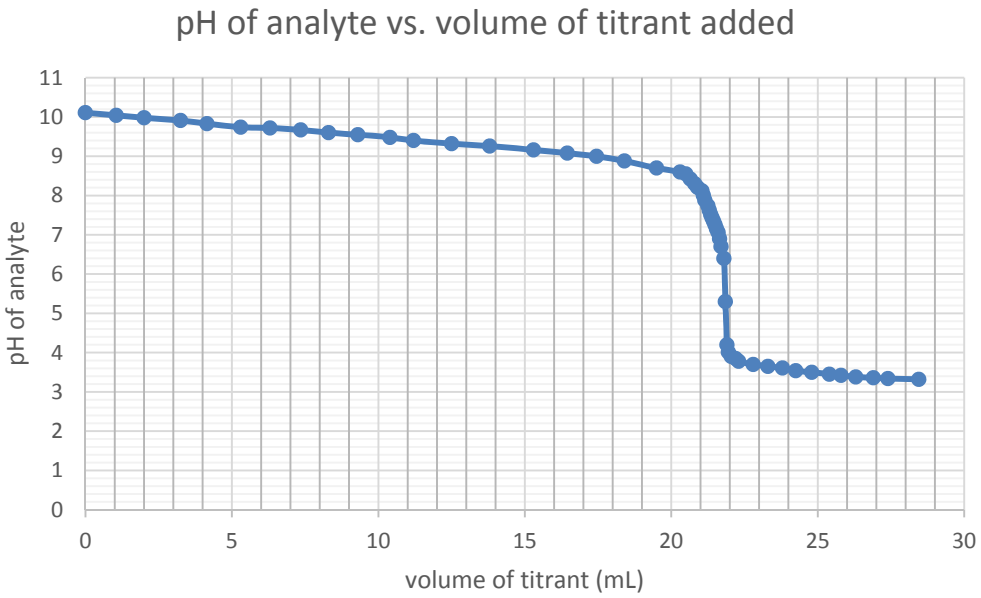
Team Round

1) The key ingredient in baking soda is sodium bicarbonate ($NaHCO_3$), which is used regularly in the kitchen. However, it is also used as a treatment for acid reflux; thus, sodium bicarbonate is referred to as an antacid. Jamie decided to titrate 1.32 g $NaHCO_3$ using the titrant 0.60 M HCl to determine the K_b of HCO_3^-. She recorded the pH at various points in the titration and plotted these as shown in the graph below (i.e. pH of analyte as a function of the volume of titrant added).



a) Write the net ionic equation for the reaction occurring in this titration.

$$HCO_3^- + H_3O^+ \rightleftarrows H_2CO_3 + H_2O$$

b) At the start of the titration, Jamie notices that gas evolves upon the addition of titrant. Identify this gas.

Carbonic acid breaks down to form water and carbon dioxide, which is the gas released.

c) Based on the titration curve, how many milliliters of HCl were needed to bring the titration to its equivalence point? Write your answer to 3 significant figures.

Any answer from 21.7-22.1 mL, 3 significant figures needed for correct answer.

d) What is the experimental pK_b of HCO_3^- ?

At half-equivalence point, pH=pK_a. Thus, pK_a=9.4, pK_b=4.6.

e) What is the experimental molar mass of $NaHCO_3$?

$$\frac{1.32g}{0.0217L * 0.60M} = 101.38\frac{g}{mol}$$

$$\frac{1.32g}{0.0221L * 0.60M} = 99.55\frac{g}{mol}$$

Any answer between 99.55 and 101.38 grams per mole is acceptable.

f) Jamie compared the experimental molar mass of sodium bicarbonate with the actual molar mass of the compound, and she realized that she made a mistake when reading the buret. It turns out that she misread the volume of the titrant to be lower than the actual volume of titrant. Does this help explain the disparity in molar mass?

Yes, this would cause Jamie to calculate fewer moles of hydrochloric acid being consumed in the titration, leading to her calculating fewer moles of sodium bicarbonate being present. Because molar mass is equal to the measured mass of sodium bicarbonate divided by the number of moles, a lower number of moles would cause the experimental molar mass to be higher than the actual molar mass of 84.01 g/mol.

g) The table below lists various indicators and their corresponding pH ranges.

Indicator	pH range
Thymol Blue (1st change)	1.2 – 2.8
Methyl Orange	3.2 – 4.4
Bromocresol Green	3.8 – 5.4
Methyl Red	4.8 – 6.0
Bromomethyl Blue	6.0 – 7.6
Phenol Red	6.8 – 8.4
Thymol Blue (2nd change)	8.0 – 9.6
Phenolphthalein	8.2 – 10.0

Which indicator would have been best for Jamie to use in the titration of the antacid with hydrochloric acid?

Methyl Red; changes color in the same pH range as the equivalence point of the titration.

h) Jamie's best friend, Steven, did the same experiment. Unfortunately, Steven didn't listen to Jamie's advice; although Jamie recommended a certain indicator, Steven decided to go ahead and use Phenol Red as his indicator. How would have this

selection changed his experimental molar mass of $NaHCO_3$ (lower, higher, or the same compared to the actual molar mass). Explain your reasoning.

