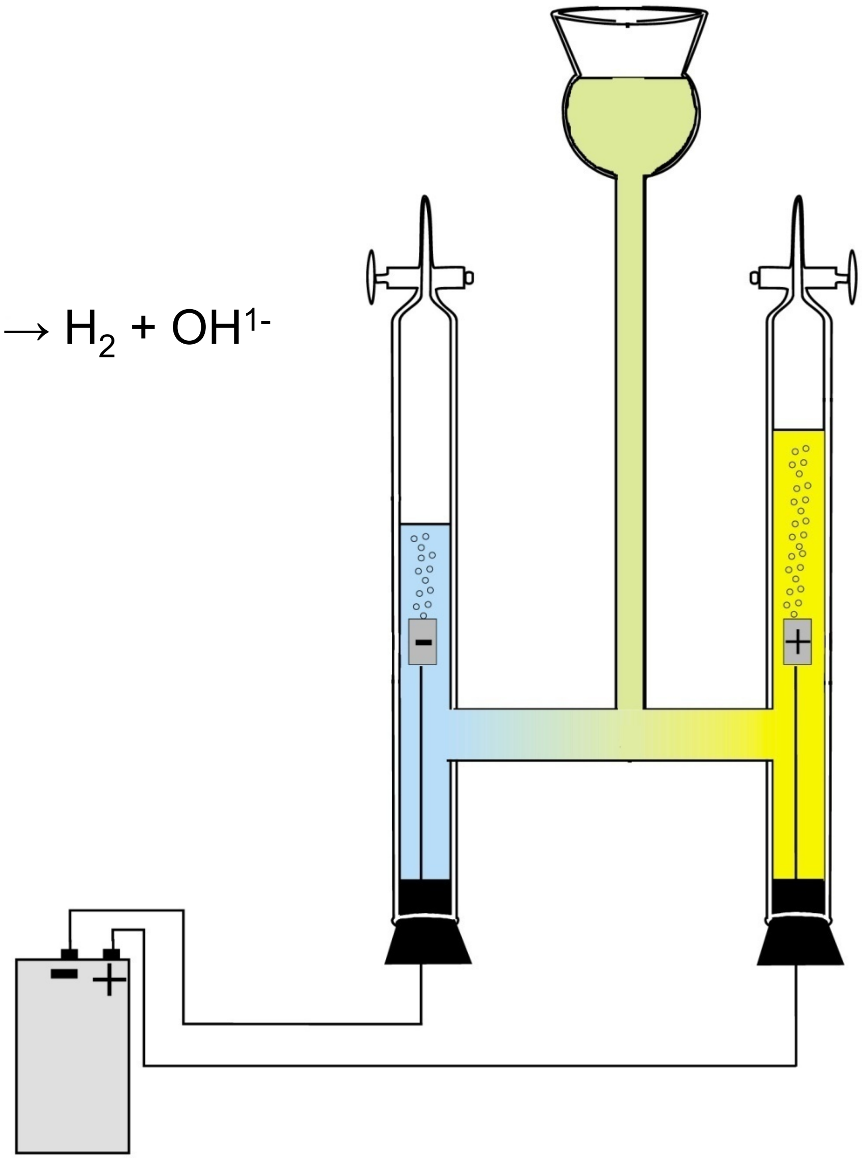
$H_2O \rightarrow O_2 + H^{1+}$

ion responsible for acidic solution

These equations, however, violate conservation of charge.

