Physics Extended Essay

How does salt concentration of water affect the period of a spring placed in water?

Word Count: 3692

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Introduction

Springs are one of the most frequently used objects in our daily day lives and therefore is also a very crucial topic to learn in school. They are mostly used to keep pieces of mechanics together, to keep vibrations minimum and to provide those pieces motion. In almost all machinery springs are encountered. To learn the working principles of springs and their limitations are some of the most significant things to acknowledge in physics as they embrace a huge part in the subject. While learning this topic in class it came to my mind that it is almost impossible to provide the same conditions in every mechanism and therefore the urge to work on springs occurred to understand how mechanisms work with different springs. I have always loved working with different machines and their parts. Tearing something up and then combining the pieces again was always a joyful hobby of mine. Learning about a part of a machine, the springs, was a chance for me to improve my skills and I did not hesitate the waste the chance. This essay aims to understand how springs work in different conditions, density of mediums in order to use them more efficiently. The experiment contains measurements of periods of spring oscillation at different concentrations of salt in water. Different salt amount will be dissolved in water and the oscillation times will be measured. The result will then be checked if the hypothesis is supported or not.

Background Information

An event that repeats itself again and again is called the “periodic motion” which is also called in this occasion “simple harmonic motion where acceleration is directly proportional to the displacement but in opposite direction and towards the equilibrium position.”. Period is referred as the time of one cycle in a repetitive event, expressed with the letter T. Period of a mass m on a spring with a constant k, a number that tells us how rigid a spring is, can be calculated with the formula,

$$T=2\pi\sqrt{\frac{m}{k}}$$ [1]

The figure above shows the periodic motion of a mass spring which results in oscillation. Oscillation means “a repetitive variation, typically in time, of some measure about a central value (often a point of equilibrium) or between two or more different states”. The period of a spring depends on many variables. If we pull the mass attached on the spring to expand the spring and then let it go, it will move back and forth until it comes back to the state where it was at the beginning. This movement happens because of the restoring force. Restoring force is a force that is acted on the opposite direction of the movement of the object to bring it back to its equilibrium position. Most common examples of restoring force is seen in springs. The force can be measured by multiplying the spring’s constant and with the amount of stretch, also known as Hooke’s Law:

$$F_S = -kx$$ [2]

[1] Khan Academy (n.d.) *Simple harmonic motion In spring-mass systems review* Retrieved September 2021, from https://www.khanacademy.org/science/in-in-class11th-physics/in-in-11th-physics-oscillations/in-in-simple-harmonic-motion-in-spring-mass-systems/a/simple-harmonic-motion-of-spring-mass-systems-ap#:~:text=The%20period%20of%20a%20spring,root%20of%20the%20spring%20constant

[2] Wikipedia (2021, December 15) *Hooke’s Law* Retrieved September 2021, from https://en.wikipedia.org/wiki/Hooke%27s_law#For_linear_springs

Where k is the spring constant and x is the stretch of spring in meters. There is a negative sign in front of the formal definition because the restoring force is always in the opposite direction to the direction of movement.

If we assume the ground is frictionless, it will have a non-ending motion with the spring compressing and loosening. If a graph was drawn about the motion of the mass, a "sinusoidal wave" would be seen. Sinusoidal wave means a curve that describes a periodic oscillation, and it is continuous, one like in figure 1:

