



Activity 3 Into Solution: the Role of Charge

Activity Overview

Key concepts:

Water is polar. It is a great solvent, but substances that water dissolves must be either polar or charged ionic compounds, made from negatively and positively charged atoms. Polar water attracts polar molecules and ions and pushes out non-polar and non-charged substances.

In this model-based activity, students will learn the main concepts behind the process of dissolving. They begin by discovering the properties of polar and ionic compounds and observe that in order to be water-soluble molecules should carry an electrical charge.

Working with models, students compare the solubility between ionic compounds such as table salt, polar organic molecules such as glucose and non-polar organic molecules, such as oil or animal fat. They observe how water molecules attract ionic or polar substances, leading to the dissolving of various materials, and how non-polar molecules are repelled by water, "preferring" to stick to each other.

Students:

1. Are introduced to and compare the chemical structures of ionic polar and non-polar chemical compounds.
2. Explore both on the computer and in kinesthetic modeling, the interaction between ions, polar or neutral molecules with the polar water molecules. Students should be able to reason why some substances can be dissolved in water, but others cannot.

3. Revise their interpretation of the model of erythrocytes in saline solution from Activity One to incorporate their experiences with dissolving.

Learning Objectives:

Students will be able to:

- Describe how the presence or absence of electrical charge (positive, negative, polar and neutral) effects whether a substance will be dissolved by water.
- Explain that on the microscopic level the dissolving includes three simultaneously occurring dynamic processes:
 - interaction between water molecules,
 - interaction between particles of the substance, and
 - interaction between those particles and water.
- Reason that for the dissolving to occur the interaction between molecules of the substances with water molecules must be stronger than their attraction to each other

Macro to Micro Connection

Students see that substances dissolve at a macroscopic level when, on the atomic level, particles of the substances such as ions or polar molecules, are attracted to water molecules more strongly than they are attracted to each other.

Science Background

The strong polar nature of the water molecule allows it to be one of the most universal solvents. Pure water is practically non-existent in nature because water dissolves so much - both organic and inorganic substances - easily.

In this activity students will consider what happens when different types of substances are added to water:

- Ionic compounds such as sodium chloride.
- Polar organic substances, such as sugar or ethanol.
- Lipids, partially charged organic molecules consisting of long non-polar chains at one end and a charged group of atoms on another end, such as fatty acids or phospholipids.

- Completely neutral non-polar substances such as paraffin from a candle or animal fat.

1. Dissolving ionic compounds such as sodium chloride

Table salt (NaCl) is a crystal, held together by strong ionic bonds. An ionic bond is formed from the electrostatic attraction between oppositely charged ions. In ions, electrons of one atom are transferred to another atom. The atom that loses the electrons becomes a positively charged ion, or a cation, while the one that gains electrons becomes a negatively charged ion, or an anion.

When we try to dissolve an ionic compound by stirring it in water, the positive-poles of the water molecules are attracted to the anions, while the negative poles of other water molecules are attracted to the cations, so the polar water molecules "pull" the ions out of a crystal. As a result of these interactions, the ionic bonds eventually break and ions are released into the water. When the salt is dissolved, every ion is surrounded by water molecules, creating kind of concentric shells of polar water molecules centered on the ions (they also look like petals of a daisy). This process is called "hydration."

The hydration of its ions causes a salt crystal to break apart (dissolve) in the water. Therefore, when table salt (NaCl) is dissolved, two hydrated ions appear in the water: a positively cation Na^+ and a negative charged anion Cl^- . Each is surrounded with a shell of closely attracted water molecules that prevent the ions from reconciling into a crystal again.

Hydrated ions jostle around the solution, diffusing from the area of high to the areas of low concentration and therefore are getting distributed evenly in the solution. The hydrated ions are so small that we cannot see them even with a strong microscope. and therefore we see the process as a disappearance of particles from view as the dissolving progresses.

Different ions can attract different number of water molecules into the "watery shell" because they can have different strength (density) of their charge. The density of the charge depends on the ratio of charge to surface area of an ion; the larger the ratio, the larger the hydration number will be.

2. **Polar Molecules.** Compared to ions, polar molecule carry much weaker localized charges, which are located on different "poles" of a molecule. It happens when atoms are linked with polar covalent bonds (a shared pair of electrons gets

"shifted" towards one of the atoms). For example, an oxygen atom on the -OH group, has a localized negative charge. The hydrogen, from which an electron was shifted to Oxygen, becomes positively charged. Such polar groups are typical for ethanol as well, since it has an -OH group.

3. **Lipids.** Things gets tricky when we try to dissolve lipids, large organic molecules that carry a highly polar group of atoms at their head and long, non-polar hydrophobic (water-fearing) tails. One of the most common lipid is oleic acid, a fatty acid abundant in olive oil, peanuts, and sunflower seed. The polar "head" of such molecule is welcomed by water molecules that attempt to make a hydrated shell around the "head". But the long "water-fearing tail" of the molecule will be pulled away from the water.

As a result of this dual action of water, such molecules will create a film on the water surface with their polar heads attracted into the water and hydrophobic tails sticking out of the water surface. If you shake such a mixture, tiny lipid vesicles called "micelles" form, with their neutral, hydrophobic tails herded towards each other, their hydrophilic "heads" are linked with hydrogen bonds to water.

4. **Non-Polar molecules.** Substances such as animal fat or a candle's paraffin do not dissolve in water. They are non-polar, completely neutral. We call them "hydrophobic" (water-fearing) because polar water molecules, being attracted to each other, push the hydrophobic molecules away, usually to the surface.

