Chemical Principles

Contents

Objectives

- To understand the basic atomic structure of the elements essential to life
- To understand the structure of water an its properties
- Understand what pH measures
- Understand the pH scale
- Measure the pH of various fluids
- Follow the change in pH when an acid and base are added to water
- Observe how a buffer influences changes in pH

Introduction

One of the unifying concepts of biology today is that life is chemical. Consequently to explore and understand the functions of living organisms, one needs to have at least a limited understanding of some chemical principles. The activities in this exercise are to provide some basic background of atomic structure in preparation for discussions of the formation and interaction molecules, of the water molecule and some of its properties and of pH and changes of a solution's pH.

Activity 3.1
Atomic Structure

Biological organisms are created from molecules which in turn are created from atoms. Only four types of elements comprise the greatest mass of organisms. These are carbon, oxygen, hydrogen and nitrogen (these make up approximately 96% of human body weight). Another 21 elements are essential for life but are utilized is much smaller quantities.

The majority of these 25 essential elements are found in the first 3 periods of the periodic table of elements. In the Chemistry Principles simulation on the BiologyOne DVD, review the atomic structure of these elements (depicted using the Bohr model). Be sure to note the electron shells and the number of electrons in each shell. Bonds between atoms result from interactions between these electrons.

Each electron shell has a characteristic energy level. Electrons in the shell closest to the nucleus have the least energy while those progressively farther away from the nucleus have more energy. When an atom absorbs energy, during photosynthesis for example, electrons move to an electron shell farther from the nucleus. When an electron falls to an electron shell closer to the nucleus, energy is released, usually in the form of heat.

If atoms lose or gain electrons, that atom will acquire a positive or negative charge. This is called an ion. Many ions such as Na+, K+, Ca2+ play critical roles in biological processes and you will see them crop up again and again in discussions of various metabolisms.

After reviewing the basic structure of atoms, label the diagram of an atom and answer the questions in the Results Section.

Activity 3.2
Water

There's a Star Trek episode in which an alien threatening the Enterprise refers to the crew as bags of water. To a large extent this is true of all living organisms on Earth. Water makes up between 70 to 95% of the body weight of most organisms. Our lives and the lives of all organisms on Earth rely on the presence of water and the special chemical properties of water.

Some of the special properties of water which has allowed life to evolve and persist on Earth are the following: Water is a polar molecule which allows it to form hydrogen bonds with itself and other compounds. As a result, solid water (ice) is less dense than liquid water allowing the solid to float rather than sink and crush anything below it. Water is an excellent solvent. Because of water's polarity, many substances easily dissolve in water, especially other polar or ionic compounds. Water molecules are very cohesive, sticking to themselves and giving water a high surface tension. Water molecules are also very adhesive, adhering to other compounds making them wet. Water also has a high specific heat making it resistant to changes in temperature. And finally, water has a natural tendency to dissociate into ions which greatly influence the chemical reactions which may take place in the water solution.

Review the section regarding the structure of water molecules and the interactions between water molecules in the Chemical Principles simulation on the BiologyOne DVD. Label the diagram of water molecules and ions in the Results Section.

Activity 3.3
pH of Common Solutions

Water molecules will separate to a small extent on their own to form hydrogen ions (H^+) and hydroxide ions (OH^-) from the H2O molecule. The chemical reaction for this is