$H_2O \rightarrow H_2 + OH^{1-}$

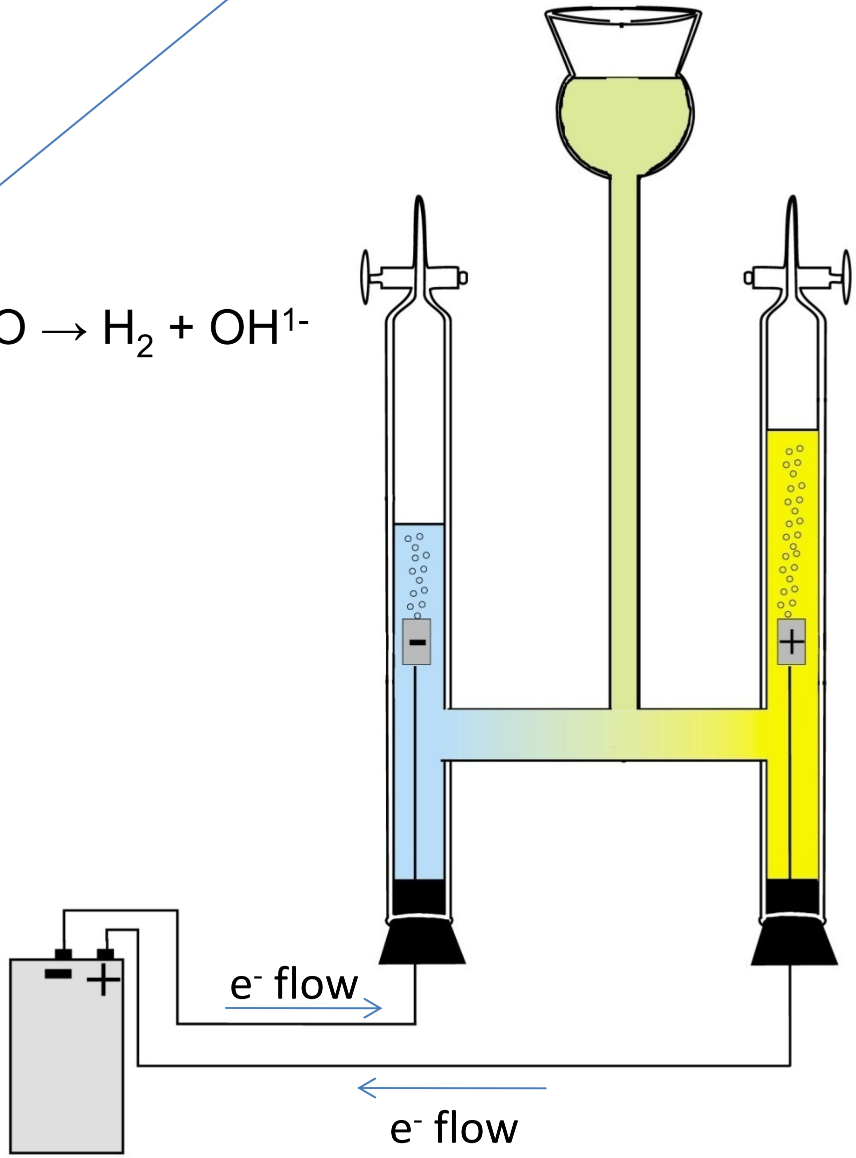
$H_2O \rightarrow O_2 + H^{1+}$



To bring charge back into balance, we recognize that electricity is entering the system at the cathode, and leaving the system at the anode.