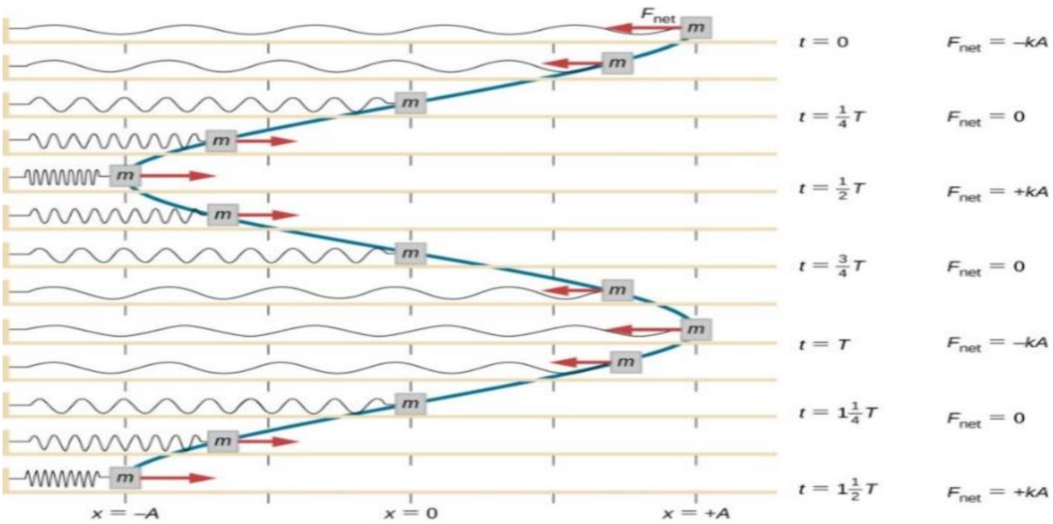


Figure 1: oscillation of mass spring attached to a wall[3]

In gaseous mediums the variable that eventually stops the periodic motion is the friction force and air resistance. When things move at a certain direction, a force from the opposite direction will be encountered when two surfaces are in contact with each other and thus aggravating the movement. Air resistance is also another force acting on the moving object in the opposite direction. When the medium changes to water instead of air resistance another force called water resistance will take place. Air and water resistances are both called drag forces and they can be calculated with the formula

[3] Lumen Learning (n.d.) *Simple Harmonic Motion* https://courses.lumenlearning.com/suny-osuniversityphysics/chapter/15-1-simple-harmonic-motion/

$$F_D = \frac{1}{2}\rho v^2 C_D A$$ [4]

Where C is the drag coefficient, A is the surface area of object facing the fluid, v is the velocity and ρ is the fluid density. The formula proves that as the density of liquid increases so does the resistance force, which will make the periodic motion harder.

When salt is dissolved in water, the mass increases, affecting the density of water, proven by the formula of:

$$\rho = \frac{M}{V}$$ [5]

where d is density, *M* is mass and *V* is volume. The volume does not change unless identical water is added, the salt molecules does not change the volume, but they come in between H_2O molecules forming the water. But M increases because salt has its own mass and is added to the mass of water.

Theory

The experiment measures the oscillation time in seconds, the period. The movement, spring makes up and down is thought to be the period of the spring. The spring will be held upwards until the spring cannot tighten more and will be let go. The measure of the cycle will give the period.

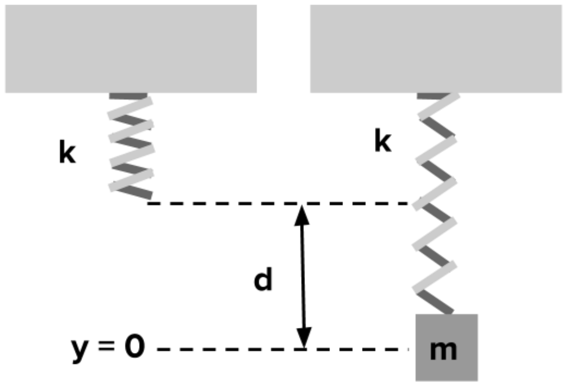
When more salt is dissolved, the drag force will increase, proven by the formula given:

$$F_D = \frac{1}{2}\rho v^2 C_D A$$ [6]

[4] Nancy Hall (2021, 13 May) The Drag Equation, *National Aeronautics and Space Administration* https://www.grc.nasa.gov/www/k-12/airplane/drageq.html
[5] Toppr (n. d.) Density Formula, *Physics Formulas* https://www.toppr.com/guides/physics-formulas/density-formula/
[6] Nancy Hall (2021, 13 May) The Drag Equation, *National Aeronautics and Space Administration* https://www.grc.nasa.gov/www/k-12/airplane/drageq.html

Where ρ is the density of the fluid. Density is directly proportional to the drag force, F_D, so when the salt concentration increases the drag force will also increase.

For the other part of the experiment, applying the appropriate amount of force is also very crucial. The same amount of force may not be possible but similar amounts of force should be applied on the spring to make it take the same amount of distance in each data set.



