

Standard Level Chemistry Internal Assessment

Temporary Hardness in Hard Water Sample Heated to Different Temperatures

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SCH4U7-3: SL Chemistry

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Introduction

As an active tea and coffee drinker, limescale formed due to heating tap water brings many issues. Not only it affects the taste and releases white flakes in tea and coffee, but limescale also decreases the efficiency and increases the time to reach specific temperatures for kettles and coffee machines by covering the heating coil or bottom and blocking the pipes. Figure 1 shows a picture of limescale formed on the bottom of my kettle after a year of frequent usage. Descaling kit, such as the one for my coffee machine in Figure 2, can effectively dissolve limescale but the cleaning cycles vary with the amount of usage. Thus it is valuable to investigate how limescale is formed and the amount formed under different temperatures to calculate the appropriate cycle to apply descaling solutions for kettle and coffee machines, which is the focus of this investigation.



Figure 1 (Left). Limescale in my kettle.

Figure 2 (Right). Descaling kit for my coffee machine. (Nespresso S.A., n.d.)

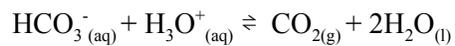
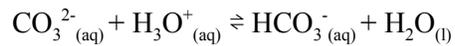
Limescale is formed due to water hardness. Natural soft water such as rain collects polyvalent metallic ions, mostly calcium and magnesium, while passing through sedimentary rocks. Water becomes “hard” due to the increase of metallic ions it contains and the hardness is expressed as milligrams of calcium carbonate equivalent per litre. Water containing calcium carbonate at concentrations below $60 \text{ mg}\cdot\text{L}^{-1}$ is generally considered as soft; $60\text{--}120 \text{ mg}\cdot\text{L}^{-1}$, moderately hard; $120\text{--}180 \text{ mg}\cdot\text{L}^{-1}$, hard; and more than $180 \text{ mg}\cdot\text{L}^{-1}$, very hard. There are two kinds of hardness: carbonate (temporary) and non-carbonate (permanent). (World Health Organization, 2011) After water is heated, some calcium carbonate is deposited and became limescale. The theory about the deposition will be explained in the theory section.

Purposed Question

How does the temporary hardness level in water sample with an original hardness of $180 \text{ mg}\cdot\text{L}^{-1}$ change after being heated to different temperatures?

Theory

Temporary hardness, the hardness associated with carbonate, varies with temperature. The change in hardness is related more to equilibrium than solubility. In a CaCO_3 solution, the following equilibriums are present.



Since temperature increases the equilibrium constant in this endothermic reaction, equilibrium shifts to the right. Therefore, more CO_2 gas escapes from this open system and carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions are removed from the solution. The higher the temperature, the more the equilibrium shifts to the right, the more carbonate and bicarbonate ions are removed. More temporary hardness is removed, and more limescale are formed on the bottom of the beaker. Thus the solubility of CaCO_3 appears to decrease as temperature increases, as shown in Figure 3.

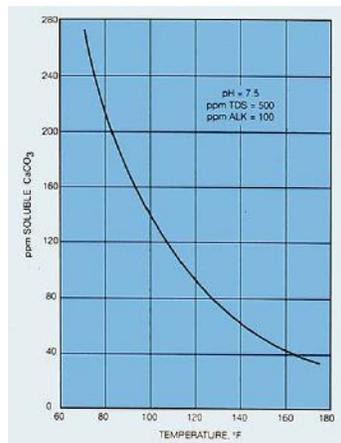


Figure 3. Solubility vs Temperature Graph for CaCO_3 . (SUEZ Water Technologies., n.d.)

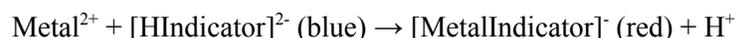
Hypothesis

Based on the theory outlined in the previous section, this investigations hypothesizes as the temperature of hard water increases, the temporary hardness decreases and the percentage of precipitated calcium carbonate or limescale increases.

Experiment Design

To simulate the situation of hard water forming limescale while heated up in coffee machines and kettles, temperatures of 60 °C, 80 °C, 100 °C are chosen as they represent the typical temperature in those appliances. The solution is heated to reach a certain temperature, and then a titration is designed to calculate the total hardness caused by Ca^{2+} . To focus the investigation only on temporary hardness, which changes while heating, a solution of CaCO_3 is prepared rather than directly using tap water. The solution is made of distilled water and $180 \text{ mg}\cdot\text{L}^{-1}$ (the boundary value between hard and very hard indicated by the World Health Organization) of CaCO_3 .

For the titration, eriochrome black T indicator (pH 7-11) is used. Some pH 10 buffer is added to ensure the correct starting pH. The indicator is chosen because it shows intense colour change from blue to red in the presence of metal ions. (Cemeg, 2002)



EDTA is used in the titration to liberate metal ion from the indicator and cause a colour change from red to blue. Ultimately using the volume of EDTA titrated, the total hardness can be calculated.



