3-D Molecular Designs

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Water Kit© pH Lesson

Objectives

Students will:

- **Create** a physical representation of the autoionization of water using the water kit.
- **Describe** and **produce** a physical representation of the dissociation of a strong acid and a strong base.
- **Associate** a high hydronium ion (H_3O^+) concentration with low pH and a high hydroxide ion (OH^-) concentration with a high pH.
- **Demonstrate** how the structure of an amino acid is affected by the pH of the environment into which it has been placed.

Materials

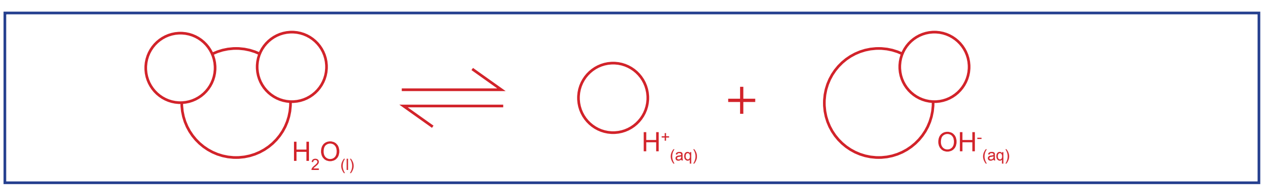
- 1 Water Kit© cup per small group
- 1 copy of this packet per person

Water Dissociation

The water kit may also be used to introduce the concepts of water dissociation (autoionization) and pH to students. A small percentage of water molecules (about 1 in 10,000,000) break apart in pure water at room temperature. Positively charged hydrogen ions (H^+) and negatively charged hydroxide ions (OH^-) are formed in this dissociation.

Remove two water molecules from the water cup. Begin the dissociation of water by pulling off a hydrogen from one of the water molecules.

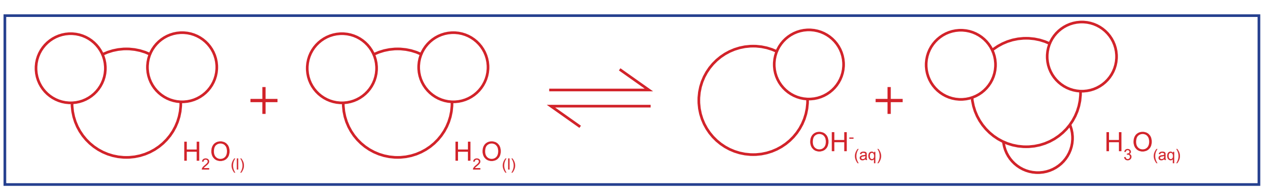
Sketch the model representation of the first step in the dissociation of water.



$$H_2O_{(l)} \rightleftharpoons H^+_{(aq)} + OH^-_{(aq)}$$

When water dissociates, one of the hydrogen nuclei leaves its electron behind with the oxygen atom to become a hydrogen cation (H^+). The hydrogen ion is not stable and bonds to the oxygen atom of a second unionized water molecule to form a hydronium ion (H_3O^+).

Sketch the model representation of the next step in the dissociation of water with hydronium ion formation.



$$H_2O_{(l)} + H_2O_{(l)} \rightleftharpoons OH^-_{(aq)} + H_3O^+_{(aq)}$$

Water Kit© pH

Optional Mathematical Connection

Teachers may want to add a mathematical component to this activity. You may want to have your students answer the following questions:

Questions

1. Calculate the approximate number of water molecules in an 8 oz. glass of water.

   7.91×10^{24} molecules.

   8 ounces of H_2O is about 236.6 grams of water. 18 grams of water in one mole of water.

   1 mole contains Avagadro's number of molecules.

$$\left(236.6 \text{ grams of } H_2O \,/\, \frac{18 \text{ grams}}{1 \text{ mole}}\right) \times (6.02 \times 10^{23} \text{ molecules}) = 7.91 \times 10^{24}$$

2. Calculate the number of water molecules that would autoionize in an 8 oz. glass of water.

   7.91×10^{17} molecules.

