

INVESTIGATION OF THE USAGE OF CALCIUM HYDROXIDE AMONG OTHER
EARTH ALKALINE HYDROXIDES LIKE MAGNESIUM HYDROXIDE AND BARIUM
HYDROXIDE DURING ENDODONTIC TREATMENT AT VARIOUS
TEMPERATURES IN TERMS OF ACID-BASE CHEMISTRY

Extended Essay in Chemistry HL

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ABSTRACT

The research question in this study is how usage of Earth Alkaline Hydroxides differ in relation to their usage in endodontic root canal treatment according to their solubilities.

Method employed has three main components:

- Review of usage of calcium hydroxide in endodontic root canal treatment, and preferred solubility properties of the antibacterial material for success in the treatment.
- Formulation of the titration experiment by determining types and volumes of the materials that will be used during the experiment, and tools that will be utilized.
- Conducting the experiment, doing required measurements, and doing the calculations to compare solubility levels.

A titration experiment was set up to observe and measure solubilities for the Earth Alkaline Hydroxides investigated. In the experiment, by using 0.10M HCl solution and by adding bromothymol blue indicator same volumes of saturated solutions of group IIA hydroxides were titrated. Volume and type of water used, pressure acting on the solutions and concentration of the titrant, type of indicator, drops of bromothymol blue are kept constant to eliminate impact of varying values of these on the calculated value of solubility. Experiment was conducted not only at room temperature but also at body temperature in order to replicate temperature level relevant in endodontic treatment. K_{sp} Values were calculated in order to compare the solubility levels.

Magnesium hydroxide and barium hydroxide are chosen in this study in addition to calcium hydroxide, to compare solubility levels. Experiment showed that K_{sp} values ranked as follows: $K_{spMg(OH)_2} < K_{spCa(OH)_2} < K_{spBa(OH)_2}$. This result confirmed that calcium hydroxide is more suitable for endodontic treatment as average solubility level is necessary for successful root canal treatment.

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NOTATION

K_{sp}: Solubility Product Constant

Ca(OH)₂: Calcium Hydroxide

Mg(OH)₂: Magnesium Hydroxide

Ba(OH)₂: Barium Hydroxide

HCl: Hydrochloric Acid

1. INTRODUCTION

Most people suffer from dental problems some of which affect daily life activities in a very painful way. Last year, my father was suffering may be one of the most painful dental problems. His dentist said it can be cured only by root canal treatment. I was in the clinique when the treatment took place. The dentist explained the method and the materials used during the process as I was curious about the subject. He especially mentioned the importance of one material, calcium hydroxide.

We were discussing the daily-life applications of acid-base materials and presence of solubility in real life situations in my IB chemistry classes this year, I thought that calcium hydroxide must be starting chemical reaction to cure the infected area through neutralization. Solubility and other chemical properties such as the biocompatibility of the materials used for the treatment must be very important while considering which material to use during the procedure. To investigate this further, I decided to choose usage of calcium hydroxide in endodontic treatments as my research subject by focusing on solubility.

During literature review on this subject, I read that chemical used in endodontic treatment is preferred to have average solubility. This is because very slight solutes are incapable of forming the required curing bridge, and high soluble substances spread all over the body with blood minimizing the effect of the material used as a curing agent, and they may lead to transmission of potentially toxic amounts of the material to other parts of the body ¹.

Aim:

Objective in this study is to investigate why calcium hydroxide is being used rather than other earth alkaline metal hydroxides during endodontic treatment in terms of acid base chemistry, by titrating 0.10M HCl solution with saturated Ca(OH)_2 , Mg(OH)_2 and Ba(OH)_2 solutions separately, at room and body temperatures, and by calculating and comparing K_{sp} values of Ca(OH)_2 and Mg(OH)_2 and Ba(OH)_2 .

¹ Baski A, Eyuboglu T, Sen B, et al. The effect of three different sealers on the radiopacity of root fillings in simulated canals. Oral Med Oral Pathol Oral Radiol Endod 2007; 103; 138-41.

Hypothesis:

Hypothesis in this study is that earth alkaline metals have very different solubility properties. Otherwise, if all had similar solubilities, other hydroxides could have been preferred also by dentists in root canal treatments instead of present preference towards using calcium hydroxide as the curing agent. Calcium hydroxide is highly preferred with its average solubility level for a successful treatment.

2. BACKGROUND

Endodontic treatment is used to refer to any treatment related to curing of infected dental pulp of teeth. Dental pulp is the internal area under the hard white enamel area of the teeth and it is a soft tissue with nerve, blood and lymph vessels.

2.1 APPLICATION OF CALCIUM HYDROXIDE IN ROOT CANAL TREATMENT

When dental pulp is damaged and unable to repair itself, bacteria spreads deep into the root of the tooth resulting in loss of tooth. In the root canal treatment, infected dental pulp is removed. Root canal is filled with temporary filling materials for sterilization. Once infections are cured fully, permanent artificial filling materials are injected into the tooth canal ². (See **Appendix 1** for details).

Calcium hydroxide is used in root canal treatment as temporary filling material for sterilization and killing of the bacteria. It is the main antibacterial filling substance used in the root canal treatment ³. Chemical reaction calcium hydroxide creates to cure the infected area is neutralization. Infected area means there is an acidic environment that should be neutralized to heal. Calcium hydroxide has an alkaline property with high pH values and ability to release hydroxyl ions that leads to neutralization among other functions. Saliva in the inflected area acts as a solvent to any medication leading to releasing of ions. (See also **Appendix 2**).

2.2 OTHER HYDROXIDES USED IN THE EXPERIMENT

²American Dental Association, Endodontic Treatment, 23.09.2010, <<http://www.ada.org/2890.aspx>>

³ Siqueira, Lopes, International Endodontic Journal, 1999, 32, 361-369.

Calcium hydroxide is not the only hydroxide complex which can dissociate into ions. In the group 2A in the periodic table, we see that earth alkaline metals group consists of calcium (Ca), magnesium (Mg) and barium (Ba), beryllium (Be), strontium (Sr), and radium (Ra).

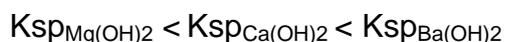
Maximum mole numbers of a matter that can dissolve in 1 liter of its saturated solution is referred to as molar solubility⁴. (See also **Appendix 3**).

Solubility of Earth Alkaline Hydroxides increases as we go from top to bottom in the periodic table⁵. This can be explained by the attraction to give electrons to maintain a stable electron configuration. As the atomic radius increases with the increase in atomic number, shielding effect appears. As shielding effects becomes stronger, the attraction force applied from the nucleus to the valence electrons decreases. This results in for the element with large atomic number to make bonds much easier compared to those elements with small atomic number. As a result, theoretically, solubility is expected to increase in group 2A with atomic number.

In the actual experiment, only calcium hydroxide, magnesium hydroxide and barium hydroxide will be used. This is because remaining metals were not available in the laboratory. When we consider calcium, magnesium and barium, we see that the atomic radii of the elements are arranged as:



As a result, we should expect to see in an experimental study, following relative solubilities for calcium hydroxide, magnesium hydroxide and barium hydroxide:



3. DESIGN AND CONDUCT OF THE EXPERIMENT

3.1 METHOD DEVELOPMENT AND PLANNING

Purpose in the Experiment:

⁴ Zuhmdahl S, Zuhmdahl S, Houghton Mifflin, Sixth Edition, Chemistry, Solubility Equilibria, p. 751-754.

⁵ Database of Murdoch University, 10.09.2010

<<http://www.see.murdoch.edu.au/info/student/chemtutorials/ptsr.htm>>

During this investigation, saturated Ca(OH)_2 , Mg(OH)_2 and Ba(OH)_2 solutions will be titrated with 0.10M HCl solution. The concentrations of OH^- , Ca^{+2} , Mg^{+2} , Ba^{+2} ions will be determined for $\text{Ca(OH)}_{2(\text{aq})}$, $\text{Mg(OH)}_{2(\text{aq})}$, $\text{Ba(OH)}_{2(\text{aq})}$. By using the data obtained, the K_{sp} values of $\text{Ca(OH)}_{2(\text{aq})}$, $\text{Mg(OH)}_{2(\text{aq})}$ and $\text{Ba(OH)}_{2(\text{aq})}$ will be calculated and compared.