Additionally, because that permanent hardness is absent in this experiment, the temporary hardness equals the total hardness.

$$\text{temporary hardness} = \text{total hardness} - \text{permanent hardness} = \text{total hardness} - 0 = \text{total hardness}$$

Three trials are performed for each temperature setting and titration is performed to calculate their temporary hardness. Titration is performed right after heating. Note that the temperature drops and affects the equilibrium, so it does not necessarily reflect the hardness under the heated temperature. However, since the time to perform each titration is approximately the same, the trend between trials is still valid.

List of Variables

Table 1 shows the independent and dependent variables investigated in this investigation.

Type	Description
Independent	The temperature that the CaCO_3 solution is heated up to is the independent variable. The designated temperature values will include three settings: 60 °C, 80 °C, 100 °C. These settings demonstrated the typical temperature to make coffee and tea. The solution will be heated in a beaker using a heat bed and thermometer with an uncertainty of $\pm 0.5^\circ\text{C}$ is used to monitor the temperature. Beaker clamp is used to remove the beaker from heat bed to ensure no further heat is absorbed.

Dependent	Hardness level left in the solution after heating will be dependent as explained in the theory section. The CaCO_3 are poured from the beaker to titrate, and there will be some leftover CaCO_3 on the bottom of the beaker forming limescale, a situation similar to a kettle. The concentration of CaCO_3 of the poured out solution is measured using titration and eventually converted into hardness level, $\text{mg CaCO}_3 \cdot \text{L}^{-1}$. The hardness level should vary with temperature heated up to, and it can represent the temporary hardness because in this case, permanent hardness is absent.
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Table 1. The independent and dependent variables.

Controlled Variables

Table 2 shows a list of controlled variables and the importance for them to be controlled. The designs and measures taken to control them are also listed.

Variable controlled	Importance to be controlled	Means of control
Mass of CaCO_3 added	Variations in the mass of CaCO_3 added can affect the concentration of CaCO_3 in solution and hence the starting hardness level.	Use an electronic balance to measure exactly $0.090 \pm 0.001\text{g}$; use a wash bottle to wash any leftover particles on the weighing boat.
Mass of EDTA powder added	Variations in the mass of EDTA powder added can affect the concentration of the EDTA solution and hence the titration results.	Use an electronic balance to measure exactly $0.186\text{g} \pm 0.001\text{g}$; use a wash bottle to wash any leftover particles on the weighing boat.
Moles of CaCO_3 in a beaker	Variations in moles of CaCO_3 in the trial sample can affect the titration results and hence the hardness level.	Rotate the volumetric flask to let any undissolved CaCO_3 particles on the bottom redistribute and dissolve in water.

Volume of CaCO ₃	Evaporations of the water content in CaCO ₃ solution can cause variations in concentration, especially when it is boiled	When the sample solution in beaker reaches 100°C, the beaker is immediately removed.
Temperature being heated to	Variations in temperature heated up can cause minor differences in hardness level for the same group of trials due to its relationship with temperature.	A thermometer is placed and closely monitored. When it reaches the designated temperature, the beaker is immediately taken away.
Time being titrated	Time being titrated can vary and affect the temperature of the solution hence the CaCO ₃ concentration.	Titration is immediately performed after heating and takes approximately the same amount of time.
Volume of EDTA added	Variations in the volume of EDTA added can vary the CaCO ₃ concentration.	The stopcock is turned carefully to allow only drops of EDTA solution to be titrated.
Titration colour change time	In this reaction, the colour change is not permanent. Thus it is essential to have a standard.	Only 10 or more seconds of colour change is considered the end of a titration.
Eriochrome Black T indicator volume	Various amount of indicator can cause the colour to be darker or lighter than anticipated but does not affect the time of colour shift.	Use a 3mL graduated plastic pipette to drop 10 drops slowly and refill it every trial.
pH 10 buffer volume	Variations in pH 10 buffer volume can affect the starting pH of the titration.	Use a 3mL graduated plastic pipette to measure exactly 1 mL of pH 10 buffer twice.

Table 2. The controlled variables and the importance and means of control.

Materials

The lab is conducted in a high school chemistry laboratory under supervision. Table 3 shows the list of apparatus and chemicals used in the experiment.

