

The Chemistry of Natural Waters

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## **Introduction:**

Water is the most essential element to the survival of all living species on Earth. The natural cleaning process of water is known as the water cycle. In this cycle, the water on the earth receives heat from the sun and evaporates into the atmosphere. It then condenses into clouds until it eventually precipitates back down to the earth. Through this cycle, water is purified from any dissolved substances that it might have picked up during its time on the earth's surface. Among all of the impurities that filter into water, two of the most common are the cations of calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ )[15].

Water hardness is determined by the presence of these dissolved divalent cations, calcium and magnesium, in water. Waters that contain a high concentration of calcium and magnesium cations are harder than that of waters that contain a low concentration of calcium and magnesium cations. Water with low concentration are said to be soft. Since we are using water faster than it can be replaced, as one can imagine, the hardness of the water is gradually increasing on average [8].

Calcium carbonate, measured in milligrams per liter, determines the hardness of water. Water hardness is often measured in terms of calcium carbonate equivalent, which is an expression of the concentration of calcium and magnesium ions in water in terms of their equivalent value of calcium carbonate[17]. Calcium carbonate occurs in water because when carbon dioxide dissolves in water it creates a weak carbonic acid. This acid dissolves such rock sources as limestone and other minerals in the earth. The carbon dioxide will trickle through the limestone releasing calcium and magnesium ions as their soluble bicarbonates into the water [18]. These calcium ions can also be found in other rock sources besides limestone, such as dolomite and gypsum. Magnesium ions can also be found in rock sources such as olivine, pyroxenes, dolomite, and dark colored micas [15].

It is especially important for to know and understand water hardness because of the many problems associated with it. For example, in the areas of soap and industrial boilers the increase in water hardness increases problems. Soap's purpose is to lessen surface tension in order to remove "dirt" when used with water. However, if the water contains a high concentration of calcium and magnesium, the ions will react with the soap to produce an insoluble precipitate that deters the effectiveness of soap [15]. Manufactures that use pipes, boilers, evaporators, and any other devices to heat up hard water sources face the major problem called scale formation. When hard water is heated the excess ions are left behind forming rocklike deposits. These deposits coat the surface of the pipes, boiler walls, and many other surfaces that the hard water comes in contact with. This causes a number of problems for the industries. It can reduce water flow, heat transfer is insufficient, pipes become blocked and narrow, and eventually metal corrosion and structural weakness occurs. It is very expensive to remove the scale buildup or replace the corroded pipes. This is why many industries have chosen to soften their water to prevent the buildup of cation deposits [3].

Water is also a vital component of life and is an essential necessity to the survival of all living organisms. That is why it is important we understand the chemistry behind what is affecting our water supply.

"The Chemistry of Natural Waters" experiment from the PSU Version of Chemtrek was designed to compare the hardness of selected samples of water through various methods. The first method in this experiment was the Total Dissolved Solids (TDS) test. Dissolved solids refer to any minerals, salts, or metals dissolved in a water sample. The Total Dissolved Solids test provides a qualitative measure of the amount of dissolved ions in a water sample. The amount of residue left over after evaporating the water is referred to as total dissolved solids (TDS) [15]. This method will measure ions that contribute to water

hardness, like calcium and magnesium, but also those that do not, like sodium. This method does not tell us the nature or ion relationship in the water [16].

One method used to examine the hardness of water through the use of divalent cation analysis was by the EDTA titration process. Ethylenediaminetetraacetic acid (EDTA) reaction with a certain water sample is what determines the amount of cations. This process also uses eriochrome black T (EBT), a water-soluble dye, as an acid-base indicator. This method can be carried out in a serial manner using a well strip. This process first starts by adding a drop of water sample to each well. Then one drop of  $\text{NH}_3/\text{NH}_4$  buffer is added to each well to adjust the pH to 10. Then EBT indicator is added, which in its original form is blue. The indicator should turn red indicating the presence of magnesium cations. Then EDTA solution is added. The EDTA will first react with the calcium cations, forming a colorless chelate. When the EDTA has fully reacted with all the calcium then it will start reacting with the magnesium, again forming a colorless chelate. Once the EDTA has fully reacted with all the magnesium it will then turn back to blue. The reaction process is summarized in the following equation:



