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Experiment 10:

The Chemistry of Natural Waters

Chem. 111-107

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Introduction:

As defined by the New Hampshire Department of Environmental Services, water hardness is the concentration of metallic solids dissolved in a water source¹. The degree of the water hardness in a source can be determined by the concentration of the ions such as Ca^{2+} and Mg^{2+} ; a hard water source contains a high concentration of the ions while a soft water source contains a low concentration of the ions. Water is a polar solvent and readily dissolves many different compounds such as ions and impurities as it flows over rocks and other solids in its natural environment. Most of the soluble calcium ion comes from soluble sedimentary rocks like limestone (CaCO_3). The soluble magnesium ions come from rock sources from pyroxenes, dolomites, and olivine.² These ions dissociate when combined with water which results in magnesium and calcium ions present in the water sources.

Water hardness is important for a wide variety of different reasons. Water hardness does not pose an immediate health risk, however it can require more soap and synthetic detergents for home laundry and washing and contributes to scaling in boilers and industrial pipelines. Scaling is the deposition of rocklike compounds consisting mostly of calcite crystals on the surface of pipes.³ Deposits of Ca^{2+} and Mg^{2+} can form limestone deposits that can partially block pipelines and cause the lines to be extremely inefficient. To remedy this issue, it often times results in needing to dig up the pipelines and entirely replace the pipes, which can take a significant amount of time as well as being an extremely costly process to undergo. In addition to pipeline inefficiency, water hardness can also cause clothing to become scratchy and harsh because the ions damage the fibers in the clothing. When soaps are used, they weakened chemical bonds between dirt and the surface the is being cleansed. If the concentration of a cation such as Ca^{2+} is high, the soap

anion will produce an insoluble scum-like substance which will coat the cleaned surface.

Metallic ions in water can also cause metal corrosion and structural weakness on buildings and bridges.⁴

Water hardness can be measured in either parts per million (ppm) or grains per gallon (grains/gal). The Environmental Protection Agency regulates the standards for drinking water on health and safety factors. Depending on a person's area, there are limits as to how hard their water can be and this can vary from county to county. Some counties have extremely hard water, while others can have water that contains a much lower concentration of ions. The book, *Chemistry- The Molecular Science*, contains a chart that classifies hard/soft water based on the ppm and grains/gal measurements.⁵

Table 1. Classification of Water

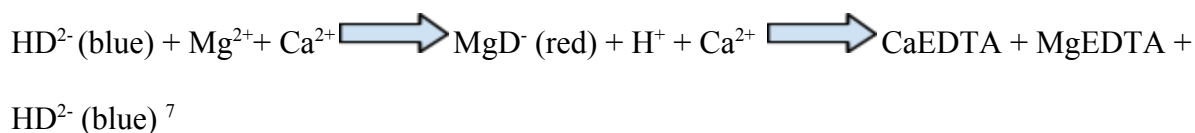
Classification	ppm	grains/gal
Soft	0.0- 17.1	0.0-1.0
Slightly Hard	17.1-60.0	1-3.5
Moderately Hard	60.0-120.0	3.5-7.0
Hard	120.0-180.0	7.0-10.5
Very hard	180.0 & over	10.5 & over

There are many different tests available to test water hardness, with some being more specific and other being less specific than others. A very basic way of testing for water hardness in a sample is a Total Dissolved Solids (TDS) test, which is when the sample is evaporated and the remaining solids are examined. This is a very unspecific test that is useful for determining if there are in fact ions present in the water and what the concentration of the ions are by observing

how condensed the leftover solids are, but is relatively useless in determining the exact numerical values of cations present.