[7]

Figure 2: spring stretch when mass is applied

k: spring constant (N/m)
d: distance between spring at equilibrium and stretched spring (m)
m: mass (kg)

The figure above shows how a spring hanged on a surface facing above makes its periodic movement. The essay is using the spring as the image shows. When the spring is pulled upwards, it will then be let go to make it start its movement. Enough force should be applied as too much can harm the spring and too less may not start its movement. The angle it is applied is also very crucial. The spring should be held directly upwards, without any angular position.

[7] Khan Academy (n.d.) *Simple harmonic motion In spring-mass systems review* Retrieved September 2021, from https://www.khanacademy.org/science/in-in-class11th-physics/in-in-11th-physics-oscillations/in-in-simple-harmonic-motion-in-spring-mass-systems/a/simple-harmonic-motion-of-spring-mass-systems-ap#:~:text=The%20period%20of%20a%20spring,root%20of%20the%20spring%20constant

If the spring is not making an angle of 90 degrees to the surface it is attached to then the oscillation movement will be circular instead of directly up and down.

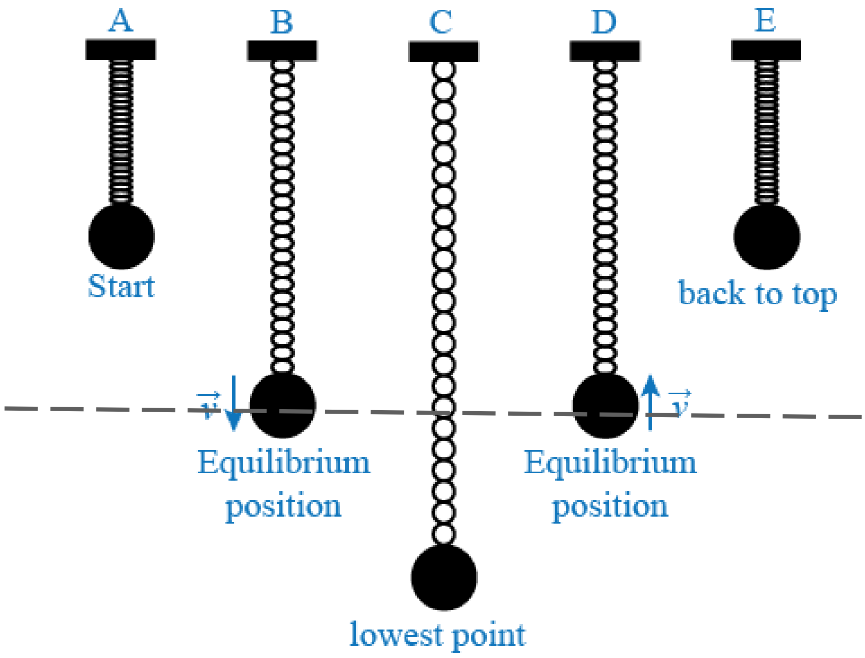


Figure 3: Oscillation of spring with mass attached to a wall [8]

The image shows all the positions a spring makes when oscillating. The equilibrium position happens when the spring is put in its very first position without any external forces. When a force other than gravitational force or the pressure of water is applied to it, periodic movement starts to happen, making the spring change positions. The movement time of a spring from the start to back to top positions will be measured in different salt densities and the aim is to see the decrease in periodic time within the increasing salt amount.

[8] NC State Physics Department (2013) Simple Harmonic Motion – Concepts, *Mechanics* https://www.webassign.net/question_assets/ncsucalcphysmechl3/lab_7_1/manual.html

Methodology

Independent Variables

- NaCl amount dissolved in water (0 grams, 50 grams, 100 grams, 150 grams, 200 grams): as more salt is dissolved, density increases since more Na and Cl molecules come in between H_2O molecules and thus the water gets denser.

Dependent Variables

- Period of a spring with mass: measured by a chronometer and a camera, the camera will film the spring doing its oscillation movement and the chronometer will record the time of it. The camera will film it to check whether the recorded time is accurate or not.

