What is Chemistry?

- Chemistry is the science that tries to understand how matter behaves by studying the behavior of atoms and molecules.
- The central science: needed in study of biology, physics, geology, medicine, environmental sciences, and engineering
- Matter is anything that occupies space and weighs something ("stuff")

Other Needed Definitions

- Properties = the characteristics that give something its unique identity. Examples:
  - Water freezes at 32°F and boils at 212°F (at sea level)
  - Water reacts with iron and O_2 to form rust.
- Substance = a form of matter that has a definite composition and distinct properties
  - Composition: The types and amounts of simpler substances in a sample.
  - Example: Water is always 1/9 hydrogen by mass and 8/9 oxygen by mass

Metal Atoms

- Aluminum is a substance. The smallest possible piece of aluminum that has all of the properties of aluminum is submicroscopic (that is, extremely small) and is called an atom of aluminum.
- The smallest possible particle of any pure metal, such as copper or iron, that has all of the properties of that metal is an atom of that metal.
- A substance, such as aluminum, that is composed of only one kind of atom is called an element.

Air is composed primarily of oxygen gas and nitrogen gas.

- Oxygen gas has properties that make it distinctly different from nitrogen gas (for example: oxygen gas supports life, nitrogen gas does not).
- A sample of pure oxygen gas can be subdivided until the smallest possible sample that remains that has the properties of pure oxygen gas. In this case, this is a particle called a <u>molecule</u> of oxygen.

Atoms vs. Molecules

- A molecule of oxygen gas can be split in half. Two identical particles, with properties than differ from those of oxygen gas are formed. These are atoms of oxygen.
- Therefore, the formula for oxygen gas is O_2, which is an example of a diatomic molecule. Hydrogen gas is also diatomic, and so has the formula H_2.
- An ozone molecule is composed of three oxygen atoms, and so has the formula O_3. Ozone has different properties from those of diatomic oxygen. Both O_2 and O_3 are forms of the element oxygen.

Other Properties of Molecules and Atoms

- Atoms cannot be split into smaller particles by ordinary chemical means. Any element is composed of only one kind of atom.
- There are currently 116 known elements, of which 88 occur naturally.
- Oxygen, nitrogen and hydrogen, along with aluminum, are all examples of elements.
- Water (H_2O) is an example of a compound, a substance composed of two or more elements (two or more kinds of atoms) in fixed definite proportions.

Chemical Reactions

- If one molecule of O_2 gas reacts with two molecules of H_2 gas, two molecules of H_2O form immediately while producing large amounts of heat.
- H_2O (= water) has properties that are very different from those of either O_2 or H_2.
- A chemical reaction (= chemical change) has occurred between H_2 and O_2.
- This can be represented by a chemical equation: $2\,H_2 + O_2 \longrightarrow 2\,H_2O$
- A famous example of this reaction is shown on the next slide.

John Dalton's Atomic Theory (1808)