$e^{-} + H_2O \rightarrow H_2 + OH^{1-}$

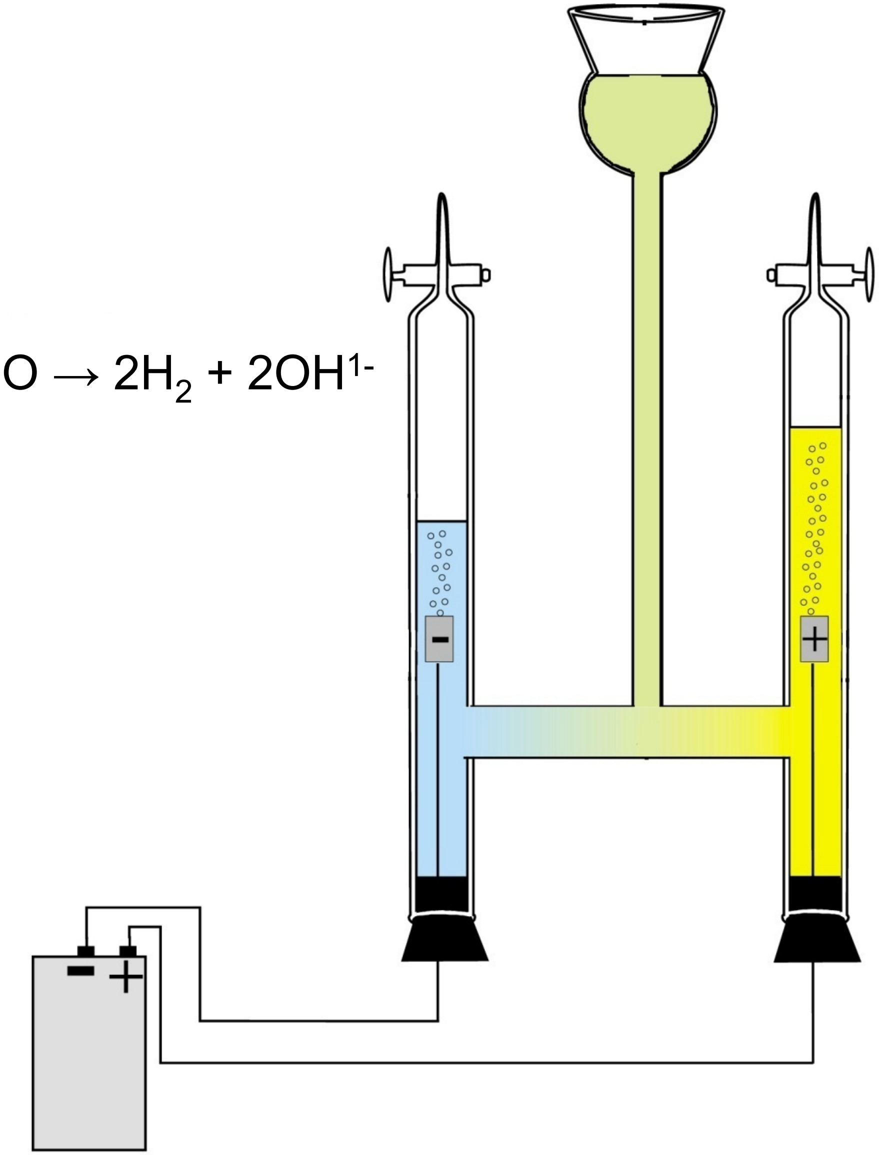
$H_2O \rightarrow O_2 + H^{1+} + e^{-}$



The overall half-reaction equations must be balanced:

$2e^- + 2H_2O \rightarrow 2H_2 + 2OH^{1-}$

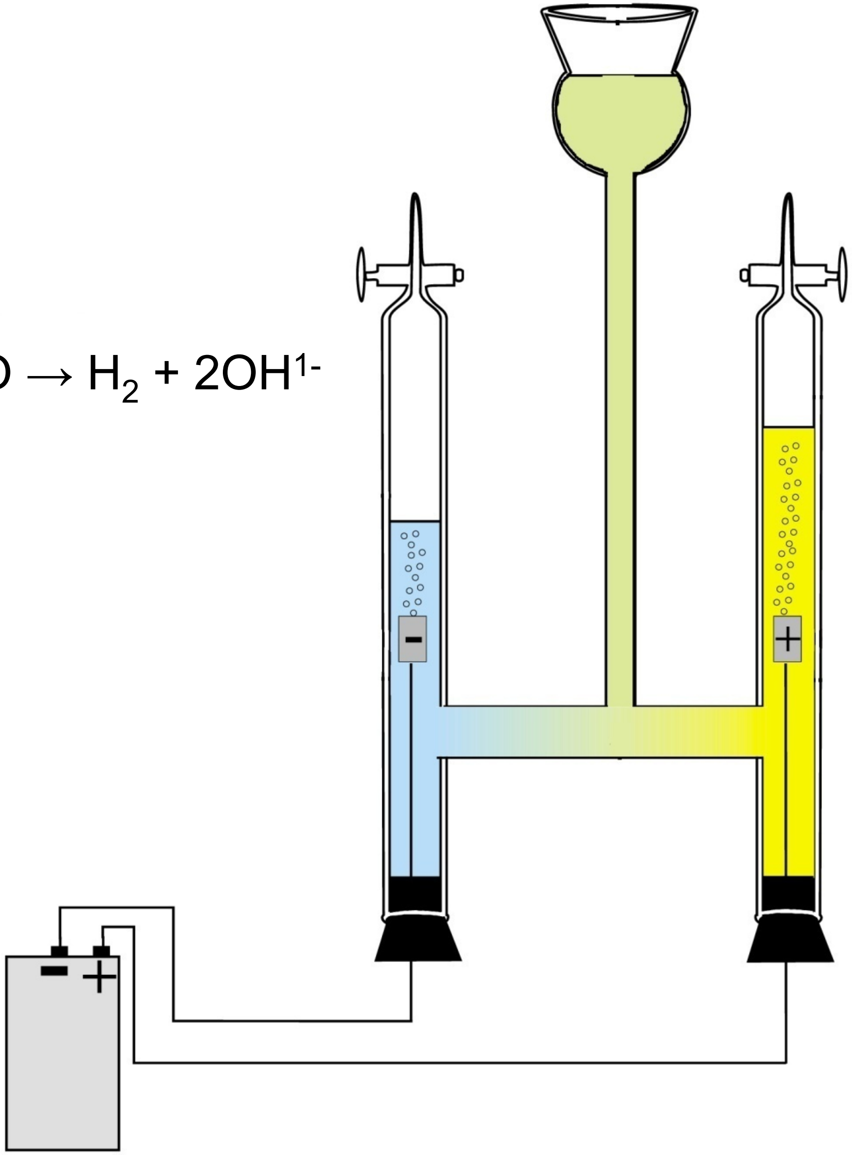
$2H_2O \rightarrow O_2 + 4H^{1+} + 4e^-$



However, we must also balance the exchange of electrons to avoid violation of the Law of Conservation of Energy.