Controlled Variables

- Spring type/length: so it does not affect the period (by using the same spring in all trials)
- Water amount/pH: so the density only depends on dissolved salt (using the same water source and putting the water with measuring cups to put the same amount in all trials)
- Mass on the spring: when the same amount of force is applied, the period does not change, unless density affects. (the same mass is used in all trials)
- The amount of force applied on the mass spring initially to start the periodic motion (for the displacement of the mass spring): when different forces are applied it may affect and harm the spring, so it is crucial to put just enough force. (the force applied was mainly a rule of thumb but the spring was carefully observed and putting too much force was avoided by observing the reactions of the spring)
- Gravitational force: the period time may be affected by the strength of the force applied by the planet's surface to the masses on it (it is controlled by making the experiment in the same location in all trials)

- Kind of salt ($NaCl$): the salt type should be identical in each trial as different types of salts might affect the density of water when dissolved. Each salt type has different qualities, and their impacts may also be different. (it is controlled by using the identical common table salt in each trial)

<u>Experimental Apparatus</u>

- Metal spring (12.000 cm long, 3.000 cm wide, 30.000 mm spring strand, made up of iron), lengths measured by slide calliper ($\pm 0.001\ cm$)
- NaCl (50.00 grams, 100.00 grams, 150.00 grams, 200.00 grams), measured by electronic precision scale ($\pm 0.01\ g$)
- Water (3.00 litres), measured by measuring cup ($\pm 0.01\ l$)
- A container with spring attached to one of its surfaces (volume of 3.50 litres, 50.00 cm long, 30.00 cm wide), lengths measured by ruler ($\pm 0.05\ cm$)
- Camera to measure the length of period
- Mass on spring (200.00 grams), measured by electronic precision scale ($\pm 0.01\ g$)

<u>Procedure</u>

1. Measure the weighs of the masses put on string
2. Measure the weight of water before putting it inside the bucket
3. Prepare the camera to film the whole process
4. Put the water inside the bucket and submerge the spring in a position where all the spring is inside the water with the mass fixed to one of the ends
5. Pull the mass upwards until the spring is fully condensed, but not too much because the spring leaving the water even a little bit is not wanted

6. Pull the spring with the same amplitude in all trials. Check the stretching amount and pull the spring until the spring is stretched with same length in all trials.
7. Start the chronometer as you let go of the spring to make the spring oscillate. Be careful to start the chronometer at the same time of letting go as a minor mistake can change the time of oscillation recorded.
8. Stop the chronometer when the spring starts to make less than 4 cm of periodic distance and take notes of the recorded time
9. Then weigh 50 grams of salt and put it into water
10. Mix the water until the salt is fully dissolved
11. Repeat the steps from 5 to 7 eight times, for each trial
12. Repeat adding 50 grams of salt and record the oscillation time each time
13. Repeat the steps from 1 to 12, for 100, 150 and 200 grams of salt addition, mixture and measurement of period time
14. Record each of the measurements and graph the results
15. Compare the period time and the dissolved salt amount
16. Check if the hypothesis was supported or not

Precautions

- When putting a force on the mass spring to start the periodic motion, be careful not to use too much force as the spring can be corrupted.
- Make sure that NaCl is fully dissolved before starting to measure the period.

Hypothesis

As more salt is dissolved, the mass of water will also increase, resulting in a higher density, proven by the formula. The higher density will increase the drag force applied on the object by the water. Therefore, the oscillation time will decrease as more force is applied in the opposite direction.

