Experiment 6
Acids and Bases

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Name:

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Key Objectives

1. Write acid-base reactions.
2. Calculate pH and [H^+] of strong and weak acid/base solutions.
3. Acid/Base properties of cations and anions in solution.
4. pH measurements in lab using pH paper, pH meters and indicators.

Discussion

Importance of Acid-Base Reactions

Acid-Base chemistry is a fundamental topic in chemistry that extends to many other disciplines due to the ubiquitous nature water in our lives. Water has the ability to auto-dissociate according to the reaction in Equation 1 and 2 which can be written one of two formats.

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq) \quad (1)$$
$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq) \quad (2)$$

Since water is essential to life the importance of acid-base chemistry in biology can't be understated, and its obvious importance in chemistry since the majority of chemical reactions also occur in water is obvious. Some simple examples you can read about elsewhere include the pH buffer system our bodies (shown below in Figure 6.1), acid rain in the atmosphere and pH in our ocean environments.

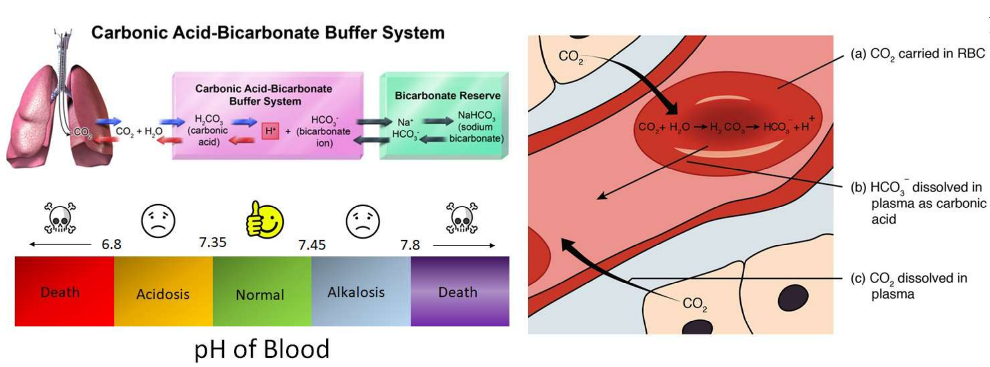

Figure 6.1: An important biological application of acid-base chemistry is the blood buffer system, if the pH is too high or low death can result. credit: upper left - Bruce Blaus, https://commons.wikimedia.org/wiki/File:Buffer_Part_1.png, lower left - author, right - By OpenStax College - Anatomy and Physiology, Connexions Web site http://cnx.org/content/col11496/1.6/, CC BY 3.0

Acid and Bases

A complete discussion of Acid and Bases can be found in your OER textbook Chapter 14-15. A brief summary is provided below.

Many types of compounds when added to water affect the pH of the solution. A not so short list includes:

1. Strong Acids or Strong Bases dissociate completely (100%) to produce acidic or basic solutions.

$$\mathrm{HCl(aq) + H_2O(l)} \longrightarrow \mathrm{Cl^-(aq) + H_3O^+(aq)} \quad (3)$$

$$\mathrm{NaOH(aq)} \longrightarrow \mathrm{Na^+(aq) + OH^-(aq)} \quad (4)$$

2. Weak Acids and Weak bases dissociate only partially (normally $<$ 10%) to also make acidic and basic solutions.

$$\mathrm{HF(aq) + H_2O(l)} \rightleftharpoons \mathrm{F^-(aq) + H_3O^+(aq)} \quad (5)$$

$$\mathrm{NH_3(aq) + H_2O} \rightleftharpoons \mathrm{NH_4{}^+(aq) + OH^-(aq)} \quad (6)$$

3. Salts (Ionic Compounds) typically dissociate (100%) in water and the resulting cations and anions can react with water to form acidic, basic, or if they fail to react a neutral solution. When considering how a salt affects the pH of a solution, we need to focus on three types atoms.