One method for determining the amount of dissolved metals present in a water sample is Atomic Absorption Spectroscopy (AA). The instrument used, the AA Spectrometer, has an aspirator (collection of the liquid sample), a lamp to emit specific wavelengths, a flame (heat source) and a photon detector. Depending on what ion is being tested for, a specific lamp will have to be used to emit a wavelength specific to that ion, such as calcium or magnesium. Once the aspirator obtains the sample, it feeds the sample to the flame where the sample will be evaporated and any ions of the sample will absorb the light from the lamp before the light reaches the photon detector. If a sample has high levels of a specific ion, such as calcium, then the Spectrometer will read high absorbance values because much of the light from the lamp did not reach the photon detector since it was absorbed by the ions. Once the absorbance level is determined, it can be used to calculate the concentration through the use of a calibration graph.⁶

Another way that can be utilized to determine water hardness is through the complexation reactions of ethylenediaminetetraacetic acid (EDTA) with the water solution containing the ions. This method calculates how many divalent cations with a plus-two charge are present in the sample of water through a complexation reaction.⁷



To begin the EDTA titration, a clean 1 x 12 well and 1 drop of erichrome black T (EBT) was added to each of the wells and one drop of the $\text{NH}_3/\text{NH}_4\text{Cl}$ was added to each. The EBT is used as the indicator and can undergo a color change due to pH change or due to a reaction with

a metallic ion. When the EBT indicator is added, it is in the HD^{2-} form so the pH is high and the solution will be a blue color as indicated in the reaction above. If Mg^{2+} is present, it will react with the indicator and turn a red color. Then, EDTA solution is added which reacts with the Ca^{2+} and magnesium indicator to produce MgEDTA chelate. Once this is formed, the solution returns to the blue color which indicates the point where an excess of EDTA is present. While the drops of EDTA in increasing fashion (1 to first well, 2 to second well), the point at which the solution turns blue is the end point of the reaction and the amount of drops of EDTA it took to turn blue should be recorded for further calculations.

The EDTA and AA methods of determining water hardness both obtain relatively accurate results, however they are both different in their procedures. The AA analysis evaluates only one ion at a time and with the use of a spectrometer machine while EDTA calculates the sum of the ions and cannot differentiate between the two. EDTA also relies on titrating the sample with indicators and chelate-forming EDTA while AA relies on a lamp source, flame, and a photon detector which coupled with a computer system to calculate the concentration. AA tends to be more exact because the machine calculates the absorbance of only one ion at a time which reduces the chance of human experimental and calculation error that would be present in the EDTA test through the titrations that must be needed and recording accurate numbers of drops of each solution. Two separate methods are used in this experiment to verify the results of each separate experiment. If the determined concentrations from the EDTA and AA are severely off, it indicates that one of the experiments may have been performed incorrectly, and in the case of the AA that the calibration of the machine is wrong. Performing both methods allows the scientists two methods to obtain results and to be sure that the results are accurate.

Water “softening” is also a very common procedure as it can reduce the ion concentration and prevent the damaging effects of hard water that were discussed prior. Cation exchange resins are very useful in softening water. In both the commercial softening agent and resin, cation exchange was utilized to soften the water by reducing the amount of metallic ions present. The resin takes in calcium and magnesium ions (divalent cations) and releases sodium and hydrogen ions (monovalent cations). This “softens” the water as the monovalent cations are more “soft” than the “hard” divalent cations. By this logic, both of the softening techniques lowered the hardness of the water in ppm greatly.

In this experiment, five different water sources were tested: water from East Halls of Penn State, South Halls, West Halls, Pollack Halls, and a bottled water sample. The dorm water samples will be taken from tap water. Bottled water companies tend to market their water as having a “pure” taste and being more purified than water from the tap. At a municipal level, the county is required to keep water hardness at a specific level and the chemicals that are used to do that can leave the water with a disatisfying taste. The bottled water sample that was used was from spring water which is typically naturally softened through cation exchange, resulting in a lower hardness level. While the municipal water of Penn State is regulated to a certain extent, Centre County Pennsylvania is noted of having a very high water hardness which has been measured at up to fifteen grains/gal. The hypothesis of this experiment is that the bottled spring water will have the lowest water hardness while the dorm water will collectively have a higher water hardness than the bottled water due to the high water hardness in Centre County. While the hardness of spring water varies depending on its location, they are treated for hardness before being sold so are typically softer than tap water.