Dependent Variables: K_{sp} values of the solutions Ca(OH)_2 , Mg(OH)_2 , Ba(OH)_2

Controlled Variables: Volume of saturated solutions, type and volume of water, pressure acting on concentrations, concentration of HCl, type and drop number of the indicator

Independent Variable: Temperature

Temperature Level:

Most of the experiments are performed at room temperature. However, I conducted the experiment also at body temperature as this paper focuses on a chemical reaction in human body. After doing further research, I decided to use the temperature effects of approximately 25°C in room and $36,5^{\circ}\text{C}$ in body ^{6 7}.

List of Apparatus Used:

- Ring and ring stand
- Four 100 mL beakers
- Four 150 mL erlenmeyer flask
- Two 50 mL graduated cylinders
- Two 10mL graduated cylinders
- Two 50 mL buret
- Buret clamp
- Filter paper
- Filter funnel
- Thermometer
- Heating bath

⁶ UC Santa Cruz, Chemistry and Biochemistry, 18.11.2010

<http://www.chemistry.ucsc.edu/teaching/roland/Chem1N/procedures/1N_10_Kspproc.pdf>

⁷ Washington University in St. Louis, Department of Chemistry, 19.11.2010,

<http://www.chemistry.wustl.edu/~courses/genchem/Labs/Solubility/prelab5_sp09.pdf>

- Vacuum filtration system

In addition, since all $\text{Ca}(\text{OH})_2$, $\text{Mg}(\text{OH})_2$, $\text{Ba}(\text{OH})_2$ are caustic and highly acidic HCl solution can cause blindness, goggles are used.

List of Chemicals Used:

- Solid $\text{Ca}(\text{OH})_2$
- Solid $\text{Mg}(\text{OH})_2$
- Solid $\text{Ba}(\text{OH})_2$
- Acetone
- 37% W/W HCl Solution
- Bromothymol Blue indicator
- Distilled water

Method for Controlling Variables:

- Pressure: Keep pressure constant to stabilize the pressure acting on the saturated solutions in order to minimize any possible errors by doing the experiments in the same room and checking the atmospheric pressure from the barometer respectively.
- Concentration of HCl: While calculating the K_{sp} value of the titrant, molarities of the materials used is important since the calculation formula includes them. In order to calculate accurate K_{sp} values, keep concentration of HCl constant at 0.10M.
- Volume of Saturated $\text{Ca}(\text{OH})_2$ and $\text{Mg}(\text{OH})_2$ and $\text{Ba}(\text{OH})_2$ Solutions: Effect of the indicator and titrant, volumes of the materials used depends on the volume of material to be titrated so in order to minimize the effect of this factor keep volume of $\text{Ca}(\text{OH})_{2(aq)}$, $\text{Mg}(\text{OH})_{2(aq)}$ and $\text{Ba}(\text{OH})_{2(aq)}$.
- Type of Indicator: Use same indicator bromothymol blue, during all trials since the type of the indicator will affect the results of the experiment by changing the observable equivalence point.
- Drop Number of Bromothymol Blue: All calculations and measurements are dependent on the color change of the solution. Amount of bromothymol blue directly affects this change. Add 4 drops of bromothymol blue to keep this factor constant during all trials.

3.2 PREPARATION OF SOLUTIONS

All solutions are prepared just before the investigation. The reason for not using pre-made materials was to eliminate any possible spontaneous reactions which might occur in the flasks.

Despite the fact that the experiment could be done by using 50ml of water it was completed by using 20ml of solutions per trial. The actual reason of this is to reduce the volume of water being used and to decrease to amount of chemical materials that are being used during the investigations with an high environmental awareness.

Since all of the hydroxides are slightly soluble in this experiment I should be using a strong acid to determine the $[\text{OH}^-]$. While preparing HCl solution, the formula $V_1M_1 = V_2M_2$ was used to decide on what amount of chemical was required to prepare the solution. Instead of using a standard beaker, HCl solution was prepared in a volumetric flask, which minimizes the possible errors resulting from usage of excess material.

After preparing the saturated solutions, beakers were enclosed to prevent the air connection. The saturated solutions of calcium hydroxide, magnesium hydroxide and barium hydroxide are tend to react with air and form $\text{CaCO}_{3(s)}$, $\text{MgCO}_{3(s)}$ and $\text{BaCO}_{3(s)}$ as a product which appears as a white, blurry layer at the top of the solutions. This formation did not cause a problem because the carbonate layer will be filtrated with excess chemicals in the saturated solutions during filtration. Vacuum filtration was used rather than classic ways of filtration to speed up the filtration time. Vacuum filtration accelerates the process by applying an extra external force besides gravitational force.

During all trials of titration a stirring magnet was used to stir the solution in the erlenmeyer flask to observe the color change precisely.

Method for Preparing $\text{Ca}(\text{OH})_2$ Solution:

1. Pour 100ml distilled water in a beaker.

2. Slowly add some solid Ca(OH)_2 and stir until it dissolves.
3. There should be some observable $\text{Ca(OH)}_{2(s)}$ at the bottom of beaker, to be sure that the solution is saturated.
4. If there is not $\text{Ca(OH)}_{2(s)}$ at the bottom of the beaker, add more $\text{Ca(OH)}_{2(s)}$.
5. Place filter paper into filter funnel and connect it to vacuum filtration system in order to separate excess $\text{Ca(OH)}_{2(s)}$ from its saturated solution

Method for Preparing Mg(OH)_2 Solution:

1. Pour 100ml distilled water in a beaker and add some of solid Mg(OH)_2 .
2. Stir until it dissolves, but there should be some observable $\text{Mg(OH)}_{2(s)}$ at the bottom of beaker, to be sure that the solution is saturated.
3. If there is not $\text{Mg(OH)}_{2(s)}$ at the bottom of the beaker, add more $\text{Mg(OH)}_{2(s)}$.
4. Place filter paper into filter funnel and connect it to vacuum filtration system in order to separate $\text{Mg(OH)}_{2(s)}$ from its saturated solution.

Method for Preparing Ba(OH)_2 Solution:

1. Pour 100ml distilled water in a beaker.
2. Slowly add some solid Ba(OH)_2 and stir until it dissolves.
3. There should be some observable $\text{Ba(OH)}_{2(s)}$ at the bottom of beaker, to be sure that the solution is saturated.
4. If there is not $\text{Ba(OH)}_{2(s)}$ at the bottom of the beaker, add more $\text{Ba(OH)}_{2(s)}$.
5. Place filter paper into filter funnel and connect it to vacuum filtration system in order to separate excess $\text{Ba(OH)}_{2(s)}$ from its saturated solution

Method for Preparing Standard 0,10M HCl Solution:

1. Full fill the volumetric flask with 496ml of distilled water
2. Add 4 ml of 37% W/W HCl solution. Stir while mixing.

Method for Determining the K_{sp} of $\text{Ca(OH)}_{2(aq)}$, $\text{Mg(OH)}_{2(aq)}$ and $\text{Ba(OH)}_{2(aq)}$ at Room Temperature:

1. Measure 20mL of filtered $\text{Ca(OH)}_{2(aq)}$ and pour it into 100ml erlenmeyer flask.
2. Add 4 drops of bromothymol blue.
3. Put magnetic stirrer into the erlenmeyer flask.
4. Fill the burette with 0.10M HCl and record the initial volume.

5. Measure and record the temperature.
6. Start titration by gently adding 0.10M HCl to $\text{Ca(OH)}_{2(\text{aq})}$, continue adding until the equivalence point, the color of the solution turns from blue to greenish yellow.
7. Record final volume of the 0.10M HCl.
8. Clean Erlenmeyer flask first with distilled water and then clean it with acetone to diminish water drops in the flask.
9. Repeat steps 3-8 at least 3 more times for $\text{Ca(OH)}_{2(\text{aq})}$ and conduct 4 trials for both $\text{Mg(OH)}_{2(\text{aq})}$ and $\text{Ba(OH)}_{2(\text{aq})}$ solutions.