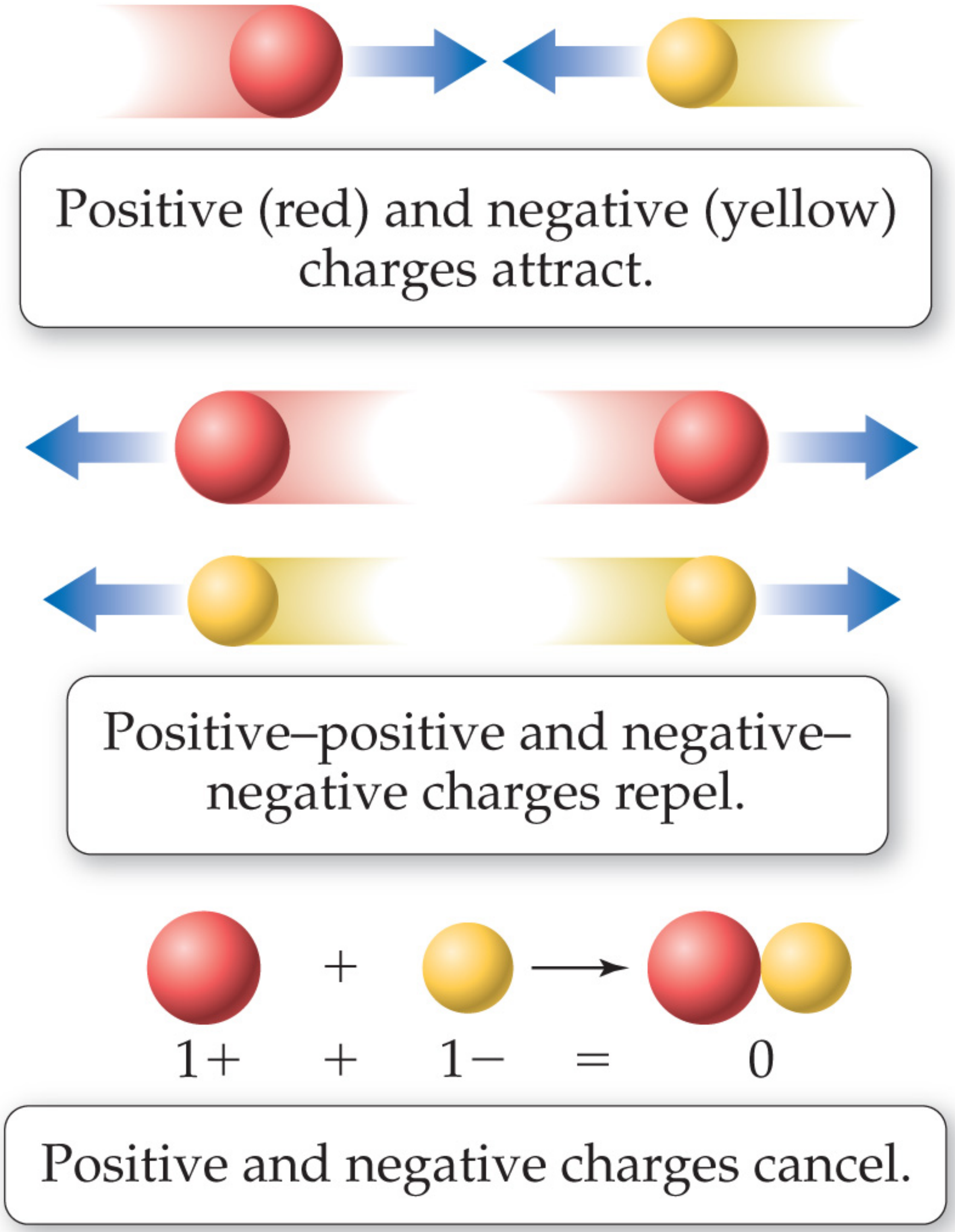
- All matter is composed of small, indestructible particles called atoms.
- All atoms of a given element are identical in size, mass and chemical properties.
- Atoms of one element differ from atoms of all other elements in these properties.

Dalton's Atomic Theory [continued]

- Chemical reactions involve the separation, combination or rearrangement of atoms, not their creation or destruction or conversion into atoms of other elements.
- Atoms of different elements combine only in whole number ratios to form chemical compounds. There are many millions of known compounds.

Electrical Charge

- Electrical charges are responsible for static electricity and electrical current. There two kinds of electrical charges: positive and negative.
- Like charges repel, unlike charges attract. Therefore, two negatively charged objects will repel each other, as will two positively charged objects.
- A positively charged object and a negatively charged object will be attracted to each other.


Positive (red) and negative (yellow) charges attract.
Positive–positive and negative–negative charges repel.
+
1+ + 1− = 0
Positive and negative charges cancel.

