

Investigating the Effect of Temperature on the Temporary Hardness of Tap Water

Introduction

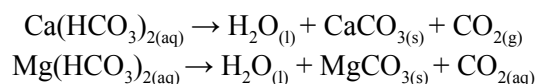
Growing up, I had many issues with acne. As a result of this, I had to pay extra attention to my skin and how certain products could harm it. After a while, I started to notice how different qualities of water in different regions in my city caused skin irritation. After a quick research I found out that ions in water such as calcium and chloride could affect the dissolvability of water and therefore making it harder for the water to dissolve soap and other surfactants, leading to skin pores becoming clogged.

The concentration of dissolved ions in water results in the determination of water hardness. The hardness of water is expressed as milligrams of calcium carbonate per liter (ppm), CaCO₃ mg/L, and is primarily caused by cations such as Ca²⁺ and Mg²⁺ (World Health Organisation [WHO], 2011). The classification of hardness determined by its CaCO₃ mg/L concentration, based on the WHO's standards, can be seen in Table 1. The unit of calcium ion concentration is expressed in ppm since the amount of Ca²⁺ in water is very small.

Classification of Hardness	CaCO ₃ as mg/L or ppm
Soft	0-60 ppm
Moderately hard	60-120 ppm
Hard	120-180 ppm
Very hard	>180

Table 1: Classification of water hardness

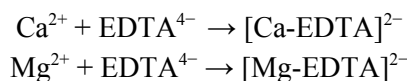
The total hardness of water can be determined by concentrations of Mg²⁺ and Ca²⁺ salts present in water. The hardness of water could be classified in terms of permanent and temporary hardness. Permanent hardness is caused by anions, sulfate, and chloride, of magnesium and calcium which cannot be removed or precipitated by supplying heat therefore, the only way of softening the water is to use a chemical agent which replaces these ions in water. The temporary hardness can be determined by precipitation of Mg²⁺ and Ca²⁺ ions through heating. Temporary hardness can only be removed if mineral carbonation takes place as a result of an endothermic reaction between carbon dioxide gas and metal oxides between 25°C and 95°C, which influences the thermal stability of the complex (Ahn et al. 2018, 8). Temporary hardness is removed by heating water as it is associated with the thermal decomposition of magnesium and/or calcium hydrogencarbonates, which form insoluble carbonate, or limescale precipitates resulting from the heat supply. . These precipitation reactions expressed below are a result of this method of removal:



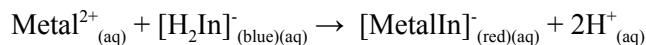
Preliminary titration was conducted to determine the hardness of the tap water used in the school lab to ensure that the results obtained were based on the water hardness in this region. Although there were pre-existing water quality reports from the Istanbul Water and Sewerage Administration (İSKİ), these reports were made to study the quality of water in the water treatment plants outlets, therefore, they did not take into consideration the quality of water in regions where the water is distributed to. The water samples were titrated against EDTA with the Erichromeblack-T indicator to compare to tap water results in order to estimate the initial water hardness in the tap water used in the school laboratory. This experimental method is called complexometric titration in which a titrant containing a complexing agent that interacts with a metal ion determines the end point of a titration, electrochemically or with an indicator (Oxford University Press, 2006).

Ethylenediaminetetraacetic acid (EDTA), is used for complexometric titration as colorless EDTA complexes metal ions with a 1:1 ratio. In this experiment it will be assumed that all the hardness is resulted from Ca²⁺ ion concentration and Mg²⁺ concentration will not be considered, however, since the stoichiometric relationship between Mg²⁺ and EDTA is identical with Ca²⁺ and EDTA therefore it will not affect the calculations. Water

hardness is a result of Ca^{2+} and Mg^{2+} ions in water and when titrated against EDTA they form the following reactions:



Erichromeblack-T, EBT, is an indicator used in complexometric titration to determine the color change from red to blue. When EBT is added to the solution, it reacts with the metal ions, Ca^{2+} and Mg^{2+} , forming a red complex ion shown below:



When excess EDTA is added to the solution, it displaces the indicator which formed a complex with the metal ions since it is a stronger agent as well as more stable. For this reaction to occur, the solution needs to have a pH range of 7-11, hence an ammonium buffer with a pH range of 10-11 is used (University of Canterbury, n.d.). As a result, the color changes from red to blue determining the end-point:

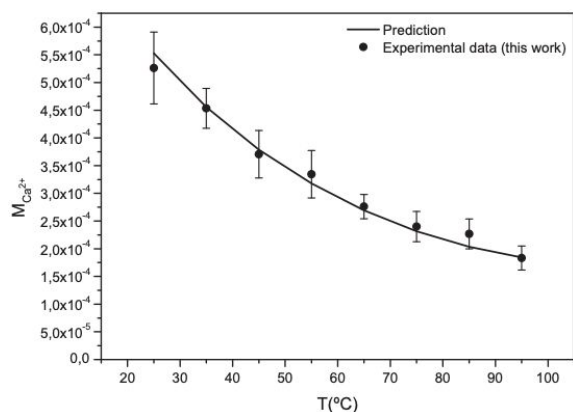
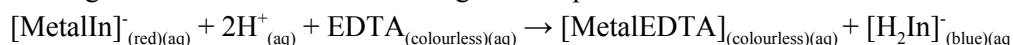