Procedure:

The entire procedure can be found for Experiment 10: The Chemistry of Natural Waters in chapter 10 of *PSU Chemtrek*.⁷ In the experiment, the five water samples were tested using a TDS, AA, and EDTA for hardness of the sample. The procedure in the *Chemtrek* was followed exactly besides in Section G. where it gave sample calculations; these calculations were only performed in reference to the actual values.

The first method used to determine the water hardness was the Total Dissolved Solids (TDS) test. A drop of each sample was placed on aluminum foil along with a distilled water sample and a Ca^{2+} and then placed on a hot plate as a heating source. The foil was left on the hot plate until the distilled water sample, the Ca^{2+} , and the water sample being tested were evaporated. The white residue remaining on the foil indicated the presence of the dissolved solids in the water samples which help determine the hardness of the samples. A strong white ring from the water sample being tested indicated a high presence of ions and a high water hardness while a more faint ring indicated a lower concentration and a lower water hardness. The higher water hardness rings should look like the ring left by the Ca^{2+} sample while the lower water hardness rings should be more faint.

The next method used was Atomic Absorption (AA) Spectroscopy. The samples were tested by a machine that measures the calcium and magnesium ions separately. The aspirator was inserted into the water sample where the absorption level (in nanometers) of both Ca^{2+} and Mg^{2+} were calculated. Using the absorption level, as well as the calibrated equation values determined by the machine for each ion, the hardness of each ion was able to be calculated by inserting the values into an equation of a linear line. The ppm values that were calculated were then

transferred into the equivalent concentration of CaCO_3 and then were added together for the total hardness of the sample.

The last method was the EDTA titration, where the concentration was determined through a series of dilutions. EDTA is a complexation reaction with the water samples in order to determine the concentration of the Mg^{2+} and Ca^{2+} ions. While performing the titration, the first well to turn a blue color is the end point of the reaction where an excess amount of the EDTA is present and is considered the volume of EDTA necessary for the titration, measured in drops of EDTA. The results in this experiment can be subject to human error because it is possible to miscount the number of drops administered or deliver a drop without thoroughly mixing the solution, as is said in the *Chemtrek*. The number of drops used and the concentration of the EDTA is used to calculate the hardness of the water sample in ppm and grains/gal. Additionally, the samples were observed by EDTA titration with a commercial softening agent and with resin. The commercial softening agent was added to a vial of the water sample where the hardness was calculated by performing another EDTA titration and determining the percent change from the initial EDTA titration. The divalent cation removal exchange was performed by allowing the water to filter in a solution with the resin. Once filtered, another EDTA titration was performed where the hardness was calculated and then compared to the original titration by the percent change.

Results:

The results and information is gathered from the lab notebooks of the following people: Matthew Ryan,⁹ Amelia Rogus,¹⁰ Rafael Sakuma,¹¹ Zach Saparito,¹² and Mason Santilli.¹³

Total Dissolved Salts (TDS) Results:

Using the TDS method to investigate water hardness, these are the results.

Table 2. Total Dissolved Solids (TDS) of Each Water Sample

Water Sample:	Observations:
Distilled Water	No residue
Ca ²⁺ solution reference	White residue
East Halls Sample	White ring
South Halls Sample	Strong white ring
West Halls Sample	Brown/white light ring residue
Pollack Halls Sample	Strong white ring
Great Value Spring Water	White ring

In comparing the results of the TDS test, South Halls and Pollack Halls exhibited the strongest presence of residue due to their pronounced white rings that were even more white than the Ca²⁺ reference. The sample from East Halls and the Great Value Spring Water sample were a moderately white residue while the West Halls sample had a brown color and was the lightest residue.

Atomic Absorption (AA) Results:

These are the results obtained after running each individual sample through the AA spectrometer.