The Structure of Atoms

- **Atoms are composed of protons, neutrons and electrons.**
- **Electrons are negatively charged (discovered by J. J. Thomson in 1897).**
- **Protons are positively charged.**
- **Electrons are as negatively charged as protons are positively charged.**
- **Neutrons have no electrical charge (discovered by James Chadwick in 1936).**

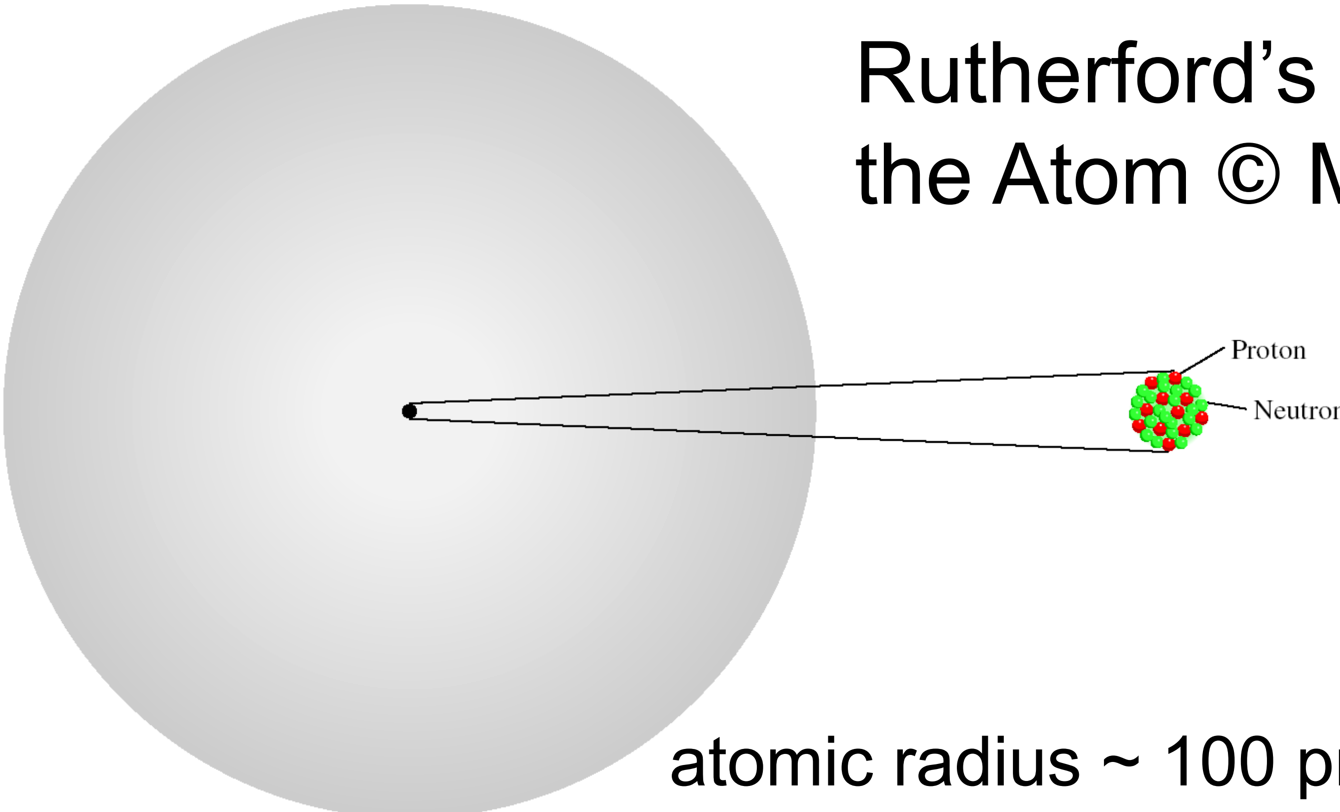
A General Model of the Atom (Continued)

- The protons and neutrons are found only in a very small region in the center of the atom called the nucleus (discovered by Ernest Rutherford in 1910). A cloud of electrons surrounds the nucleus.
- Protons and neutrons weigh about the same and are almost 2000 times heavier than electrons.
- The nucleus has a diameter that is only about 1/10,000 that of the atom, although the nucleus contains nearly all the mass of the atom.
- Analogy; a swarm of bees (electrons) surrounds a hive (the nucleus).

