Parent Guide

Unit 5: Solutions, Acids, and Bases

SC6. a. Develop a model to illustrate the process of dissolving in terms of solvation versus dissociation.

In this standard, students will use drawings to show the differences in dissolving an ionic solid (dissociation) versus a covalent solid (solvation). The substance that is being dissolved is called a solute, and the substance that is doing the dissolving is the solvent. A substance will only dissolve if the intermolecular forces between solute and solvent are strong enough.

Dissociation occurs when ionic solids break up into their anions and cations in a polar solvent. These separated anions and cations are then surrounded by the oppositely-charged end of the polar solvent molecules.

Solvation is very different, and occurs in the dissolving of covalent solute. The process of solvation does not involve splitting into ions, as there are no ions in covalent compounds. Instead, the molecules of the covalent compound are each surrounded by the molecules of the solvent (water).

All solvents have a limit on how much solute they can dissolve. This limit is known as the saturation level. A solution that has not yet met its limit is called unsaturated. A solution that is exactly at its limit is called saturated; and a solution that has surpassed the limit is called supersaturated. Changing the temperature of the solution also changes the saturation level. A supersaturated solution is created by heating a solvent and adding the maximum amount of solute, then slowly cooling it down so that the solute remains dissolved. This is how rock candy and the science kits that allow you to “grow crystals” work.

SC6.b. Plan and carry out an investigation to evaluate the factors that affect the rate at which a solute dissolves in a specific solvent.

In this standard, students will design their own experiment to test what factors affect how fast something dissolves in a specific solvent (like water). Through their investigation, students should discover that temperature, stirring, and surface area all affect how quickly a solute can dissolve in a given solvent. To make something dissolve faster, one can increase the temperature of the solvent, stir the solution, and increase the surface area of the solute (granulated sugar has more surface area than sugar cubes, and so will dissolve faster).

SC6.c. Use mathematics and computational thinking to evaluate commercial products in terms of their concentrations (i.e., molarity and percent by mass).

In this standard, students will learn how to calculate concentration in terms of molarity and percent by mass. Concentration is a measure of how many particles of solute are dissolved in a certain amount of solvent. A more concentrated solution contains more solute particles than a dilute solution. Concentration can be given in different units. Molarity expresses the concentration in terms of moles of solute per liter of total solution; whereas percent by mass expresses concentration in terms of the percentage of the solution’s mass that comes from the solute.

Molarity calculations may or may not require unit conversions, depending on what is given. The equation for molarity is: $M = \frac{moles\ solute}{L\ solution}$. For example:

“Calculate the molarity of a 2.0 L solution that contains 0.005 moles of solute” requires no conversions as we already know both the moles of solute and liters of total solution. The solution is given below:

$$M = \frac{0.005 moles}{2.0 L} = 0.0025 \frac{mol}{L} or\ 0.0025\ M$$

“Calculate the molarity of a 1505 mL solution that was made using 15.91 g of sodium chloride” requires two conversions, as the volume of solution must be in liters (not milliliters) and the solute (sodium chloride) must be in moles (not grams). The problem is worked below:

$$M = \frac{15.91g \div 58.44\ g/mol}{1505mL \div 1000mL/L} = \frac{0.272245\ moles\ NaCl}{1.505L\ solution} = \frac{0.1809mol}{L}\ or\ 0.1809\ M$$

Percent by mass calculations are calculated from the equation: $Mass\% = \frac{mass\ solute}{mass\ total\ solution}x100\%$. For example, “Calculate the percent by mass of a 189.5 g solution that contains 3.85 g of solute” would be calculated as follows:

$$Mass\% = \frac{3.85g\ solute}{189.5\ g\ solution}x100\% = 2.03\%\ solute$$

Sometimes the mass of total solution is not given. In order to determine this, students need to add the mass of the solute to the mass of the solvent in order to determine the mass of total solution (since mass is conserved during the dissolving process). For example, “Calculate the percent by mass of a solution made using 5.9 g of calcium chloride and 500.0 g of water.” Because the total mass of solution is not given, the solution is:

$$Mass\% = \frac{5.9g\ calcium\ chloride}{500.0g\ water + 5.9\ g\ calcium\ chloride} = \frac{5.9\ g\ solute}{505.9\ g\ total\ solution}x100\% = 1.2\%\ solute$$

SC6.d. Communicate scientific and technical information on how to prepare and properly label solutions of specified molar concentration.