Table 3. Absorption Rates According to AA of Each Water Sample

Sample Name	Ca²⁺ Absorbance (@ 422.7 nm)	Mg²⁺ Absorbance (@ 202.5 nm)
East Halls	0.2913nm	0.2379nm
South Halls	0.2196nm	0.1950nm
West Halls	0.010nm	0.0012nm

Pollack Halls	0.3171nm	0.2144nm
Great Value Spring Water	0.0463nm	0.0099nm

The AA spectrometer device in the Whitmore Laboratory, obtained these standard values of calibration of the Ca^{2+} and Mg^{2+} concentrations.

Table 4. AA Standards of Ca^{2+} Concentration

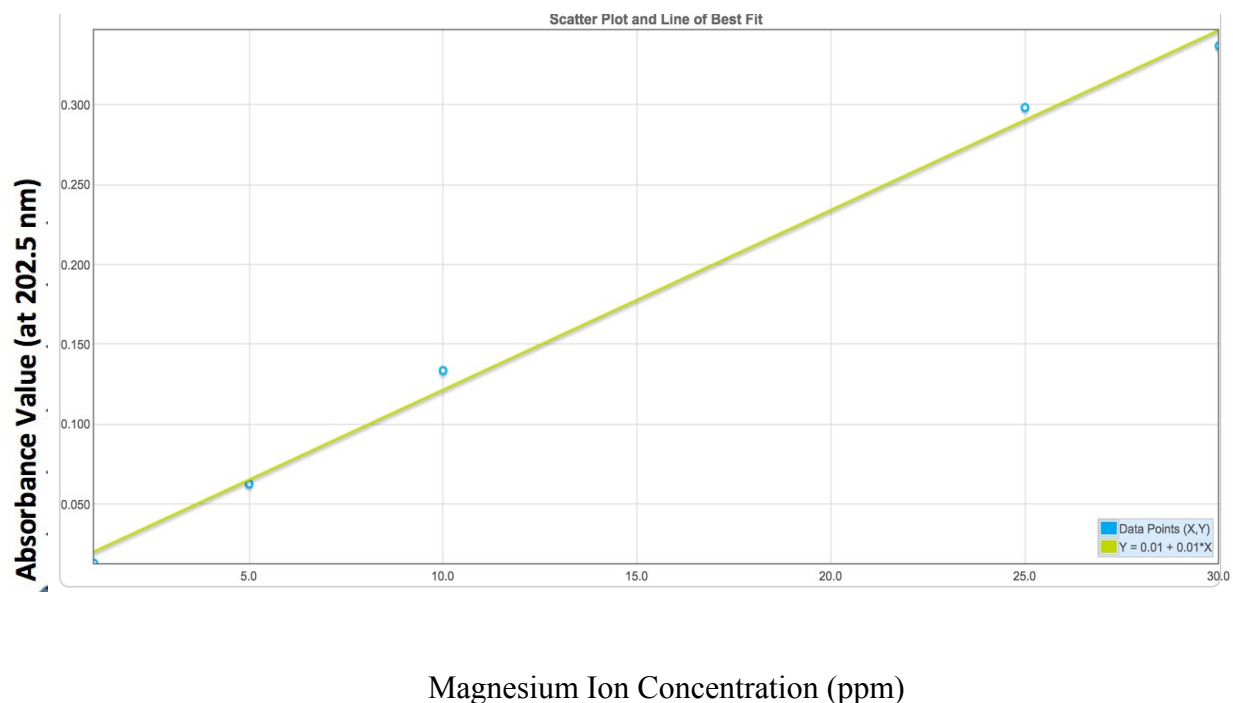
Ca^{2+} Concentration (ppm)	Ca^{2+} Absorbance (@ 422.7 nm)	Check Standard for Ca^{2+} (ppm)
0	--	--
1.000	0.00774	1.11
5.000	0.04006	5.04
10.000	0.08116	9.90
25.000	0.19343	24.30
50.000	0.34893	49.73

Table 5. AA Standards of Mg^{2+} Concentration

Mg^{2+} Concentration (ppm)	Mg^{2+} Absorbance (@ 202.5 nm)	Check Standard for Mg^{2+} (ppm)
0	--	--
1.000	0.01302	1.01
5.000	0.06257	5.50
10.000	0.13361	10.0
25.000	0.29825	24.8
30.00	0.33689	29.6

The absorbance standards from the spectrometer were used to calculate the calibration curve on the following graphs. The linear equations determined from those graphs were then used to calculate the hardness for both ions.