Fig 1: Influence of the temperature on CaCO_3 solubility

The purpose of this investigation was to determine the effect temperature had on the temporary hardness of tap water we use in our region, using complexometric titration. There is a negative correlation between the solubility of CaCO_3 (mol/L) and the supply of temperature ($^{\circ}\text{C}$), as seen in Fig. 1 (Coto et al. 2012, 5). This supports the hypothesis of the investigation which is that as the temperature of tap water is increased, the temporary hardness of tap water decreases however, there is an extent of this decrease in hardness. After a certain temperature Ca^{2+} ion concentration will remain the same and this is the permanent hardness of water.

Research Question

How does temperature (25.0°C , 35.0°C , 45.0°C , 55.0°C , 65.0°C) affect the hardness of tap water (CaCO_3 mg/L) determined by complexometric titration method?

Variables

Independent Variable: Temperature of tap water ($\pm 0.5^{\circ}\text{C}$)	When the probe reads 25.0 , 35.0 , 45.0 , 55.0 and 65.0°C the water sample will be taken out using a $50.0 \pm 0.2 \text{ cm}^3$ graduated pipette and put into separate beakers to cool down until they reach room temperature.
Dependent Variable: Hardness of tap water (ppm)	The hardness of water will be determined by complexometric titration with EDTA. Water samples will be taken out using a $50.0 \pm 0.2 \text{ cm}^3$ graduated pipette and poured into a 250 cm^3 Erlenmeyer flask; EBT and ammonium buffer will be added to the sample and titrated against 0.005M EDTA.

Controlled Variables	How is it controlled?	Significance
Volume of water sample ($20.0 \pm 0.2 \text{ cm}^3$)	A $50.0 \pm 0.2 \text{ cm}^3$ graduated pipette is used to measure out $20.0 \pm 0.2 \text{ cm}^3$ of water sample for each trial.	Differing water volumes may alter the accuracy of the results when comparing as there are more/fewer calcium ions present.
Concentration of EDTA solution ($0.005 \text{ mol dm}^{-3}$)	A stock solution of 0.005 M EDTA is prepared and kept in a volumetric flask and used for each trial.	The concentration of EDTA needs to be known in order to carry out calculations. Different concentrations might be more diluted or concentrated, influencing the complexes formed thus the end-point.
Source of tap water	A sample is taken from the school laboratories tap water and poured into a beaker to use.	The quality of the water changes when taken from different regions as they are distributed from a different plant, the calcium content might differ.
Volume of EBT indicator (1-2 drops)	The indicator is prepared and poured into a 100 cm^3 beaker. Using a graduated plastic pipette, 1-2 drops are added to the sample.	Given the sample being colorless, adding more EBT would make its color very dark, making it harder to see the end-point thus affecting the accuracy of the results.
Volume of Ammonium buffer ($1.0 \pm 0.5 \text{ cm}^3$)	Ammonium buffer was prepared as stock and poured into a volumetric flask. $1.0 \pm 0.5 \text{ cm}^3$ buffer was measured using a $10.0 \pm 0.5 \text{ cm}^3$ measuring cylinder and added to the sample.	A Buffer is required for the sample to have a pH of 10-11 to show color, if added too much the sample might become too concentrated, thus affecting the visibility of the color-change.
Room temperature (25.0°C)	All trials were conducted in the same laboratory and all external sources of heat were insulated. The room temperature was approximately 25.0°C .	All the heated samples should be left in the laboratory to reach room temperature before titrations.
Apparatus used	The materials used were washed with distilled water thoroughly before each trial.	Each apparatus has a different set of values and uncertainties, using the same equipment allows uncertainty to be constant.