Higher molar mass; he would record the equivalence point at a higher pH, leading him to use less HCl, which would mean fewer calculated moles of sodium bicarbonate and a higher molar mass.

2) The following question tests concepts related to physical equilibria.

a) An egg boils at 100°C at sea level. However, if you boil the same egg at Mt. Everest's basecamp (elevation of 17388 feet), you will see that the egg boils at 82°C. Explain why this phenomenon is observed.

At higher elevation, the atmospheric pressure is lower. Boiling occurs when vapor pressure of a liquid equals the atmospheric pressure, and at high elevation, it takes a lower temperature for water to reach a vapor pressure equal to the atmospheric pressure.

b) In Marshland, individuals are immune to toxic liquids. Dr. Lee, the founder of Marshland, wants to make spinach lasagna for his chemistry students' graduation, but he's running out of time! He needs to boil liquid at as high a temperature as possible to cook his lasagna. He has a variety of liquids that he can use:

Octane: $CH_3(CH_2)_6CH_3$

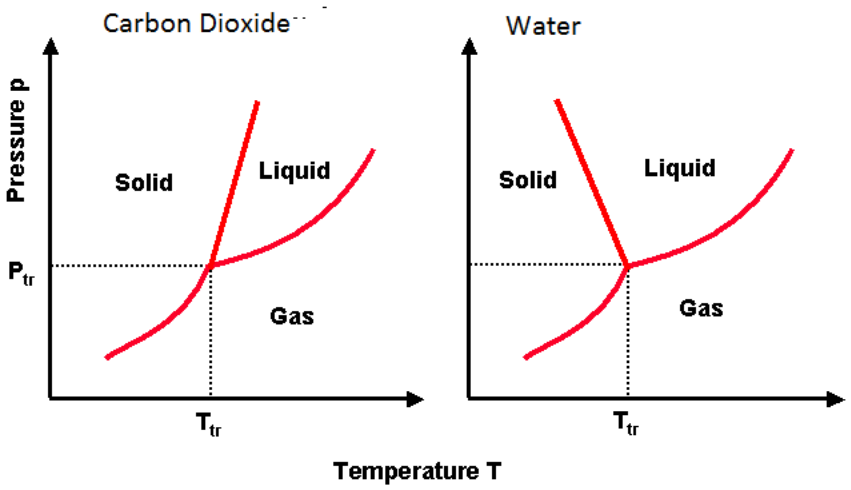
Pentane: $CH_3(CH_2)_3CH_3$

Neopentane: $C(CH_3)_4$

Which liquid should he boil his lasagna in? Briefly rationalize your choice.

Octane, because it has the highest dispersion forces so it will have the highest boiling point.

c) Below are two phase diagrams, illustrations that describe the different temperatures and pressures corresponding to solid, liquid, and gas forms of water.



Explain why the solid – liquid boundary has a positive slope in most solids (such as CO_2), while the solid – liquid boundary has a negative slope in water.

Most solids are denser than their liquid state, so they have a positive solid-liquid boundary slope. Water, however, is less dense in its solid state compared to liquid state, so the slope is negative.

d) The enthalpy of solution is given by $\Delta H_{sol,}$ which is the sum of the lattice enthalpy (ΔH_L) and the hydration enthalpy (ΔH_{hyd}).

In equation form: $\Delta H_{sol} = \Delta H_L + \Delta H_{hyd}$

Lattice enthalpy is the amount of energy that it takes for the conversion of an ionic solid to its gaseous ions. Enthalpy of hydration is the amount of energy it takes to convert the gaseous ions into their aqueous form.

$NaCl_{(s)} \longrightarrow Na^+_{(g)} + Cl^-_{(g)}$ $\quad \Delta H_L = 787$ kJ/mol

$Na^+_{(g)} + Cl^-_{(g)} \longrightarrow Na^+_{(aq)} + Cl^-_{(aq)}$ $\quad \Delta H_{hyd} = -784$ kJ/mol

We see an overall $\Delta H_{sol} = +3$ kJ/mol, which is endothermic. Yet, we see NaCl spontaneously dissolve in water. Explain why this process is spontaneous.

This process is spontaneous because there are entropic factors that favor solvation and cause the overall process to be spontaneous ($\Delta G_{rxn} < 0$).

e) Detergents are molecules that have both nonpolar tails and polar head groups. For example, sodium dodecyl sulfate (SDS) (shown below) is a detergent. It is a molecule that has a long nonpolar hydrocarbon tail and an anionic head group.

Oils are molecules that are made of multiple hydrocarbon tails bonded to a three carbon glycerol molecule. The hydrocarbon tails are long enough to cause the entire molecule to be extremely hydrophobic.

Based on the above information, rationalize why the chemical properties of SDS make it an effective detergent for removing oils from clothing.

The nonpolar portion of the SDS interacts with the grease droplets and forms a shell around them, while the polar portion of the SDS are pointing out from the grease

droplet and are able to interact with water or other polar solvents and be washed away. This carries the grease droplets in the center of the shell away from the clothes.