Graph 1. Calibration of Mg^{2+} Concentration by AA

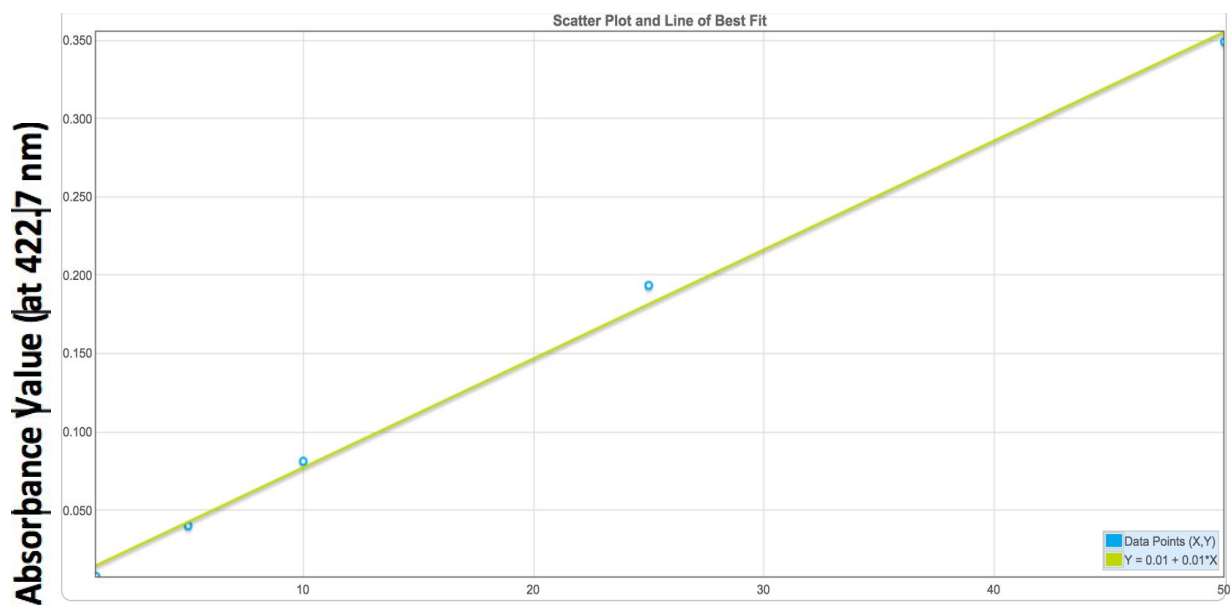


$$y = 0.01 + 0.01x$$

$$R^2 = 0.99557$$

This graph, and the one below, both show that as the concentration (ppm) of the ion increases, the absorbance value (nm) increases as well. The relationship between these two values creates a linear equation that can be used to calculate the hardness of the sample.

Graph 2. Calibration of Ca^{2+} Concentration by AA



Calcium Ion Concentration

$$y = 0.01 + 0.01x$$

$$R^2 = 0.99674$$

For the calibration equations:

y-value = absorbance (nm)

x-value = concentration (ppm)

For Ca^{2+} : $y = 0.01 + 0.01x$

$$(0.2913 \text{ nm}) = 0.01 + 0.01x$$

$$0.2813 = 0.01x$$

$$x=28.13\text{ppm}$$

For Mg^{2+} : $y=0.01+0.01x$

$$(0.2379\text{nm})=0.01+0.01x$$

$$0.2279=0.01x$$

$$x=22.79\text{ppm}$$

The next step involved converting the values of the concentration of each ion into their equivalent of calcium carbonate. This will help determine the hardness of the sample.