Apparatus

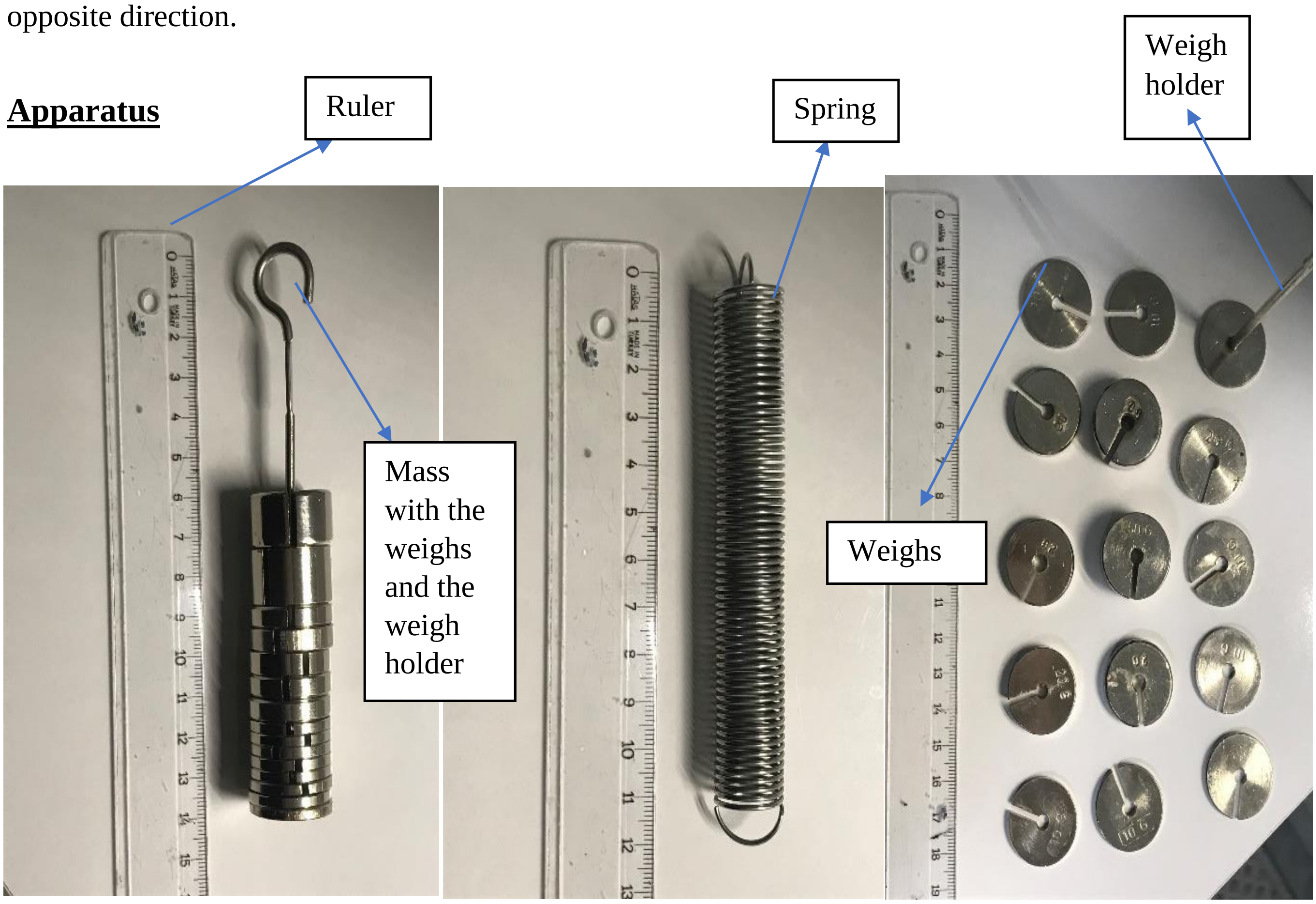


Figure 5: The apparatus used in the experiment

The apparatus used in the experimentation process is given above. Figure 5 shows the weight separated into its pieces carried by the spring. The whole weight was measured to be 200 grams, 180 grams of weight disks and 20 grams of the apparat which is holding the weight and connects to the spring. The radius of the pieces was measured to be 2 cm each. The spring was made up of steel and had the radius of 3 cm. 200 grams of weight was used because the spring was too strong not to oscillate with less weight and using more weight could harm the spring with a point of no return. 2 of the weighs had a mass of 25 grams, 2 of them had a mass of 20 grams and 10 of them had a mass of 10 grams and the weigh holder weight to be 10 grams. One of the ends of the spring held the weights while the other end was held by the experimenter. The weight was pulled down with a certain amount of force to start the oscillation movement.