Blue                                      Red                                      (immediately)                                      Blue

After the volume of EDTA needed to turn the solution blue again is observed, you can then calculate the original concentration of  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  by using  $M_{\text{EDTA}}V_{\text{EDTA}}=M_1V_1$  [9]. This method, however, can be less accurate due to the fact that the EDTA also measures other divalent cations that may be present in the water. It is also easier for human error to occur through this method because since it is quantitative measure, drop sizes could vary. Also when the sample turn to blue is determinate by where a certain individual thinks it may lie.

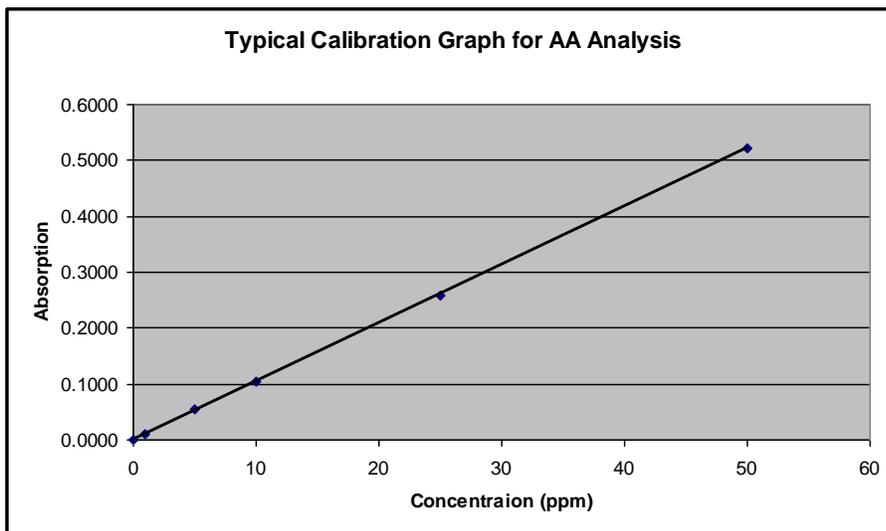
Another method used for determining water hardness is through Atomic Absorption Spectrophotometry, also known as AA. This method is used to determine the concentration of a specific element. The atomic absorption spectrophotometer consists of three regions. The first region supplies the monochromatic light through a water sample. When the light is shown through the sample being aspirated, the atoms in the sample with the same electronic energy separation (measured by  $\Delta E$ ) as the light will absorb the light. The absorbance of light will correspond to the change in energy associated to that particular element [15]. The amount of absorbance is directly proportional to the concentration of the metal atoms. The Beer-Lambert law ( $A = a(\lambda) * b * c$  where  $A$  is the measured absorbance,  $a(\lambda)$  is a wavelength-dependent absorptivity coefficient,  $b$  is the path length, and  $c$  is the analyte concentration) is the linear relationship between absorbance and concentration of an absorbing species and can be used to calculate the unknown metal concentration in the sample.[3]

The atomic absorption process begins in region one when a monochromatic light, in this case either a calcium or magnesium hollow cathode lamp, passes through the water sample in region two, the sample chamber.[9] In the sample chamber water is aspirated and converted from a liquid to a aerosol. An intense heat of approximately 2300 degrees Celsius atomizes the water sample. The light from region one then passes through these newly formed atoms. The light that is passing through will only be absorbed if it matches the same element that is present in the sample. The remaining light that wasn't absorbed goes to region three [15].

In region three, the monochromator is a grating that allows only a set wavelength of light through which correspond with the element that is being tested. The second part of region three is the detector which is a photo multiplier tube (PMT). Since metal atoms absorb some of the light passing through the flame from the lamp, a decrease in the initial signal is detected by the PMT. This decrease is also proportional to the concentration of the metal in the sample [15]. The concentration of a metal in a

water sample can be determined through a calibration graph. The typical calibration graph is shown below:

Graph 1: Typical Calibration graph



Softening techniques are one way to remove some of the divalent cations from water. One way to remove divalent cations is through ion exchange. Ion exchange works by passing water through cation exchange resins [15]. This resin contains monovalent cations, such as  $\text{Na}^+$  or  $\text{H}^+$ . When the water is perchlorated with these resins the monovalent cations are exchanged with the divalent cations in the water. Therefore large amounts of monovalent cations are left in the water instead of divalent cations. Since monovalent cations, such as  $\text{Na}^+$  or  $\text{H}^+$ , do not contribute to water hardness, the water becomes softer [ 14].