Relative Size of the Proton and the Electron

- If a proton had the mass of a baseball, an electron would have the mass of a rice grain.
- The proton is nearly 2000 times as massive as an electron.

Rutherford's Model of the Atom © McGraw-Hill



atomic radius ~ 100 pm = 1×10^{-10} m

nuclear radius ~ 5×10^{-3} pm = 5×10^{-15} m

"If the atom is the Houston Astrodome, then the nucleus is a marble on the 50-yard line."

Protons and an Element's Identity

- All atoms of a given element have the same number of protons.
- Therefore, <u>all</u> oxygen atoms have 8 protons in their nuclei. An atom containing 8 protons is, <u>by definition</u>, an atom of oxygen.
- An atom containing only 7 protons is not an oxygen atom but is, by definition, a nitrogen atom.
- To be electrically <u>neutral</u>, any atom <u>must</u> possess exactly as many electrons as there are protons in its nucleus.

Numbers of Neutrons

- The number of neutrons in the nucleus of an atom of a given element can vary from one atom to the next.
- Certain ratios of the number of protons to the number of neutrons make that atom radioactive, which means that atom spontaneously emits radiation and may be quite harmful to living things.

Numbers of Electrons

- The number of electrons possessed by an atom of a given element can also vary from one atom to the next.
- For example: an atom of iron, which has 26 protons by definition, can also have 26 electrons (as found in an iron nail) or 24 electrons (as found in foods and in the blood) or only 23 electrons (as found in iron rust).

The Periodic Table

- The number of protons in an atom can be obtained from the periodic table, (first devised by the Russian chemist Dmitri Mendeleev in 1870).
- When the elements are arranged in order of increasing numbers of protons, the properties of the elements tend to repeat periodically.
- The number of protons possessed by an atom of a particular element will always be a whole number in a periodic table. The number of electrons in a neutral atom will be the same as the number of protons.
- The number of protons plus the average number of neutrons in an atom of a given element is shown on a periodic table as a decimal.

Ions

- Ions are atoms or groups of atoms in which the total number of protons does not equal the total number of electrons. For example:
- The ion H_3O^+ has a total of 11 protons but only 10 electrons.
- The ion OH^- has a total of 9 protons but has 10 electrons.
- These two ions will play a central role in our discussion of acids and bases.

Water and the Ions H_3O^+ and OH^-

- Even in pure water, two water molecules will very occasionally react with each other to form one ion each of H_3O^+ and OH^- as follows: $H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$
- The equilibrium sign ($\rightleftharpoons$) is used to indicate that as soon as these ions form, they react with each other to reform two water molecules.

Expressing the Concentration of Ions

- Chemists express the concentration of these ions in a solution in moles per liter.
- The mass of an atom, ion or molecule in grams is numerically equal to the total number of protons plus the average number of neutrons and can be obtained from the periodic table. This is the mass of one mole of this substance.
- The mass of the electrons present is so small it can be neglected.
- Therefore, one mole of H_3O^+ ions weighs 19 grams, and one mole of OH^- ions weighs 17 grams. [3 quarters weighs about 17 grams.]

The Concentration of Ions in Water

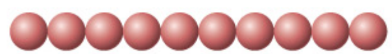
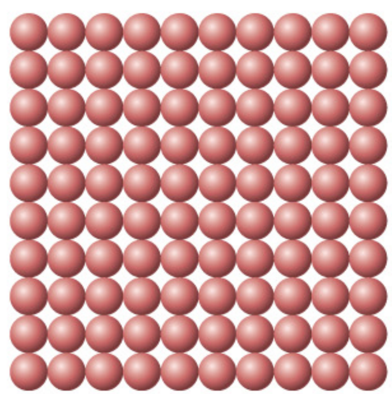
- In pure water at room temperature, the concentration of the H_3O^+ ions equals that of the OH^- ions and is 0.00000010 moles per liter. This very small number can be written in scientific notation as 1.0×10^{-7} moles per liter.
- A solution in which the concentration of each of these ions is 1.0×10^{-7} moles per liter is called a neutral solution.
- Adding any acidic substance to pure water will increase the concentration of H_3O^+ ions and will decrease the concentration of OH^- ions.
- Adding any basic (or alkaline) substance to pure water will have the opposite effect.