Method for Determining the K_{sp} of $\text{Ca(OH)}_{2(\text{aq})}$, $\text{Mg(OH)}_{2(\text{aq})}$ and $\text{Ba(OH)}_{2(\text{aq})}$ at Body Temperature:

1. Heat 300ml of distilled water in 500ml beaker to approximately 37°C. (It can be heated up to 38-40°C in order to minimize the possible heat loss until dissolving Ca(OH)_2 measuring the temperature.)
2. Add some $\text{Ca(OH)}_{2(\text{s})}$ and stir until it dissolves, but still some $\text{Ca(OH)}_{2(\text{s})}$ should be observable which indicates the solution is saturated.
3. Record the temperature, it should be between 37-40°C .
4. Filter the solution quickly by using filter paper and vacuum filtration system and transfer the filtered solution to 100ml beaker
5. Measure 20ml of filtered $\text{Ca(OH)}_{2(\text{aq})}$ in to Erlenmeyer flask.
6. Add 4 drops of bromothymol blue.
7. Fill the burette with 0.10 M HCl and record the initial volume.
8. Start titration by gently adding 0.10M HCl to $\text{Ca(OH)}_{2(\text{aq})}$, continue adding until the equivalence point, the color of the solution turns from blue to greenish yellow.
9. Record final volume of 0.10M HCl.
10. Repeat steps 1-9 at least 3 more times for $\text{Ca(OH)}_{2(\text{aq})}$ and also do 4 trials for $\text{Mg(OH)}_{2(\text{aq})}$ and $\text{Ba(OH)}_{2(\text{aq})}$.

4. OBSERVATIONS AND MEASUREMENTS

4.1 DATA COLLECTION AND OBSERVATIONS FOR THE EXPERIMENTS

Quantitative Data Obtained During Room Temperature Experiment:

Table 1 below shows for the room temperature experiment, measured temperature, drop number of bromothymol blue added, concentration of HCl, initial and final volumes of saturated $\text{Ca(OH)}_{2(\text{aq})}$, $\text{Mg(OH)}_{2(\text{aq})}$, $\text{Ba(OH)}_{2(\text{aq})}$.

	Temperature($^{\circ}\text{C}$) (± 0.5)	Number of Drops of Bromothymol Blue (drops)	Concentration of HCl (M)	Saturated Ca(OH)_2		Saturated Mg(OH)_2		Saturated Ba(OH)_2	
				Initial Volume of HCl (ml) (± 0.2)	Final Volume of HCl (ml) (± 0.2)	Initial Volume of HCl (ml) (± 0.02)	Final Volume of HCl (ml) (± 0.02)	Initial Volume of HCl (ml) (± 0.2)	Final Volume of HCl (ml) (± 0.2)
Trial 1	24.0	4	0.10	50.0	42.9	10.00	0.05	50.0	16.2
Trial 2	24.0	4	0.10	50.0	42.6	10.00	0.04	50.0	16.4
Trial 3	24.0	4	0.10	50.0	42.5	10.00	0.04	50.0	16.7
Trial 4	24.0	4	0.10	50.0	42.6	10.00	0.06	50.0	16.3

Table 1: Data collected during room temperature experiment.

Qualitative Notes Observations During Room Temperature Experiment:

- Since very small amount of HCl was enough for $\text{Mg(OH)}_{2(\text{aq})}$ to reach equivalence point, a narrow tipped dropper was used during its titration to have more accurate results.
- Since dropper was used during the titration of $\text{Mg(OH)}_{2(\text{aq})}$ it was not possible to see the exact final volume of HCl, so by counting the drops the approximate volume required for titration of $\text{Mg(OH)}_{2(\text{aq})}$ was determined.
- Uncertainty of volumetric flask which contains 0,10M HCl is $\pm 0,25$.
- Uncertainty of graduated cylinder which was used during preparing the HCl solution is $\pm 0,5$ ml.
- Since saturated $\text{Ca(OH)}_{2(\text{aq})}$ was prepared and filtrated first, the big pores of the first filter paper was noticed during the first filtration. The first filter paper was not sufficient to filter the excess $\text{Ca(OH)}_{2(\text{s})}$ so the solution was blurry after first filtration. So by using another filter paper, $\text{Ca(OH)}_{2(\text{aq})}$ was filtrated twice.

Quantitative Data Obtained During Body Temperature Experiment:

Table 2 below shows for the body temperature experiment, measured initial and final temperature, amount of bromothymol blue added, initial and final volumes of saturated $\text{Ca(OH)}_{2(aq)}$, $\text{Mg(OH)}_{2(aq)}$, $\text{Ba(OH)}_{2(aq)}$ for all trials.

	Amount of Indicator (Drops)	Initial Temperature($^{\circ}\text{C}$) (± 0.5)	Final Temperature($^{\circ}\text{C}$) (± 0.5)	Saturated Ca(OH)_2		Saturated Mg(OH)_2		Saturated Ba(OH)_2	
				Initial Volume of HCl (ml) (± 0.2)	Final Volume of HCl (ml) (± 0.2)	Initial Volume of HCl (ml) (± 0.2)	Final Volume of HCl (ml) (± 0.05)	Initial Volume of HCl (ml) (± 0.05)	Final Volume of HCl (ml) (± 0.05)
Trial 1	4	37.5	38.5	50.0	43.3	50.0	48.4	50.0	10.7
Trial 2	4	38.0	39.3	50.0	43.6	50.0	48.6	50.0	11.5
Trial 3	4	37.0	38.8	50.0	43.6	50.0	48.8	50.0	11.2
Trial 4	4	39.0	40.0	50.0	43.6	50.0	49.0	50.0	11.0

Table 2: Data collected during body temperature experiment.

Qualitative Notes and Observations During Body Temperature Experiment:

- Concentration of HCl was 0.10M for trials of $\text{Ca(OH)}_{2(aq)}$ and $\text{Ba(OH)}_{2(aq)}$ but as it was observed from the room temperature trials 0.10M was not applicable to truly maintain the actual equivalence point of the trials of $\text{Mg(OH)}_{2(aq)}$ so 0.01M HCl concentration was prepared to accurately measure the equivalence point. The height values of HCl obtained from $\text{Mg(OH)}_{2(aq)}$ trials will be divided by 10 to compare with the values of $\text{Ca(OH)}_{2(aq)}$ and $\text{Ba(OH)}_{2(aq)}$.
- Distilled water which would be used to solve the chemicals was pre-heated in the water bath and to minimize the errors from heat loss temperature was arranged as 40°C .

- Approximate volumes of chemicals were added to distilled water as in the room temperature trials to prevent the possible formation of oversaturated solutions.
- To prevent heat loss during titration the heater mechanism of the magnetic stirrer was open.
- To equilibrate the temperature of the solutions after vacuum filtration they were placed in the water bath again.
- Uncertainty of volumetric flask which contains 0,10M and 0,01 HCl is $\pm 0,25$ ml.
- Uncertainty of graduated cylinder which was used during preparing the HCl solution is $\pm 0,2$ ml.

Additional Qualitative Notes and Observations for both Room Temperature and Body Temperature:

- Thin white layer of carbonate was observed on all solutions but mostly on $\text{Ba(OH)}_{2(\text{aq})}$ and least on $\text{Mg(OH)}_{2(\text{aq})}$.
- Solid chemical was mostly observed in $\text{Ba(OH)}_{2(\text{aq})}$ and least in $\text{Mg(OH)}_{2(\text{aq})}$.
- Saturated Ca(OH)_2 and Ba(OH)_2 solutions were blurry but saturated Mg(OH)_2 solution was colorless before filtration.
- Saturated Ca(OH)_2 and Ba(OH)_2 solutions become colorless after filtration.
- Color change was rapid during the titration of $\text{Mg(OH)}_{2(\text{aq})}$.
- While preparing 0.10M HCl solution no temperature change was observed in the flask however it was expected since the acid-water reaction is an exothermic reaction.

5. DATA PROCESSING AND CALCULATIONS

5.1 CALCULATION OF K_{sp} FOR ROOM TEMPERATURE EXPERIMENT

K_{sp} calculation uses measured volume change of HCl solution in the experiment.

Table 3 below lists volume change of HCl for all trials of all 3 solutions for room temperature experiment.

Volume Change of HCl Solution at Room Temperature Experiment			
	For Saturated Ca(OH) _{2(aq)}	For Saturated Mg(OH) ₂	For Saturated Ba(OH) ₂
Trial 1	7.1	0.07	33.8
Trial 2	7.4	0.05	33.6
Trial 3	7.5	0.07	33.3
Trial 4	7.4	0.06	33.7

Table 3: Volume change of HCl for all trials of all 3 solutions at room temperature experiment.