   (a) Cations from Strong Acids and Anions form Strong Bases will not react with water, do not produce either H^+ or OH^- ions and so result in a neutral solution. An example of a salt in this category would be NaCl.

$$\mathrm{Na^+(aq) + H_2O(l)} \longleftarrow \mathrm{NaOH(aq) + H^+(aq)\ (No\ Reaction)} \quad (7)$$

$$\mathrm{Cl^+(aq) + H_2O(l)} \longleftarrow \mathrm{HCl(aq) + OH^-(aq)\ (No\ Reaction)} \quad (8)$$

   (b) Cations from weak bases will react with water to produce H^+ or H_3O^+ ions resulting in an acidic solution.

$$\mathrm{NH_4{}^+(aq) + H_2O(l)} \rightleftharpoons \mathrm{NH_3(aq) + H_3O^+(aq)} \quad (9)$$

   (c) Anions from weak acids will react with water to produce OH^- ions resulting in a basic solution.

$$\mathrm{F^-(aq) + H_2O(l)} \rightleftharpoons \mathrm{HF(aq) + OH^-(aq)} \quad (10)$$

   (d) A salt made from the cation for a weak base and the anion of a weak acid will create a solution that can be acidic or basic depending on the strength (measured by K_a or pK_a) of the ions. If we combine the cation and anion from the previous two examples (NH_4F) then both reactions occur. The final pH of the solution is determined by the relative values of K_a and K_b.

$$K_a > K_b : \text{Acidic} \qquad \mathrm{NH_4{}^+(aq) + H_2O(l)} \rightleftharpoons \mathrm{NH_3(aq) + H_3O^+(aq)} \qquad K_a = 5.6 \times 10^{-10}$$

$$K_a \approx K_b : \text{Neutral} \qquad \mathrm{F^-(aq) + H_2O(l)} \rightleftharpoons \mathrm{HF(aq) + OH^-(aq)} \qquad K_b = 2.9 \times 10^{-11}$$

$$K_a < K_b : \text{Basic} \qquad \text{Since } K_a > K_b \text{ the resulting solution will be acidic.}$$

4. Metal cations will form a hydrated cation (sometimes refered to as a complex, hydration shell, or coordination compound) with water that can then undergo hydrolysis resulting in an acidic solution.

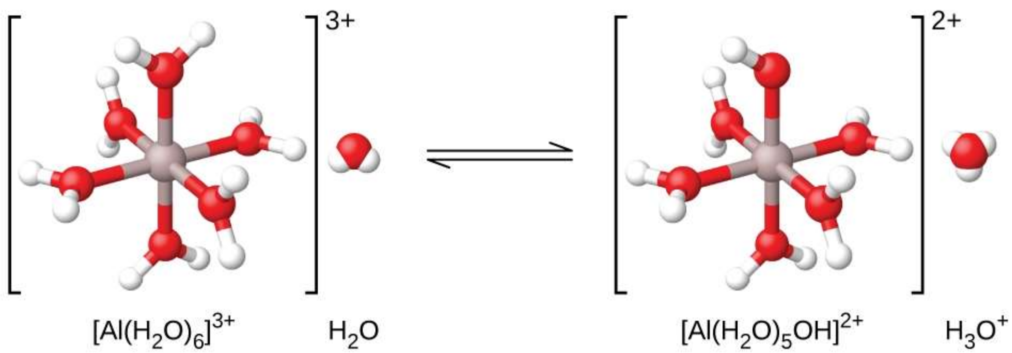

Figure 6.2: Example of hydrated aluminum (Al) cation. credit: `https://opentextbc.ca/chemistry/chapter/14-4-hydrolysis-of-salt-solutions/`

5. Acid Anhydrides are non-metal oxides that produce acids when reacting with water.

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq) \tag{11}$$

6. Base Anydrides are metal oxides that produce bases when reacting with water.

$$Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq) \tag{12}$$

7. Amphoteric species can act as either an acid or a base, some examples include water, carbonic acid (H_2CO_3 - illustrated in Figure 6.1, amiono acids (sometimes referred to as zwitterions), proteins, metal oxides and many other species. An example of an amino acid zwitterion is shown in Figure 6.3