   1 in 10,000,000 autoionize.

$$\frac{7.91 \times 10^{24} \text{ molecules of } H_2O}{10{,}000{,}000} = 7.9 \times 10^{17}$$

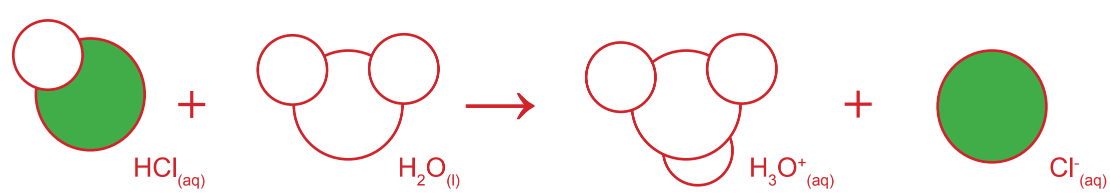
Acid/Base Dissociation

Acid

An acid is a compound that produces H^+ cations in solution. Hydrochloric acid (HCl) is an example of a strong acid found in the stomach. In an aqueous solution hydrochloric acid breaks into H^+ and Cl^- ions.

$$HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

Use the water kit to model the dissociation of hydrochloric acid in water.



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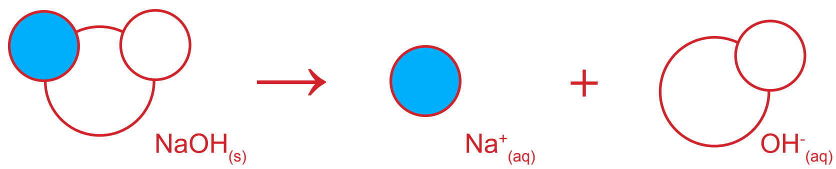
Base
The oldest Arrhenius theory identifies a base as a ***hydroxide ion anion donor***.
Sodium hydroxide (NaOH) is an example of a strong base commonly found in drain cleaners.

$$NaOH_{(s)} \rightarrow Na^{+}_{(aq)} + OH^{-}_{(aq)}$$

Use water kit to model NaOH and dissociation in water.



Alternate definitions of a base include the Brønsted-Lowry theory which defines a **base** as a ***proton (hydrogen cation) acceptor***. The more general Lewis theory defines a base as an ***electron pair donor***.

Questions:

1. Why are acids called proton donors?
   Acids donate hydrogen ions (protons) to bases.

2. What happens when an aqueous NaOH donates OH^- anions to an aqueous acidic solution with many H^+ cations?
   A neutralization reaction will occur. The OH^- will combine with the H^+ to form water.

3. Given the equation below, identify HNO_3 as an acid or base and explain your choice.

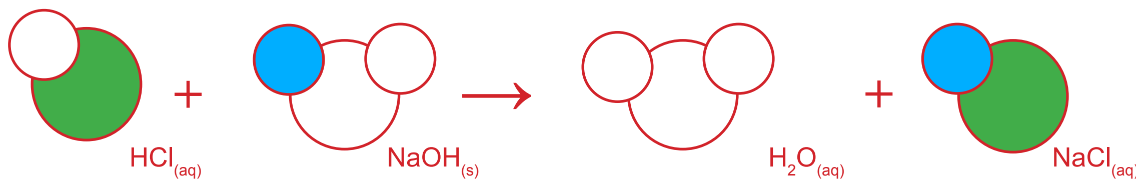
$$HNO_{3(s)} + H_2O_{(l)} \rightarrow H_3O^{+}_{(aq)} + NO_{3\ (aq)}^{-}$$

   HNO_3 is an acid because it donates a proton to the water.

Water Kit© pH

Neutralization

Hydrochloric acid and sodium hydroxide are considered to be a strong acid and a strong base respectively. Model a neutralization reaction using parts from the water kit that you have assembled. Sketch in the space below.



Questions

1. Write the neutralization reaction for sodium hydroxide and hydrochloric acid.
   $HCl_{(aq)} + NaOH_{(s)} \rightarrow H_2O_{(l)} + NaCl_{(aq)}$.