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

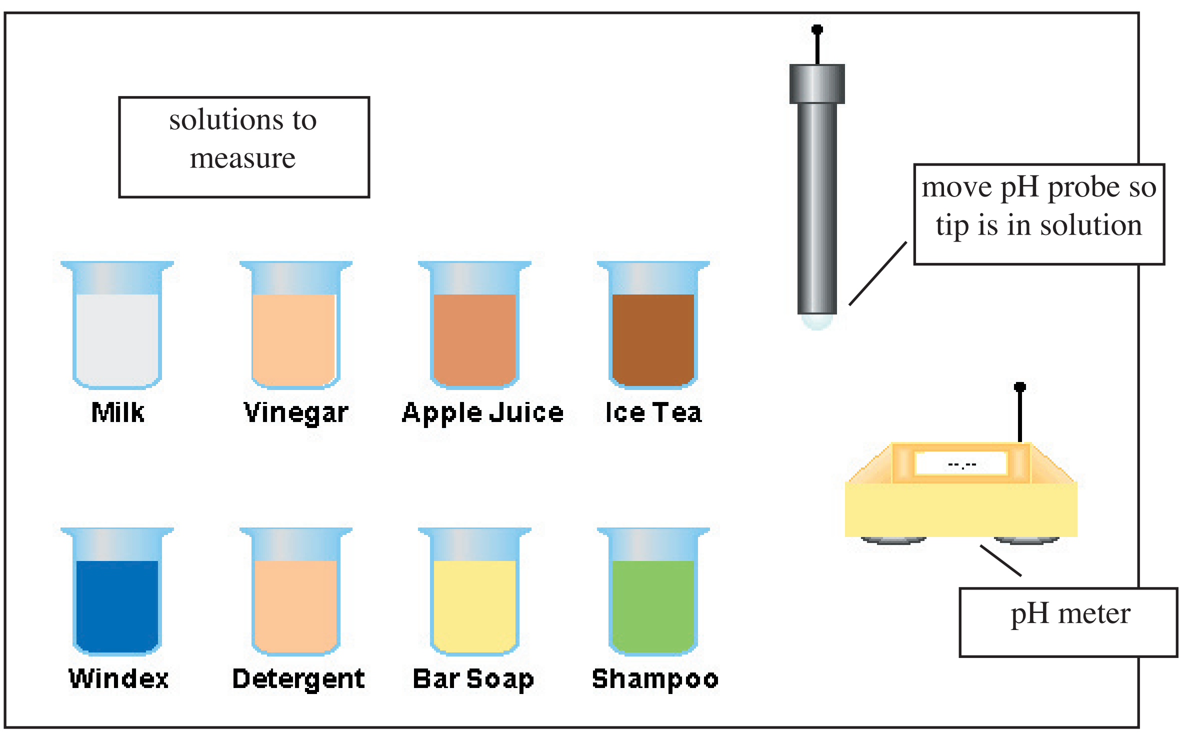
(As illustrated in this reaction, the H+ ion produced by the dissociation of water attaches to another water molecule. For simplicity sake, these ions will simply be referred to as H^+ in the remainder of the lab exercise.)

The arrows pointing in both directions in this reaction indicate that the reaction can occur in both directions and some equilibrium between the two sides of the reaction be reached. In pure water, the equilibrium point for the dissociation of water will produce an equal amount of H^+ ions and OH^- ions, both equal to a concentration of 1.0 x 10^{-7} moles per liter (moles is a measure of the number of chemical particles). This value, 1.0 x 10^{-7} mol/L, is somewhat awkward to work with so another expression of concentration is often used. This is the pH scale. Mathematically, the pH of a solution is equal to the negative log of the H^+ ion concentration. For pure water, the pH value of the solution will be 7.0, what is referred to as a neutral pH.

If substances are added to the water that cause the concentration of H^+ ions to increase, the pH value decreases and the solution is said to be acidic. If substances in the water cause the concentration of H^+ ions to decrease, the pH value increases and the solution is said to be basic (or alkaline). Under most circumstances, the pH values of a solution will range between 0 (a strong acid) and 14 (a strong base).

Note that the pH value is derived from the negative log of the H^+ concentration. This means that for every one unit of pH change, the H^+ concentration actually changes 10 fold. For example, a solution with a pH of 6 had ten times as many H^+ ions in the solution as a solution with a pH of 7. In the simulation, move the pH slider to see how the concentrations of H+ and OH- ions change with pH.

Simulation for measuring pH of solutions



Activity 3.4
Acid - Base Titration

From the introductory page for this activity, advance to the first activity by clicking on the forward arrow in the lower right.