Longer Background

http://www.concord.org/~barbara/workbench_web/unitIII_mini/more_solutions.html

Activity Design and Execution

Major Science Concepts	Charge, ions, dissolving, hydration, ionic bonds, hydrogen bonds
Assumed Previous Knowledge:	Water molecule
Time:	Two 50 minute classes

Materials:	Sashes for each student, with a colored segment across the back.
Advanced preparation	Prepare sashes

Steps

1. Students will begin this activity by comparing polar molecules with the ionic compounds. Have students in pairs complete the Molecular Workbench "Salt" activity in which they exploring ionic compounds.

See screenshots of the model "Salt".

http://www.concord.org/~barbara/workbench_web/unitlll_mini//salt_shots/salt_shots.html

2. After students have completed the activity, have them reason about the connections between the properties of ionic compounds and their ability to dissolve in water. Ask students: Why does water dissolve table salt? What happens to salt as it dissolves? Your students may come up with the idea that either table salt was converted into some other "invisible" chemical, or that this ionic compound was dispersed into such little particles that you cannot see them. Students could discuss these alternative ideas. Why does it reappear when water is evaporated? (Your students may perform an evaporation experiment at home).

3. To help identify your students' prior concepts, have them consider: What is a solution? Write their ideas on the board

By the end of this activity, when students are asked about solutions, they should be able to describe the atomic and molecular perspectives, e.g. say that it separates the material of the solute into single ions the size of an atom each; similarly when sugar is dissolved, it is separated into single molecules that are also very small. For now, accept any student responses!

4. This activity can take a substantial amount of the class time, though it can be very rewarding, if you have students derive the procedures. On the other hand, you could do it as an imaginative exercise. You will want the students to develop the rules for dissolving.

Get students into the water kinesthetic movement positions of the previous activity and then ask:

a) **What happens when a positive ion joins a drop of water?** Have students come up with a way to represent a positive ion and its interactions with water molecules. (or you can help out by suggesting the following: a positive ion could be represented as three kids roped together facing outward with six hands ready to form hydrogen bonds, or three kids roped together facing outward with six hands to form hydrogen bonds, but there is a + sign in their hand.) Then run the kinesthetic simulation.

b) **What happens when a negative ion joins a drop of water?** Have students come up with a way to represent a negative ion and its interactions with the water molecules. (Or you can suggest: A negative ion could be represented as a student with lots of tassels and arms folded so they are not used. Or three kids roped together facing outward with six hands to form hydrogen bonds, but there is a - sign in their hand.) Then run the kinesthetic simulation.

c) **What happens when a completely neutral molecule enters a drop of water?** Have students come up with a way to represent a neutral non-polar molecule and its interactions with the water molecules. This could be represented by a group of students roped together with no tassels and arms crossed.

d. **What happens to a big molecule like soap that is hydrophobic at one end and hydrophilic at the other?** Once students get the hang of becoming water molecules then have them figure out how to represent a large lipid molecule together with other students. Then have them simulate what would happen when this lipid was placed in the water in a glass. (The hydrophobic end sticks out of the water.) **What if there the container was filled, and there was no surface?)**

Have students summarize what they have learned.

- Positively charged poles of the water molecules lined up against the negative ion, and the negatively charged poles lined up around the positive ion.
- Neutral will not be dissolved
- [This may be a stretch] Molecules with one end charged and the other neutral will behave in a special way. The polar "head" of such molecule is makes hydrogen bonds with water molecules, but the long "water-fearing tail" of the molecule will be pushed away from the water.

d) Ask students how they would represent dissolving salt, pulling an ionic compound apart.

5. Go to the computer. Have students, separately or in small pairs or teams, open the Molecular Workbench "Dissolving" activity and complete it as directed. In this activity, students determine what holds ions in solution and they experiment with dissolving different solutes in various solvents.

See screenshots of the model "Dissolving".

http://www.concord.org/~barbara/workbench_web/solution_revised2/index.html

Extensions:

Hands and Minds on Sugar and Oil:

Let students discover that a solution of salts conducts electricity but not sugar. Ask their opinion about why ionic solutions conduct electricity but solutions of polar organic molecules such as sugar do not. After all, they both are water-soluble (*hint: ions carry true charges, are polar molecules which are overall electrically neutral or charged?*).

Experiment with oil to fix the idea of hydrophobicity. Shake the test-tube: Observe how over time what first looked as a solution is separating into two phase - water and fat. Why?

Sense receptors: Ions in solution in our cells act as triggers for all of our nervous signals, including senses (sight, smell, touch, TASTE)

Evolution: The Earth's oceans contained enormous quantities of dissolved salts and organic materials, from which living cells eventually emerged. Read about the early materials.

Students can also build a matchstick model of a polar lipid structure in order to discover lipid vesicles, prototypes of our cell membranes, and films: Using red-tipped matchsticks, they could begin by deciding whether the red tips are hydrophobic (dislike water) or hydrophilic (attracted to water). Then see how many arrangements they can make. There are at least three possible arrangements (films, spherical micelles or inverted micelles). These represent 2-Dimensional arrangements. Once students have come up with a structure, they should guess what the shape would look like in 3-D.

Benzene vs. Phenol Compare these two formulas. Guess which is completely water insoluble and which is soluble.

Additional Resources

Read about Solutions

Experiments in Solubility (Think-Quest)

<http://library.thinkquest.org/10429/low/sol/solbody.htm>

Introduction to Solutions 3 periods

<http://educ.queensu.ca/~science/main/concept/chem/c10/C10CDVR2.htm>

Arizona Water tutorial

<http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html>

Solutions and Temperature BU

<http://polymer.bu.edu/Wasser/robert/work/node12.html#SECTION00041000000000000000> Gene Stanley <http://polymer.bu.edu/Wasser/robert/work/work.html>]