Calculation of K_{sp} For Saturated Ca(OH)₂:**Step 1: Formulas:**

- If $A_aB_b \Rightarrow aA + bB$

$$K_{sp} = [A]^a[B]^b$$

- Use dimensional analysis while converting units.
- While calculating moles and molarities use $M = n / V$
- Take $[OH^-] = [H^+]$ since we are focusing on the equivalence point.

Step 2: Application of Formulas:

In the first trial of saturated Ca(OH)₂ solution,

$$K_{sp}: [Ca^{+2}][OH^-]^2 \text{ if } [Ca^{+2}] = x \text{ then } K_{sp} = 4x^3$$

$$\text{Convert } \Delta h \text{ of HCl from ml to L : } 7,1 \text{ ml} \times 1L / 1000\text{ml} = 7,1 \times 10^{-3} L$$

$$\text{Find moles of } H^+ \text{ ions : } 7,1 \times 10^{-3} \times 0,1 = 7.1 \times 10^{-4} \text{ moles}$$

$$[H^+] = [OH^-] \Rightarrow 7.1 \times 10^{-4} / 20 \times 10^{-3} = 0,035 M$$

$$\text{Since } [H^+] = [OH^-] \text{ and } [Ca^{+2}] = 2[OH^-] \quad x = 0,035 / 2 = 0,018M$$

$$\text{Hence, } K_{sp} \text{ of Ca(OH)}_2 \text{ for Trial 1} = 2,24 \times 10^{-5} \text{ since } K_{sp} = 4x^3$$

In this section, actual K_{sp} calculation using measurements in the experiment is showed step by step only for the first trial of saturated Ca(OH)₂ solution. Since method is same for the calculation of K_{sp} for other trials of Ca(OH)_{2(aq)} and all trials of Mg(OH)_{2(aq)} and Ba(OH)_{2(aq)}, they are provided in **Appendix 4**. Below **Table 4** shows resultant values of K_{sp} for all trials of all three solutions for room temperature experiment.

Calculated Ksp Values for Room Temperature Experiment

	Saturated $\text{Ca(OH)}_{2(\text{aq})}$	Saturated $\text{Mg(OH)}_{2(\text{aq})}$	Saturated $\text{Ba(OH)}_{2(\text{aq})}$
Trial 1	2.24×10^{-5}	2.79×10^{-11}	2.41×10^{-3}
Trial 2	2.53×10^{-5}	2.60×10^{-11}	2.37×10^{-3}
Trial 3	2.64×10^{-5}	2.79×10^{-11}	2.31×10^{-3}
Trial 4	2.53×10^{-5}	2.64×10^{-11}	2.39×10^{-3}

Table 4: Calculated K_{sp} values for all trials of all three solutions for room temperature experiment.

Due to potential uncertainties caused by the apparatus used during the experiment, the average uncertainty and percentage error values were included during the calculations to obtain measure of the accuracy for each case. Another method was applied for the average K_{sp} values to be used in the percentage error calculations, as only at room temperature K_{sp} values were available, but not at the body temperature ones.

K_{sp} values corresponding to four trials were averaged out and this average value was used as the K_{sp} value in the percentage error calculation. As listed on **Table 5**, results show that percentage errors were low for room temperature experiment. (See **Appendices 5 and 6** for details of uncertainty and percentage error calculations.)

	Average K_{sp} Values	Average Uncertainty	Total Percentage Error	Average Percentage Error
$\text{Ca(OH)}_{2(\text{aq})}$	2.48×10^{-5}	7.89%	20.17 %	5.04 %
$\text{Mg(OH)}_{2(\text{aq})}$	2.71×10^{-11}	33.48%	12.53 %	3.14 %
$\text{Ba(OH)}_{2(\text{aq})}$	2.37×10^{-3}	5.75%	5.06 %	1.68 %

Table 5: For room temperature experiment, average K_{sp} values and average uncertainty of all trials of $\text{Ca(OH)}_{2(\text{aq})}$, $\text{Mg(OH)}_{2(\text{aq})}$, $\text{Ba(OH)}_{2(\text{aq})}$.

5.2 CALCULATION OF K_{sp} FOR BODY TEMPERATURE EXPERIMENT

Table 6 below lists volume change of HCl for all trials of all 3 solutions for body temperature experiment. These will be used in the calculation of K_{sp} values.

Volume Change of HCl Solution at Body Temperature Experiment			
	For Saturated Ca(OH) _{2(aq)}	For Saturated Mg(OH) _{2(aq)}	For Saturated Ba(OH) _{2(aq)}
Trial 1	6.7	0.16	39.3
Trial 2	6.4	0.14	38.5
Trial 3	6.4	0.12	38.8
Trial 4	6.4	0.10	39.0

Table 6: Volume change of HCl for all trials of all 3 solutions at approximate body temperature.

Calculation of K_{sp} For Saturated Mg(OH)₂:**Step 1: Formulas:**

- Same formulas are used as in the calculation part of room temperature trial.

Step 2: Application of Formulas:

In the first trial of saturated Mg(OH)₂ solution,

$$K_{sp}: [Mg^{+2}][OH^-]^2 \text{ if } [Mg^{+2}] = x \text{ then } K_{sp} = 4x^3$$

$$\text{Convert } \Delta h \text{ of HCl from ml to L : } 0,16 \text{ ml} \times 1\text{L} / 1000\text{ml} = \mathbf{0,16 \times 10^{-3} \text{ L}}$$

$$\text{Find moles of H}^+ \text{ ions : } 0,16 \times 10^{-3} \times 0,1 = \mathbf{0,16 \times 10^{-4} \text{ moles}}$$

$$[H^+] = [OH^-] \Rightarrow 0,16 \times 10^{-4} / 20 \times 10^{-3} = 8 \times 10^{-4} \text{ M}$$

$$\text{Since } [H^+] = [OH^-] \text{ and } [Mg^{+2}] = 2[OH^-] \quad x = 8 \times 10^{-4} / 2 = \mathbf{4 \times 10^{-4}}$$

$$\text{Hence, } K_{sp} \text{ of Mg(OH)}_2 \text{ for Trial 1} = \mathbf{2,56 \times 10^{-10}} \text{ since } K_{sp} = 4x^3$$

Since method is same for the calculation of K_{sp} for other trials of Mg(OH)_{2(aq)} and all trials of Ca(OH)_{2(aq)} and Ba(OH)_{2(aq)}, they are provided in **Appendix 4**. Below **Table 7** shows resultant values of K_{sp} for all trials of all three solutions for body temperature experiment.

Calculated K _{sp} Values for Body Temperature Experiment			
	Saturated Ca(OH) _{2(aq)}	Saturated Mg(OH) _{2(aq)}	Saturated Ba(OH) _{2(aq)}
Trial 1	1.88x 10 ⁻⁵	2.56 x 10 ⁻¹⁰	3.79 x 10 ⁻³
Trial 2	1.67 x 10 ⁻⁵	1.72 x 10 ⁻¹⁰	3.57 x 10 ⁻³
Trial 3	1.67 x 10 ⁻⁵	1.08 x 10 ⁻¹⁰	3.65 x 10 ⁻³
Trial 4	1.67 x 10 ⁻⁵	0.63 x 10 ⁻¹⁰	3.71 x 10 ⁻³

Table 7: Calculated K_{sp} values for all trials of all three solutions at approximate body temperature.

As listed on **Table 8**, results show that percentage errors were low in body temperature experiment with the exception of magnesium hydroxide. (See **Appendices 5 and 6** for details of uncertainty and percentage error calculations.)

	Average Ksp Values	Average Uncertainty	Total Percentage Error	Average Percentage Error
Ca(OH) _{2(aq)}	1.77 x 10 ⁻⁵	8.23%	23.16 %	5.79 %
Mg(OH) _{2(aq)}	1.50 x 10 ⁻¹¹	20.53%	171.20 %	42.80 %
Ba(OH) _{2(aq)}	3.68 x 10 ⁻³	5.66%	7.58 %	1.90 %

Table 8: For body temperature experiment, average Ksp values and average uncertainty of all trials of Ca(OH)_{2(aq)}, Mg(OH)_{2(aq)}, Ba(OH)_{2(aq)}.