Apparatus

Hotplate $\pm 1^{\circ}\text{C}$
Thermometer $\pm 0.5^{\circ}\text{C}$
Electronic balance $\pm 0.001\text{g}$
Weighing boat
Glass funnel
50 mL beaker
2 x 140 mL beaker
300 mL beaker
Beaker clamp
250 mL volumetric flask $\pm 0.24\text{ mL}$
500 mL volumetric flask $\pm 0.20\text{ mL}$
2 \times rubber stopper
2 \times 3 mL graduated plastic pipettes $\pm 0.125\text{ mL}$
10 mL pipette $\pm 0.04\text{ mL}$
25 mL pipette $\pm 0.06\text{ mL}$
2 \times wheel pipette pump
2 \times 125 mL Erlenmeyer flask
Seal membrane
50 mL buret $\pm 0.05\text{ mL}$
Titration stand
Distilled water bottle
Whitepaper
Marker
Paper towel
Safety goggles
Rubber gloves

Chemicals

Distilled water
Calcium carbonate powder
pH 10 buffer tablets (sodium carbonate and sodium bicarbonate)
Eriochrome black t indicator
EDTA (ethylene diamine tetraacetic acid)
disodium powder

Table 3. List of apparatus and chemicals used.

Procedure

1. Prepare 500 mL of CaCO_3 solution with a concentration of $180 \text{ mg}\cdot\text{L}^{-1}$ by adding 0.090g of CaCO_3 to 500 mL of distilled water in a 500 mL volumetric flask sealed with a rubber stopper. Shake the solution before pouring out for later use and re-prepare the solution when used up.
2. Prepare 250 mL of EDTA solution with a concentration of $0.002 \text{ mol}\cdot\text{L}^{-1}$ by adding 0.186g of EDTA disodium powder to 250 mL of distilled water in a 250 mL volumetric flask sealed with a rubber stopper.
3. Prepare 30 mL of pH 10 solution by dissolving the tablet in distilled water in a 125 mL Erlenmeyer flask.
4. Perform 3 sets of titrations with different settings and perform 3 trials each set.
 - a. Pour about 80 mL CaCO_3 from the 500 mL volumetric flask into a 140 mL beaker.
 - b. Transfer 50 mL of CaCO_3 solution from the 140 mL beaker to a 50 mL beaker by using a 25 mL pipette twice.
 - c. Pour about 80 mL EDTA from the 250 mL volumetric flask into a 140 mL beaker.
 - d. Fill the 50 mL buret if empty by transfer 50 mL of EDTA solution from the 140 mL using the 10 mL pipette five times.
 - e. Add 2 mL of pH 10 buffer solution from the 125 mL Erlenmeyer flask filled with pH 10 buffer to an empty 125 mL Erlenmeyer flask using a 3mL graduated plastic pipette.
 - f. Add 10 drops of eriochrome black indicator to the 125 mL Erlenmeyer flask in a 3mL graduated plastic pipette.
 - g. Turn on the hot plate. Place the 50 mL beaker filled with the CaCO_3 solution using a beaker clamp. Hold a thermometer above and let the tip of the thermometer stay in the middle of the solution.
 - h. When the temperature reaches the target temperature for each setting (60°C or 80°C or 100°C), remove the 50 mL beaker from the hot plate using a beaker clamp.
 - i. Use the beaker clamp to pour solution content from 50 mL beaker into the 125 mL Erlenmeyer flask. Do not use a distilled water bottle to wash down the CaCO_3 on the bottom of the beaker.
 - j. Perform titration until observing an apparent colour change that lasts at least ten seconds.
 - k. Use a thermometer to measure the temperature of the solution in the 125 mL Erlenmeyer flask after titration.
 - l. Record trial number, target and final temperature, initial and final buret volume.

Note: The procedure is modified after an online experiment handbook. (Cemeg, 2002)

Safety, Environmental, & Ethical Risk Assessments

Table 4 shows a list of risks and concerns regarding safety, environment, and ethics, and the corresponding control measures are taken.

Risk & Concern	Control Measure
Safety: Heating CaCO_3 solution to high temperatures can cause burn in skin and eye.	Wear eye protection and rubber gloves. Use a beaker clamp to move the beaker containing the sample solution.
Safety: CaCO_3 powder and solution are non-hazardous	Although considered non-hazardous, but eye protection and rubber gloves are worn.
Safety: EDTA disodium powder and solution are non-hazardous	Although considered non-hazardous, but eye protection and rubber gloves are worn.
Safety: pH 10 buffer tablet (sodium carbonate and sodium bicarbonate) and solution have acute toxicity if swallowed, can cause skin and severe eye corrosion. (Flinn Scientific, Inc., 2014)	A professional lab teacher performs the task of making the solution from a tablet. Eye protection and rubber gloves are worn and always use a 3mL graduated plastic pipette to access buffer solution.
Safety: eriochrome black t indicator is non-hazardous	Although considered non-hazardous, but eye protection and rubber gloves are worn.
Environmental: Waste CaCO_3 can contribute to forming limescale in pipes.	Solutions after experiment are poured into a waste beaker that the lab teacher will dispose appropriately, instead of pouring into the sink.
Ethical: No ethical issues identified.	N/A

Table 4. List of risks and concerns for the experiment and control measures used.