Another way to soften water is through using a commercial water-conditioning agent. The commercial softening agent is made from sodium bicarbonate. It performs in a similar way as the cation ion exchange, in which the divalent cations calcium and magnesium in the water are replaced by the monovalent cations in the softening agent [2].

The methods used to determine water hardness mentioned above were used to test four different samples. A sample of rainwater taken from a puddle located in the parking lot adjacent to Whitmore Laboratory, University Park, PA [12]. Another sample was taken from tap water run through a Brita water filtration pitcher using the tap water from Porter Hall, University Park, PA [9]. Another sample was taken from an Aquafina water bottle [10]. The last example was taken from a Fiji water bottle [7].

Knowing that the hardness of water is a result of dissolved calcium and magnesium cations in water, I could then hypothesize the hardness of the four samples based on this information [18]. I hypothesized that the Aquafina water would be the softest because it goes through a seven step filtration system to remove every impurity in the water, according to Aquafina's website [www.aquafina.com](http://www.aquafina.com) [1]. Therefore, I expect there to be little to no calcium and magnesium cations present in the sample. I believe this will make the sample the least hard.

I expected the Fiji water to be the hardest since its only main filtration is through mineral-rich rocks, such as the volcanic rocks located in Viti Levu, part of the Fiji Islands, according to Fiji's website [fijiwater.com](http://fijiwater.com) [5]. The only man-made filtration the water goes through is to remove particle matter and potential pathogens. Therefore there is no attempt to remove any of the calcium or magnesium cations in the water. I expect that the mineral-rich rock sources will leave large traces of calcium and magnesium divalent cations in the water.

Next, I expected the Brita water filtration system using tap water from Porter Hall to be moderately harder than the Aquafina water but softer than the Fiji water. I expected there to be traces of calcium and magnesium cations in the water because even though the water source has been treated and filtered at the city water facility and run through a softening Brita filtration pitcher [4]. This would make sense since that there would still be large traces of ions since Pennsylvania water is among the hardest in the nation, around 120-350 ppm hardness, according to the Water Encyclopedia [13]. The water also has to travel through many pipes which will cause the water to pick up even more divalent cations, such as calcium and magnesium. Even though the Brita water is filtered through ion exchange, I predicted that not all calcium and magnesium will be removed.

Lastly, I expected the puddle rainwater from the parking lot adjacent to Whitmore Laboratory, University Park, PA to be harder than the Aquafina water sample, but softer than the Brita sample. Even though rainwater occurs naturally soft, I expected the puddle water to pick up traces of hardness through its short-term contact with potential sedimentary rock sources [15].

In summary my hypothesis is that, the bottle Aquafina water should be the least hard, followed by the puddle rainwater being slightly hard, the tap water from the Brita filter to be moderately hard, and the Fiji water to be the hardest.

### **Procedure:**

The complete and detailed procedure of “The Chemistry of Natural Water” experiment can be found in Penn State’s Version of Chemtrek [15].

In order to observe the total dissolved solids in our water sample, we placed a drop of distilled water, a drop of the water sample, and a drop of  $1 \times 10^{-3}$  moles of  $\text{CaCl}_2$  solution side by side a small

piece of aluminum foil. We then heated the foil so the water drops could evaporate on it and observe the total dissolved solids it left behind.