Materials and Chemicals

1. Digital Instruments

- 400W Hot Plate
- "Vernier" Temperature Probe ($\pm 0.5 \text{ cm}$)
- Analytical Scale ($\pm 0.001 \text{ cm}^3$)
- Magnetic Stirrer
- C7 Stir Bar

2. Glassware and other materials used for measuring

Name	Size	Absolute Uncertainty	Number
Volumetric flask	1000cm ³	$\pm 6.0 \times 10^{-7}$	2
	100.0cm ³	$\pm 0.1\text{cm}^3$	1
Graduated pipette	50.0cm ³	$\pm 0.2\text{cm}^3$	1
Burette	50.00cm ³	$\pm 0.05\text{cm}^3$	1
Measuring cylinder	10.0cm ³	$\pm 0.5\text{cm}^3$	1
	100.0cm ³	$\pm 0.1\text{cm}^3$	1
Pasteur pipette	3.0cm ³	$\pm 0.1\text{cm}^3$	1
Beaker	900cm ³	-	1
	150cm ³	-	6
	100cm ³	-	1
Erlenmeyer flask	125cm ³	-	1
Glass funnel	-	-	1
Weighing boat	-	-	1
Ring stand with clamp	-	-	1
Spatula	-	-	1
Thermometer	-	$\pm 0.1^\circ\text{C}$	-

3. Chemicals

Name of Chemical	Amount ($\pm 0.001\text{g}$)	Concentration	Volume of Solution Prepared
Calcium Nitrate <chem>Ca(NO3)2</chem>	0.180	-	1dm ³
Disodium EDTA	-	0.005 mol/dm ³	1dm ³
Ammonium Chloride <chem>NH4Cl</chem>	6.755	-	-
Ammonia <chem>NH3</chem>	-	-	57cm ³
Erichromeblack-T indicator	0.504	-	-
Ethanol	-	95% (v/v)	50cm ³

Safety, Environmental and Ethical Precautions

Throughout the experiment appropriate safety measurements should be taken into consideration. Heating the water samples on a hot plate should be done carefully to avoid burns. The hot plate should be kept away from the edge of the table and heat resistant apparatus should be used. In case of burn, the burnt area should be cooled with lukewarm water for 20 minutes (NHS). Glassware should be handled carefully to avoid injuries due to broken glass. Medical attention should be called immediately to avoid infections and the pieces of glass should be cleaned using a broom. Dispose of all chemicals and solutions should be done by pouring them into the chemical waste bin. Chemicals are toxic to aquatic life and hazardous to the environment therefore pouring them down the drain should be avoided as the wastewater reaches natural systems harming the ecological balance (MSDS). There were no significant ethical concerns regarding the experiment.

- **EDTA** is harmful if inhaled, could cause mild irritation, and damage internal organs through repeated exposure. Wear eye protection, lab coat, gloves, and carry out the experiment in a ventilated area. Rinse the region of exposure with water for 15mins and get medical attention (MSDS).
- **Calcium nitrate** is harmful if swallowed. Wear eye protection, gloves and a lab coat. Rinse the region of exposure with water for 15mins and get medical attention if irritation continues or if it is swallowed (MSDS).
- **Ethanol** is highly inflammable and causes serious skin irritation and damage to internal organs if swallowed. Wear eye protection, gloves and a lab coat when handling the chemical, keep away from heat sources, avoid inhaling and keep the lab ventilated. Rinse the exposed region with water for 15 mins and call medical attention if irritation continues (MSDS).
- **Erichromeblack-T indicator** causes eye, skin, and respiratory tract irritation. Rinse the exposed region with water for 15mins, drink 2-4 cups of water if ingested, get medical attention (MSDS).
- **Ammonium Buffer**, $\text{NH}_3 \cdot \text{NH}_4\text{Cl}$, is corrosive and causes serious skin burns. Wear eye protection, gloves, a lab coat, and avoid inhaling the chemical. Mix liquid NH_3 with solid NH_4Cl in a ventilated fume cupboard to avoid inhaling toxic fumes. If on skin or eyes, rinse the region with water for several minutes and remove any contaminated clothing. Immediately call medical attention if symptoms are severe (MSDS).

Method

Preliminary experiment

While deciding the range of the standard $\text{Ca}(\text{NO}_3)_2$ solution, ISKĪ October 2019 Water Quality Report was used. The water hardness was reported to have an approximate range between 120ppm and 170ppm. This range was stimulated in the experiment by titrating the $\text{Ca}(\text{NO}_3)_2$ solutions against EDTA. 0.1, 0.01 and 0.05M varying concentrations of EDTA solutions used against tap water, all of which showed a very rapid color change therefore were deemed unfit for the experiment as they were too concentrated. When 0.005M EDTA was used it was easier to detect the end point, therefore this concentration was chosen.

Part I: Preparation of standard solution of water samples for varying calcium nitrate concentrations.