For Ca^{2+} hardness:

$$28.13\text{ppm } \text{Ca}^{2+} \times (100\text{g } \text{CaCO}_3 / 1 \text{ mole}) / (40.0\text{g } \text{Ca}^{2+} / 1 \text{ mole}) = 70.325 \text{ ppm hardness}$$

For Mg^{2+} hardness:

$$22.79\text{ppm } \text{Mg}^{2+} \times (100\text{g } \text{CaCO}_3 / 1 \text{ mole}) / (24.3\text{g } \text{Mg}^{2+} / 1 \text{ mole}) = 93.786 \text{ ppm hardness}$$

The Ca^{2+} and Mg^{2+} hardness were added together to obtain the total hardness from the AA analysis.

Total Hardness:

$$70.325\text{ppm} + 93.786\text{ppm} = 164.11 \text{ ppm (for east halls)}$$

The following table gives the total hardness values and individual ion values from the AA analysis from each of the water samples.

Table 6. Hardness for Each Sample Calculated Through AA Analysis

Sample	Ca^{2+} Hardness (ppm)	Mg^{2+} Hardness (ppm)	Total Hardness (ppm)
East Halls	28.13ppm	22.79ppm	164.11ppm
South Halls	20.96ppm	18.5ppm	144.0ppm

West Halls	N/A (too soft)	N/A (too soft)	N/A (too soft)
Pollack Halls	30.71ppm	20.44	160.89ppm
Great Value Spring	7.51ppm	4.21ppm	48.1ppm

EDTA Results:

The water samples were also analyzed by an EDTA titration to determine the water hardness.

The following calculations were performed for each individual sample:

Ppm calculated through titration:

$$M_{\text{EDTA}} V_{\text{EDTA}} = M_{\text{sample}} V_{\text{sample}}$$

This equation shows that the molarity of the EDTA added x the volume of the EDTA added = the molarity of the sample x the volume of the sample. Since the molarity of the sample was not known and the rest of the values were, the molarity can be determined through simple algebra.

$$(2.0 \times 10^{-4} \text{M})(12 \text{ drops EDTA}) = (\text{sample concentration})(1 \text{ drop sample})$$

$$2.4 \times 10^{-4} \text{M} = \text{sample concentration (the sample changed after 12 drops)}$$

$$(2.4 \times 10^{-4} \text{ mol CaCO}_3/\text{L}) \times (100 \text{g CaCO}_3/\text{mol CaCO}_3) \times (1000 \text{ mg CaCO}_3/\text{g CaCO}_3) =$$

240mg/L solution

240mg = 240 ppm (The density of dilute aqueous solutions is close to 1g/mL, and there for 1mg of solute/ 1 L solution is equivalent to 1mg of solute per 10⁶ of solution. 1 mg/L is equivalent to 1 ppm.)⁷

$$(240 \text{ppm}) \times ((1 \text{ grain/gal}) / (17.1 \text{ppm})) = 14.04 \text{ grains/gal}$$

Table 7. EDTA Titration for Water Samples

Sample	EDTA Volume	Hardness (M)	Hardness ppm	Grains/gal	Diluted?
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East Halls	12 drops	240 mg/L	240 ppm	14.04 grains/gal	No
South Halls	10 drops	200 mg/L	200 ppm	11.70 grains/gal	No
West Halls	5 drops	100 mg/L	100 ppm	5.85 grains/gal	No
Pollack Halls	15 drops	300 mg/L	300 ppm	17.54 grains/gal	Yes
Spring Water	13 drops	260 mg/L	260 ppm	15.21 grains/gal	No

Commercial Softening Agent Results:

The calculations as followed determine the hardness of a sample after the addition of a commercial softening agent.

$$M_{\text{EDTA}} V_{\text{EDTA}} = M_{\text{sample}} V_{\text{sample}}$$

$$(2.0 \times 10^{-4} \text{M})(11 \text{ drops EDTA}) = (\text{concentration of sample})(1 \text{ drop sample})$$

$$2.2 \times 10^{-3} \text{ M} = \text{sample concentration (The sample changed color after 11 drops)}$$

$$(2.2 \times 10^{-3} \text{ mol CaCO}_3/\text{L}) \times (100 \text{g CaCO}_3/\text{mol CaCO}_3) \times (1000 \text{ mg CaCO}_3/\text{g CaCO}_3) =$$

$$220 \text{ mg/L}$$

$$220 \text{ mg/L} = 220 \text{ ppm}$$

$$(220 \text{ ppm}) \times ((1 \text{ grain/gal}) / (17.1 \text{ ppm})) = 12.87 \text{ grains/gal}$$

