Experiment 17
Acids and Bases

Jay C. McLaughlin
Colorado Northwestern Community College

Name:

Date:

Key Objectives

1. Definitions of Acid and Base.
2. Use of litmus paper to determine if a solution is acidic or basic.
3. Use of pH paper and pH meter to determine pH.
4. Complete Acid/Base reactions.
5. Recognize acid anhydrides, base anhydrides, and neutral salt.

Discussion

Acid-Base reactions are an important, fundamental class of reactions. Equally important is learning how to make good pH measurements using a variety of tools including a pH meter, universal indicator, red and blue litmus paper and pH paper.

Acid and Bases

A complete discussion of Acid and Bases can be found in your textbook, a brief summary is provided below.

There are many definitions of Acids and Bases, the most simple was from Arrhenius which suffices for most discussions, though the Bronsted-Lowry defintion is useful in that it allows one to include the common base NH_3. The Lewis definition is useful in that it extends acid/base chemistry to a whole new series of compounds, though that is beyond the scope of this course.

	Arrhenius	**Bronsted-Lowry**	**Lewis**	**Jay's Dfn.**
Acid:	excess H^+	proton (H^+) donor	electron pair acceptor	H___
Base:	excess OH^-	proton (H^+) acceptor	electron pair donor	___OH (+NH_3)

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 when dissolved in water, dissociate completely (100%) to produce ions and make an acidic or basic solutions.

$$\mathrm{HCl(aq) + H_2O(l) \longrightarrow Cl^-(aq) + H_3O^+(aq)} \tag{48}$$

$$\mathrm{NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)} \tag{49}$$

2. Weak Acids and Weak bases when dissolved in water, dissociate only partially (normally $<$ 10%) to produce ion and make acidic and basic solutions.

$$HF(aq) + H_2O(l) \rightleftharpoons F^-(aq) + H_3O^+(aq) \quad (50)$$
$$NH_3(aq) + H_2O \rightleftharpoons {NH_4}^+(aq) + OH^-(aq) \quad (51)$$

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.

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.

5. Acid Anhydrides are non-metal oxides that produce acids when reacting with water. This is a new type of reaction called a **Combination** reaction in which the reactants combine together to for a single product. In the case of a non-metal oxide it will combine to produce a acid.

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq) \quad (52)$$

6. Base Anydrides are metal oxides that produce bases when reacting with water. This is a new type of reaction called a **Combination** reaction in which the reactants combine together to for a single product. In the case of a non-metal oxide it will combine to produce a base.

$$Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq) \quad (53)$$

pH and Concentration of [H^+] ions

The strength of an acid or base is generally measured one of two ways. First by calculating the concentration (Molarity) of hydrogen ions [H^+] or hydroxide ions [OH^-] in solution. Second by using a log scale, pH or pOH which is defined as follows. The equations do not need to be memorized and can also be found on your Cheat Sheet.

$$pH = -\log[H^+] \qquad [H^+] = 10^{-pH}$$
$$pOH = -\log[OH^-] \qquad [OH^-] = 10^{-pOH}$$
$$pH + pOH = 14 \qquad [H^+][OH^-] = 1 \times 10^{-14}$$

Figure 17.1: Equations relating pH, pOH, [H^+] and [OH^-]. The most frequently used scales are the pH and [H^+] scales.

Figure 17.2 the relationship between concentration of hydrogen ions [H^+] and pH.

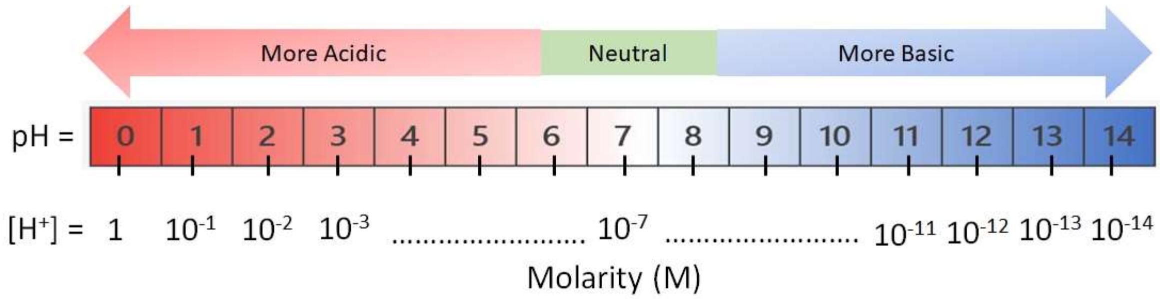

Figure 17.2: Hydrogen ion concentration scales $[H^+]$ in Molarity (M) and pH scale. credit: author

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.