In the first simulation regarding pH you will measure the pH of several solutions commonly encountered. To measure the pH, you will use a pH meter which utilizes a probe with a glass ball at its end. The machine measures the electrical potential across the glass ball which is converted into pH units. When measuring the pH of a solution, be sure the tip of the probe is in the solution. (If this were a real pH meter, you would also need to calibrate the machine using solutions of known pH. Also, when moving the probe between solutions, it is important to rinse the probe with distilled water to avoid erroneous reading or contamination. Neither of these steps are required in this simulation.)

Click on the probe and while holding the mouse button down, drag to probe to a position so its tip is 'within' one of the solutions on the screen. You should then be able to read the pH value of this solution from the pH meter. Record this value in table in the Results Section at the back of this module. Indicate in the table if this solution is an acid, a base, or neutral.

Record the pH of all eight solutions.

Click on the forward arrow in the lower right to advance to the second pH simulation in this activity. In this simulation, you will observe the effect on pH when adding an acid (HCl) and a base (NaOH) to pure water.

Begin this activity by adding 20 ml of water to the beaker. To do this, click on the water button. You will see that the label on the Buret tube indicates you will be dispensing water. Then, clicking once on the stopcock will open it part way, releasing water into the beaker one drop at a time. If you click on the 'on' end of the stopcock again it will open all the way to release the water rapidly. From this position, clicking on the 'off' end of the stopcock will close it part way. A second click on the 'off' end will stop the flow of water.

If too much water is added to the beaker and you want to start over, click on the 'New Experiment' button to reset the simulation.

After adding the 20 ml of water to the beaker, move the pH probe into the water to measure the pH. Record the value in the Results Section.

Next, select the 0.25 M HCl solution to add to the beaker by clicking on its button. Add 0.5 ml of HCl to the water in the beaker. Record the solution's pH in the Results section. Add another 0.5 ml (for a total of 1.0 ml) and Record the solution's pH. Add 0.5 more, measure and record, and then 0.5 more to reach a total volume of 2.0 ml of the HCl added to the water in the beaker. Record the solution's pH in the Results Section.

Without changing the acidic solution in the beaker, change the solution in the buret to the 0.25 M NaOH.

Begin to add NaOH drop-wise to the solution, recording the solution's pH at every 0.2 ml NaOH added until a total of 4.0 ml has been added.

Using your data, in the Results Section graph the change in pH as acid and base are added to pure water. How rapidly do these acids and bases change the pH of pure water?

Activity 3.5
Titration of a Buffer

Advance to the next simulation by clicking on the forward arrow in the lower right. In this simulation, rather than initially using HCl to acidify the water in experiment 2 below, you will be using a acetic acid/acetate ion buffer solution. The first experiment follows the pH change to an unbuffered solution, the second experiment follows pH change to a buffered solution.

Experiment 1:
To the empty beaker, add 20 ml of water and then move the pH probe into the water. Record the initial pH of the water. No buffer will be added to the water.

Now, change the solution in the buret to 0.1 M NaOH. Begin to add NaOH, recording the pH of the solution at every 1.0 ml of NaOH added. Continue adding NaOH until you have two pH readings above 12.0.