It should be noted that according to experiment results, although the solubilities of barium hydroxide and magnesium hydroxide increase with temperature, whereas calcium hydroxides solubility decreases as temperature increases. We expect solubility of a substance to increase as the temperature goes up. Therefore, reduction in $K_{sp_{Ca(OH)_2}}$ as temperature increase is an exception.

Experiments confirm that a) Solubilities of calcium hydroxide, magnesium hydroxide and barium hydroxide are very different than one another, and b) in each trial, relative solubilities for calcium hydroxide, magnesium hydroxide and barium hydroxide are as follows:



6. CONCLUSION AND FUTURE RESEARCH

The objective in this research was to determine the solubility levels of calcium hydroxide, magnesium hydroxide and barium hydroxide by conducting titration experiments with HCl solution, and compare them with respect to their usage in endodontic treatment with a chemical point of view.

The experiment showed that magnesium hydroxide had the lowest K_{sp} value, barium hydroxide had the highest K_{sp} value, and K_{sp} value of calcium hydroxide was in between.

This result confirmed that calcium hydroxide is more suitable for endodontic treatment as average solubility level is necessary for successful root canal treatment. Low solubility of magnesium hydroxide makes it difficult to supply enough ions to cure the infected dentin. On the other hand, high solubility of barium hydroxide makes it easier to transport potentially toxic amounts of material to other parts of the body during treatment via blood that may be harmful. However very little amounts of Mg^{+2} and Ba^{+2} ions exist in human body, large number of these can cause heavy metal poisoning.

It was also observed that solubility of calcium hydroxide decreased when experiments were conducted at body temperature compared to at room temperature, even though solubilities of barium hydroxide and magnesium hydroxide increased with temperature.

Main limitation of the experiment was not being able to include all Group IIA Hydroxides. Since it was not possible to find Beryllium (Be), Strontium (Sr), and Radium (Ra), these were not used in the experiment. Because the experiment was not conducted by including all Earth Alkaline Hydroxides, a generalization was made rather than a strict implication about calcium hydroxide having the most preferred solubility property for success in canal treatment, among "all" hydroxides.

There were some issues that impacted the results of the experiment.

This first issue was due to the unpreventable uncertainties introduced by the apparatus used during the experiment. Because of this, the average uncertainty and percentage error values were included during the calculations to demonstrate the accuracy for each case.

A method was applied for the average K_{sp} values to be used in the percentage error calculations, as only the literary K_{sp} values were available for room temperature, but not for the body temperature ones.

K_{sp} values corresponding to four trials were averaged out and this average value was used as the K_{sp} value in the percentage error calculation. Results showed that percentage errors were low with only one exception. For magnesium hydroxide percentage error was high in the case of at body temperature experiment. This high percentage error can be related to the magnesium hydroxides lowest solubility among other hydroxides in the experiment.

The other issue was related with the distilled water used in the experiment. The measurements performed after the experiment showed that pH value of distilled water was approximately in between 5.5 – 6.0. This value indicated that the water was slightly acidic instead of being neutral, because of the dissolution of carbon dioxide gas in air when it contacts to the solutions, which may have caused the equivalence point to shift.

The last issue noted was about the vacuum filtration. It is possible that not all solid materials were filtered completely. Some invisible particles of chemicals may have remained and potentially led to somewhat biased results.

In order to minimize these possible errors, improvements can be made to the experimental method in future applications. If possible, the chemical limitations should be eliminated. Experiment should be done with all Group IIA Hydroxides. The apparatus with lower uncertainty should be used to minimize the percentage error caused. pH of the distilled water should be calibrated to neutral pH to clearly see the equivalence point. Although the formula $V_1M_1 = V_2M_2$ was used to determine the molarity and volume of the hydrochloric acid, it may not be possible to be positively

certain about the molarity of HCl. Standardization process of the solution should be applied to improve accuracy of the molarity of HCl.

APPENDICES

APPENDIX 1: Root Canal Treatment and Its Steps

In the situations requiring root canal treatment, there is an infection in the dental pulp and the root tip of the tooth. When the dental pulp is damaged and unable to repair itself, bacteria spreads deep into the root. If these infections are not removed, whole tooth and the surrounding tissues are exposed to the same infection, resulting in loss of tooth. Root canal treatment removes the infected tissues and places them with artificial materials. Although root canal treatment is a difficult, painful and long process, it is preferred to keep the natural tooth via root canal treatment, because under existing technology, artificial teeth do not perfectly substitute for natural tooth. Although the pulp is important for development and growth of the tooth, once tooth becomes mature it can survive without the pulp by surrounding tissues ².

In the root canal treatment, as a first step, infected pulp is removed, and emptied tooth canal is reshaped for future filling using small instruments with thin tips. During this stage, canal is filled with temporary filling materials for sterilization using preloaded syringes. Once infections are removed fully and tooth canal reshaping is finalized, permanent, rubber like filling materials called gutta-percha are injected into tooth canal. Finally, to close up the opening, regular dental fillings are applied to the top of the tooth ².

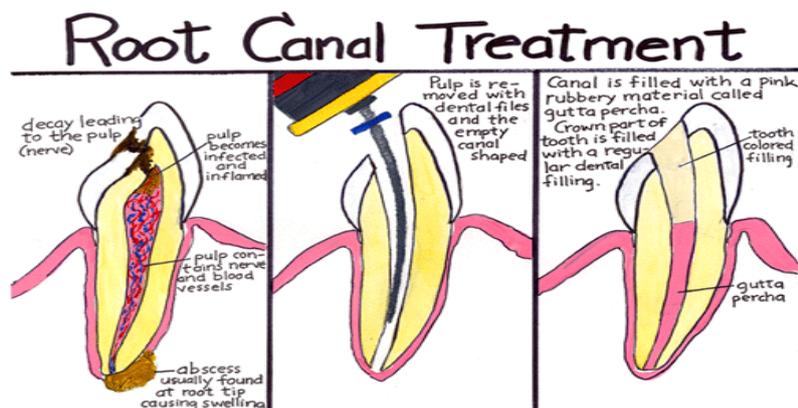


Figure 1: Stages of root canal treatment (Source: <http://www.dentistelwood.com.au/wp-content/uploads/rootcanal.gif>)

APPENDIX 2: Chemical Effects of Calcium Hydroxide In Root Canal Treatment

From a chemical point of view calcium hydroxide is an ionic compound in crystal structure where each calcium ion has two hydroxyl ions.



Calcium hydroxide can be classified as a strong basic substance which has an approximately pH of 11-12.⁷ In an aqueous solution, calcium hydroxide releases calcium ions and hydroxyl ions. It is slightly soluble in water and insoluble in alcohol. Its low solubility in water is a useful characteristic while considering the biocompatibility in the problematic area. A long period of time is required before all calcium hydroxide to be solved in the tissue fluids and diverge into the body with blood and lose its direct effectiveness.

Most of the effects of calcium hydroxide as a temporary intra canal filling material are related to this release of ions and low water solubility. The major topics of related effects ⁸ are;

1. Antimicrobial and antibacterial activity
2. Activation of some related enzymes for healing
3. Accelerating healing
4. Cell stimulation, migration, proliferation and mineralization

The antimicrobial and antibacterial effects of calcium hydroxide totally depend on the presence of hydroxyl ions. The bacterial cytoplasmic membrane composes of phospholipids which supplies some important functions of the cellular interaction and intraction. Hydrogen atoms are removed from unsaturated fatty acids by hydroxyl ions which yields a free lipidic radical. Lipidic peroxide is formed as a product of the reaction between oxygen and free lipidic radical which causes removal of another hydrogen ion from a second unsaturated fatty acid inducing chain reactions. This reactions can be defined as autocatalytic that canalizes to excess loss of unsaturated fatty acids that ends up with membrane damage.

Metabolism of living organisms dominantly depends on the enzymatic activities. All of enzymes have different pH ranges where they can show optimum effectiveness. The basic environment alkalization, provided by calcium hydroxide causes ionic bonds between tertiary structure of proteins to break down. So, it can be stated that bacteria's structural proteins are damaged by the basic environment which is provided by hydroxyl ions. Besides the damage on cytoplasmic membrane, activity of enzymes, structure of proteins and the splitting of DNA strands of bacteria is related to the reaction with hydroxyl ions. Thus, it has been generally accepted that the ability of calcium hydroxide to absorb carbon dioxide, which

⁸ Research Database, Chemistry, Earth alkaline metals, 22.11.2010
<http://chemistry.about.com/od/elementgroups/a/alkalineearths.-Ns_.htm>

is a reason of acidic environment in the problematic area, may contribute to its antibacterial activity. All of this breaking down conditions can be explained by the high concentration of hydroxyl ions, reaching high pH levels where bacteria can not survive which leads the destruction of microorganisms.