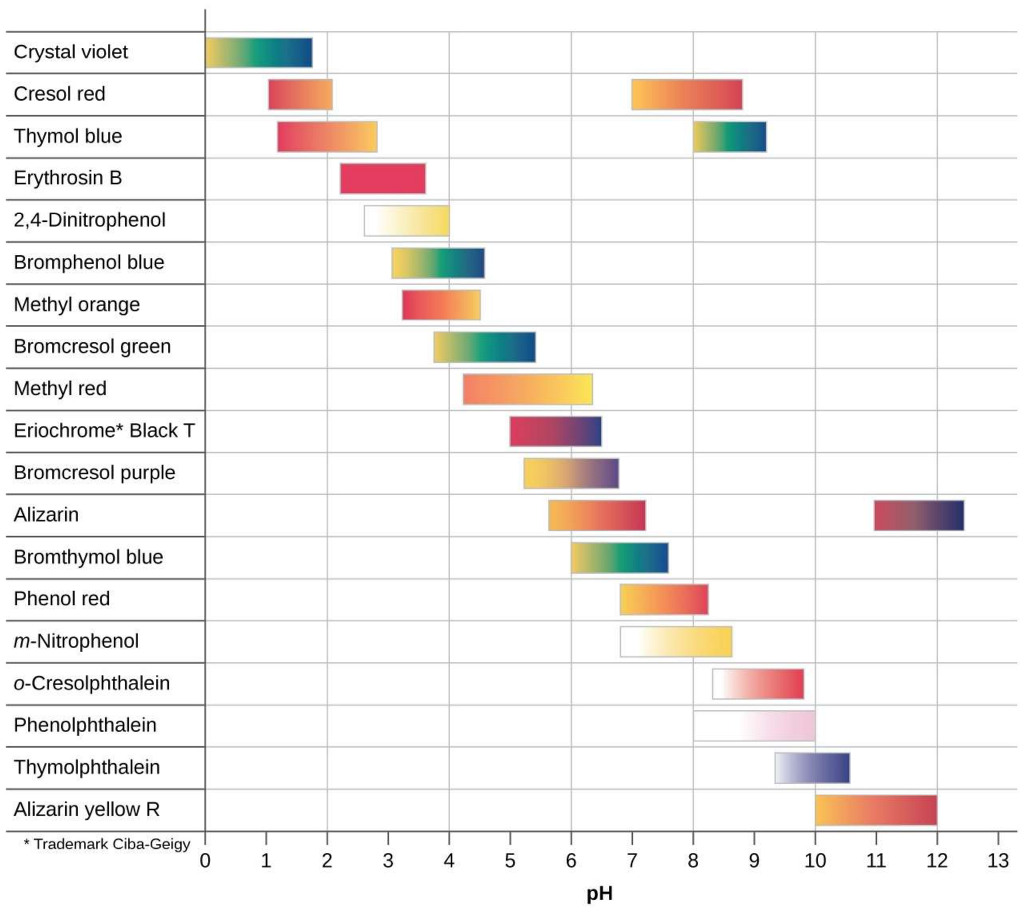

Figure 17.3: pH Range of Different Indicators. credit: `https://commons.wikimedia.org/wiki/File:CNX_Chem_14_07_indicators.png`

One of the most common indicators, Phenolphthalein, you may recall was used 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.

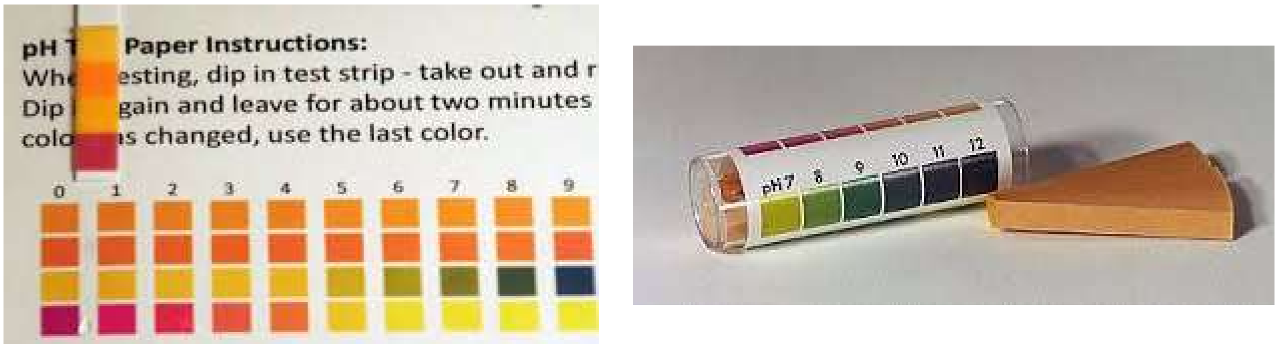

Figure 17.4: Different Brands of pH paper. Those used in lab may be different than those shown here. credit: unknown