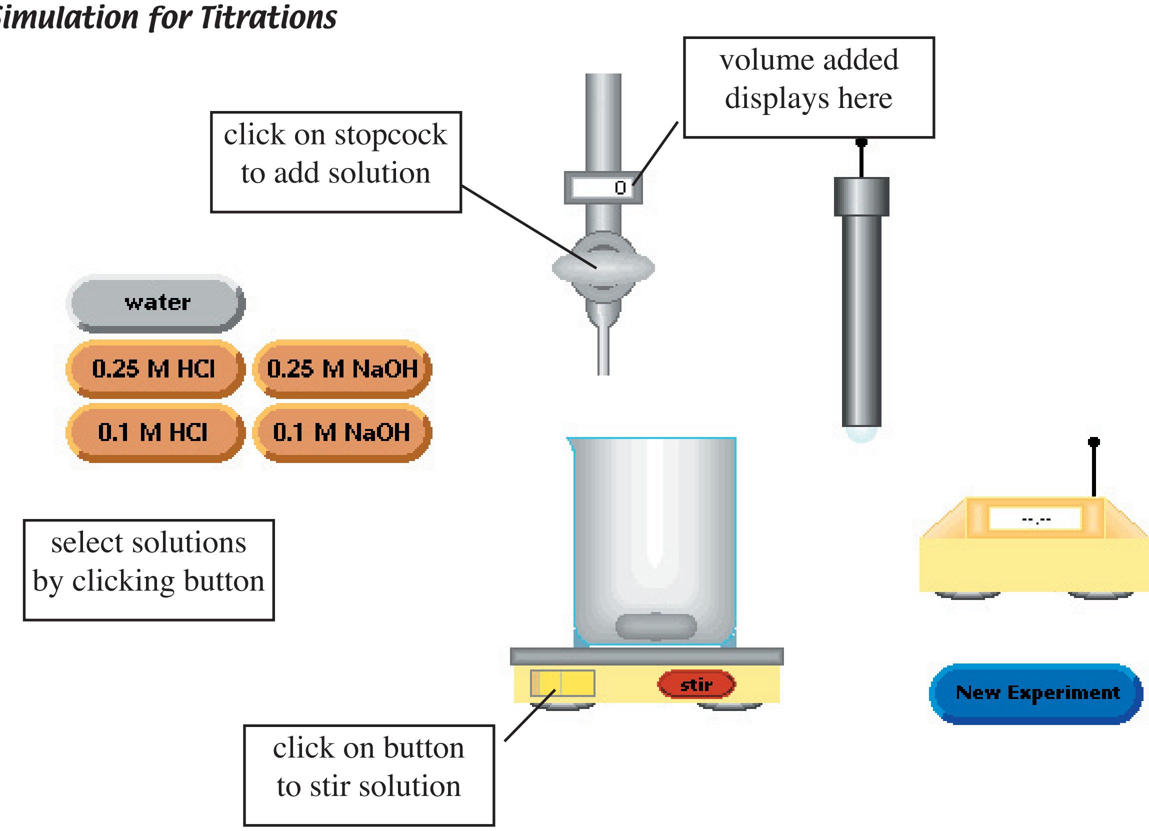
Experiment 2:
To the empty beaker, add 15 ml of water and then move the pH probe into the water. Record the initial pH of the water. Next add 5.0 ml of buffer to the water (total volume equals 20 ml). Measure the pH of the solution. This should be a pH of 4.74.

Now, change the solution in the buret to 0.1 M NaOH. As before, begin to add NaOH, recording the pH of the solution at every 1.0 ml of NaOH added. Continue adding NaOH until you have two pH readings above 12.0.

Using your data, in the Results Section graph the change in pH as NaOH is added to the unbuffered solution and the buffer solution.

Answer the questions in the Results Section.