The pH Scale

- Since most of us do not like to deal with very small numbers, the pH scale was invented. The pH of a given solution is defined as the negative logarithm of the H_3O^+ concentration. pH values range from about 0 to about 14.
- On this scale, a neutral solution will have a pH of 7, an acidic solution will have a pH less than 7, and a basic solution will have a pH greater than 7.
- A decrease of 1 pH unit scale corresponds to an increase in H_3O^+ concentration by a factor of 10.
- Example: If the H_3O^+ concentration is 1.0×10^{-4} moles per liter, what is the pH?

The pH Scale Is a Logarithmic Scale

- A *decrease* of 1 unit on the pH scale corresponds to an *increase* in H_3O^+ concentration by a factor of 10.

pH	$[H_3O^+]$	$[H_3O^+]$ Representation
4	10^{-4}	
3	10^{-3}	
2	10^{-2}	

$\left(\text{Each circle represents } \dfrac{10^{-4}\text{ mol H}^+}{\text{L}}\right)$

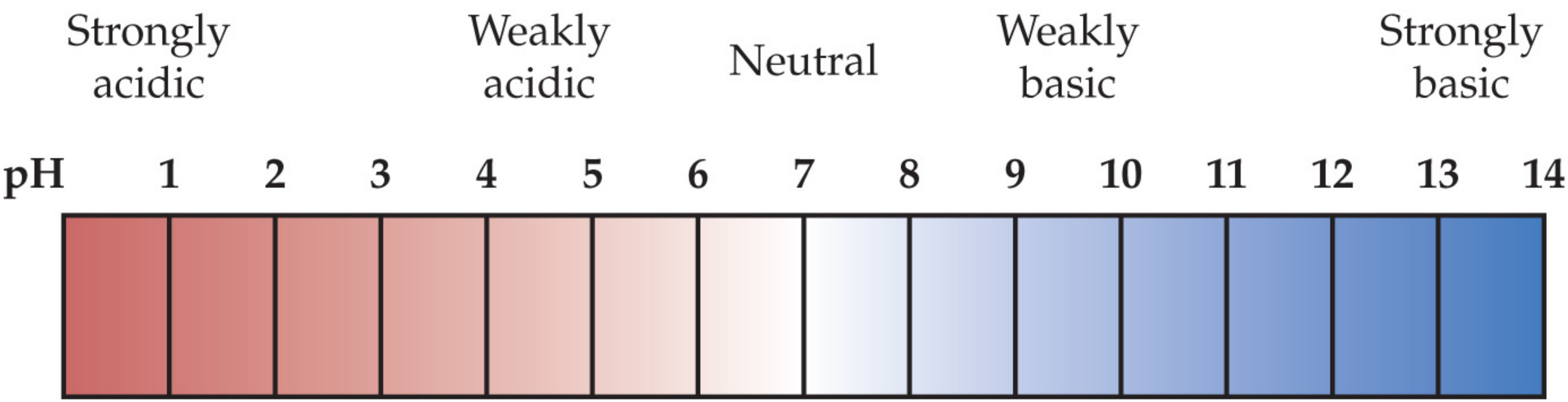
The pH and pOH Scales: Ways to Express Acidity and Basicity

At 25 °C:

pH < 7 ***acidic*** solution

pH > 7 ***basic*** solution

pH = 7 ***neutral*** solution



Properties and Examples of Acids

- Properties: Acids have a sour taste and react with many metals to give H_2 gas.
- Acids are a source of H^+ ions, which react with water to form hydronium ions, H_3O^+.
- Formulas for acids usually begin with H.
- Some common examples of acids: hydrochloric acid, HCl (stomach acid), acetic acid, $HC_2H_3O_2$ (present in vinegar), sulfuric acid, H_2SO_4 (battery acid)

Properties and Examples of Bases

- Properties: Bases have a bitter taste and feel slippery to the touch.
- Bases are a source of OH^- ions in water-based solutions.
- Bases will react with acids to form ionic compounds and water.
- Two common bases: sodium hydroxide, $NaOH$ (present in drain cleaner) and magnesium hydroxide, $Mg(OH)_2$ (milk of magnesia).