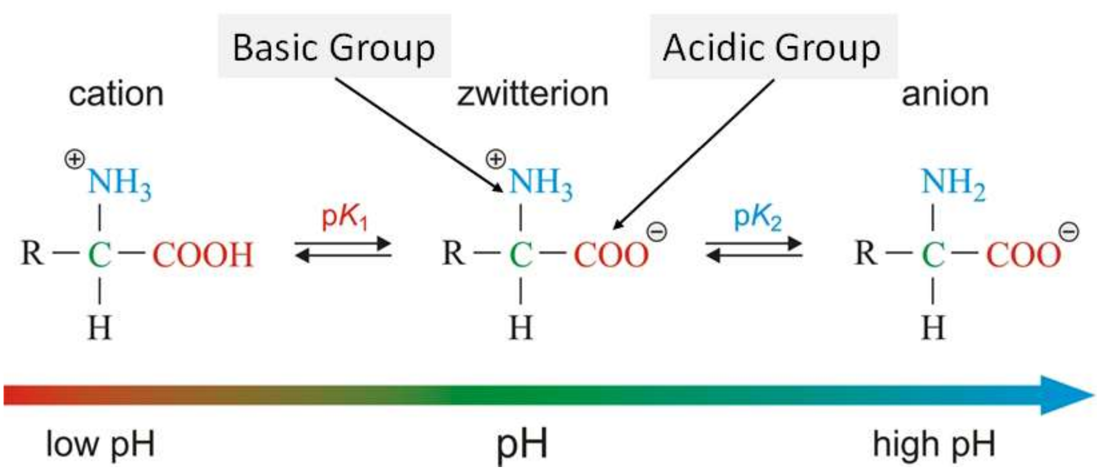

Figure 6.3: Zwitterion of a generic amino acid in different pH's. An amino acid contains a basic group ($-NH_2$) and an acidic group ($-COOH$). credit: author modified.

Measuring pH - Test Paper and Indicators

Two methods will be used to measure the pH of the solutions used in lab.

Indicators are organic compounds whose structure is sensitive to the H^+ concentration, and the resulting change in structure is accompanied by a change in the color of the solution.

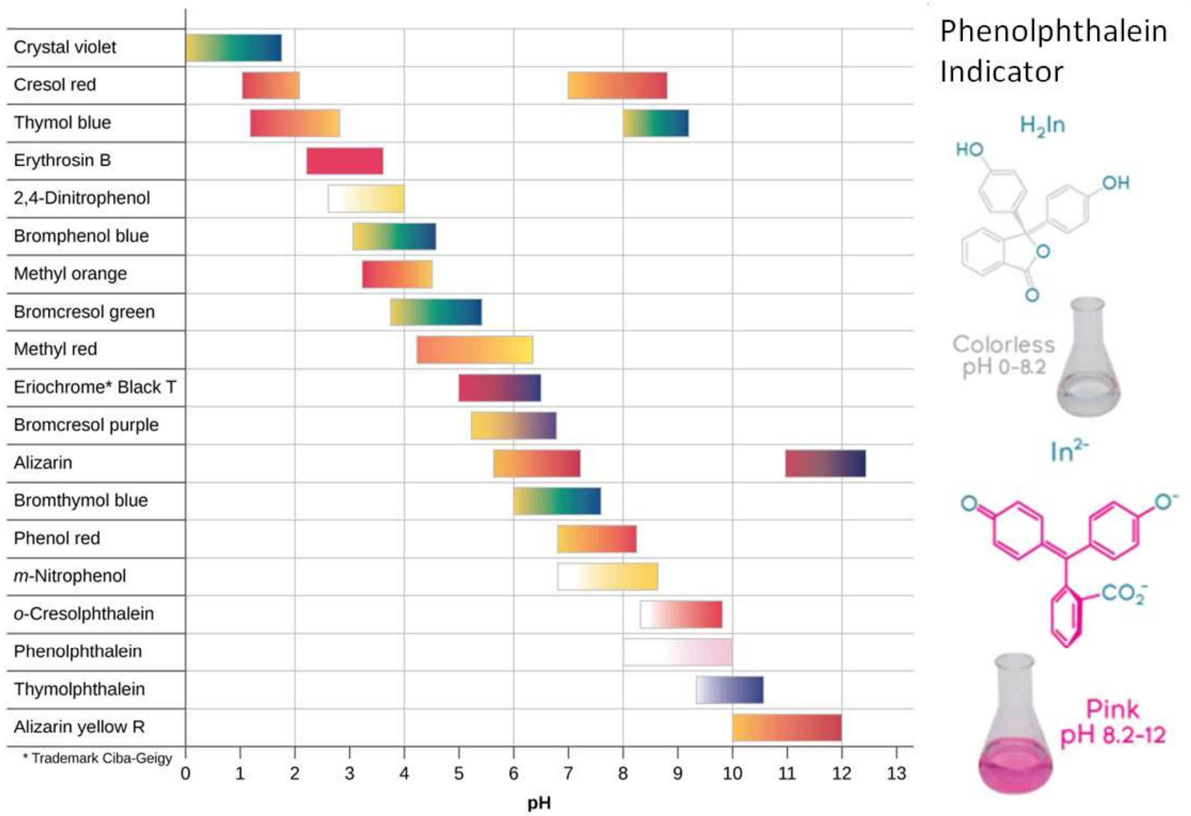

Figure 6.4: Left - pH Range of Different Indicators. Right - Example of a Phenolphthalein Indicator. Credit: Left - `https://commons.wikimedia.org/wiki/File:CNX_Chem_14_07_indicators.png` Right - Public Domain