Simulation for Titrations



Lab Exercise **3** **Name** ______________________

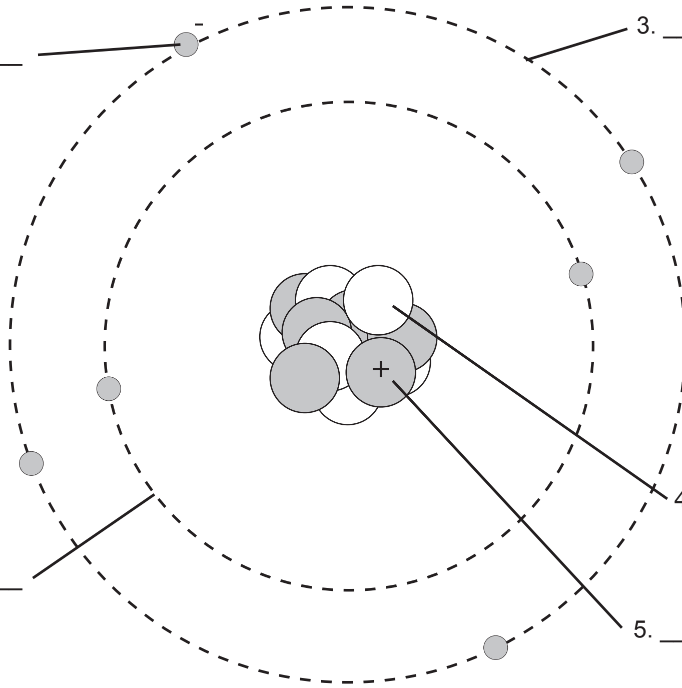
Results Section

Activity 3.1
Atomic Structure

Label the illustration of an atom

1. ______________________

3. ______________________ (which electron shell)



2. ______________________ (which electron shell)

4. ______________________

5. ______________________

What atom is illustrated above? ___________________________

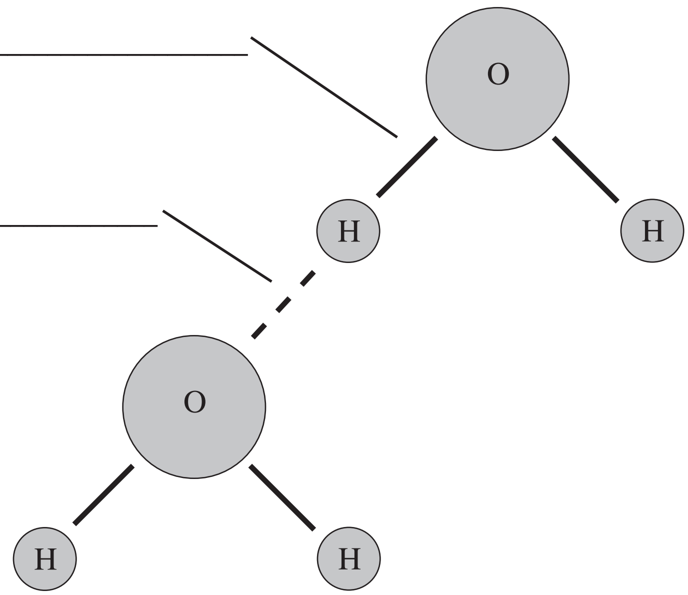
On earth, life is said to be carbon based. Some have suggested that life on other worlds might be silica based. What similarities to carbon and silica atoms have that suggest silica might be a good substitute for carbon in living organisms?

Activity 3.2
Water

Label the bonds in these water molecules.

1. ______________________

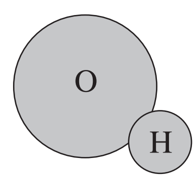
2. ______________________



Label the ions created by a dissociated water molecule.

Name for this ion: ____________

Charge: ___________



Name for this ion: ____________

Charge: ___________

Activity 3.3
pH of Common Solutions

Record the pH of these common solutions.

Solution	**pH**
Milk	_________
Vinegar	_________
Apple Juice	_________
Ice Tea	_________
Windex	_________
Detergent	_________
Bar Soap	_________
Shampoo	_________

Which of the above solutions has the highest concentration of H+ ions?

Which of the above solutions has the lowest concentration of H+ ions?