Strong Acids

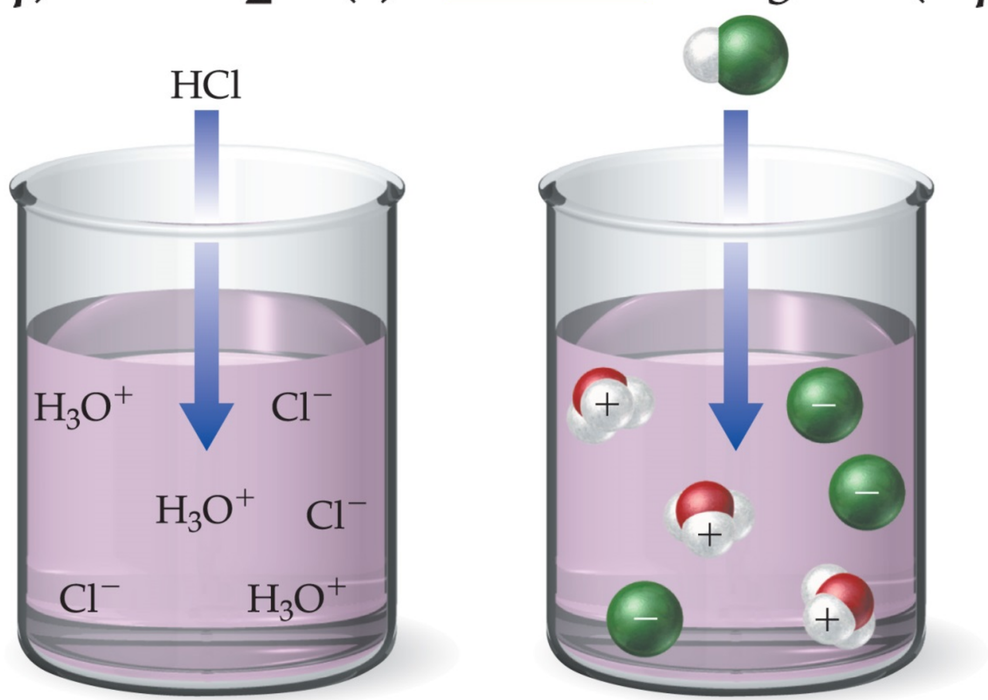
- Strong acids dissociate completely when dissolved in water, and so produce only ions when dissolved in water. See the diagram in the laboratory experiment or the next slide.
- Example: $HCl + H_2O \longrightarrow H_3O^+ + Cl^-$
- Therefore, HCl is a strong electrolyte because it forms ONLY ions when dissolved in water. No molecules of HCl are present when dissolved in water.

A Strong Acid

When HCl dissolves in water, it completely ionizes into H_3O^+ and Cl^- ions. The solution contains no intact HCl.