2. What are the reactants in this neutralization reaction?
   HCl and NaOH

3. What are the products of this reaction?
   H_2O and NaCl

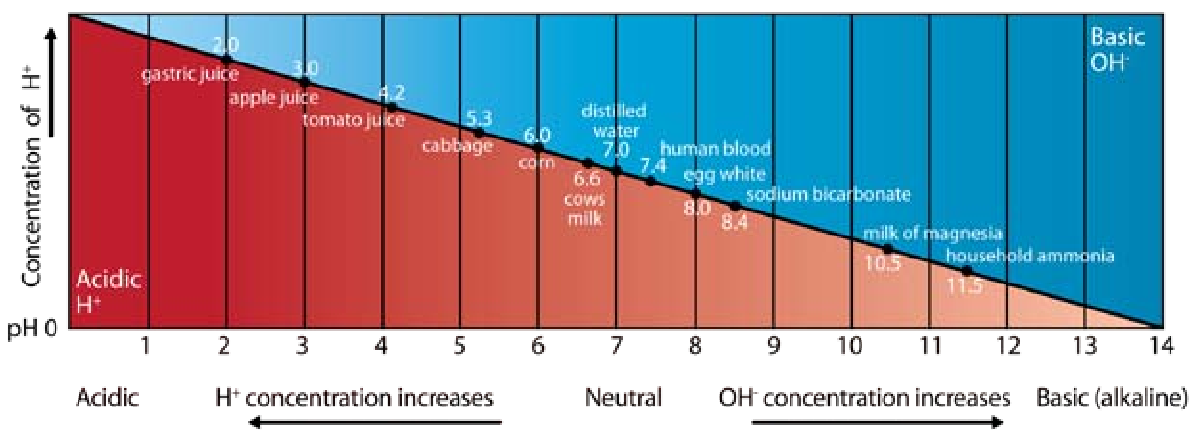
Water Kit© pH

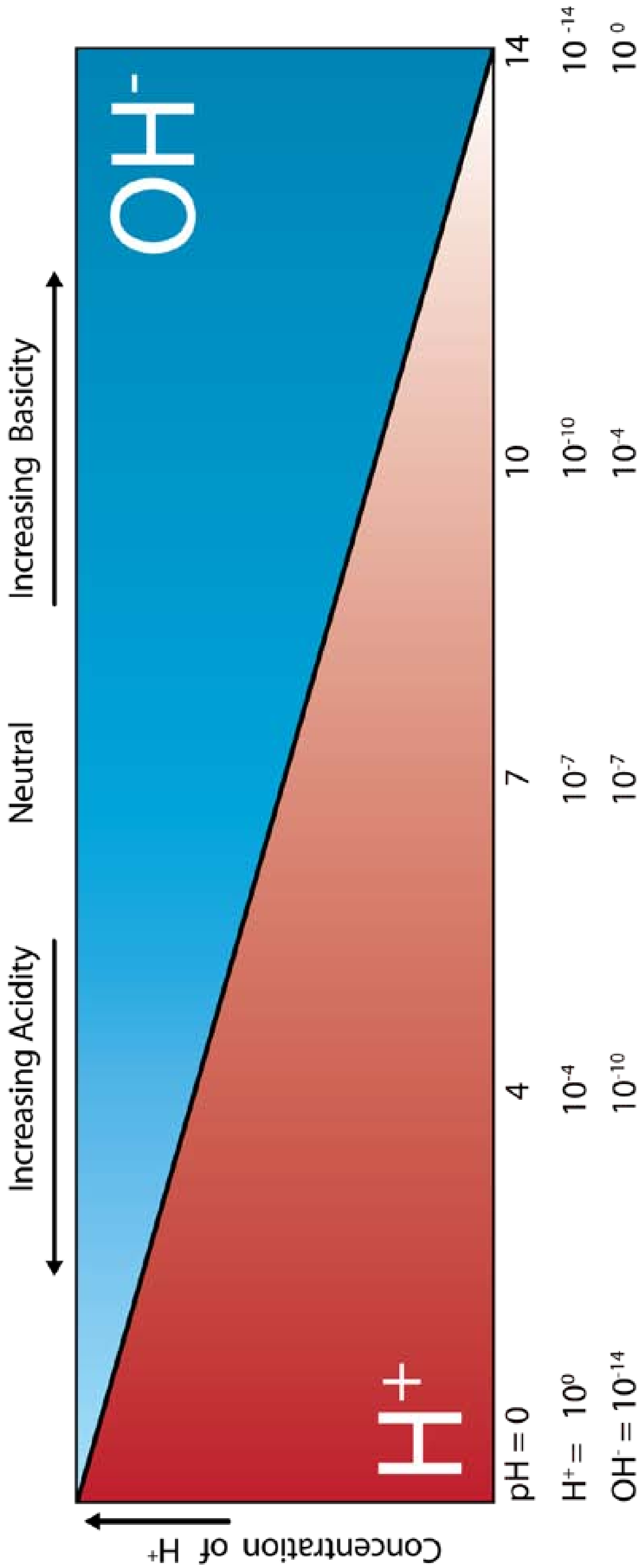
pH

The pH of the various solutions found within living organisms plays a very significant role in many biochemical reactions. Certain enzymes in the body get activated only at certain definite pH values. Blood pH must be maintained at a pH value of 7.36 – 7.42. A mere change of 0.2 pH units can cause death.

The pH of a solution is a measure of the concentration of hydrogen ions in the solution and describes how acidic or basic a solution is. The letters "pH" stand for "power of hydrogen". The usual range of pH values most commonly encountered is between 0 and 14. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are said to be basic or alkaline. A solution with a pH of 7 is considered to be neutral.

Use the chart on the next page and the Water Kit© to model the relative concentration of H_3O^+ cations and OH^- anions on the pH chart below. Place the hydronium cations and the hydroxide anions where you believe the highest concentration of each would be located on the graph.





Increasing Acidity
Neutral
Increasing Basicity
H^+
OH^-
pH = 0
4
7
10
14
$H^+ = 10^0$
10^{-4}
10^{-7}
10^{-10}
10^{-14}
$OH^- = 10^{-14}$
10^{-10}
10^{-7}
10^{-4}
10^0
Concentration of H^+

Water Kit© pH

Each pH unit represents a tenfold change in the concentration of H_3O^+ cations. For example, lemon juice at a pH of 2 has 10 times more H_3O^+ cations than an equal amount of orange juice at pH 3.