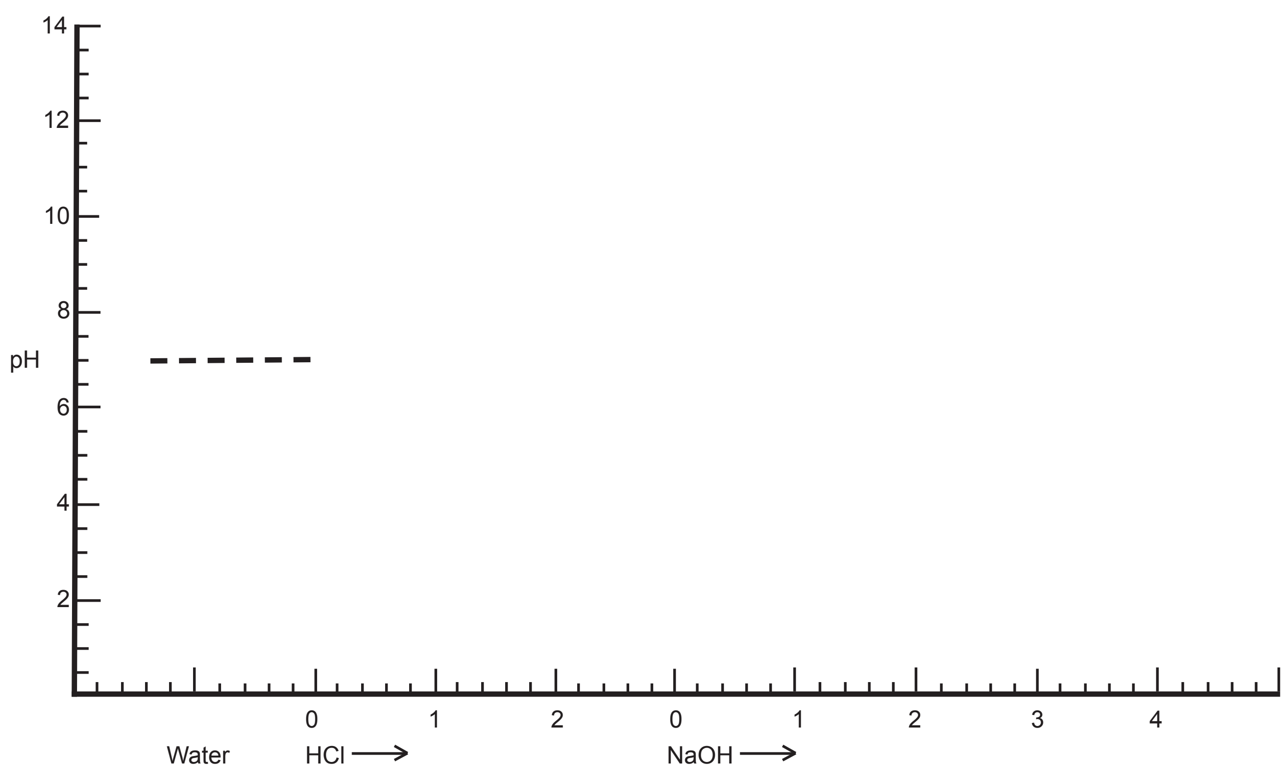
Which of the above solutions is closest to having an equal concentration of H+ and OH- ions?

Activity 3.4
Acid - Base Titration

Data

Solution	ml Added	pH	Solution	ml Added	pH
Water	20.0	7.0	NaOH	1.6	_____
HCl	0.5	_____		1.8	_____
	1.0	_____		2.0	_____
	1.5	_____		2.2	_____
	2.0	_____		2.4	_____
NaOH	0.0	_____		2.6	_____
	0.2	_____		2.8	_____
	0.4	_____		3.0	_____
	0.6	_____		3.2	_____
	0.8	_____		3.4	_____
	1.0	_____		3.6	_____
	1.2	_____		3.8	_____
	1.4	_____		4.0	_____