Diagram

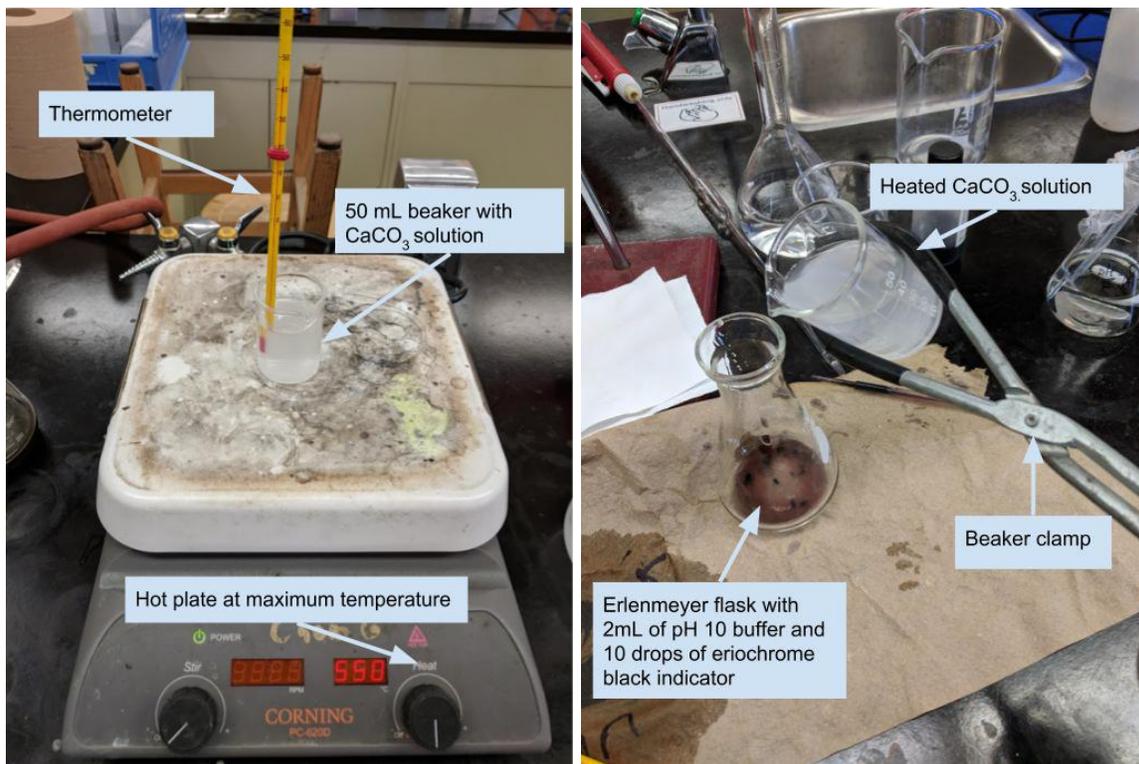


Figure 4. (Left) Figure 5. (Right) Experiment procedure while and after heating.

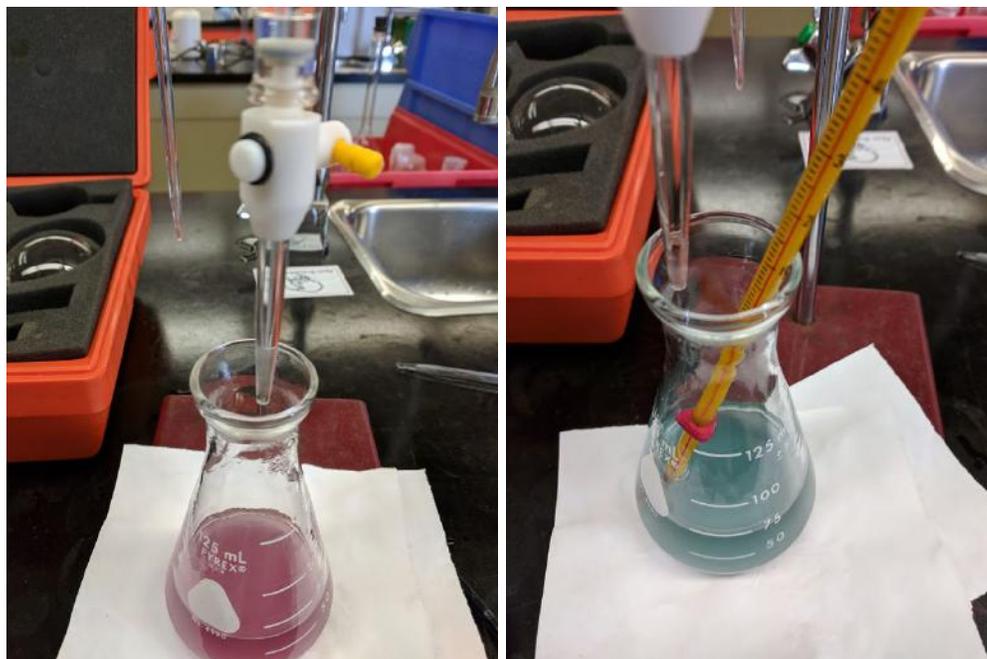


Figure 6. (Left) Figure 7. (Right) Erlenmeyer flask colour before and after a titration.