In this standard, students will both prepare and label a solution of a specified molar concentration, which requires them to use the molarity equation. Students must then write out accurate steps for preparing that solution. For example,

“How would you create 2 L of a 0.5 M NaCl solution?”

First, you must determine how much NaCl is needed, using the molarity equation:

$$M = \frac{moles}{liters} \rightarrow 0.5\ M = \frac{x\ moles}{2\ L} \rightarrow x = 0.5 * 2\ moles = 1\ mole\ NaCl$$

Next, you must use the molar mass of NaCl to determine the mass of this amount of NaCl so that it can be measured on a lab scale:

$$\frac{1\ mole\ NaCl}{1}x\frac{58.44\ g\ NaCl}{1\ mole\ NaCl} = 58.44\ g\ NaCl$$

Finally, write out the steps for preparing the solution: 1) Measure 58.44 g of NaCl and place into a 2L volumetric flask. 2) Add deionized water until the 2L line is reached. 3) Stir/heat until dissolved.

SC6.e. Develop and use a model to explain the effects of a solute on boiling point and freezing point.

In this standard, students will model the effects of solute on boiling and freezing. Students should record the boiling point of water as certain amounts of solute are added. This data can then be graphed to demonstrate the effect of molality (solute amount) on the boiling point of the water. Students could also draw the molecules present in a cup of pure water vs the molecules in a cup of salty water. Students can use this drawing to explain that the higher boiling point of salty water is due to the stronger forces holding the salty solution together.

SC6.f. Use mathematics and computational thinking to compare, contrast, and evaluate the nature of acids and bases in terms of percent dissociation, hydronium ion concentration, and pH.

(*Clarification statement:* Understanding of the mathematical relationship between negative logarithm of the hydrogen concentration and pH is not expected in this element. Only a conceptual understanding of pH as related to acid/basic conditions is needed.)

In this standard, students will use numerical data to explain and compare acids and bases. First, students must understand that the pH scale measures the amount of hydrogen ions present in a solution. Second, students must understand that in water, hydrogen ions react with the water molecules, forming hydronium ions (H_3O^+). The hydronium ion behaves like a hydrogen ion and gives the same pH reading. Water is unique in that it can react with itself to form ions, according to the equation below:

$$2\ H_2O \leftrightarrow H_3O^+ + OH^-$$

When the pH measurement is made, if the amount of hydroxide ions (OH^-) equals the amount of hydronium ions, then the solution is neutral (pH reads 7). If the amount of hydronium ions is greater, the solution is acidic (pH range from 0 - 6). If the amount of hydroxide ions is greater, then it is basic (pH range from 8 - 14). Students must be careful to understand that a low pH does not mean a strong acid is present, as pH only measures the concentration of hydrogen ions, which also depends on how much water the acid is dissolved in.

Lastly, students must understand that the strength of an acid or base is related to its percent dissociation, not only its pH value. Strong acids and bases completely dissociate in water. Weak acids and bases do not completely dissociate in water.

SC6.g. Ask questions to evaluate merits and limitations of the Arrhenius and Bronsted-Lowry models of acid and bases.

In this standard, students will discuss the pros and cons of the various theories of acids and bases. According to the Arrhenius model, acids produce hydrogen ions and bases produce hydronium ions. This leaves out several well-known acids and bases, such as ammonia (NH_3), that produce the necessary ions when dissolved in water. The Bronsted-Lowry model states that acids are proton donors and bases are proton acceptors. This definition is far more broad and does include ammonia as a base (since it reacts with the hydrogen ions in the water).The Bronsted-Lowry model ignores the roles that electrons play in acid-base chemistry, as there are yet other substances that do not become acidic or basic by adding or accepting protons, but by introducing electrons.

SC6.h. Plan and carry out an investigation to explore acid-base neutralization.

In this standard, students will design and do a lab focusing on the neutralization of an acid or base. Students must first understand that a neutralization reaction is when an acid reacts with a base to produce a salt (ionic compound) and water. This means that if you have an acid of unknown concentration, you can find the concentration by neutralizing it with a base of known concentration. The amount of base you had to add to neutralize it allows you calculate the acid concentration, knowing that at pH 7, the amount of hydronium ions equal the amount of hydroxide ions. This process is known as a titration. In titrations, an indicator solution is often used to tell us when exactly the pH reaches 7, although a digital pH meter or probe would also work. Indicator solutions are special chemicals that only change color at a certain pH range.