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 electrode. 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 17.5: pH Probe and Lab Quest 2 from Vernier. credit: (a) https://www.vernier.com/files/manuals/gdx-ph-bnc/gdx-ph-bnc.pdf (b) https://www.vernier.com/product/labquest-2/

"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.

$$\mathrm{CO_2(aq) + H_2O(l) \rightleftharpoons HCO_3{}^{-}(aq) + H^{+}(aq)} \tag{54}$$

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. Qualitative Measurements of pH

1. Obtain 7 Test Tubes, fill each with 1.0 mL of the solution to be tested.
2. Using a glass rod place a small drop of each solution onto the pH test paper. Record the color observed and the value of the pH according to the chart.
3. Using a glass rod place a small drop of each solution onto the Blue Litmus paper and note the results.
4. Using a glass rod place a small drop of each solution onto the Red Litmus paper and note the results.
5. Add 1 drop of Universal Indicator. Record your results.
6. In the last column indicate if the solution was Acidic (A), Basic (B) or Neutral (N). If there are contradictory results consult with your instructor.
7. Dispose of pH paper in the trash can.
8. Dispose of the Test Tube containing the Universal Indicatior in the ACID/WASTE jar.

B. Quantitative pH Measurements of Aqueous Solutions

1. Calibrate the pH meter.
   (a) On the Lab Quest, choose the Sensors $\longrightarrow$ Calibrate $\longrightarrow$ pH $\longrightarrow$ Calibrate Now.
   (b) Place the pH probe in the pH 4.0 buffer and while swirling input the value of the buffer on the Lab Quest and click "Keep".
   (c) Click Calibrate Now.

(d) Place the pH probe in the pH 10.0 buffer and while swirling input the value of the buffer on the Lab Quest and click "Keep".

(e) Click "OK".

(f) Test your calibration using the 7.0 buffer, if it does not read between 6.9 and 7.1 consult your instructor.

2. Fill a small beaker/Erlenmeyer flask with 15-20 mL of the solution to be tested.

3. Measure the pH of each solution, record your results. Be sure to rinse the electrode between measurements with de-ionized water.

4. When you are done making he pH measurements, pour the solution back into the bottle.

C. Reactions of Acids

1. Perform the following reactions in test tubes 1-7.

2. For each test tube write the complete reaction (balanced, states etc).

3. Perform reactions 1-4 by filling a test tube with 2.0 mL of the acid listed on the table 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. In the hood, test the gas generated by placing a burning split into the mouth of the tube. **EXTINGUISH THE SPLINT IN THE WATER.** Record your observations, was the gas flammable or non-flammable

4. Perform reactions 5-6 by placing a pea sized (or tip of spatula sized) portion of the solid in the bottom of a test tube. Place 4-5 mL of the acid listed in the table in the test tube. Place a cork in the test tube and allow the reaction to proceed for 1 minute. In the hood test the gas generated by placing a burning split into the mouth of the tube. **EXTINGUISH THE SPLINT IN THE WATER.** Record your observations, was the gas flammable or non-flammable

5. Perform reaction 7 by placing 25 mL of water into a beaker, add 3 drops of phenolphthalein and 5 drops of HCl to the solution. Note the color. Drop by drop slowly add the 6.0 M NaOH solution to the beaker. Stir after each drop. Stop adding the base when the phenolphthalein changes color.

6. Dispose of all solutions in the waste container labeled "ACID/BASE WASTE".

D. Reactions of Metal Oxides

1. Perform the following reactions in test tubes 1-2.

2. For each test tube write the complete reaction (balanced, states etc).

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

4. Test the solution with both blue and red litmus paper, and pH paper and note the results.

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

E. Reactions of Nonmetal Oxides and Water

1. Do the following reaction in the hood.
2. For each test tube write the complete reaction (balanced, states etc).
3. Prepare a wide mouth bottle by placing 15 mL of water in it and obtaining a stopper for it.
4. Place a small amount (marble sized) of sulfur powder in a deflagrating spoon and start it burning by heating in a bunsen burner.
5. Holding the wide mouth bottle near horizontal, place the burning sulfur in the deflagration spoon in the wide mouth bottle and collect the gas given off.
6. **EXTINGUISH THE BURNING SULFUR IN THE DEFLAGRATION SPOON IN THE WATER.**
7. Place a stopper in the bottle and shake to mix the water and gas given off.
8. Remove the deflagration spoon and place it in the distilled water nearby to quench it.
9. Test the solution with both blue and red litmus paper, and pH paper and note the results.
10. Dispose of all solutions in the waste container labeled "ACID/BASE WASTE".