1. According to the ISKĪ water quality report, the lowest water hardness value recorded was 122ppm and the highest water hardness value was 168ppm for tap water distributed (ISKĪ, 2019). Therefore, 4 different hardness values were stimulated to represent a range in which the actual hardness of water was predicted to be in, using a 180ppm stock solution.
2. $0.180 \pm 0.001\text{g}$ of hydrated $\text{Ca}(\text{NO}_3)_2$ was measured using a weighing boat on an electronic scale and transferred into a 1dm^3 volumetric flask. The volumetric flask was filled with distilled water until it reached the 1dm^3 line.
3. Using the equations $\text{moles } (n) = \frac{\text{mass } (g)}{\text{molar mass } (Mr)}$, $\text{molarity } (M) = \frac{\text{moles } (n)}{\text{volume } (V)}$ and $M_1V_1 = M_2V_2$ the stock solution was diluted into 160, 140 and 120ppm for use in the experiment.
4. $20.0 \pm 0.2\text{cm}^3$ of $\text{Ca}(\text{NO}_3)_2$ sample was measured using a $50.0 \pm 0.2\text{cm}^3$ graduated cylinder and poured it into the 125cm^3 erlenmeyer flask. 2-3 drops of EBT indicator and 1cm^3 of buffer solution was added into the flask using a pasteur pipette and $10.0 \pm 0.5\text{cm}^3$ measuring cylinder, respectively.

- The solutions were titrated against EDTA and the volume of EDTA was recorded when the color changed from wine-red to blue. This procedure was repeated 5 times for each sample.

Part II: Determination of hardness of tap water in the school laboratory.

- 20.0±0.2cm³ of tap water sample from the school laboratory was measured using a 50.0±0.2cm³ graduated cylinder and poured it into the 125cm³ Erlenmeyer Flask. 2-3 drops of EBT indicator and 1cm³ of buffer solution was added into the flask using a pasteur pipette and 10cm³ measuring cylinder, respectively.
- The solutions were titrated against EDTA and the volume of EDTA was recorded when the color changed from wine-red to blue. This procedure was repeated 5 times for each sample.

Part III: Preparation of stock solutions.

- Using the equations $moles (n) = \frac{mass (g)}{molar\ mass (Mr)}$ and $molarity (M) = \frac{moles (n)}{volume (V)}$, 0.005M EDTA, NH₃NH₄Cl buffer and erichromeblack-t indicator was prepared.
- To prepare 0.005M EDTA, 1.461±0.001g of EDTA powder was measured using an electronic scale and poured into a 1dm³ volumetric flask which was filled with distilled water up until the 1dm³ line.
- To prepare 100.0±0.1cm³ of NH₃NH₄Cl buffer, 6.755±0.001g of NH₄Cl powder was measured using an electronic scale and transferred into a 100.0±0.1cm³ beaker. Using a 100.0±0.1cm³ measuring cylinder, 57.0±0.1cm³ of NH₃ solution was measured and poured into the beaker under a fume hood where it was mixed using a magnetic stirrer. The solution was transferred into a 100.0±0.1cm³ volumetric flask and filled gradually with distilled water until it reached the 100cm³ line.
- To prepare the EBT indicator; 0.504±0.001g of powdered EBT was measured using an electronic scale and poured into a 100cm³ beaker where 50.0±0.1cm³ of 95% (v/v) ethanol was added using a 100.0±0.1cm³ measuring cylinder. The indicator solution was then mixed using a magnetic stirrer.

Part IV: Complexometric titration of tap water samples heated to different temperatures against EDTA.

- Attach the clamp to the ring stand. Using the clamp attach the temperature probe and position it so that the sensor records the water temperature when it is being heated by the hot plate (see **Figure 2**).
- Pour 700cm³ tap water from the tap into the 900cm³ beaker and place the beaker on the hot plate.
- When the probe reads the value needed, take out 50.0±0.2cm³ of the sample using a 50.0±0.2cm³ graduated pipette into one of the 150cm³ beakers, label it and let it cool down to room temperature.

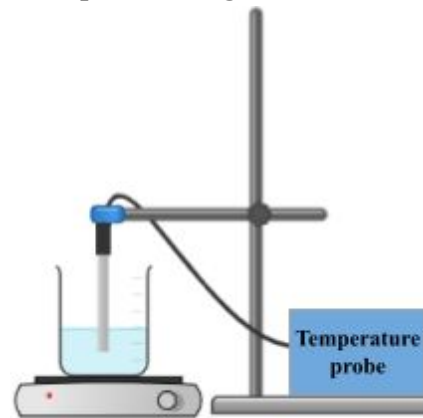


Figure 2: Heating samples

- Repeat this procedure for 25.0, 35.0, 45.0, 55.0 and 65.0 C(±0.5°C).
- Attach a 50.00±0.10cm³ burette to the ring stand using a clamp and place a white tile underneath.
 - Using a 50.0±0.2cm³ graduated pipette, pipette out 20.0±0.2cm³ of the heated water sample into a 125cm³ erlenmeyer flask. Add 1-2 drops of indicator solution and 1.0±0.5cm³ of buffer solution into the flask to establish a basic environment for the color change to occur during titration.
 - Using a glass funnel, pour EDTA into the 50.00±0.10cm³ burette. Make sure that there are no air bubbles inside the burette to avoid random errors.
 - Titrate the water sample against the EDTA solution and record the volume of EDTA when it has turned blue. (The solution reaches the end-point when the color turns blue and stays on for 30 seconds. If the color turns red again, continue the titration until the end-point is reached.)
 - Repeat the experiment five times for each variable. Be sure to clean all the equipment thoroughly with distilled water after each trial and follow the safety protocols during the experiment.