Questions

1. In which solution would you find the most H+ cations?

   Battery Acid.

2. In which solution would you find the most OH- anions?

   Liquid drain cleaner.

3. Would the pH increase or decrease if an acid were added to wate?

   pH would decrease.

4. How would the pH change if a basic solution were added to orange juice?

   The pH would increase.

5. Using the table on the next page, compare the pH values of tomato juice to milk. Mathematically describe the relationship of the H_3O^+ concentration of the tomato juice to that of the milk.

   There are 100x's more H_3O^+ ions in tomato juice than in milk.

6. Which living system component listed in the chart below has the highest concentration of H^+ cations?

   Gastric acid of the stomach.

7. If the pH value of a living system component changes, how might this component reestablish the normal pH value?

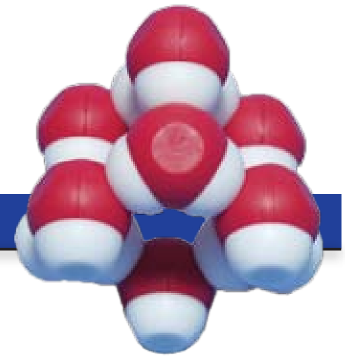
   Use a solution which will counteract the change. For example, if a solution is more acidic than it should be, a basic solution may be added to bring it back into homeostatic balance.

Common pH Value

Substance	pH Value
Battery Acid	0
Gastric Acid	1
Lemon Juice, Vinegar	2
Orange Juice, Soda	3
Tomato Juice, Acid rain	4
Black Coffee, Bananas	5
Urine, Milk	6
Distilled Water	7
Sea Water, Eggs	8
Baking Soda	9
Milk of Magnesia, Great Salt Lake	10
Ammonia Solution	11
Soapy Water	12
Bleach, Oven Cleaner	13
Liquid Drain Cleaner	14