They act as neutralizing agents in the problematic area which is acidic due to formation of lactic acid. Lactic acid can be classified one of the biomolecules which highly oxidant free hydroxyl ion radicals show extreme reactivity. But for this neutralization reaction to achieve its target a period of time is required. Hydroxyl ions released by the temporary filling material requires some time, 1-7 days, to reach the outer root of dentine and 3-4 weeks are necessary to increase in pH levels and stabilization of it. Besides the release of hydroxyl ions calcium hydroxide paste also releases calcium ions which activates some enzymes responsible from healing and helps cell stimulation, migration, proliferation and mineralization as the structure of dentin highly includes calcium^{9 10}.

Most of the characteristics of calcium hydroxide explained above and biocompatibility in the problematic area can be related to its solubility in water and level of solubility. High solubility of materials causes cytotoxic effects in human body which is not valid for calcium hydroxide because of its low solubility in water however high pH levels of aqueous saturated solution of calcium hydroxide has cytotoxic potential. But regarding its low solubility in water and low diffusion through tissues it is biocompatible in human body. With respect to these qualities cytotoxicity of calcium hydroxide is limited. One may think that even this low solubility of calcium hydroxide may cause some problems may recall that the presence of hydroxyl and calcium ions depends on its solubility. The low solubility and low diffusion of calcium hydroxide may make it difficult to gain a rapid increase in pH to maintain the prohibition of bacteria, but this property of calcium hydroxide is beneficial while considering the fact that the rapid absorption of hydroxyl and calcium ions by surrounding tissues will cause their concentration to decrease which leads reduction of antibacterial effects³.

APPENDIX 3: K_{sp} for Calcium Hydroxide, Magnesium Hydroxide and Barium Hydroxide

⁹ Rehman K, Saunders WP, Foye RH, Sharkley SW, Calcium ion diffusion from calcium hydroxide containing materials in endodontically-treated teeth: an in vitro study, 1996, 29 - 271-279.

¹⁰ Carnes DI, Del Rio CE, Esberard RM, Changes to pH at the dentin in roots obturated with calcium hydroxide pastes, 1996, 22- 402-405.

Calcium hydroxide is a chemical compound with the formula Ca(OH)_2 and an ionic solid which is sparingly soluble in water. Calcium hydroxide has pH value of 11-12, which can be determined as a medium base that violently reacts with acids and attracts with many metals in presence of water. A saturated, aqueous solution of Ca(OH)_2 is represented in equation below:



Magnesium Hydroxide is found as an odorless white powder with the formula Mg(OH)_2 . It has pH value of 9.5-10.5. It appears to be insoluble in water but if you shake the beaker and then filter the solution and test the pH of the solution it is slightly basic. This shows that some OH^- ions exist in it. Magnesium hydroxide is considered as an antacid. A saturated, aqueous solution of Mg(OH)_2 is represented in equation below:



Barium hydroxide is an odorless white crystals found solid in room temperature. It is moderately soluble in water and its aqueous solutions are strongly alkaline. In aqueous form it releases Ba^{+2} and OH^- ions. The equation, dissociation into ions, is represented below:



The solubility product expression indicates, in mathematical terms, the solubility of an ionic compound³. It can also be defined as the equilibrium that is established between solid substance and its dissolved ions in an aqueous system. All compounds have their own K_{sp} values. However, K_{sp} value is commonly considered only when the compound is slightly soluble and the ions dissolved in its aqueous solution is not simple to measure.

The equilibrium for K_{sp} of Ca(OH)_2 , Mg(OH)_2 and Ba(OH)_2 is shown below:

$$K_{\text{spCa(OH)}_2} = [\text{Ca}^{+2}] [\text{OH}^-]^2$$

$$K_{\text{spMg(OH)}_2} = [\text{Mg}^{+2}] [\text{OH}^-]^2$$

$$K_{\text{spBa(OH)}_2} = [\text{Ba}^{+2}] [\text{OH}^-]^2$$

APPENDIX 4: Full List of K_{sp} Calculations

K_{sp} Calculations For Room Temperature Experiment:

<u>Ca(OH)_{2(aq)}:</u>	<u>Mg(OH)_{2(aq)}:</u>	<u>Ba(OH)_{2(aq)}:</u>
<u>Trial 1:</u> K _{sp} : [Ca ⁺²][OH ⁻] ² if [Ca ⁺²] = x then K _{sp} = 4x ³ Convert Δh of HCl from ml to L : 7,1 ml x 1L / 1000ml = 7,1 x 10⁻³ L Find moles of H ⁺ ions : 7,1 x 10 ⁻³ x 0,1 = 7.1 x 10⁻⁴ moles [H ⁺] = [OH ⁻] => 7.1 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,035 M Since [H ⁺] = [OH ⁻] and [Ca ⁺²] = 2[OH ⁻] x = 0,035 / 2 = 0,018M K _{sp} of Ca(OH) ₂ for Trial 1 = 2,24 x 10⁻⁵ since K _{sp} = 4x ³	<u>Trial 1:</u> 0,07 x 10 ⁻³ x 0,1 = 0,07 x 10⁻⁴ moles 0,07 x 10 ⁻⁴ / 20 x 10 ⁻³ = 3,4 x 10 ⁻⁴ M 3,4 x 10 ⁻⁴ / 2 = 1,75 x 10⁻⁴ M K _{sp} = 2,79 x 10⁻¹¹	<u>Trial 1:</u> 33,8 x 10 ⁻³ x 0,1 = 33,8 x 10⁻⁴ moles 33,8 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,169 M 0,169 / 2 = 0,0845 M K _{sp} = 2,41 x 10⁻³
<u>Trial 2:</u> 7,4 x 10 ⁻³ x 0,1 = 7,4 x 10⁻⁴ moles 7,4 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,037 M 0,037 / 2 = 0,0185M K _{sp} = 2,53 x 10⁻⁵	<u>Trial 2:</u> 0,05 x 10 ⁻³ x 0,1 = 0,05 x 10⁻⁴ moles 0,05 x 10 ⁻⁴ / 20 x 10 ⁻³ = 2,5 x 10 ⁻⁴ M 2,5 x 10 ⁻⁴ / 2 = 1,25 x 10⁻⁴ M K _{sp} = 2,60 x 10⁻¹¹	<u>Trial 2:</u> 33,6 x 10 ⁻³ x 0,1 = 33,6 x 10⁻⁴ moles 33,6 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,168 M 0,168 / 2 = 0,084 M K _{sp} = 2,37 x 10⁻³
<u>Trial 3:</u> 7,5 x 10 ⁻³ x 0,1 = 7,5 x 10⁻⁴ moles 7,5 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,0375 M 0,037 / 2 = 0,01875M K _{sp} = 2,64 x 10⁻⁵	<u>Trial 3:</u> 0,07 x 10 ⁻³ x 0,1 = 0,07 x 10⁻⁴ moles 0,07 x 10 ⁻⁴ / 20 x 10 ⁻³ = 3,4 x 10 ⁻⁴ M 3,4 x 10 ⁻⁴ / 2 = 1,75 x 10⁻⁴ M K _{sp} = 2,79 x 10⁻¹¹	<u>Trial 3:</u> 33,3 x 10 ⁻³ x 0,1 = 33,3 x 10⁻⁴ moles 33,3 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,1665 M 0,1665 / 2 = 0,08325 M K _{sp} = 2,31 x 10⁻³
<u>Trial 4:</u> 7,4 x 10 ⁻³ x 0,1 = 7,4 x 10⁻⁴ moles 7,4 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,037 M 0,037 / 2 = 0,0185M K _{sp} = 2,53 x 10⁻⁵	<u>Trial 4:</u> 0,06 x 10 ⁻³ x 0,1 = 0,06 x 10⁻⁴ moles 0,06 x 10 ⁻⁴ / 20 x 10 ⁻³ = 3 x 10 ⁻⁴ M 3 x 10 ⁻⁴ / 2 = 1,50 x 10⁻⁴ M K _{sp} = 2,64 x 10⁻¹¹	<u>Trial 4:</u> 33,7 x 10 ⁻³ x 0,1 = 33,7 x 10⁻⁴ moles 33,7 x 10 ⁻⁴ / 20 x 10 ⁻³ = 0,1685 M 0,1685 / 2 = 0,08425 M K _{sp} = 2,39 x 10⁻³