To find the amount of divalent cations by EDTA titration, there were two parts to the experiment we had to do. EDTA titration uses a “serial” titration method to find the ending point for the EDTA. For the first part of the EDTA titration we added one drop of eriochrome black T (EBT), the indicator, with one drop of  $\text{NH}_3/\text{NH}_4\text{Cl}$  buffer and one drop of  $1 \times 10^{-3}$  moles of  $\text{MgSO}_4$  solution to each well of a 1x12 well strip. This solution was then titrated with EDTA solution in a “serial” method, meaning adding one drop in the first well, two in the second and so on, all the way town to the 12<sup>th</sup> well. The first well that turned blue is the point where it had excess EDTA, which is the endpoint. That well number corresponds to the number of EDTA drops that were used. This number was then recorded and will be used for future calculations to obtain the amount of  $\text{Ca}^{2+}$  concentration in the water sample. The next part of this EDTA process was repeated again, but this time instead of adding one drop of  $1 \times 10^{-3}$  moles of  $\text{MgSO}_4$ , one drop of  $1 \times 10^{-3}$  moles of  $\text{CaCl}_2$  was added to each well and the results recorded. We then did the same serial titration with our water sample instead of using the  $1 \times 10^{-3}$  moles of  $\text{CaCl}_2$  and  $\text{MgSO}_4$  solutions. The rainwater from a puddle had to be diluted to observe a color change. The EDTA titration method showed us the amount of hardness in the water including the calcium and magnesium [15].

We then determined our water sample’s water hardness by using the Atomic Absorption Spectroscopy. Before using this complex instrument, we had to fill two large pipets, one which was used for finding the concentration of calcium and the other one for finding the concentration of magnesium. The rainwater taken from a puddle, however, had to be diluted once since it was too hard for the machine to read. We then proceeded to insert the aspirator tube from the AA fitted with the calcium hollow cathode lamp into one of the pipets and did the same procedure with the AA fitted with the

hollow magnesium cathode lamp and the other pipet. After several seconds, the absorbance of both, calcium and magnesium, in our water samples was shown on the screen, which we recorded for further calculation in this section.

We experimented the softening of the water samples by adding a commercial water conditioning agent and tested the hardness using the EDTA titration method. We mixed a small amount of the water sample and commercial conditioning product in a vial and stirred it for a while. We then titrated “serially” once again to test the hardness of this solution. After obtaining the hardness for the treated water sample, we compared it with the results from the untreated water sample where there was no softening agent.

Divalent cation removal by ion exchange was another method used as a softening process. This was completed by mixing a sample of our water with the cation exchange resin in a vial. After stirring it, the solution was taken out with a pipet and it was used to test the pH by using a piece of pH paper. The soften sample was then again tested through EDTA titration and results were compared to that of the untreated sample.

**Results:**

Table 1: Error for Ca<sup>2+</sup> using AA

<i>Ca Conc ppm</i>	<i>Check Standard ppm</i>	<i>Error ppm</i>	<i>% Error</i>
1	0.87	0.13	15%
5	4.78	0.22	4.40%
10	10.12	0.12	1.20%
25	24.54	0.46	1.80%
50	49.15	0.85	1.70%

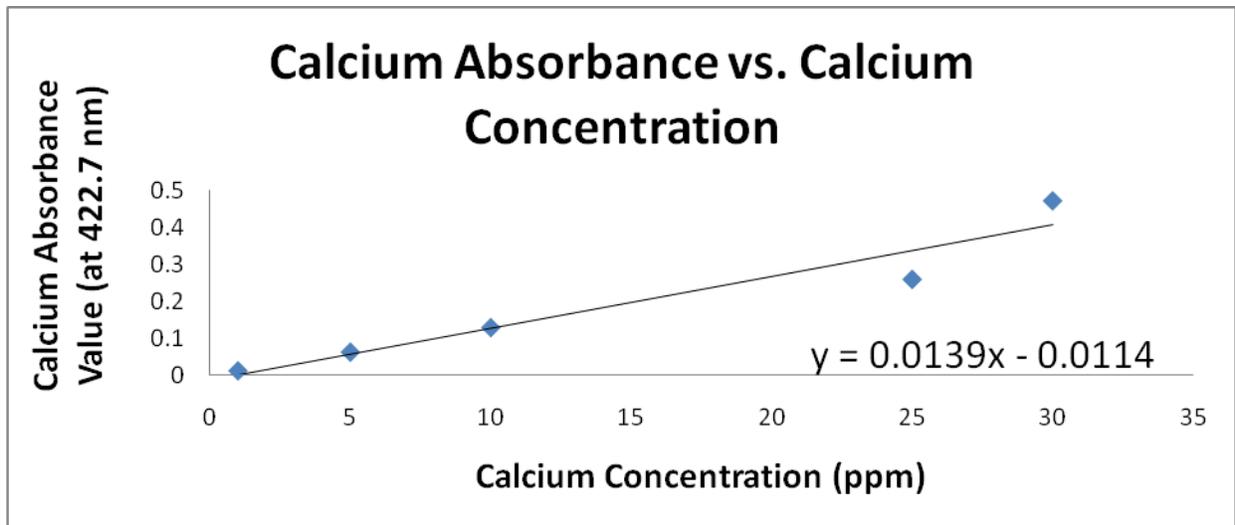
Table 2: Error for Mg<sup>2+</sup> using AA