Single arrow indicates complete ionization

$$HCl(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$



Weak Acids

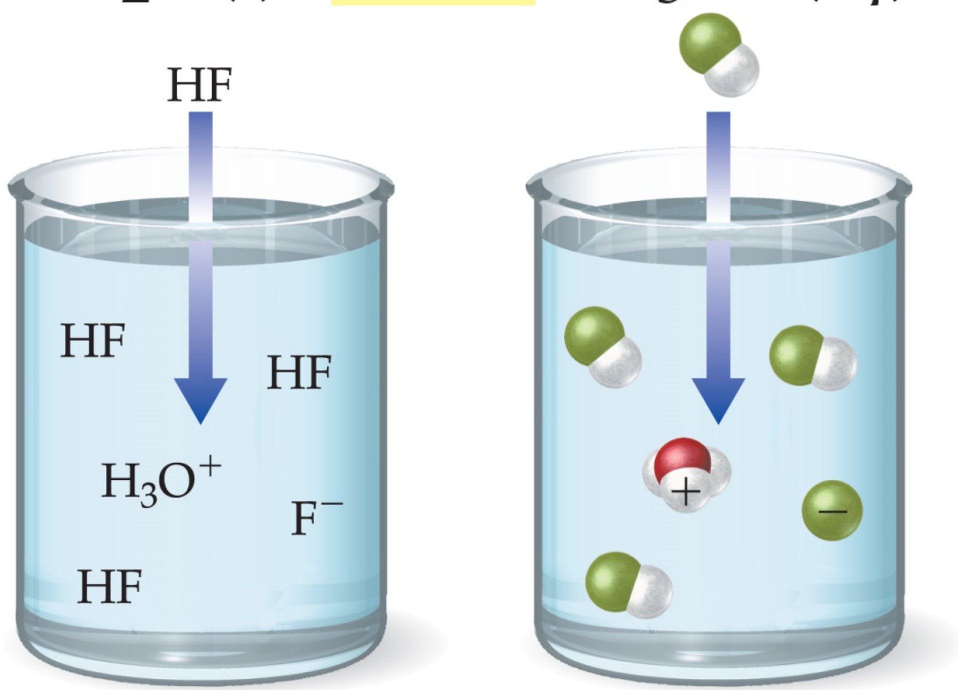
- Weak acids are weak electrolytes = compounds that exist mostly as molecules in water-based solutions but that also exist to a small extent as ions.
- Acetic acid and hydrofluoric acid are weak acids: they exist 95% to 99% of the time as molecules when dissolved in water and only 1% to 5% of the time as ions, depending on concentration.
- This is illustrated by the equation:
  $HF + H_2O \rightleftarrows H_3O^+ + F^-$.

A Weak Acid

When HF dissolves in water, only a fraction of the dissolved molecules ionize into H_3O^+ and and F^- ions. The solution contains many intact HF molecules.

Double arrow indicates partial ionization

$$HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$$



An ***electrolyte*** is a substance that, when dissolved in water, results in a solution that can conduct electricity.

A ***nonelectrolyte*** is a substance that, when dissolved, results in a solution that does not conduct electricity.