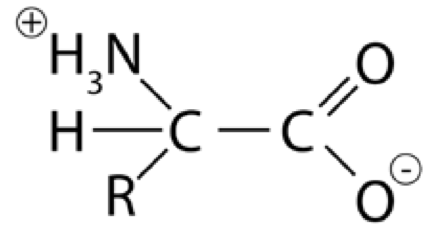
pH Values in a Living System

Component	pH value
Gastric Acid of the Stomach	1
Lysosomes	4.5
Granules of Chromaffin Cells (cells found in the medulla of adrenal glands)	5.5
Human skin	5.5
Urine	6
Neutral H_2O at 37°C	6.81
Cytosol	7.2
Cerebrospinal Fluid	7.3
Blood	7.43-7.45
Mitochondrial Matrix	7.5
Pancreas Secretions	8.1



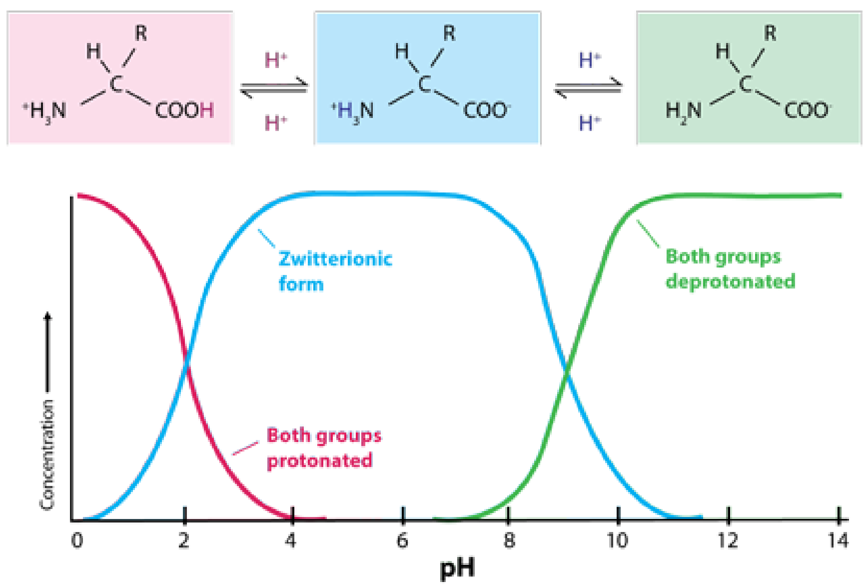
Water Kit© pH

Molecules That Can Act Like an Acid or a Base: A Connection to the Amino Acid Starter Kit



An amino acid may act as either an acid or a base depending on the surrounding environment. The carboxyl group of the amino acids can donate a proton to water while the amino group can accept a proton from water. This exchange happens simultaneously in solution so that the amino acids form doubly ionized species called ***zwitterions*** in solution. At a neutral pH, amino acids would have the following structure:

Changing the pH affects the protonation of the amino acid. See the graph below.



Questions

1. Chose one of the amino acids from the Amino Acid Sidechain List (page 10) and sketch how it would appear in the presence of high pH.

   Answer varies. Alanine example — CH_3 — CH (COO^-)(^+H_3N)

2. Chose a second amino acid from the amino acid chart and sketch how it would appear as in a low pH.

   Answer varies. Alanine example — CH_3 — CH (COO^-)(H_2N)