One of the most common indicators, Phenolphthalein, you may recall was used last semester as the indicator in the Titrations Lab.

pH paper is generally made with one or more acid-base indicators impregnated on paper, which will turn different colors depending on the pH. There are a wide variety of pH papers, some with broad ranges (measure pH 1-14), some with very narrow ranges (measure pH $\pm$ 1.0 units). We will use a variety of pH papers in lab, so be careful to note the type used and the observed color and pH.

Measuring pH - pH Meters

A pH meters is a device that measures the H^+ concentration and converts it into an electrical potential which is then read by a volt meter. The electrical conductivity of a solution is measured using an electrochemical half-cell consisting of twi glass electrodes, a reference electrode and the measuring

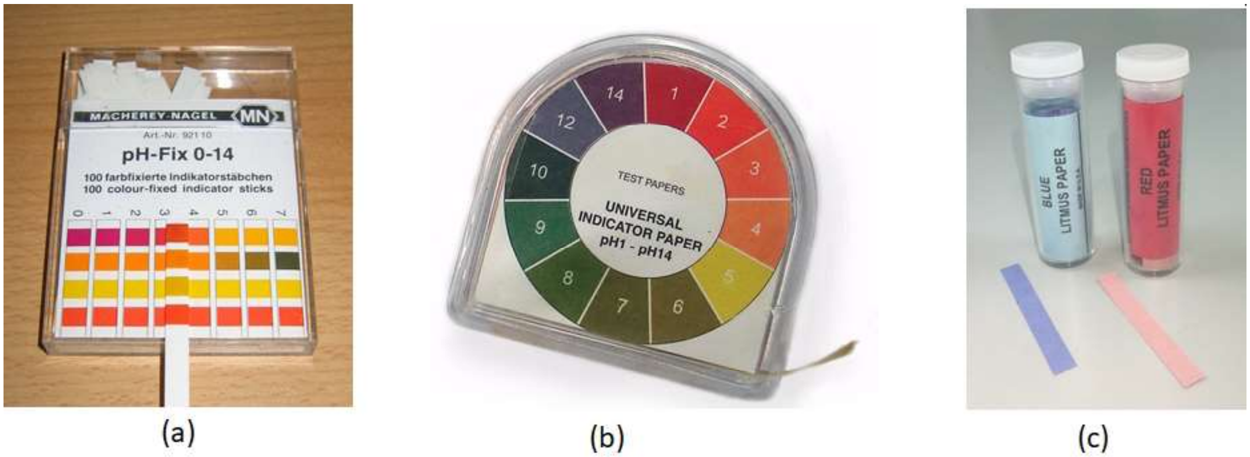

Figure 6.5: Different types of pH paper. credit: (a) - `https://commons.wikimedia.org/wiki/File:PH_indicator_paper.jpg`, (b) - `https://commons.wikimedia.org/wiki/File:Universal_indicator_paper.jpg`, (c) - `https://commons.wikimedia.org/wiki/File:Blue_and_Red_litmus_papers.jpg`.

electrode. We will learn more about pH meters in McMurry, Chapter 17.4. For this laboratory we will just focus on learning to calibrate and use a pH meter.

A pH meter (like all electronic instruments) needs to be calibrated. The Vernier pH meter needs to know to pH values so it can extrapolate a line between them to measure the pH. We will use two buffer solutions pH = 4.00 and pH = 10.00 to calibrate the meter. Once calibrated it is important to occasionally check the calibration with any one of the buffer (pH = 4,5,7, or 10) solutions available.