$$2e^- + 2H_2O \rightarrow H_2 + 2OH^{1-}$$

$$2H_2O \rightarrow O_2 + 4H^{1+} + 4e^-$$

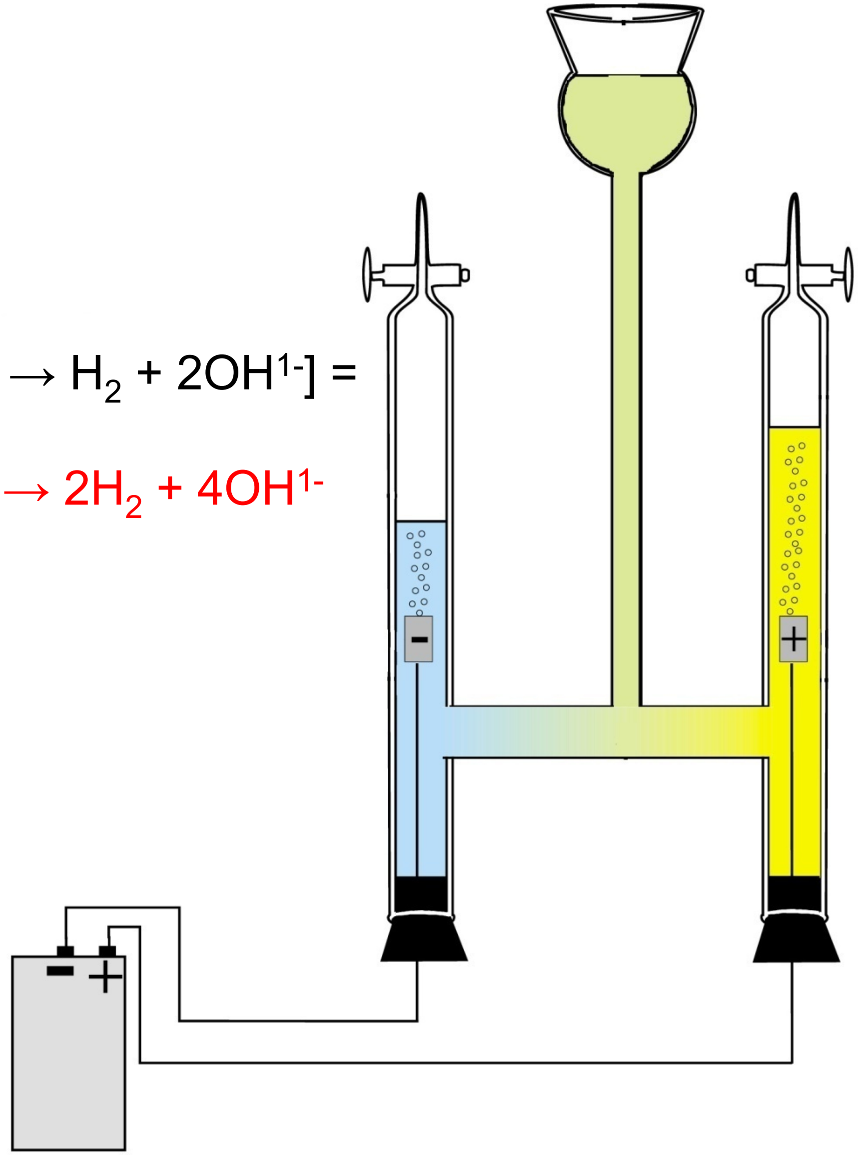


The half-reaction equations when balanced to reflect energy conservation:

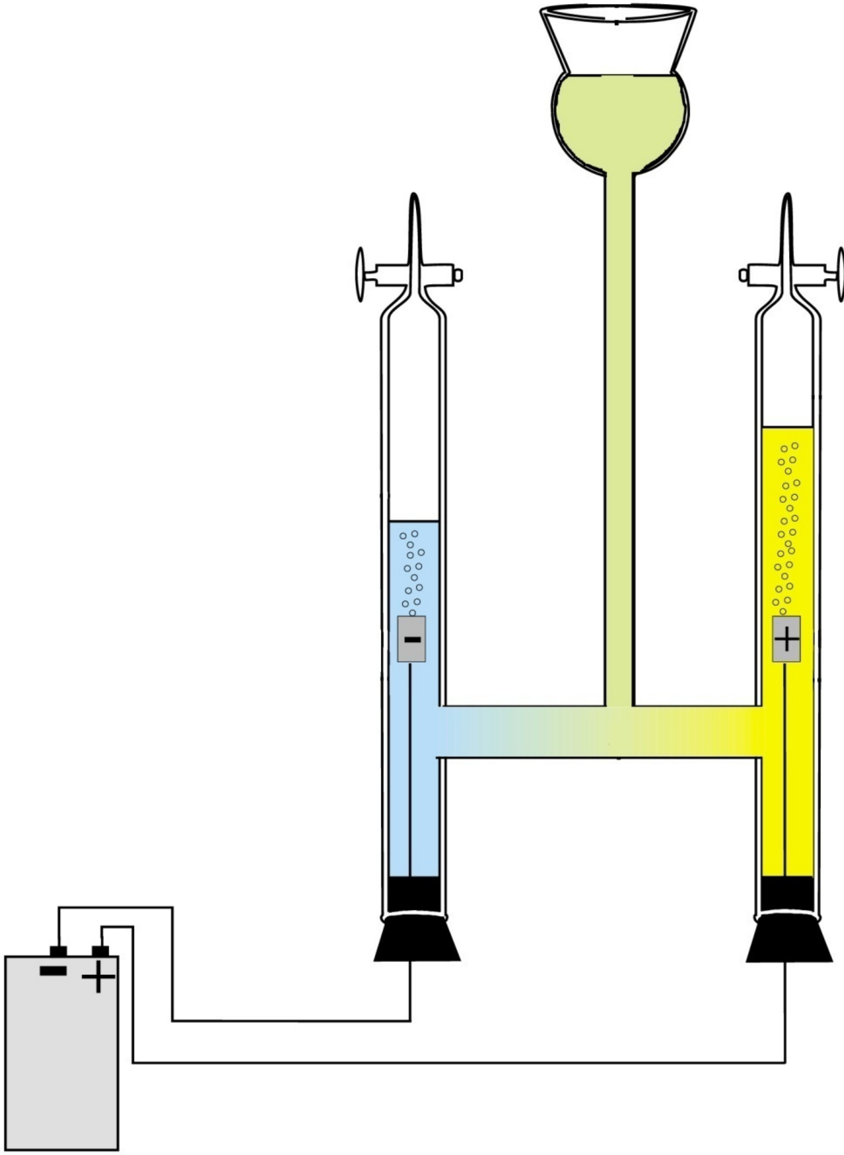
$2[2e^{-} + 2H_2O \rightarrow H_2 + 2OH^{1-}] =$