K_{sp} Calculations For Body Temperature:

<u>Ca(OH)_{2(aq)}:</u>	<u>Mg(OH)_{2(aq)}:</u>	<u>Ba(OH)_{2(aq)}:</u>
<u>Trial 1:</u>	<u>Trial 1:</u>	<u>Trial 1:</u>

$6,7 \times 10^{-3} \times 0,1 = 6,7 \times 10^{-4}$ moles $6,7 \times 10^{-4} / 20 \times 10^{-3} = 0,0335$ M $0,0335 / 2 = 0,01675 \text{ M}$ $K_{sp} = 1,88 \times 10^{-5}$	$0,16 \times 10^{-3} \times 0,1 = 0,16 \times 10^{-4}$ moles $0,16 \times 10^{-4} / 20 \times 10^{-3} = 8 \times 10^{-4}$ M $8 \times 10^{-4} / 2 = 4 \times 10^{-4} \text{ M}$ $K_{sp} = 2,56 \times 10^{-10}$	$39,3 \times 10^{-3} \times 0,1 = 39,3 \times 10^{-4}$ moles $39,3 \times 10^{-4} / 20 \times 10^{-3} = 0,1965 \text{ M}$ $0,1965 / 2 = 0,09825 \text{ M}$ $K_{sp} = 3,79 \times 10^{-3}$
<u>Trial 2 – 3 – 4 :</u> $6,4 \times 10^{-3} \times 0,1 = 6,4 \times 10^{-4}$ moles $6,4 \times 10^{-4} / 20 \times 10^{-3} = 0,032 \text{ M}$ $0,032 / 2 = 0,016 \text{ M}$ $K_{sp} = 1,67 \times 10^{-5}$	<u>Trial 2:</u> $0,14 \times 10^{-3} \times 0,1 = 0,14 \times 10^{-4}$ moles $0,14 \times 10^{-4} / 20 \times 10^{-3} = 7 \times 10^{-4}$ M $7 \times 10^{-4} / 2 = 3,5 \times 10^{-4} \text{ M}$ $K_{sp} = 1,72 \times 10^{-10}$	<u>Trial 2:</u> $38,5 \times 10^{-3} \times 0,1 = 38,5 \times 10^{-4}$ moles $38,5 \times 10^{-4} / 20 \times 10^{-3} = 0,1925 \text{ M}$ $0,1925 / 2 = 0,09625 \text{ M}$ $K_{sp} = 3,57 \times 10^{-3}$
	<u>Trial 3:</u> $0,12 \times 10^{-3} \times 0,1 = 0,12 \times 10^{-4}$ moles $0,12 \times 10^{-4} / 20 \times 10^{-3} = 6 \times 10^{-4}$ M $6 \times 10^{-4} / 2 = 3 \times 10^{-4} \text{ M}$ $K_{sp} = 1,08 \times 10^{-10}$	<u>Trial 3:</u> $38,8 \times 10^{-3} \times 0,1 = 38,8 \times 10^{-4}$ moles $38,8 \times 10^{-4} / 20 \times 10^{-3} = 0,194 \text{ M}$ $0,194 / 2 = 0,097 \text{ M}$ $K_{sp} = 3,65 \times 10^{-3}$
	<u>Trial 4:</u> $0,10 \times 10^{-3} \times 0,1 = 0,10 \times 10^{-4}$ moles $0,10 \times 10^{-4} / 20 \times 10^{-3} = 5 \times 10^{-4}$ M $5 \times 10^{-4} / 2 = 2,5 \times 10^{-4} \text{ M}$ $K_{sp} = 0,63 \times 10^{-10}$	<u>Trial 4:</u> $39,0 \times 10^{-3} \times 0,1 = 39,0 \times 10^{-4}$ moles $39,0 \times 10^{-4} / 20 \times 10^{-3} = 0,195 \text{ M}$ $0,195 / 2 = 0,0975 \text{ M}$ $K_{sp} = 3,71 \times 10^{-3}$

APPENDIX 5: Uncertainty Calculations

Uncertainty Calculations For Room Temperature Experiment:

Ca(OH)_{2(aq)}

Average Volume Change of 0,10M HCl : $(7,1 + 7,4 + 7,5 + 7,4) / 4 = 7,3 \text{ ml}$

Uncertainty of Burette: $\frac{0,2}{7,3} \cdot 100 = 2,74 \%$

Uncertainty of Pipette: $\frac{0,02}{20} \cdot 100 = 0,10 \%$

$$\text{Uncertainty of Volumetric Flask: } \frac{0,25}{500} \cdot 100 = 0,05 \%$$

$$\text{Uncertainty of Graduated Cylinder: } \frac{0,20}{4,00} \cdot 100 = 5,00 \%$$

$$\text{Total Uncertainty : } 2,74\% + 0,10\% + 0,05\% + 5,00\% = 7,89\%$$

$$\text{Average Ksp of Ca(OH)}_2: [(2,24 + 2,53 + 2,64 + 2,53) \times 10^{-5}] / 4 = 2,48 \times 10^{-5} \pm 7,89\%$$

Mg(OH)_{2(aq)}:

$$\text{Average Volume Change of 0,10M HCl : } (0,07 + 0,05 + 0,07 + 0,06) / 4 = 0,06\text{ml}$$

$$\text{Uncertainty of Burette: } \frac{0,02}{0,06} \cdot 100 = 33,33 \%$$

$$\text{Uncertainty of Pipette: } \frac{0,02}{20} \cdot 100 = 0,10 \%$$

$$\text{Uncertainty of Volumetric Flask: } \frac{0,25}{500} \cdot 100 = 0,05 \%$$

$$\text{Uncertainty of Graduated Cylinder: } \frac{0,20}{4,00} \cdot 100 = 5,00 \%$$

$$\text{Total Uncertainty : } 33,33\% + 0,10\% + 0,05\% + 5,00\% = 38,48\%$$

$$\text{Average Ksp of Mg(OH)}_2: [(2,79 + 2,60 + 2,79 + 2,64) \times 10^{-11}] / 4 = 2,71 \times 10^{-11} \pm 33,48\%$$

Ba(OH)_{2(aq)}:

$$\text{Average Volume Change of 0,10M HCl : } (33,8 + 33,6 + 33,3 + 33,7) / 4 = 33,6\text{ml}$$

$$\text{Uncertainty of Burette: } \frac{0,2}{33,6} \cdot 100 = 0,60 \%$$

$$\text{Uncertainty of Pipette: } \frac{0,02}{20} \cdot 100 = 0,10 \%$$

$$\text{Uncertainty of Volumetric Flask: } \frac{0,25}{500} \cdot 100 = 0,05 \%$$

$$\text{Uncertainty of Graduated Cylinder: } \frac{0,20}{4,00} \cdot 100 = 5,00 \%$$

$$\text{Total Uncertainty : } 0,60\% + 0,10\% + 0,05\% + 5,00\% = 5,75\%$$

$$\text{Average Ksp of Ba(OH)}_2: [(2,41 + 2,37 + 2,31 + 2,39) \times 10^{-3}] / 4 = 2,37 \times 10^{-3} \pm 5,75\%$$

Uncertainty Calculations For Body Temperature Experiment:

Ca(OH)_{2(aq)}:

Average Volume Change of 0,10M HCl : $(6,7 + 6,4 + 6,4 + 6,4) / 4 = 6,5\text{ml}$

Uncertainty of Burette: $\frac{0,2}{6,5} \cdot 100 = 3,08\%$

Uncertainty of Pipette: $\frac{0,02}{20} \cdot 100 = 0,10\%$

Uncertainty of Volumetric Flask: $\frac{0,25}{500} \cdot 100 = 0,05\%$

Uncertainty of Graduated Cylinder: $\frac{0,20}{4,00} \cdot 100 = 5,00\%$

Total Uncertainty : $3,08\% + 0,10\% + 0,05\% + 5,00\% = 8,23\%$

Average Ksp of Ca(OH)₂: $[(1,88 + 1,67 + 1,67 + 1,67) \times 10^{-5}] / 4 = 1,77 \times 10^{-5} \pm 8,23\%$