Raw Data and Processing

Data Table 1: Raw data table indicating the initial and final volumes of EDTA obtained following the titration of 4 values of water hardness in all 5 trials for the preliminary work with tap water used in the laboratory.

Water Hardness (ppm) ↓		Trial 1 (±0.10cm ³)	Trial 2 (±0.10cm ³)	Trial 3 (±0.10cm ³)	Trial 4 (±0.10cm ³)	Trial 5 (±0.10cm ³)
180	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	3.70	3.00	3.90	3.80	3.00
160	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	2.40	2.60	2.30	2.40	2.50
140	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	1.60	1.50	1.30	1.40	1.50
120	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	0.90	0.60	0.80	0.90	0.70

Data Table 2: Raw data table indicating the initial and final volumes of EDTA obtained following the titration of 5 different temperature values in all 5 trials with tap water used in the school laboratory.

Water sample temperature (±0.5 °C)		Trial 1 (±0.10cm ³)	Trial 2 (±0.10cm ³)	Trial 3 (±0.10cm ³)	Trial 4 (±0.10cm ³)	Trial 5 (±0.10cm ³)
25.3	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	6.30	6.00	6.00	6.50	6.60
35.2	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	5.60	5.80	5.70	5.10	5.30
45.6	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	3.60	3.50	3.30	3.80	3.40
55.5	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	2.60	2.30	2.50	2.80	2.60
65.7	Initial volume (cm ³)	0.00	0.00	0.00	0.00	0.00
	Final volume (cm ³)	1.10	1.30	1.40	1.30	1.50

Qualitative Data

The qualitative data obtained from the complexometric titration was the color change from wine-red to violet to light blue. All the water samples initially had colourless solutions which turned to a wine-red color when the indicator and buffer were added.

Calculations

Note that calculations, uncertainty propagations and percent errors are only given for 25.3°C as an example. All the calculations were made based on the values from the IB Chemistry Data Booklet.

- The mean titre used in the experiment was calculated using the formula; $mean = \frac{x_1+x_2+x_3+\dots+x_n}{n}$

$$\text{Mean volume of EDTA} = \frac{(6.30+6.00+6.00+6.50+6.60)}{5} \approx 6.28 \text{ cm}^3 \text{ (at } 25.3^\circ\text{C)}$$

- The mean volume of EDTA calculated in cm^3 was converted into dm^3 by the division of the value by 1000.

$$6.28 \text{ cm}^3 \div 1000 = 6.28 \times 10^{-3} \text{ dm}^3$$

Data Table 3: The mean volume of EDTA needed for the color change in each temperature.

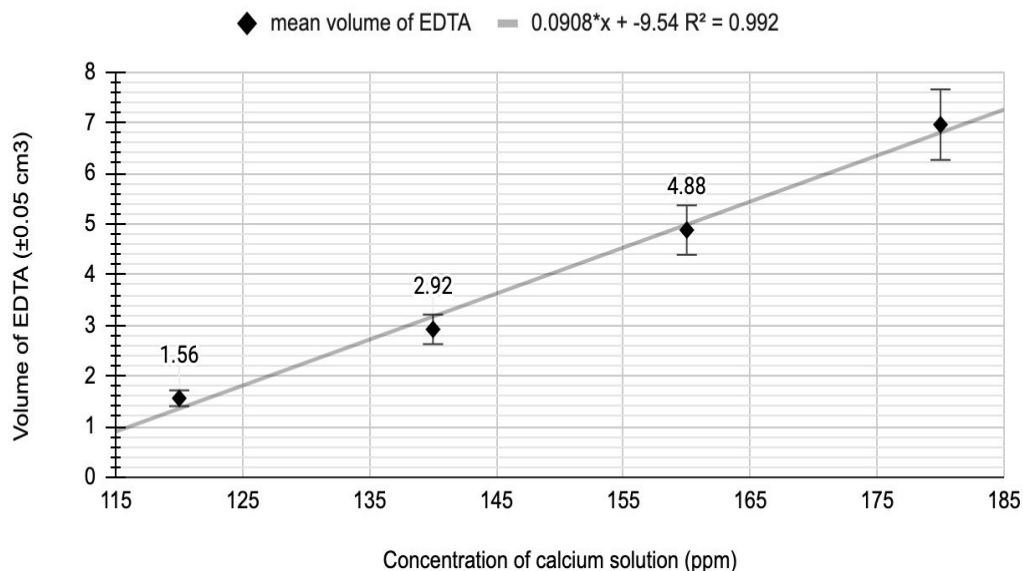
Water sample temperature ($\pm 0.5^\circ\text{C}$)	Mean volume of titre in cm^3 ($\pm 0.10 \text{ cm}^3$) ¹	Mean volume of titre in dm^3 ($\pm 1.0 \times 10^{-4} \text{ dm}^3$)
25.3	6.28	6.28×10^{-3}
35.2	5.50	5.50×10^{-3}
45.6	3.52	3.52×10^{-3}
55.5	2.56	2.56×10^{-3}
65.7	1.32	1.32×10^{-3}