.

Results

Data Table A: Qualitative Measurements of pH

TT #	Compound	Color pH Paper	Value pH Paper	Red Litmus	Blue Litmus	Universal Indicator	A/B/N
1	0.1 M KNO_3						
2	0.1 M $HC_2H_3O_2$						
3	0.1 M HCl						
4	0.1 M NaOH						
5	0.1 M NH_3						
6	Tap Water						
7	Distilled Water						

1. Blue Litmus paper turns Red when it reacts with? 1. ____________

2. Red Litmus paper turns Blue when it reacts with? 2. ____________

3. Did all the methods used (pH paper, Litmus paper and Universal Indicator) agree on whether the tested solution was an Acid, Base or Neutral. If not which solutions gave contradictory results? Explain.

Data Table B: Quantitative Measurements of pH

TT #	Compound	pH meter	A/B/N	Calc. $[H^+]$ conc.
1	0.1 M KNO_3			
2	0.1 M $HC_2H_3O_2$			
3	0.1 M HCl			
4	0.1 M NaOH			
5	0.1 M NH_3			
6	Tap Water			
7	Distilled Water			

4. Which Test Tubes (#) were:

   (a) Acidic: 4(a) ______________

   (b) Basic: 4(b) ______________

   (c) Neutral: 4(c) ______________

5. Compare the results from Table A (ph Paper) and the values in Table B (ph Meter). Did any compounds tested produce contradictory results (ie one says a solution is Acidic, one says its Basic, or if the values are greater then 2 pH units apart). Explain.

6. For each of the solutions based on the pH value measured by the meter calculate the concentration of hydrogen ions in solution. Show work for Test Tube # 2.

Data Table C: Reactions of Acids

TT #	Reaction	Observation
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. What class of reaction (Double Displacement, Single Displacement, Combustion, Acid/Base) occurred in each of the test tubes.
   (a) Test Tubes 1-4: 1(a) ______________
   (b) Test Tubes 5-6: 1(b) ______________
   (c) Test Tubes 7: 1(c) ______________
2. Answer the following questions about the flame tests for Test Tubes 1-6:
   (a) Based on the products for each reaction, which reactions produced a flammable gas. 2(a) ______________
   (b) Based on the products for each reaction, which reactions produced a non–flammable gas. 2(b) ______________
   (c) Based on the products for each reaction, what was the identity of the flammable gas? 2(c) ______________

(d) Based on the products for each reaction, what was the identity of the non-flammable gas? 2(d) ______________

3. Based on your observations of the flame test, did any of the acids tested in Reactions 1-4 **NOT** react as one would expect? Explain.

4. Based on your observations in reaction # 7 what color is phenolphthalein in:

   (a) Basic Solution: 4(a) ______________

   (b) Acidic Solution: 4(b) ______________

Data Table D: Reactions of Metal Oxides

TT #	Reaction	Red Litmus	Blue Litmus	pH Paper
1	___$H_2O(l)$ + ___$CaO(s) \longrightarrow$			
2	___$H_2O(l)$ + ___$MgO(s) \longrightarrow$			

Data Table E: Reactions of Nonmetal Oxides

TT #	Reaction	Red Litmus	Blue Litmus	pH Paper
1	___ $H_2O(l)$ + ___$SO_2(g) \longrightarrow$			

1. Are the solutions produced in Table D (Acidic/Basic/Neutral)? 1. ____________

2. Are the solutions produced in Table E (Acidic/Basic/Neutral)? 2. ____________

Post Lab Questions

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.

(a) $\_\_K_2O(s) + \_\_H_2O(l) \longrightarrow$

(b) $\_\_SrO(s) + \_\_H_2O(l) \longrightarrow$

(c) $\_\_SO_3(g) + \_\_H_2O(l) \longrightarrow$

(d) $\_\_N_2O_5(g) + \_\_H_2O(l) \longrightarrow$

Name: ________________________ Class: _________________ Date: _________________

Prelab Questions

1. Give the name or formula for the 10 acids you were required to memorize in class.

2. Give the name or formula for 4 bases.

3. We covered many reactions in class that included acids and bases. There are also two new reactions to learn. Complete the following reactions and in the answer blank include the class of reaction.

   (a) ___$HCl(aq)$ + ___$NaOH(aq)$ $\longrightarrow$

   (b) ___$Na_2CO_3(aq)$ + ___$HNO_3(aq)$ $\longrightarrow$

   (c) ___$H_2SO_4(aq)$ + ___$Na(s)$ $\longrightarrow$

   (d) ___$K_2O(aq)$ + ___$HOH(l)$ $\longrightarrow$

   (e) ___$HOH(l)$ + ___$CO_2(g)$ $\longrightarrow$