Figure 6.6: pH Probe and Lab Quest 2. credit: `vernier.com`

"Pure" Water, Dissolved Carbon Dioxide, and Distilled Water

A solution of pure water (tap water) should be neutral and have a pH = 7.0. However, various substances can affect the pH of the aqueous solutions used in lab. Carbon Dioxide in the atmosphere will dissolve in water and produce a slightly acidic solution due to the formation of hydrogen carbonate (bicarbonate). This will cause tap water in the laboratory to have a pH in the range of 5.5-6.5.

$$\mathrm{CO_2(aq) + H_2O(l) \rightleftharpoons HCO_3{}^-(aq) + H^+(aq)} \quad (13)$$

The distilled water produced in lab is very pure and should have a pH of 7.0. However, the water is "too pure" and most pH meters have a hard time reading the pH level, and so can often give "wrong" reading. In this instance pH paper is probably the more accurate measure of pH.

Procedure

A. Using a pH meter

1. Following the instruction manual for the pH meter, calibrate your pH meter using the pH 4.0, 7.0, and 10.0 buffer solutions.

B. pH Measurements of Aqueous Solutions

1. Fill a small beaker with 15-20 mL of the solution to be tested.
2. Calibrate the pH meter (unless you personally just finished calibrating it) using the pH 4 and 7 buffer solutions.
3. Measure the pH of each solution, record your results. Be sure to rinse the electrode between measurements with de-ionized water.
4. Measure the pH using a small drop of each solution onto the pH test paper. Record your results.
5. Place 1.0 mL of the solution in a test tube and add 1 drop of Universal Indicator. Record your results.

C. Percent Ionization of a Weak Acid or Weak Base

1. Place 15-20 mL of 0.1 M Acetic acid ($HC_2H_3O_2$)into a small (50 mL) beaker and measure the pH.
2. Carefully take 10.00 mL of the solution and perform a dilution to 100.00 mL using a volumetric pipit and flask. Measure the pH.
3. Carefully take 10.00 mL of the solution and again dilute it to 100.00 mL. Measure the pH.
4. Repeat steps 1-3 using 0.1 M Ammonia (NH_4OH).

D. Reactions of Acids

1. Perform the following reactions in the hood.
2. Perform reactions 1-4 by filling a test tube with 2.5 mL of the acid listed and place a few strips of magnesium ribbon into each tube. Place a cork in the test tube and allow the reaction to proceed for 1 minute. Test the gas generated by placing a burning split into the mouth of the tube.
3. Perform reactions 5-6 by placing a small quantity of the solid in the bottom of a test tube. Place 4-5 mL of the acid in the test tube. Place a cork in the test tube and allow the reaction to proceed for 1 minute. Test the gas generated by placing a burning split into the mouth of the tube.

4. Perform reaction 7 by placing 25 mL of water into a beaker, add 3 drops of phenolphthalein and 5 drops of acid to the solution. Note the color. Slowly add 10% solution of base to the solution. Stir after each drop. Stop adding the base when the phenolphthalein changes color.

5. Dispose of all solutions in the waste container labeled "ACID WASTE".

E. Reactions of Bases

1. Perform the following reactions in the hood.

2. Perform reactions 1-3 by placing 10 mL of water, 2 drops of phenolphthalein into each test tube. Then add the solid, swirl the solution and record the results.

3. Dispose of all solutions in the waste container labeled "BASE WASTE".

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Name: ____________________________ Class: ____________________ Date: ____________________

Results

Data Table B: pH of Aqueous Solutions

TT #	Compound	pH meter	pH Univ.	pH paper	pH Theory	Predicted A/B/N	%Error meter	%Error Univ.	%Error paper
1	0.1 M KNO_3								
2	0.1 M NH_4Cl								
3	0.1 M NaCl								
4	0.1 M $NaHCO_3$								
5	0.1 M $NaC_2H_3O_2$								
6	0.1 M NH_3								
7	0.1 M $HC_2H_3O_2$								
8	0.1 M HCl								
9	0.1 M $Al(NO_3)_3$								
10	0.1 M Na_2CO_3								
11	0.1 M $NaHSO_4$								
12	0.1 M NaOH								
13	0.1 M Na_2HPO_4								
14	0.1 M NaH_2PO_4								
15	Tap Water								
16	Distilled Water								

1. Which method of determining pH appears to be the most accurate method. In your answer note if there are any pH values are wildly inaccurate. Explain.

2. For solution 8 and 12 calculate the theoretical pH and the percent error between the theoretical value and the experimental value. Explain.