Table 8. Water Softening Agent EDTA Titration for Water Samples

Sample	EDTA Volume	Hardness (M)	Hardness ppm	Grains/gallon
East Halls	11 drops	220 mg/L	220 ppm	12.87 grains/gal
South Halls	8 drops	160 mg/L	160 ppm	9.36 grains/gal
West Halls	2 drops	40 mg/L	40 ppm	2.34 grains/gal

Pollack Halls	12 drops	240 mg/L	240 ppm	14.04 grains/gal
Spring Water	6 drops	120 mg/L	120 ppm	7.02 grains/gal

As can be seen in the results of the samples softened by the commercial softening agent, the hardness is reduced for each sample after the addition of the agent in the EDTA titrations. The end point is reached at an earlier volume of EDTA than the initial EDTA titrations.

After using the cation exchange resin to remove Ca^{2+} and Mg^{2+} to determine the effects of the resin on the softening of water samples, the following results were obtained:

Resin:

$$M_{\text{EDTA}} V_{\text{EDTA}} = M_{\text{sample}} V_{\text{sample}}$$

For the East Halls, the solution changed color after 8 drops of EDTA after being filtered by the resin.

$$(2.0 \times 10^{-4} \text{M})(8 \text{ drops EDTA}) = (\text{concentration of sample})(1 \text{ drop sample})$$

$$1.6 \times 10^{-3} \text{ M} = \text{sample concentration}$$

$$(1.6 \times 10^{-3} \text{ mol CaCO}_3/\text{L}) \times (100 \text{g CaCO}_3/1 \text{mol CaCO}_3) \times (1000 \text{ mg CaCO}_3/1 \text{g CaCO}_3) =$$

$$160 \text{mg/L}$$

$$160 \text{mg/L} = 160 \text{ppm}$$

$$(160 \text{ppm}) \times ((1 \text{ grain/gal})/(17.1 \text{ppm})) = 9.36 \text{ grains/gallon}$$

The following table compiles the results of the EDTA titration with the addition of resin for all of the water samples.

Table 9. Resin EDTA Titration for Water Samples Results

Sample	EDTA Volume	Hardness (M)	Hardness ppm	Grains/gallon
East Halls	8 drops	160 mg/L	160 ppm	9.36 grains/gal
South Halls	2 drops	40 mg/L	40 ppm	2.34 grains/gal

West Halls	1 drop	20 mg/L	20 ppm	1.17 grains/gal
Pollack Halls	4 drops	80 mg/L	80 ppm	4.68 grains/gal
Spring Water	0 drops	0 mg/L	0 ppm	0 grains/gal

According to these results, the resin softened the water even more than the commercial softening agent, as it took fewer drops in order to reach the end point in the EDTA titration.

Discussion:

In this experiment, each of the water samples was tested using the AA and EDTA titration methods. In the AA analysis, the East Halls dorm had the highest water hardness with a hardness of 164.11 ppm while the West Halls dorm had the lowest water hardness with a value of 0.0ppm because the absorbance value was so small that it would have been negative if calculated using the calibration graph equation. The Great Value Spring Water had the second lowest water hardness of 48.1 ppm while the Pollack and South Halls residence were both in between the two extreme values. For the EDTA titration, West Halls had the lowest water hardness of 100 ppm while Pollack Halls had the highest water hardness of 300 ppm. The Great Value Spring Water's hardness was 260 ppm, the second highest water hardness. East Halls and South halls had water hardness' of 240 ppm and 200 ppm, respectively. In both of the tests, West Halls had the lowest water hardness while Pollack and East Halls both had very high hardness'. The water hardness of the spring water was relatively low in comparison to the others in the experiment for the AA analysis, but higher than most in the EDTA analysis.