<i>Mg Conc ppm</i>	<i>Check Standard ppm</i>	<i>Error ppm</i>	<i>% Error</i>
1	1.21	0.21	21%
5	4.86	0.14	2.80%
10	9.7	0.3	3%
25	24.9	0.1	4%
30	29.93	0.07	2.30%

Table 3: AA calibration values obtained (see graphs 2 and 3)

<i>(ppm)</i>	<i>422.7 nm</i>	<i>(ppm)</i>	<i>202.5 nm</i>
1	0.01203	1	0.03622
5	0.06228	5	0.14125
10	0.12872	10	0.2597
25	0.25874	25	0.57663
50	0.47084	30	0.67684

Graph 2: absorption vs. Concentration of Ca<sup>2+</sup>



Graph 2: Absorption vs. Concentration of Mg<sup>2+</sup>

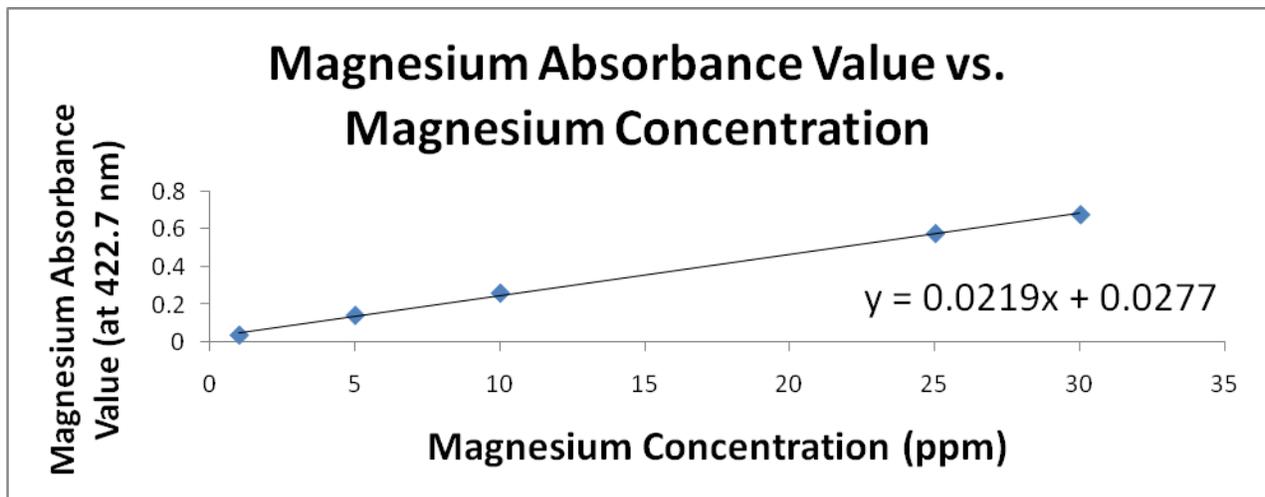


Table 4: AA absorbance and hardness values

<i>Water Sample</i>	<i>Absorbance Value for Ca</i>	<i>Absorbance Value for Mg</i>	<i>(ppm)</i>	<i>(grains/gallons)</i>
<i>Bottled Aquafina water</i>	0.0013	-0.0001	>1	>1
<i>Bottled Fiji water</i>	0.0319	0.1788	36.18	2.12
<i>Tap water from a Brita Water Filter</i>	0.3791	0.5349	165.54	9.68

<i>Rainwater from a puddle</i>	<i>0.3892</i>	<i>0.2275</i>	<i>219.19</i>	<i>12.81</i>
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Sample Calculation of Ca<sup>2+</sup> and Mg<sup>2+</sup> hardness (ppm) determined by AA:

Ca<sup>2+</sup> Absorbance Value: 0.3791.