$4e^{-} + 4H_2O \rightarrow 2H_2 + 4OH^{1-}$

$2H_2O \rightarrow O_2 + 4H^{1+} + 4e^{-}$



We now combine the half-reaction equations, recognizing that the equivalent electron terms on either side arithmetically cancel:

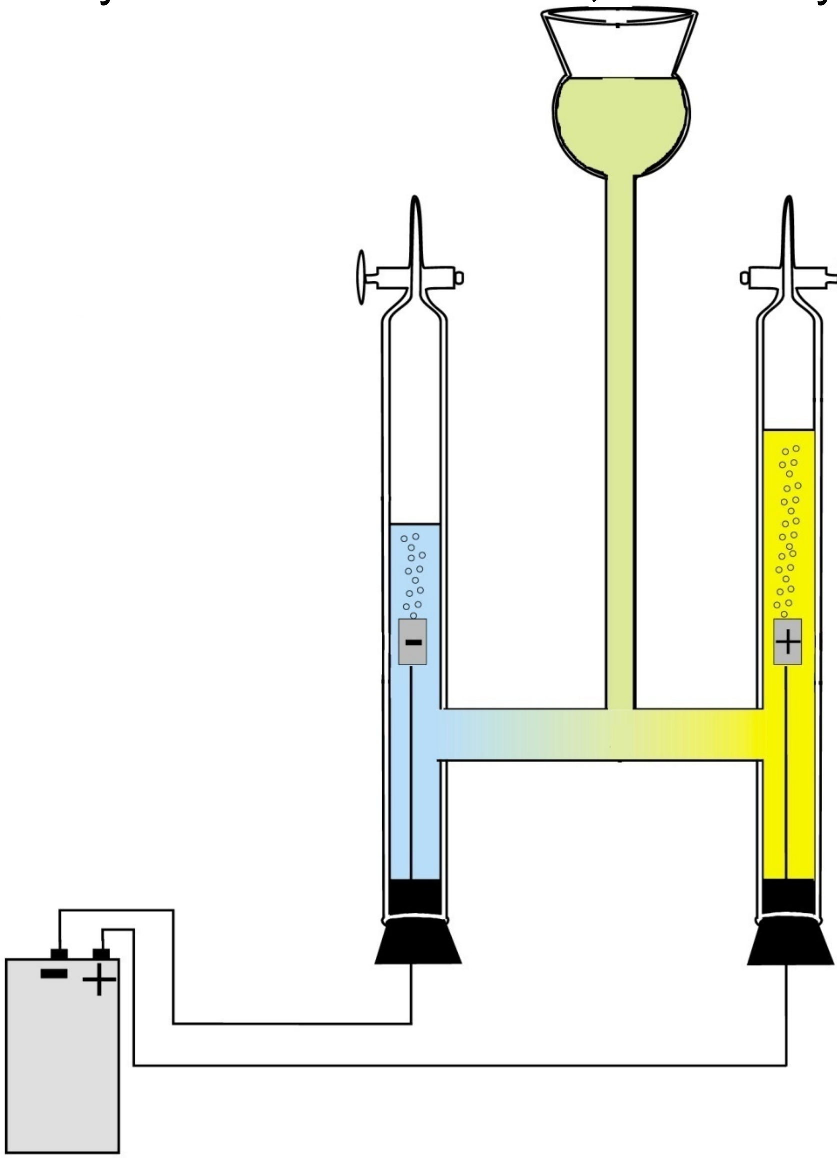


$$\cancel{4e^-} + 4H_2O \rightarrow 2H_2 + 4OH^{1-}$$

$$+ \quad 2H_2O \rightarrow O_2 + 4H^{1+} + \cancel{4e^-}$$

$$6H_2O \rightarrow 2H_2 + 4OH^{1-} + O_2 + 4H^{1+}$$

Finally, it is recognized that once the electrolysis process is terminated, the mobile hydrogen and hydroxide ions continue to move about in solution – and, when they encounter each other, chemically combine to form water.



$$6H_2O \rightarrow 2H_2 + 4OH^{1-} + O_2 + 4H^{1+}$$

$$\therefore, 6H_2O \rightarrow 2H_2 + 4H_2O + O_2$$

or, simplifying by subtraction of four water molecules from each side:

$$2H_2O \rightarrow 2H_2 + O_2$$

Some Chemistry HSCE's that apply to the electrolysis of water

C3.4 Endothermic and Exothermic Reactions

Chemical interactions either release energy to the

environment (exothermic) or absorb energy from the environment (endothermic).

C3.4A Use the terms endothermic and exothermic correctly to describe chemical reactions in the laboratory.

C3.4B Explain why chemical reactions will either release or absorb energy.

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C5.2 Chemical Changes

Chemical changes can occur when two substances, elements, or compounds interact and produce one or more different substances whose physical and chemical properties are different from the interacting substances. When substances undergo chemical change, the number of atoms in the reactants is the same as the number of atoms in the products. This can be shown through simple balancing of chemical equations. Mass is conserved when substances undergo chemical change. The total mass of the interacting substances (reactants) is the same as the total mass of the substances produced (products).

C5.2A Balance simple chemical equations applying the conservation of matter.

C5.2B Distinguish between chemical and physical changes in terms of the properties of the reactants and products.