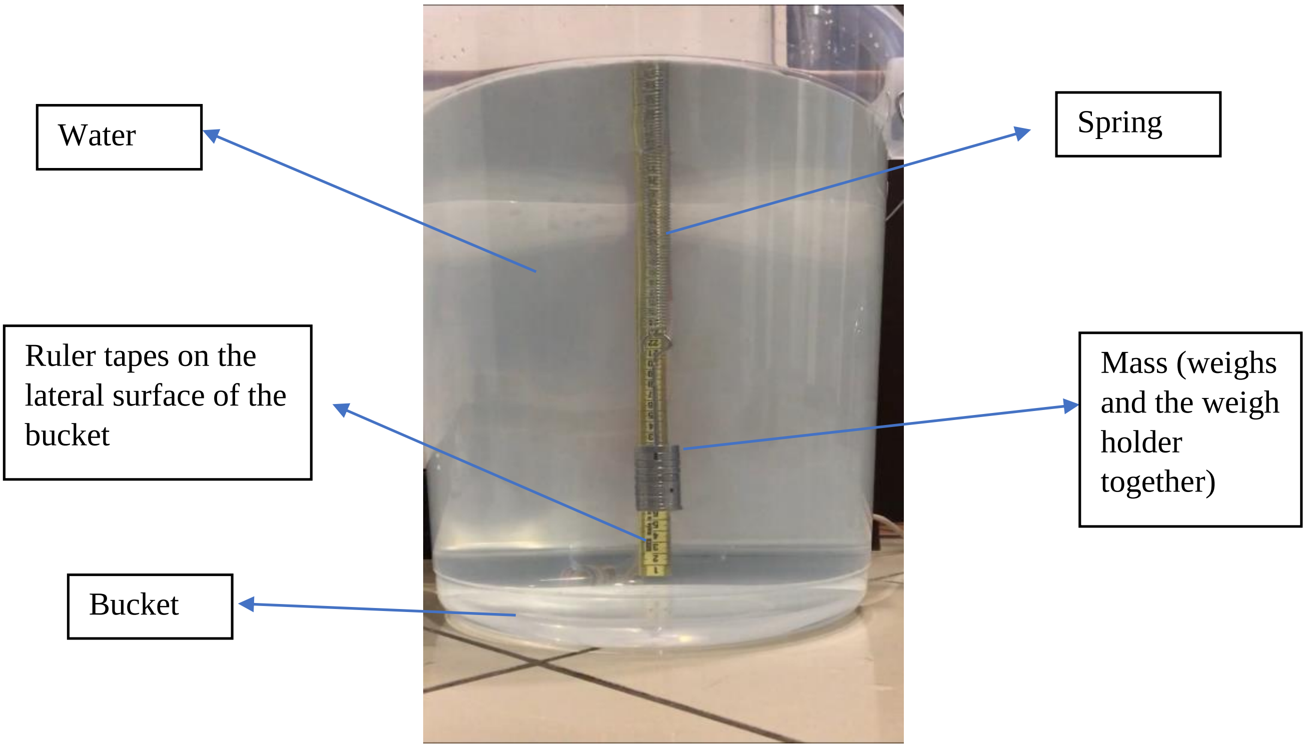


Figure 6: mass and spring in equilibrium position before the start of the experiment

Figure 6 shows the bucket used and how the spring stayed on its equilibrium state. The meter was attached on the back of the bucket with duct tape in order to measure the distance the spring takes, and how long the spring oscillates. The spring decreases the distance of movement slowly as it oscillates and when the distances became too short, it is considered to stop its oscillation movement. The bucket had a volume of 3.5 litres, a cylindrical shape, had a radius of 20 cm and a length of 40 cm. In the experiment 3 litres of water was put into the bucket and different amounts of salt and was filmed the oscillation movement of the spring.

Experimental Data

The following chart contains data from the experiment made using a bucket, 3 litres of water and different values of salt and the oscillation time, period, was calculated using a phone camera and a stopwatch. The uncertainties of salt amounts was decided based on the measurement device, electronic scale. On the label of the scale it stated that the uncertainty was 0.01 grams. The same goes for the uncertainty of oscillation time. It was measured by a chronometer and the chronometer had an uncertainty of 0.001 seconds, based on its label.

		0.00 grams of salt ($\pm$0.01)	50.00 grams of salt ($\pm$0.01)	100.00 grams of salt ($\pm$0.01)	150.00 grams of salt ($\pm$0.01)	200.00 grams of salt ($\pm$0.01)
oscllation time (seconds) ($\pm$0.001)	trial 1	10.330	8.980	8.250	8.190	6.790
	trial 2	11.050	9.160	8.400	8.460	7.510
	trial 3	10.460	9.230	8.860	7.400	7.340
	trial 4	10.550	9.930	8.930	8.160	7.570
	trial 5	11.020	9.520	8.920	8.090	7.750
	trial 6	11.100	10.010	8.110	8.490	6.890
	trial 7	10.980	9.190	9.020	7.890	7.680
	trial 8	10.240	9.370	8.460	8.070	7.880