This absorbance value approximately equals 28.09 ppm, calculated by using equation  $y = 0.0139x - 0.0114$  plug 0.3791 in for y value and solve for x (see graph 1).

$$28.09 \text{ ppm Ca}^{2+} * (100\text{g CaCO}_3 / 1 \text{ mole}) * (1 \text{ mole} / 40\text{g Ca}^{2+}) =$$

$$70.23 \text{ ppm hardness of Ca}^{2+}$$

Mg<sup>2+</sup> Absorbance Value: 0.5349.

This absorbance value approximately equals 23.16 ppm, calculated by using equation  $y = 0.0219x + 0.0277$  plug 0.5349 in for y value and solve for x (see graph 3 in the Appendix).

$$23.16 \text{ ppm Mg}^{2+} * (100\text{g CaCO}_3 / 1 \text{ mole}) * (1 \text{ mole} / 24.3\text{g Mg}^{2+}) =$$

$$95.31 \text{ ppm hardness of Mg}^{2+}$$

Total Hardness = (ppm hardness of Ca<sup>2+</sup>) + (ppm hardness of Mg<sup>2+</sup>)

$$(70.23 \text{ ppm}) + (95.31 \text{ ppm}) = 165.54 \text{ ppm of total hardness}$$

Table 5: Raw data used to determine water hardness through EDTA titration

<i>Sample</i>	<i>Drops of EDTA</i>	<i>Drops of sample</i>	<i>Diluted</i>
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<i>Bottled Aquafina water</i>	<i>5</i>	<i>2</i>	<i>none</i>
<i>Bottled Fiji water</i>	<i>5</i>	<i>1</i>	<i>none</i>
<i>Tap water from a Brita Water Filter</i>	<i>7</i>	<i>1</i>	<i>none</i>
<i>Rainwater from a puddle</i>	<i>11</i>	<i>1</i>	<i>once</i>

Table 6: Water hardness calculated using EDTA

<i>Water Sample</i>	<i>(ppm)</i>	<i>(grains/gallon)</i>
<i>Bottled Aquafina water</i>	50	2.92
<i>Bottled Fiji water</i>	100	5.85
<i>Tap water from a Brita Water Filter</i>	220	12.87
<i>Rainwater from a puddle</i>	280	16.4

Sample Calculation for Hardness (ppm):

$$M_{\text{EDTA}}V_{\text{EDTA}} = M_1V_1$$

$$(2.00 \times 10^{-4} \text{ M}) * (11 \text{ drops}) = (x) * (1 \text{ drop})$$

$$X = 2.2 \times 10^{-3} \text{ M CaCo}_3$$

$$(0.0022 \text{ M CaCo}_3 / 1 \text{ liter}) * (100\text{g CaCo}_3 / 1 \text{ mol CaCo}_3) * (1000\text{mg CaCo}_3 / 1\text{g CaCo}_3) = 220$$

ppm of hardness

Sample Calculation for Grains per Gallon:

$$(220 \text{ ppm hardness}) * (1 \text{ grain per gallon} / 17.1 \text{ ppm}) = 12.87 \text{ grains per gallon}$$

Total Dissolved Solids (TDS)

Table 7: TDS observations

<b><i>Sample</i></b>	<b><i>Observations</i></b>
<i>A. Distilled Water</i>	<i>No residue</i>
<i>B. <math>1 \times 10^{-3} \text{ M Ca}^{2+}</math> (reference)</i>	<i>Faint ring</i>
<i>C. Bottled Aquafina water</i>	<i>Faint ring compared to reference</i>
<i>D. Bottled Fiji water</i>	<i>Heavy compared to reference</i>
<i>E. Tap water from a Brita Water Filter</i>	<i>Very heavy compared to reference</i>
<i>F. Rainwater from a puddle</i>	<i>Very heavy compared to</i>