Data

Table 5 shows the raw experiment recording of temperature heated to, temperature measured after titration, and the initial and final volume of EDTA solutions in the buret.

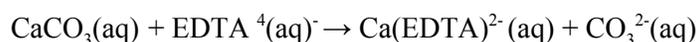
Trial	Temperature Heated / °C ± 0.5	Temperature after Titration / °C ± 0.5	Initial Volume /mL ± 0.05	Final Volume /mL ± 0.05
1	60.0	45.0	30.10	42.40
2	60.0	46.0	7.00	17.10
3	60.0	47.0	17.10	26.50
4	80.0	56.0	26.50	32.30
5	80.0	59.0	34.00	40.50
6	80.0	58.0	40.60	45.60
7	100.0	67.0	7.10	13.20
8	100.0	65.0	15.50	22.20
9	100.0	69.0	24.90	30.70

Table 5. Raw data collected after titration.

Calculations

With the raw data in Table 5, the hardness level in removed solution can be calculated, so does the percentage of CaCO₃ removed from and remained in the beaker. The following calculation demonstrates the detailed calculations, and a sample calculation is performed for trial No.1. Table 6 shows all the calculated results with uncertainties.

$$\text{Volume of EDTA added} = \text{Final Volume} - \text{Initial Volume (uncertainty} = 0.1 \text{ mL)}$$



$$\text{amount of EDTA added} = \text{concentration of EDTA solution} \times \text{volume of EDTA added}$$

The concentration of EDTA solution is 0.002 mol•L⁻¹ and it has a percent uncertainty of

$$\frac{0.001}{0.186} + \frac{0.24}{250.00} = 0.63\% \text{ and absolute uncertainty of } 1.27 \times 10^{-5}$$

The uncertainty comes from the apparatus used during preparation for the EDTA solution.

The amount of EDTA added is the same amount of CaCO₃ added due to 1:1 molar ratio

$$\text{amount of CaCO}_3 \text{ added} = \text{amount of EDTA added}$$

$$\text{mass of CaCO}_3 = \text{amount of CaCO}_3 \times \text{molar mass of CaCO}_3$$

$$\text{Molar mass of CaCO}_3 = 100.09 \text{ g}\cdot\text{mol}^{-1}$$

$$\text{hardness level measured} = \frac{\text{mass of CaCO}_3}{\text{volume of CaCO}_3}$$

$$\text{Percentage of hardness remained} = \frac{\text{hardness level measured}}{\text{original hardness level}} \times 100, \text{ where original hardness is } 180 \text{ mg}\cdot\text{L}^{-1}$$

Trial	Volume Titrated /mL ± 0.1	Hardness (CaCO ₃) Level in removed solution / mg·L ⁻¹	Percentage of temporary hardness removed from the beaker	Percentage of hardness remained in the beaker
1	12.3	49.2 ± 0.8	27.3% ± 0.4%	72.7% ± 0.4%
2	10.1	40.4 ± 0.7	22.4% ± 0.3%	77.6% ± 0.3%
3	9.4	37.6 ± 0.6	20.9% ± 0.3%	79.1% ± 0.3%
4	5.8	23.2 ± 0.5	12.8% ± 0.3%	87.1% ± 0.3%
5	6.5	26.0 ± 0.6	14.4% ± 0.3%	85.5% ± 0.3%
6	5.0	20.0 ± 0.5	11.1% ± 0.3%	89.9% ± 0.3%
7	6.1	24.4 ± 0.6	13.6% ± 0.3%	86.4% ± 0.3%
8	6.7	26.8 ± 0.6	14.8% ± 0.3%	85.1% ± 0.3%
9	5.8	23.2 ± 0.5	12.8% ± 0.3%	87.1% ± 0.3%

Table 6. Calculated hardness level removed, and hardness percentage removed and remained.

Sample calculation for trial No.1:

$$\text{Volume of EDTA added} = \text{Final Volume \#1} - \text{Initial Volume \#1}$$

$$\text{Volume of EDTA added} = (42.4 \pm 0.05 \text{ mL}) - (30.1 \pm 0.05 \text{ mL}) = 12.3 \pm 0.1 \text{ mL} = 0.0123 \pm 0.0001 \text{ L}$$



$$\text{amount of EDTA added} = \text{concentration of EDTA solution} \times \text{volume of EDTA added}$$

The concentration of EDTA solution is 0.002 mol·L⁻¹ and it has an absolute uncertainty of 1.27 × 10⁻⁵

$$\text{amount of EDTA added} = (0.002 \pm 0.0000127 \text{ mol} \cdot \text{L}^{-1}) \times 0.0123 \pm 0.0001 \text{ L}$$

$$\text{amount of EDTA added} = 2.46 \times 10^{-5} \pm 0.04 \times 10^{-5} \text{ mol}$$