- To determine the unknown hardness of water, a graphical representation of the correlation between water hardness and volume of EDTA used to titrate it was made (see **Graph 1**). From this graph, using the equation $f(x) = mx + b$ the hardness of tap water at room temperature was determined. Since the 25.3°C water sample represents room temperature, the mean value was plugged into the equation.

$$6.28 = 0.0454X + -9.54$$

$X \approx 175.4 \text{ ppm} \rightarrow$ this is the actual hardness of the tap water used in the laboratory

Graph 1: Processed data presenting the calibration curve to determine the ppm of the tap water by comparing the sample with the volume of EDTA used for titration.



¹ The uncertainty $\pm 0.05 \text{ cm}^3$ of the burette was multiplied by 2 as two readings were taken per trial.

Determining the Calcium Content

- The number of moles of EDTA was calculated; $n = \text{concentration (mol dm}^{-3}) \times \text{volume (dm}^3)$

$$n_{EDTA} = 0.005 \text{ mol dm}^{-3} \times 0.0063 \text{ dm}^3 = 3.15 \times 10^{-5} \text{ mol}$$

- The moles of Ca^{2+} present in 20.0 cm^3 of water sample was calculated; EDTA : Ca^{2+} molar ratio is 1:1

$$n_{EDTA} = n_{\text{Ca}^{2+}} = 3.15 \times 10^{-5} \text{ mol}$$

- The mass of CaCO_3 in 20.0 cm^3 sample was calculated; $\text{mass (g)} = \text{moles (n)} \times \text{molar mass (g} \cdot \text{mol}^{-1})$

The molar ratio between Ca^{2+} : CaCO_3 is 1:1

$$\text{mass}_{\text{CaCO}_3} = 3.15 \times 10^{-5} \times 100.09 \text{ g} \cdot \text{mol}^{-1} \approx 0.00315 \approx 3.15 \times 10^{-3} \text{ g}$$

- The mass of CaCO_3 in grams (g) was converted to mass in milligrams (mg) by multiplying by 1000 and was converted to parts per million; $\text{mg} = \text{parts per million (ppm)}$

$$(3.15 \times 10^{-3}) \times 1000 = 3.15 \text{ mg} = 3.15 \text{ ppm}$$

- The ppm of CaCO_3 in a 20.0 cm^3 water sample was 3.15, the ppm of CaCO_3 in 1000.0 cm^3 was calculated;

$$\frac{3.15 \text{ mg} \times 1000}{20.0 \text{ cm}^3} = 157.5 \text{ ppm}$$

- The temporary hardness removed from the tap water was calculated by subtracting the value found for the hardness of tap water and the hardness of heated water (25.3°C). This value was converted to milligrams to find the mass removed by temporary hardness by using a 1:1 ratio between ppm : mg/L.

$$175.4 - 157.5 = 17.9 \text{ ppm} \quad 17.9 \text{ mg/dm}^3 \text{ was removed}$$

- Finally, the temporary hardness in milligrams removed from the 20.0 cm^3 sample was calculated; at 25.3°C

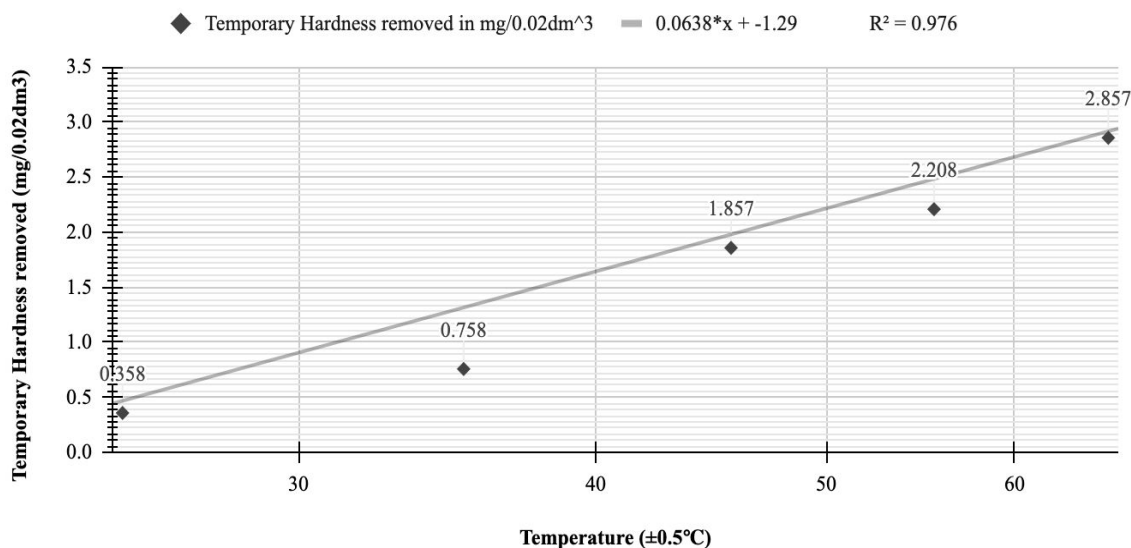
$$\frac{\text{hardness removed (mg/dm}^3) \times \text{volume of sample (dm}^3)}{1} = \text{mass of hardness removed} \quad \frac{17.9 \text{ ppm} \times 0.02 \text{ dm}^3}{1} = 0.358 \text{ mg removed}$$