*reference*

Water softening with a commercial water conditioning agent

Table 8: Water samples soften with commercial water conditioning agent results

<i>Water sample</i>	<i>(ppm)</i>	<i>(grains/gallon)</i>
<i>Bottle Aquafina water</i>	<i>n/a (too soft to soften)</i>	
<i>Bottled Fiji water</i>	<i>80</i>	<i>4.68</i>
<i>Tap water from a Brita Water Filter</i>	<i>180</i>	<i>10.52</i>
<i>Rainwater from a puddle</i>	<i>200</i>	<i>11.69</i>

Water softening through divalent cation exchange

Table 9: Water samples soften through divalent cation exchange

<i>Water Sample</i>	<i>(ppm)</i>	<i>(grains/gallon)</i>
<i>Bottled Aquafina water</i>	<i>n/a (too soft to soften)</i>	
<i>Bottled Fiji water</i>	<i>20</i>	<i>1.17</i>
<i>Tap water from a Brita Water Filter</i>	<i>20</i>	<i>1.17</i>
<i>Rainwater form a puddle</i>	<i>40</i>	<i>2.34</i>

## **Discussion:**

The rainwater sample from a puddle located in the parking lot adjacent to Whitmore Laboratory, University Park, PA resulted in being the hardest of all four water samples. It had a hardness of 219.19 ppm calculated using atomic absorption [12]. This was different from my hypothesis because I expected the water to be much softer since rainwater occurs naturally soft. This high level of hardness could be due to several factors. A combination of various run-off waters, that had a high concentration of calcium and magnesium, could have contributed to the overall hardness of the sample. Another factor is that the rainwater, in the short time from when it precipitated and when it was collected, could have passed through sedimentary rock sources releasing calcium and magnesium into the water [18]. It is hard to determine the exact what the exact source of where the traces of water hardness could have came from.

The next hardest sample was the tap water run through a Brita water filtration pitcher using the tap water from Porter Hall, University Park, PA. The total hardness of the sample was 165.54 ppm calculated using atomic absorption [9]. I expected the water to contain traces of hardness because the hardness of the tap water around this area is approximately 208 ppm, according to the Water Encyclopedia [13]. Since the filtration system uses cation ion exchange, we can then infer that not every calcium and magnesium cation is exchanged with the monovalent cations in the resin [14]. Only some of the divalent cations are exchange, causing the water to be softer than its original hardness from the tap, but still maintain a high enough concentration of 165.54 ppm to be categorized as hard, between 120-180 ppm, according to the NebGuide classification of water hardness [14]. This makes sense since the original tap water being filtered could have been possibly very hard, approximately greater than 200 ppm. Through ion exchange the hardness of the water was able to be reduced by approximately 20% , from very hard to hard [14]. Other factors that could have affected the hardness were such that the

water from the tap being filtered through the Brita filter had to travel through many pipes, picking up minerals found within the pipe [18].

The bottled Fiji water was found to be the third hardest sample. Its hardness was 38.18 ppm calculated using atomic absorption [7]. This was a much different result than expected. The Fiji water comes from an artesian well after the water has trickled through volcanic rocks, picking up minerals along the way [5]. The only other filtration the water goes through is cleaning the water of debris or harmful bacteria and other such pathogens [5]. The volcanic rock that the water is filtered through, however, must not be a high sedimentary source containing large concentrations of calcium or magnesium. We can infer this because if the rock source did contain high concentrations of such metals the water would be much harder. Since the water contained low concentration of calcium and magnesium, we can therefore infer that the rock sources the water came into contact with only had a few traces of calcium or magnesium resulting in a low concentration of hardness in the water.