Amino Acid Side Chain Chart

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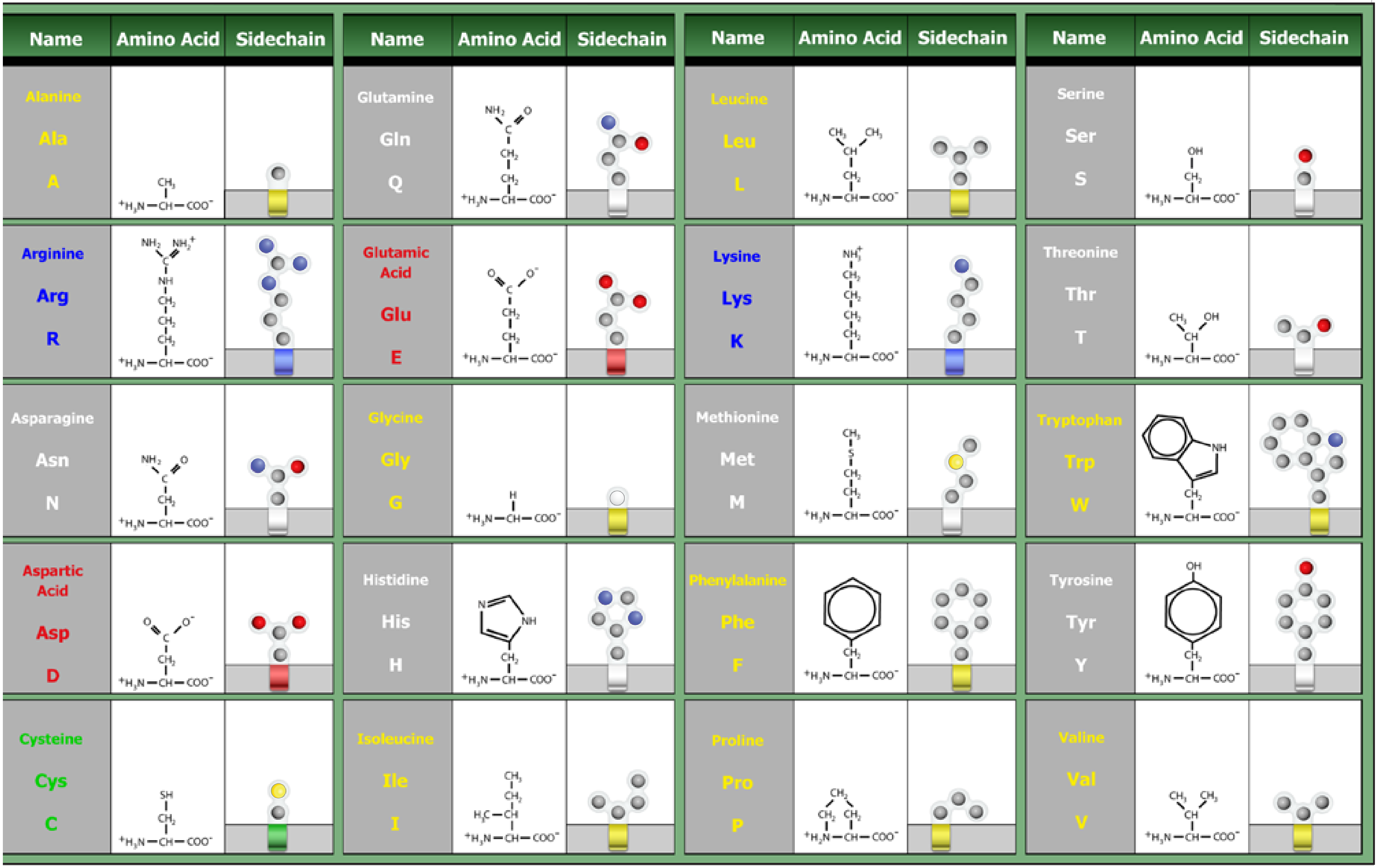

Atom olor Key

Carbon, Oxygen, Nitrogen, Sulfur, Hydrogen

Amino Acid Property Key

Amino acid clip color and name color indicate property

Negative Charge, Positive Charge, Hydrophilic, Cysteine, Hydrophobic

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Connections to: A Framework for K-12 Science Education

Practices, Crosscutting Concepts, and Core Ideas*

Dimension 1: Scientific and Engineering Practices

2. Developing and Using Models
6. Constructing Explanations and Designing Solutions

Dimension 2: Cross Cutting Concepts

1. Patterns
3. Scale, Proportion and Quantity
4. Systems and System Models
5. Energy and Matter: Flows, Cycles, and Conservation
6. Structure and Function
7. Stability and Change

Dimension 3: Disciplinary Core Ideas

Physical Sciences

HS-PS1 Matter and Its Interactions

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

Life Sciences

HS-LS1 From Molecules to Organisms: Structures and Processes

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

**The NSTA Reader's Guide to A Framework for K-12 Science Education, National Research Council (NRC), 2011. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, D.C.: National Academies Press.*