C5.2C Draw pictures to distinguish the relationships between atoms in physical and chemical changes.

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C5.5x **Chemical Bonds**

Chemical bonds can be classified as ionic, covalent, and metallic. The properties of a compound depend on the types of bonds holding the atoms together.

C5.5c **Draw Lewis structures for simple compounds.**

C5.5d **Compare the relative melting point, electrical and thermal conductivity and hardness for ionic, metallic, and covalent compounds.**

C5.5e **Relate the melting point, hardness, and electrical and thermal conductivity of a substance to its structure.**

C5.6x Reduction/Oxidation Reactions

Chemical reactions are classified according to the fundamental molecular or submolecular changes that occur. Reactions that involve electron transfer are known as oxidation/reduction (or "redox").

C5.6a Balance half-reactions and describe them as oxidations or reductions.

C5.6b Predict single replacement reactions.

C5.6c Explain oxidation occurring when two different metals are in contact.

C5.6d Calculate the voltage for spontaneous redox reactions from the standard reduction potentials.

C5.6e Identify the reactions occurring at the anode and cathode in an electrochemical cell.

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C5.7 Acids and Bases

Acids and bases are important classes of chemicals that are recognized by easily observed properties in the laboratory. Acids and bases will neutralize each other. Acid formulas usually begin with hydrogen, and base formulas are a metal with a hydroxide ion. As the pH decreases, a solution becomes more acidic. A difference of one pH unit is a factor of 10 in hydrogen ion concentration.

C5.7A Recognize formulas for common inorganic acids, carboxylic acids, and bases formed from families I and II.

C5.7B Predict products of an acid-base neutralization.

C5.7C Describe tests that can be used to distinguish an acid from a base.

C5.7D Classify various solutions as acidic or basic, given their pH.

C5.7E Explain why lakes with limestone or calcium carbonate experience less adverse effects from acid rain than lakes with granite beds.