Finally, the bottled Aquafina water was the least hard of the samples. The hardness was less than 1 ppm calculated using atomic absorption [10]. It was expected that this would be the softest sample because it has been cleaned and purified to a greater extent than the other water samples resulting in the lowest level of hardness. The water goes through an intensive 7 step filtration system. The most important step in this system, in relation to removing calcium and magnesium metals, is the reverse osmosis step. In this step every metal is removed completely and left behind, leaving the purist form of water [1]. According to Aquafina's website, found at [www.Aquafina.com](http://www.Aquafina.com), Aquafina's purification system is designed to remove trace compounds such as carbonates, bicarbonates, calcium, and magnesium to name a few [1]. This would directly explain why this extensive purification system would result in such a low level of hardness.

With any preformed experiment there is always some chance for experimental error. For this specific lab, some of the data taken was qualitative. When performing the EDTA titration, one person may see one color, while another sees a different color in the same solution. The drops squeezed from the pipets are another reason why human error might have affected the results. Each drop might have a different volume. If more liquid came out in one drop than another, then the calculations could alter, which could change the entire results. Overall, the experimental error was limited and did not affect the overall outcome of this experiment.

When comparing the two methods, AA (Atomic Absorption Spectrophotometry) and EDTA Titration used to determine the hardness in all four water sample we notice some variances between the results. For example, the sample taken from the rainwater had an AA hardness of 219.19 and an EDTA hardness of 280 [12].

The differences between the two methods may be accounted to the fact that EDTA takes into account any polyvalent 2+ cations present in the water, while AA does not. The AA is element specific. This would naturally make the value of hardness for EDTA Titration higher and the value for hardness for AA smaller. Also, experimental error may come into play. If there was a mistake in recording or interpreting which well the solution changes color during EDTA Titration the results would drastically change by approximately 10% for each well you are off [12].

There are advantages and disadvantages in both methods. Some advantages of using EDTA, however, are that it is much less expensive than determining water hardness through expensive machinery such as the AA. Its disadvantages are that it is not as accurate as AA for determining true water hardness. When testing for hardness, the endpoint will always be higher than the actual endpoint may be. In fact the true hardness of the water could have been, in fact, in between the wells. Some disadvantages of using AA, are that it is very expensive to buy the machinery and the lamps that are

needed. The lamps also need to be replaced often since they do not last very long, adding to the overall cost. The AA also uses a tremendous amount of power to operate as well. Some advantages of the AA are that it is element specific, the machine can be calibrated to what is being found, it is extremely fast, and has great accuracy [15].

The water that was treated with commercial water softener was found to be softer than the untreated water. For example the untreated water from the sample of rainwater from a puddle was water had a hardness of 219.19 ppm, while the water treated with a commercial water conditioning agent had a hardness of 200 ppm. When the rainwater softened through ion exchange it had a significant difference of 40 ppm [12].

The change in hardness of untreated to treated water is a significant difference. The commercial water softening agent reduced the water's hardness by replacing the calcium and magnesium ions with sodium ions, which were originally present in the agent as sodium bicarbonate [2]. Sodium ions do not add to the water's hardness value, therefore the water becomes softer. In the case of the ion exchange the water sample was treated with a cation exchange resin that contained  $H^+$  ions. We could tell this because when the treated water was tested with a pH paper, the paper turned red, which represented that the water had become acidic and therefore the presence of  $H^+$  ions. The exchange resin is a polymer containing numerous negatively charged  $SO_3^{2-}$  functional groups that have  $H^+$  ions attached. The exchange resin works is by exchanging the divalent cations ( $Ca^{+}$ ,  $Mg^{2+}$ ) in the water with monovalent cations ( $H^+$ ). Because the pH paper turned red the hydrogen ion replaced the polyvalent cations in the water [15].

**Conclusion:**

Based on the results obtained the rainwater taken from a puddle located in the parking lot adjacent to the Whitmore Laboratory, University Park, Pa turned out to be the hardest of the water samples. The second hardest sample was the tap water from Porter Hall, University Park, Pa filtered through a Brita filtration pitcher. The bottled Fiji water was the third hardest, follows by the bottled Aquafina water being the least hard. Through my results my hypothesis was proven wrong.

**Resources:**

- 1) Aquafina, <<http://www.aquafina.com/>> (accessed November 5, 2008).
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