2(a) pH of 0.1 M HCl 2(a) ______________

2(b) % Error 2(b) ______________

2(c) pH of 0.1 M NaOH 2(c) ______________

2(d) % Error 2(d) ______________

3. For solution 6 and 7 calculate the theoretical pH and the percent error between the theoretical value and the experimental value. Explain.

3(a) pH of 0.1 M NH_3 3(a) ______________

3(b) % Error 3(b) ______________

3(c) pH of 0.1 M $HC_2H_3O_2$ 3(c) ______________

3(d) % Error 3(d) ______________

Data Table C: Dilution Effect on pH of a Weak Acid and Weak Base.

Soln	Conc.	pH Acetic Acid	Calculated %-Dissociation	pH Ammonia	Calculated %-Dissociation
1	0.1 M				
2	0.01 M				
3	0.001 M				

1. Calculate the %-Dissociation for each of the solutions using the measured pH. Show an example calculation for the 0.01 M Solution for acetic acid **AND** ammonia.

2. What trend is observed in the %-Dissociation as the concentration decreases? Explain.

3. Does the observed trend agree with Le Chatelier's Principle? Explain.

4. For solution 2 calculate the theoretical pH and the percent error between the theoretical value and the experimental value. Show Calculations. Explain.

4(a) pH of 0.01 M $HC_2H_3O_2$ 4(a) ______________

4(b) % Error 4(b) ______________

4(c) pH of 0.01 M NH_3 4(c) ______________

4(d) % Error 4(d) ______________

Data Table D: Reactions of Acids

Soln	Reaction	Observation	Products
1	$HCl(aq) + Mg(s) \longrightarrow$		
2	$H_2SO_4(aq) + Mg(s) \longrightarrow$		
3	$HNO_3(aq) + Mg(s) \longrightarrow$		
4	$HC_2H_3O_2(aq) + Mg(s) \longrightarrow$		
5	$HCl(aq) + NaHCO_3(s) \longrightarrow$		
6	$HCl(aq) + CaCO_3(s) \longrightarrow$		
7	$HCl(aq) + NaOH(aq) \longrightarrow$		

1. Explain why some of the acids reacted with Mg and some did not.

Data Table E: Reactions of Bases

Soln	Reaction	Observation	Products
1	$H_2O(l) + CaO(s) \longrightarrow$		
2	$H_2O(l) + MgO(s) \longrightarrow$		
3	$H_2O(l) + Ca(OH)_2(s) \longrightarrow$		

1. Are the following compounds Acids, Bases, Neutral Salt, an Acid Anhydride, Base Anhydride or none.

Compound	Category	Compound	Category
CuF_2		$CaSO_4$	
$Ba(OH)_2$		C_2H_4	
LiOH		$C_{12}H_{22}O_{11}$	
$HBrO_3$		HI	
$RaCO_3$		P_2O_5	
KNO_3		HCN	
$H_2C_2O_4$		MgO	

2. Complete the following Combination reactions and name the product formed.

2(a) $K_2O(s) + H_2O(l) \longrightarrow$

2(b) $SrO(s) + H_2O(l) \longrightarrow$

2(c) $SO_3(g) + H_2O(l) \longrightarrow$

2(d) $N_2O_5(g) + H_2O(l) \longrightarrow$

Name: ____________________ Class: ________________ Date: ________________

Prelab Questions

1. List the 6 strong acids and 6 strong bases (formula or name).

2. What is the difference between a strong electrolyte, a weak electrolyte and a non-electrolyte?

3. Define the term amphoteric. Give an example (not given in lab) of an amphoteric species. Write **TWO** reactions, one with the species reacting with an acid and one with the species reacting with a base.

4. For all solutions below predict the pH (Acid/Basic/Neutral). Be sure to also copy your prediction to Table B of the lab. Explain.

TT #	Compound	Predict A/B/N	Explain
1	0.1 M KNO_3		
2	0.1 M NH_4Cl		
3	0.1 M NaCl		
4	0.1 M $NaHCO_3$		
5	0.1 M $NaC_2H_3O_2$		
6	0.1 M NH_3		
7	0.1 M $HC_2H_3O_2$		
8	0.1 M HCl		
9	0.1 M $Al(NO_3)_3$		
10	0.1 M Na_2CO_3		
11	0.1 M $NaHSO_4$		
12	0.1 M NaOH		
13	0.1 M Na_2HPO_4		
14	0.1 M NaH_2PO_4		
15	Tap Water		
16	Distilled Water		