The amount of EDTA added is the same amount of CaCO_3 added due to 1:1 molar ratio

$$\text{amount of CaCO}_3 \text{ added} = \text{amount of EDTA added} = 2.46 \times 10^{-5} \pm 0.04 \times 10^{-5} \text{ mol}$$

$$\text{mass of CaCO}_3 = \text{amount of CaCO}_3 \times \text{molar mass of CaCO}_3$$

$$\text{Where molar mass of CaCO}_3 = 100.09 \text{ g}\cdot\text{mol}^{-1}$$

$$\text{mass of CaCO}_3 = (2.46 \times 10^{-5} \pm 0.04 \times 10^{-5} \text{ mol}) \times 100.09 \text{ g}\cdot\text{mol}^{-1} = 0.00246 \pm 0.00004 \text{ g}$$

$$\text{hardness level measured} = \frac{\text{mass of CaCO}_3}{\text{volume of CaCO}_3}$$

Where volume of $\text{CaCO}_3 = 50 \text{ mL} = 0.05 \text{ L}$, and mass of CaCO_3 in mg is $2.46 \pm 0.04 \text{ mg}$

$$\text{hardness level measured} = \frac{\text{mass of CaCO}_3}{\text{volume of CaCO}_3} = \frac{2.46 \pm 0.04 \text{ mg}}{0.05 \text{ L}} = 49.2 \pm 0.8 \text{ mg}\cdot\text{L}^{-1}$$

$$\text{Percentage of hardness remained} = 100\% - \frac{\text{hardness level measured}}{\text{original hardness level}} \times 100\%$$

where original hardness is $180 \text{ mg}\cdot\text{L}^{-1}$,

and the hardness remained reference to the CaCO_3 precipitate or limescale in the beaker.

$$\text{Percentage of hardness removed} = \frac{\text{hardness level measured}}{\text{original hardness level}} \times 100\% = \frac{49.2 \pm 0.8 \text{ mg}\cdot\text{L}^{-1}}{180 \text{ mg}\cdot\text{L}^{-1}} \times 100\%$$

$$\text{Percentage of hardness removed} = 27.3\% \pm 0.4\%$$

$$\text{Percentage of hardness remained} = 100\% - \text{percentage of hardness removed}$$

$$\text{Percentage of hardness remained} = 100\% - (27.3\% \pm 0.4\%) = 72.7\% \pm 0.4\%$$

Analysis & Conclusion

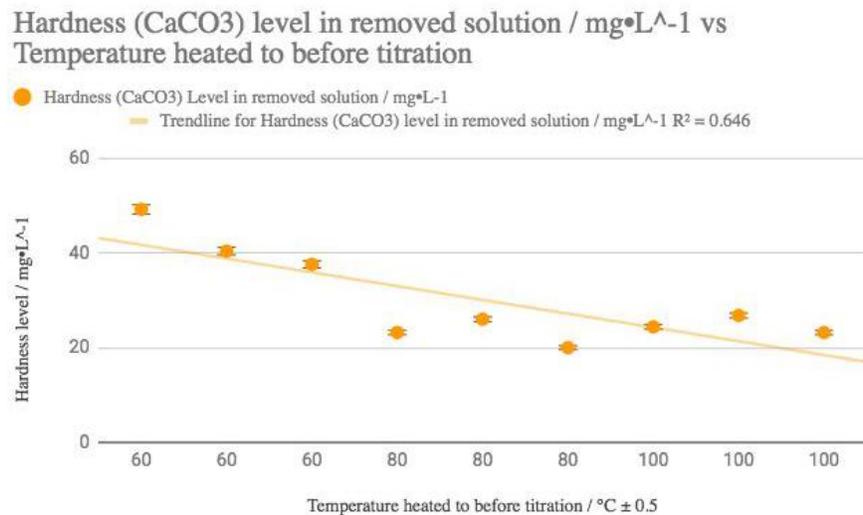


Figure 8. Hardness (CaCO_3) level in removed solution / $\text{mg}\cdot\text{L}^{-1}$ vs Temperature heated to before titration.