The results of this experiment disprove the hypothesis that the spring water would have the lowest water hardness. In both experiments, the water sample from West Halls had the lowest water hardness, while the Spring Water did not have the lowest hardness in either of the experiments. Also, the water hardness of the dorms were not around the same value, as Pollack

Halls and East Halls both had significantly higher values in both experiments than the West and South Halls. The West Halls water hardness was most likely the lowest because a lot of softening agent was added to the water which would result in a lower water hardness. This also could relate back to the TDS test because when the West Halls water was evaporated on the hot plate, the residue left over was a partially brown color which could have been due to the presence of water softener. Additionally, the Spring Water was not the lowest water hardness possibly because when in its natural environment, it picked up the Mg^{2+} and Ca^{2+} ions and when treated with water softener was never softened as much as the water from West Halls was.

After comparing the data between the AA analysis and EDTA titration, the water hardness was higher for all samples in the EDTA titration as opposed to the AA analysis. This makes sense because the AA Spectrometer measures the absorbance one cation at a time, while EDTA accounts for the hardness of all cations at once. AA is also more accurate because it gives results that are calculated by a computer after collecting data, while EDTA involves a lot of human calculation which involves counting the number of drops and being sure that the drops are mixed properly which are both examples of human error that could impact the data. In the EDTA titration, being just one drop off could change the water hardness value by 20 ppm. Additionally, the EDTA titrations account for all of impurities in a single sample instead of just the key cations being observed in the AA analysis which can also make the EDTA values higher. The AA analysis was more accurate and precise because the values were determined through computer calculation that negated human error and would return almost identical data if they were repeated, while the EDTA titrations would probably not due to the high probability of human error.

When the water samples are treated with water softening techniques, the water hardness of all samples decreased significantly. The water hardness decreased even more so in the Resin softening technique as opposed to the commercial softening agent. In the commercial softening agent test, West Halls had the lowest hardness of 40 ppm while it had the second lowest hardness in the resin test with 20 ppm. In the ion exchange test, the Spring Water sample had the lowest water hardness of 0 ppm, which was contrary to the rest of the data since West was always the lowest hardness. The rest of the water hardness' decreased significantly except in the Resin test East Halls still took 8 drops to reach the end point which was by far the highest out of all the samples.

According to the State College Borough Water Authority, the water in state college is treated with Chlorine, Fluoride, Nitrate, Barium, and other chemicals. These chemicals are primarily to disinfect that water from any potential microbes that could be present.¹⁴ This treatment is not very obvious in any of the water samples taken from the dorm besides West Halls, since all of the water had a high water hardness in accordance to Table 1. which stated that "hard" water was between 120-180 ppm and all besides the Spring Water and West Halls were between that for the AA analysis. The West Halls water was too soft to calculate, which may indicate an overuse of softening agent in the water. The Spring Water claims to have no ingredients besides the water and makes no mention of any treatment methods. The AA analysis of the Spring Water had a hardness of 48.1 ppm which was in the "slightly hard" range of 17.1-60.0 ppm. Pennsylvania is known for having hard water, and the fact that the tap water is not in the "very hard" category indicates that there is probably a significant amount of softener added to keep the hardness at a manageable amount.

Conclusions:

After analysis of the AA, EDTA titration, TDS, and both of the softening experiments, it can be concluded that West Halls possesses the softest water. This does not support the hypothesis that the Spring Water would have the softest water. The AA analysis, which is the most accurate test, determined that the West Halls hardness was 0.0 while the Spring Water's hardness was 48.1 ppm. Additionally, the EDTA titration found that the water sample from West Halls was the softest with a value of 100 ppm while the Spring Water had a value of 260 ppm. The results were overall consistent with this finding, although to entirely prove that this is true it would be useful to repeat the experiment to be sure that these results can be replicated to ensure their validity. Additionally, the West Halls water may be treated with an excess of water softener due to its brownish color in the TDS test and its extremely low hardness in the AA analysis.

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