- Calculations were repeated for all variables. The results could be seen on **Table 4**.

Data Table 4: Processed data of temporary hardness removed from total hardness of tap water ($\text{mg}/0.02 \text{ dm}^3$)

Temperature ($\pm 0.5^\circ\text{C}$)	Temporary Hardness removed ($\text{mg}/0.02 \text{ dm}^3$)
25.3	0.358
35.2	0.758
45.6	1.857
55.5	2.208
65.7	2.857

Graph 2: Processed data presenting the correlation between temperature and temporary hardness removed ($\text{mg}/0.02 \text{ dm}^3$)/($\pm 0.5^\circ\text{C}$).



The graph shows a proportional relation between temperature and removed hardness. The only anomaly that could be observed is the removed hardness value for 35.2°C. Overall there aren't other significant anomalies. This is represented by the large positive R² value (0.976).

Uncertainty Propagation

The formula used to find the percentage uncertainty was; $\% \Delta = \frac{\pm \text{absolute uncertainty}}{\text{measurement read on the apparatus}} \times 100$ and $\Delta = \frac{\text{percentage uncertainty}}{100} \times \text{measurement}$. The uncertainties of the equipment used was given in the material list (see page 4). The total percentage uncertainty was calculated by adding all percentage uncertainties used in finding the temporary hardness of water at 25.3°C.

1. The %Δ of the moles of the EDTA solution were calculated, the molar mass cannot be propagated as there is no uncertainty for molar mass.

$$\Delta n = \frac{1.461 \pm 0.001g}{292.28} = \frac{1.461}{292.28} + \frac{\pm 0.001g}{292.28} \approx 5.00 \times 10^{-3} \pm 3.42 \times 10^{-6} \text{ mol EDTA}$$

2. Then the uncertainty of molarity of EDTA was calculated by adding the %Δ of both values.

$$\Delta M = \frac{5.00 \times 10^{-3} \pm 3.42 \times 10^{-6} \text{ mol}}{1 \text{ dm}^3 \pm 0.0006 \text{ dm}^3} \rightarrow \% \Delta n = \frac{3.42 \times 10^{-6}}{5.00 \times 10^{-3}} \times 100 \approx 0.0684\%$$

$$\% \Delta v = \frac{0.0006}{1} \times 100 = 0.0600\% \rightarrow 5.00 \times 10^{-3} \pm 0.128\% \text{ M EDTA}$$

3. The %Δ of the volume of EDTA solution titrated against 20.0cm³ water sample was calculated.

$$\Delta v = \frac{0.00010}{0.0063} \times 100 = 0.0063 \pm 1.587\% \text{ dm}^3$$

4. The %Δ of the moles of EDTA used in the titration was calculated. Since there is a 1:1 ratio with CaCO₃, the %Δ stays the same. This is the total %Δ reading for 25.3°C water titrated. This was converted to absolute Δ.

$$\Delta n = (\pm 0.128\%) + (\pm 1.587\%) = 3.15 \times 10^{-5} \pm 1.715\% \text{ mol EDTA} \rightarrow 3.15 \times 10^{-5} \pm 1.715\% \text{ mol CaCO}_3$$

$$= \frac{1.715\%}{100} \times (3.15 \times 10^{-5}) = 3.15 \times 10^{-5} \pm 5.4 \times 10^{-7} \text{ mg}$$

Percent Error of the Hardness of Tap Water

According to İSKİ, the water hardness in the area where the experiment was conducted theoretically should have had a hardness of 153ppm however my calculations showed that the actual hardness was 175.4ppm. Therefore the error percentage was found to be; $\frac{\text{actual value} - \text{theoretical value}}{\text{theoretical value}} \times 100 \rightarrow \frac{175.4 - 153}{153} \times 100 = 14.6\%$