Mg(OH)_{2(aq)}:

Average Volume Change of 0,10M HCl : $(0,16 + 0,14 + 0,12 + 0,10) / 4 = 0,13\text{ml}$

Uncertainty of Burette: $\frac{0,02}{0,13} \cdot 100 = 15,38\%$

Uncertainty of Pipette: $\frac{0,02}{20} \cdot 100 = 0,10\%$

Uncertainty of Volumetric Flask: $\frac{0,25}{500} \cdot 100 = 0,05\%$

Uncertainty of Graduated Cylinder: $\frac{0,20}{4,00} \cdot 100 = 5,00\%$

Total Uncertainty : $15,38\% + 0,10\% + 0,05\% + 5,00\% = 20,53\%$

Average Ksp of Mg(OH)₂: $[(2,56 + 1,72 + 1,08 + 0,63) \times 10^{-11}] / 4 = 1,50 \times 10^{-11} \pm 20,53\%$

Ba(OH)_{2(aq)}:

Average Volume Change of 0,10M HCl : $(39,3 + 38,5 + 38,8 + 39,0) / 4 = 38,9\text{ml}$

Uncertainty of Burette: $\frac{0,2}{38,9} \cdot 100 = 0,51\%$

Uncertainty of Pipette: $\frac{0,02}{20} \cdot 100 = 0,10\%$

Uncertainty of Volumetric Flask: $\frac{0,25}{500} \cdot 100 = 0,05\%$

Uncertainty of Graduated Cylinder: $\frac{0,20}{4,00} \cdot 100 = 5,00\%$

Total Uncertainty : $0,51\% + 0,10\% + 0,05\% + 5,00\% = 5,66\%$

Average Ksp of Ba(OH)₂: $[(3,79 + 3,57 + 3,65 + 3,71) \times 10^{-3}] / 4 = 3,68 \times 10^{-3} \pm 5,66\%$

APPENDIX 6: Percentage Error Calculations

Percentage error will be calculated for the average of experimentally calculated Ksp values of the earth alkaline hydroxides and the following formula will be applied.

$$\frac{|Average Value - Experimental Value|}{Average Value} \times 100$$

Uncertainty Calculations For Room Temperature Experiment:

Ca(OH)_{2(aq)}:

Trial 1 : $(|2,48 \times 10^{-5} - 2,24 \times 10^{-5}| / 2,48 \times 10^{-5}) \times 100 = 9,68\%$

Trial 2 : $(|2,48 \times 10^{-5} - 2,53 \times 10^{-5}| / 2,48 \times 10^{-5}) \times 100 = 2,02\%$

Trial 3 : $(|2,48 \times 10^{-5} - 2,64 \times 10^{-5}| / 2,48 \times 10^{-5}) \times 100 = 6,45\%$

Trial 4 : $(|2,48 \times 10^{-5} - 2,53 \times 10^{-5}| / 2,48 \times 10^{-5}) \times 100 = 2,02\%$

Total Percentage Error: $(9,68 + 2,02 + 6,45 + 2,02)\% = 20,17\%$

Average Percentage Error: $(9,68 + 2,02 + 6,45 + 2,02)\% / 4 = 5,04\%$

Mg(OH)_{2(aq)} :

Trial 1: $(|2,71 \times 10^{-11} - 2,79 \times 10^{-11}| / 2,71 \times 10^{-11}) \times 100 = 2,95\%$

Trial 2: $(|2,71 \times 10^{-11} - 2,60 \times 10^{-11}| / 2,71 \times 10^{-11}) \times 100 = 4,06\%$

Trial 3: $(|2,71 \times 10^{-11} - 2,79 \times 10^{-11}| / 2,71 \times 10^{-11}) \times 100 = 2,95\%$

Trial 4: $(|2,71 \times 10^{-11} - 2,64 \times 10^{-11}| / 2,71 \times 10^{-11}) \times 100 = 2,58\%$

Total Percentage Error: $(2,95 + 4,06 + 2,95 + 2,58)\% = 12,54\%$

Average Percentage Error: $(2,95 + 4,06 + 2,95 + 2,58)\% / 4 = 3,14\%$

Ba(OH)_{2(aq)} :

Trial 1: $(|2,37 \times 10^{-3} - 2,41 \times 10^{-3}| / 2,37 \times 10^{-3}) \times 100 = 1,69\%$

Trial 2: $(|2,37 \times 10^{-3} - 2,37 \times 10^{-3}| / 2,37 \times 10^{-3}) \times 100 = 0\%$

Trial 3: $(|2,37 \times 10^{-3} - 2,31 \times 10^{-3}| / 2,37 \times 10^{-3}) \times 100 = 2,53\%$

Trial 4: $(|2,37 \times 10^{-3} - 2,39 \times 10^{-3}| / 2,37 \times 10^{-3}) \times 100 = 0,84\%$

Total Percentage Error: $(1,69 + 0 + 2,53 + 0,84)\% = 5,06\%$

Average Percentage Error: $(1,69 + 0 + 2,53 + 0,84)\% / 4 = \mathbf{1,68\%}$

Uncertainty Calculations For Body Temperature Experiment:

$\text{Ca(OH)}_{2(\text{aq})}$:

Trial 1 : $(|1,77 \times 10^{-5} - 1,88 \times 10^{-5}| / 1,77 \times 10^{-5}) \times 100 = 6,21\%$

Trial 2 : $(|1,77 \times 10^{-5} - 1,67 \times 10^{-5}| / 1,77 \times 10^{-5}) \times 100 = 5,65\%$

Trial 3 : $(|1,77 \times 10^{-5} - 1,67 \times 10^{-5}| / 1,77 \times 10^{-5}) \times 100 = 5,65\%$

Trial 4 : $(|1,77 \times 10^{-5} - 1,67 \times 10^{-5}| / 1,77 \times 10^{-5}) \times 100 = 5,65\%$

Total Percentage Error: $(6,21 + 5,65 + 5,65 + 5,65)\% = \mathbf{23,16\%}$

Average Percentage Error: $(6,21 + 5,65 + 5,65 + 5,65)\% / 4 = \mathbf{5,79\%}$

$\text{Mg(OH)}_{2(\text{aq})}$:

Trial 1: $(|1,50 \times 10^{-10} - 2,56 \times 10^{-10}| / 1,50 \times 10^{-11}) \times 100 = 70,60\%$

Trial 2: $(|1,50 \times 10^{-10} - 1,72 \times 10^{-10}| / 1,50 \times 10^{-11}) \times 100 = 14,60\%$

Trial 3: $(|1,50 \times 10^{-10} - 1,08 \times 10^{-10}| / 1,50 \times 10^{-11}) \times 100 = 28,00\%$

Trial 4: $(|1,50 \times 10^{-10} - 0,63 \times 10^{-10}| / 1,50 \times 10^{-11}) \times 100 = 58,00\%$

Total Percentage Error: $(70,60 + 14,60 + 28,00 + 58,00)\% = \mathbf{171,20\%}$

Average Percentage Error: $(70,60 + 14,60 + 28,00 + 58,00)\% / 4 = \mathbf{42,80\%}$

$\text{Ba(OH)}_{2(\text{aq})}$:

Trial 1: $(|3,68 \times 10^{-3} - 3,79 \times 10^{-3}| / 3,68 \times 10^{-3}) \times 100 = 2,99\%$

Trial 2: $(|3,68 \times 10^{-3} - 3,57 \times 10^{-3}| / 3,68 \times 10^{-3}) \times 100 = 2,99\%$

Trial 3: $(|3,68 \times 10^{-3} - 3,65 \times 10^{-3}| / 3,68 \times 10^{-3}) \times 100 = 0,80\%$

Trial 4: $(|3,68 \times 10^{-3} - 3,71 \times 10^{-3}| / 3,68 \times 10^{-3}) \times 100 = 0,80\%$

Total Percentage Error: $(2,99 + 2,99 + 0,80 + 0,80)\% = \mathbf{7,58\%}$

Average Percentage Error: $(2,99 + 2,99 + 0,80 + 0,80)\% / 4 = \mathbf{1,90\%}$

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