$$(R^2 = 0.646)$$

Percentage of temporary hardness in removed solution for each trial

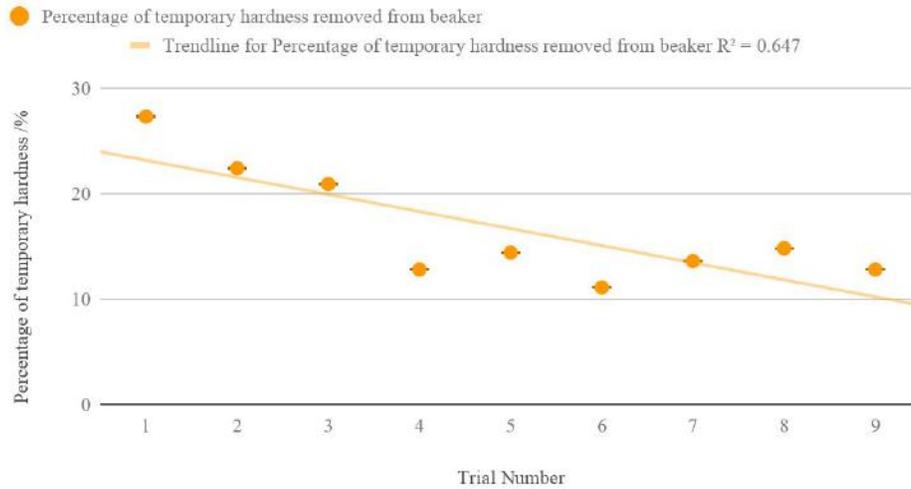


Figure 9. Percentage of temporary hardness removed for each trial. ($R^2 = 0.647$)

As shown in Figure 8 and Figure 9, the temporary hardness left in the solution is indeed affected by the temperature. As the temperature of the solution increases, less hardness is found in the removed solution. The trend can be concluded because of the substantial R^2 value (approximately 0.65). They are removed from the solution due to equilibria shifts to the right and form CaCO_3 on the bottom of the beaker. The CaCO_3 cumulates and eventually form limescale, as shown in Figure 10.

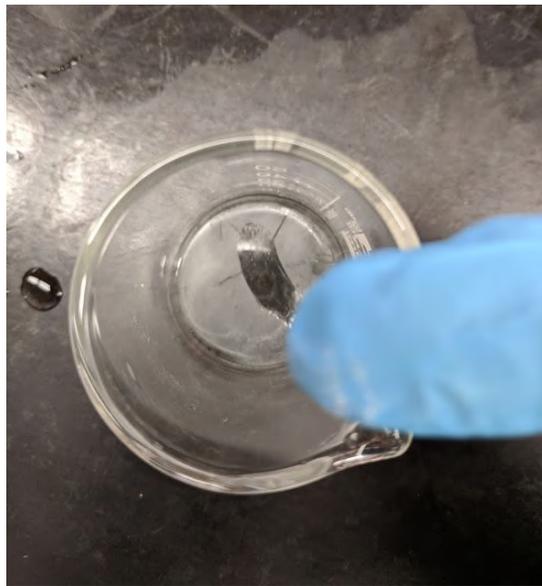


Figure 10. CaCO_3 precipitate or limescale formed on the bottom of the beaker.

As shown in the results and the graphs, the percentage of temporary calcium hardness in the beaker is considerably high (above 70% at least) under high temperatures, explaining why coffee machines and

kettles form limescale quickly. As an extension of the experiment, with appropriate data of the hardness of the tap water used and the length of the heating coil, the cleaning cycle for appliances can be calculated to maintain the desired efficiency.

Overall, the experiment proves the hypothesis. The experiment is thoughtfully designed and conducted. Safety concerns are considered. Solutions are diluted to provide more accurate data, and titrations are carefully performed. As a result, the experiment results provide reliable data with low uncertainty and substantial correlation. As temperature increases, the equilibrium shifts more to the right, and more CaCO_3 is removed from the solution and precipitate. However, note that the minor differences between the hardness levels for settings in $80\text{ }^\circ\text{C}$ (trial 4-6) and $100\text{ }^\circ\text{C}$ (trial 7-9). This could be a result of the minor differences in shifts of equilibrium and hence the solubility for those two temperatures. In contrast, there is a significant difference in the shift of equilibrium and solubility from $60\text{ }^\circ\text{C}$ to $80\text{ }^\circ\text{C}$. Figure 11 shows a similar study conducted by a technology company, and it matches the trend shown in this experiment. The solubility of CaCO_3 , under the condition with air, decreases as temperature increases. Note that the solubility difference between $80\text{ }^\circ\text{C}$ and $100\text{ }^\circ\text{C}$ is also smaller than the difference between $60\text{ }^\circ\text{C}$ and $80\text{ }^\circ\text{C}$. In the future, more sets of trails can be conducted at more temperature settings and hence gain more insights on the rate that the equilibrium shifts with increasing temperature.