Conclusion and Analysis

To conclude, the investigation determined the change in temporary hardness of tap water in 5 temperatures; 25, 35, 45, 55 and 65°C. As seen in the results, it was concluded that as the temperature of the tap water increased, the hardness of water decreased due to the temporary hardness being removed as heat was supplied. The water sample which was taken out at the lowest temperature, 25.3°C, had a hardness of 157.5ppm whereas the sample taken out at the highest temperature, 65.7°C, had a hardness of 32.5ppm showing a decrease in hardness. According to WHO water quality standards mentioned in the introduction, values under 60ppm would be considered soft and values above 120ppm would be considered hard water, hence, showing that throughout the experiment the hardness value became soft from the initial hard water. These results aligned with my initial hypothesis which stated; “as the temperature of tap water is increased, the temporary hardness of tap water decreases whereas the formation of calcium precipitate increases”. These results could be seen more clearly on Graph 2. Another significant finding in the investigation was the actual hardness of tap water calculated by using a hardness range between 120-180ppm. The results showed that the tap water in the lab was hard according to WHO, with a hardness of 175.4ppm fitting between the range, showing an error percentage of 14.6% compared to the theoretical value. From these findings it can be concluded that different regions where water is distributed from the same treatment plant could have differing hardness values, which

proves my initial observation about tap water in different regions affecting my skin differently. Despite the initial hypothesis, it was observed that the calcium concentration in the samples did not remain still after a certain temperature which proves that in order to reach the permanent hardness of water, there should be more heat supplied to the samples.

Evaluation

Strengths: To minimize errors and inaccuracies caused by impurities in the equipment, it was made sure that after each trial the equipment would be cleaned using distilled water. During the entirety of the experiment the same equipment was used to ensure there weren't any changes in uncertainty that could affect the precision of the results. Before conducting the experiment, it was made sure that the right equipment was selected to be used during the experiment, reducing systematic errors. Preliminary experiments were conducted so that the methodology could be adjusted to fit the research question, avoiding any methodological errors that could affect the entirety of the experiment. Each experiment for the independent variables were repeated 5 times to increase the precision of the raw data while also providing enough data to calculate averages for titration. All solutions were made by the experimenter under supervision in a laboratory environment, and used on the same day to ensure all desired concentrations were available and used freshly to prevent decomposition or other external disturbances which could be significant to the data collected. The hardness of tap water used in the lab was calculated by the experimenter to provide an actual value rather than an estimate which was to be used in determining the mass of CaCO_3 removed (temporary hardness) to provide accurate results. When measuring the temperature of water while heating, a temperature probe was used to provide accurate results while also reducing random errors made. Finally, a white marble tile was placed under the flasks so that the color change could be easily observed therefore reducing random errors in titration values.

Limitations: Despite there being 5 trials for each IV, repetition would have resulted in more results which could then be used to calculate more reliable and accurate titre averages, hence strengthening the experiment and conclusion. The hardness of tap water calculated by the experimenter might have resulted in inaccuracies as there weren't any available detailed comparisons specific to the region done by the government or ISKI where the experiment was conducted, hence why the results were based on estimates rather than accurate theoretical values. This would result in a very significant systematic error as the conclusion is based on these estimates. To improve this error, a water hardness test could be purchased and conducted so that the results could be compared to the actual value found by the experimenter and used in the calculations. Another limitation was the underestimation of the temperature values recorded when taking water samples as there was only one experimenter which would have not been able to take samples without any error, considering the time it takes for the experimenter to measure out samples using a pipette. This error could increase the inaccuracies in data drastically as the slightest increase in temperature could result in increase of temporary hardness. This error could be improved by having two experimenters conducting the experiment, where one could monitor the temperature and the other could take out the samples, thus lowering the time it takes to prepare the sample. Finally, when conducting the experiment there were assumptions made regarding the ratio between Mg^{2+} and Ca^{2+} which stated that these variables had a 1:1 ratio. While this ratio is mostly maintained in tap waters, there have been incidences where the geological features of a region could affect the ratio and lead to differences. If the region has a high limestone concentration around where the water is distributed, or inside the pipes where tap water is transported this could result in an increase in calcium content hence changing the ratio between magnesium and calcium (Kohri et al. 1989). To prevent this error, the calcium content in water could be measured using atomic absorption spectroscopy or inductively coupled plasma atomic emission spectroscopy, however, these processes would be expensive for a student investigation therefore a simpler technique using a Ca^{2+} meter could be used. And for the magnesium content in water, an analysis could be performed using a magnesium test and furthermore, proving if there is a 1:1 ratio assumed in the investigation.

Further Investigations: Further research could be conducted regarding the water quality and therefore, hardness, of the Ulus region considering the lack of theoretical values in the investigation. In order to further understanding, more temperature values could have been used to provide evidence that there is a positive correlation that corresponds at high/boiling temperatures as well. Another investigation could be done regarding the effect of temperature on seawater due to the increase in extreme temperatures and climate change, which could have permanent effects on the environment, especially marine life

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