Graph

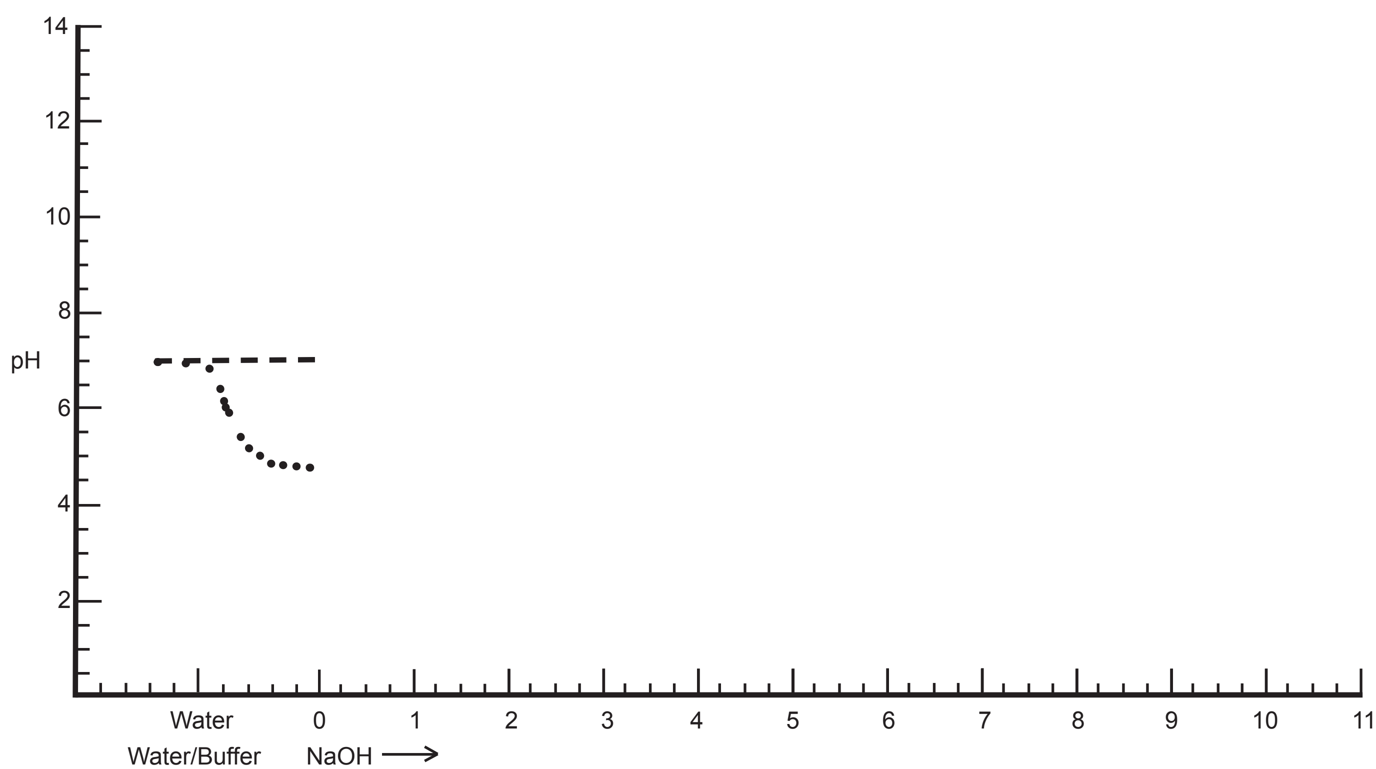


Activity 3.5
Titration of a Buffer

Data

	Experiment 1			**Experiment 2**	
Solution	ml Added	pH	Solution	ml Added	pH
Water	20.0	7.0	Water	15	7.0
Buffer	0.0	7.0	Buffer	5.0	4.74
NaOH (0.1M)	1.0	____	NaOH (0.1M)	1.0	____
	2.0	____		2.0	____
	3.0	____		3.0	____
	4.0	____		4.0	____
	5.0	____		5.0	____
	6.0	____		6.0	____
	7.0	____		7.0	____
	8.0	____		8.0	____
	9.0	____		9.0	____
	10.0	____		10.0	____
	11.0	____		11.0	____

Graph



How much did the pH change when you added 2.0 ml NaOH to the solution containing just water in activity 3.5?

How much did the pH change when you added 2.0 ml NaOH to the solution containing the water and buffer in activity 3.5?

Which solution resists changes in pH?

Why do you think its important for the fluids of cells and organisms to be buffered?