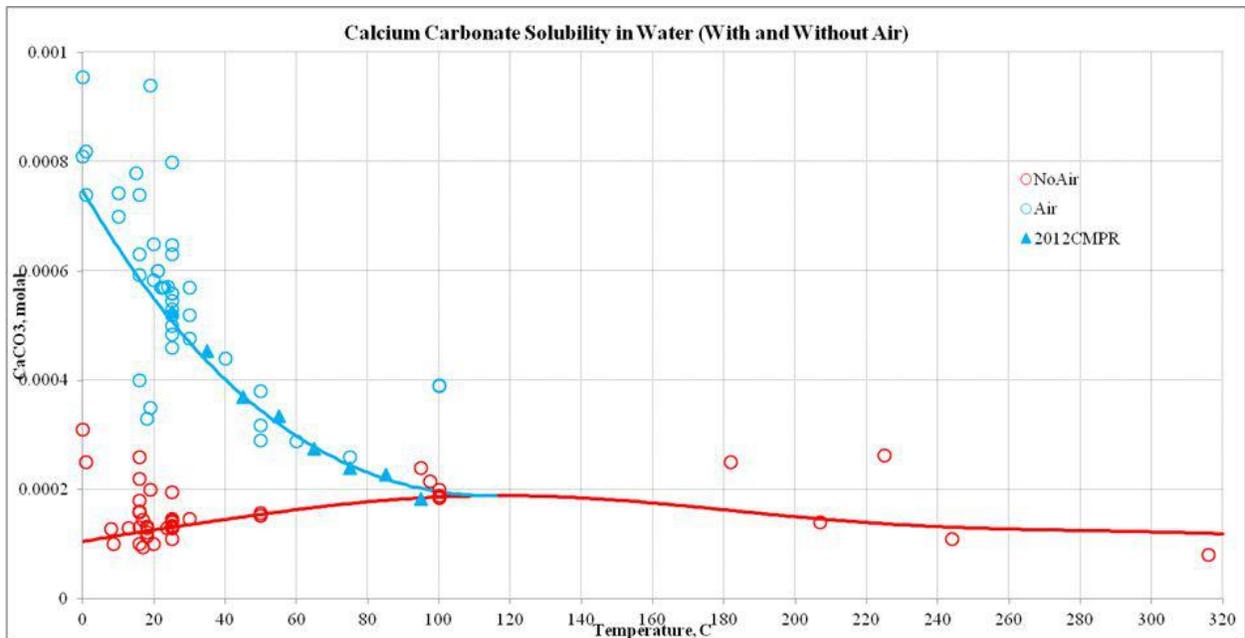


Figure 11. Calcium carbonate solubility in water (with and without Air). (OLI Systems., n.d.)

Sources of Error and Improvements

There are a number of error sources and can be improved. Table 7 shows a list of them and corresponding methods for improvement.

Weakness and source of error	Effect on data and results	Suggested procedural improvement
Too few data points; only 3 temperature settings and three trials each.	The conclusion is not conclusive due to the large gap between temperature settings.	More temperature settings can be tested and five trials can be performed for each setting.
Hardness level in CaCO_3 samples retrieved from the volumetric flask are not equally distributed due to its poor solubility over time.	Although shaken before accessing sample solution, the distribution is still varied thus affecting the amount of EDTA titrated.	Shake more to minimize unequal distributions.
Leftover CaCO_3 on the bottom of beaker from previous trials after washing.	The extra CaCO_3 from previous trials can increase the amount of EDTA added, thus the hardness level of the removed solution.	Use diluted hydrochloric acid to clean the beaker and remove all presence of CaCO_3 using the reaction $\text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{CO}_2 + \text{H}_2\text{O}$ (Rutgers University, 1998) and then clean with distilled water.
Addition of CaCO_3 and other minerals in tap water while cleaning beaker after a trial although finally rinsed with a distilled water bottle.	The additional CaCO_3 from tap water can increase the amount of EDTA added, thus the hardness level of the removed solution.	Wash with distilled water.
The temperature that the solution is heated to is underestimated because it takes some time for the human	The additional heat can cause the temperature to rise higher and hence further shifts the equilibrium to the right, decreases	Have two human experimenters performing the task; one monitors the temperature, one fetches the beaker clamp. Thus

<p>experimenter to see the thermometer reaches a certain temperature and fetches the beaker clamp while it is still heating.</p>	<p>the solubility, and increases the amount of hardness removed.</p>	<p>the overall time for additional heat to go in the beaker decreases.</p>
<p>Deciding the titration equivalence point based on the time of lasting colour change is inaccurate. The time that colour change occurs varies due to the different concentration of CaCO_3 and amount of EDTA added.</p>	<p>Inaccuracy due to the indicator colour change can increase or decrease the amount of EDTA added and hence the amount of the CaCO_3 in the removed solution.</p>	<p>Use a digital titration burette and a colour sensor with a timer to closely monitor the colour change, thus improving the accuracy.</p>
<p>The temperature of the solution during titration decreases due to the heat exchange with surroundings.</p>	<p>The decrease in temperature affect the equilibrium in the system while titrating, so the EDTA amount titrated obtains inaccuracies. Since not all titrations are finished at the same time, comparisons between trials with similar conditions also obtain inaccuracies.</p>	<p>Titrate as fast as possible while maintaining precisions. Try to perform titration in similar pace and time, but the inaccuracy is inevitable.</p>

Table 7. List of sources of errors, the possible effect on the experiment, and suggested procedural changes.

Reference

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