nonelectrolyte

weak electrolyte

strong electrolyte

Strong Bases

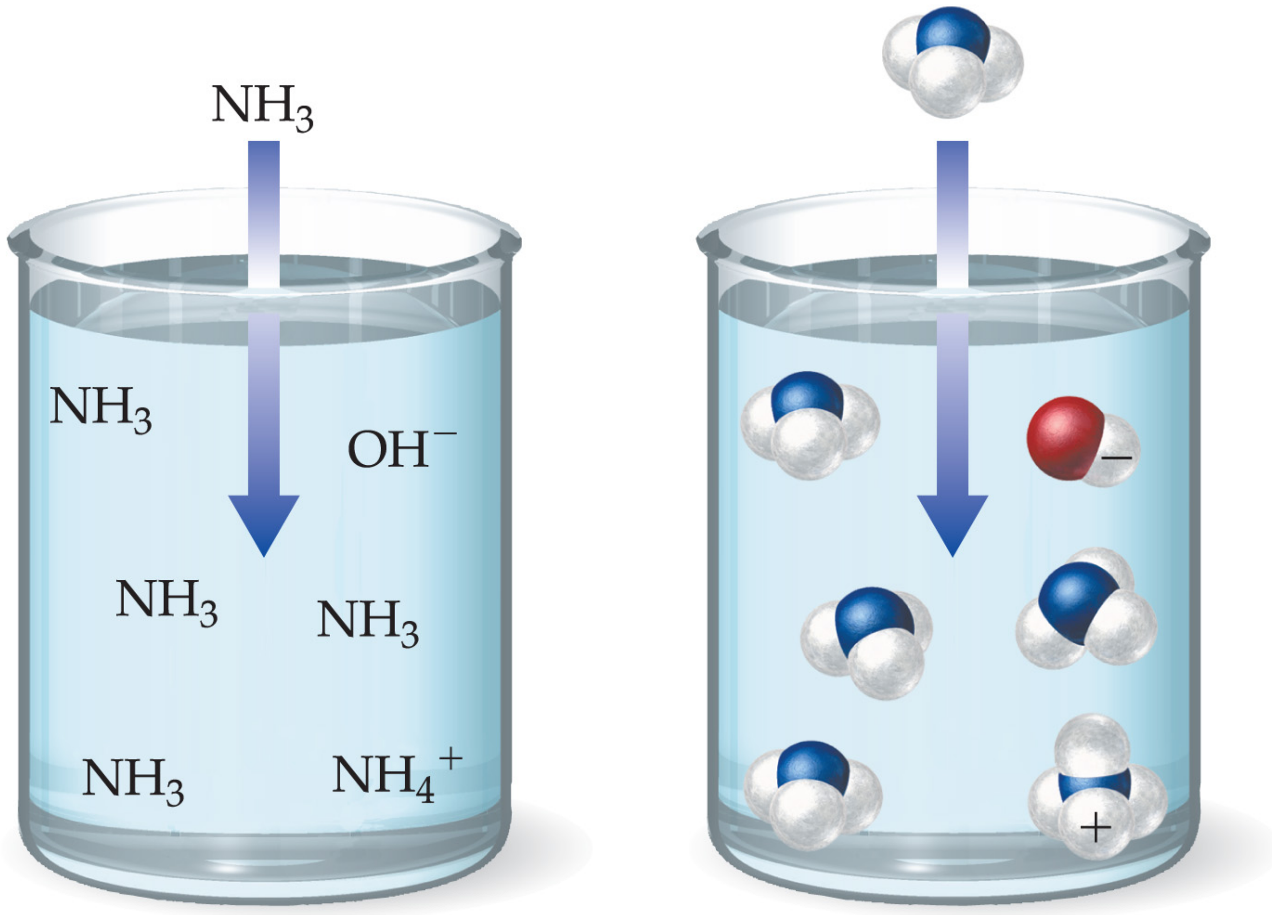
- Strong Bases: Dissociate completely in solution to give hydroxide ions.
- Common strong bases: NaOH, $Mg(OH)_2$.
- These exist ONLY as ions in aqueous solution, NOT as molecules.
- Example when dissolved in water:
  $Mg(OH)_2 \longrightarrow Mg^{2+} + 2\ OH^-$
- Note that no molecules of $Mg(OH)_2$ are present.

Weak Bases

- Weak Bases exist mostly as molecules in water-based solution but react with water to a small extent to form hydroxide ions.
- Ammonia, NH_3 (present in Windex) is a weak base: it exists 98% to 99% of the time as molecules when dissolved in water and only 1% to 2% of the time as ions, depending on concentration.
- This is illustrated by the equation:
  $NH_3 + H_2O \rightleftarrows NH_4^+ + OH^-$.

A Weak Base

When NH_3 dissolves in water, it partially ionizes to form NH_4^+ and OH^-. However, only a fraction of the molecules ionize. Most molecules remain as NH_3.



Carbonates and Bicarbonates

- Ionic compounds of CO_3^{2-} (carbonates) and HCO_3^- (bicarbonates) such as sodium carbonate and sodium bicarbonate, are also weak bases due to the following equilibria:
- $CO_3^{2-} + H_2O \rightleftarrows HCO_3^- + OH^-$
- $HCO_3^- + H_2O \rightleftarrows H_2CO_3 + OH^-$

Buffer Solutions

- Buffer solutions are solutions that resist changes in pH as long as not too much acid or base is added.
- Buffer solutions contain a weak acid and a weak base in the same solution. BOTH must be present in comparable amounts in order to have a buffer solution.
- The pH of human blood must be in the range of 7.0 to 7.8, or the patient will die. It is kept in this range by a series of buffer solutions.
- The "phosphate buffer" you will use in lab today is a solution of a mixture of K_2HPO_4, which is weakly basic, and KH_2PO_4, which is weakly acidic.