Figure 7: Raw data of period time and dissolved salt amount after experimentation

Data Analysis

Mean Value of Data Each independent Variable

For 0 grams of salt dissolved

Mean of oscillation times of springs in water with different salt amounts

$$= \frac{Sum\ of\ all\ data}{Number\ of\ data\ in\ the\ set} = \frac{10.330 + 8.890 + 8.250 + 8.190 + 6.790}{8} = 10.739\ seconds$$

In order to analyse the data more clearly, we need to find the standard error which is s statistical term that measures the accuracy of a sample of data collected. It resembles how mean of the sample deviates within actual sample mean, this deviation is counted as the standard error.

$$SE = \frac{\sigma}{\sqrt{n}}$$

SE: standard error of the sample

σ: sample standard deviation

n: number of samples

Standard deviation is the "measure of the amount of variation or dispersion of a set of values" according to Wikipedia and is used to analyse the data as a low standard deviation indicates that the data values are close to each other and if the standard deviation value is high, that means that the data collected are more spread. It can be calculated with the formula of:

$$\sigma = \sqrt{\frac{\sum(xi - \mu)^2}{N}}$$

σ: standard deviation
N: size of population
xi: each value of population
μ: population mean

The mean could be found by dividing the sum of all data to the amount of data.

If we put the data found in these equations, firstly a mean and a standard deviation like above can be found.

- For 0.00 grams of salt dissolved

  10.330, 11.050, 10.460, 10.550, 11.020, 11.100, 10.980, 10.240

  $mean\ (\pm 0.001\ seconds)\ for\ 8\ trials = 10.716$ second

  Standard deviation $(\sigma) \approx 0.537$

Now we find the standard error value with the formula given.

- For 0.00 grams of salt dissolved

$$SE = \frac{0.537}{\sqrt{5}} \approx 0.240$$

The following graph of the data collected is shown below

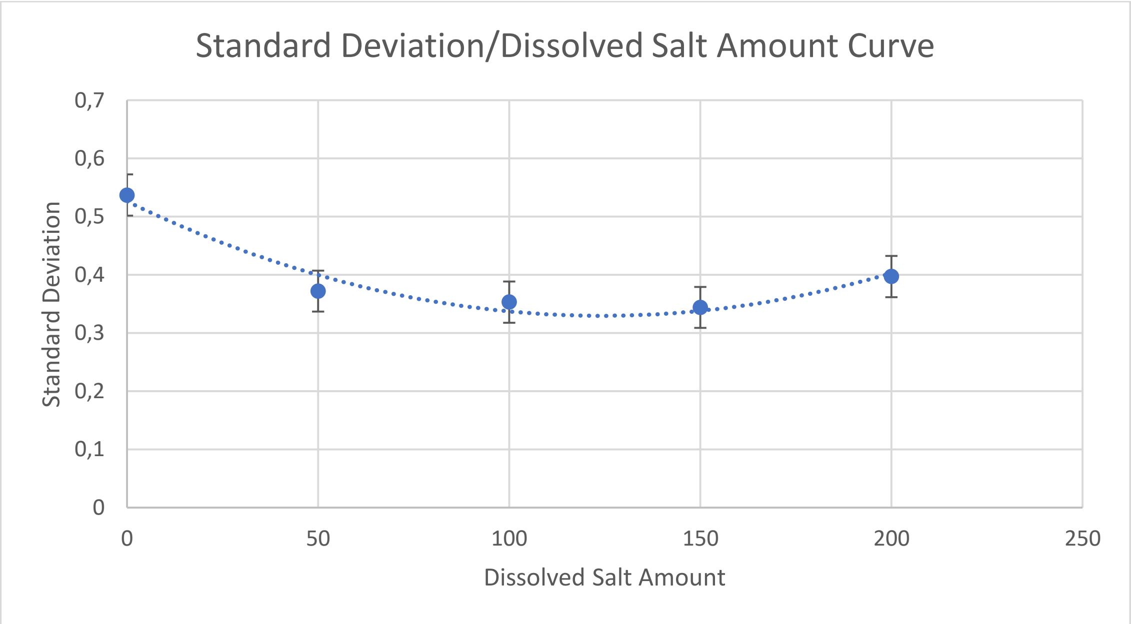


Figure 8: Graph of standard deviation versus dissolved salt amount

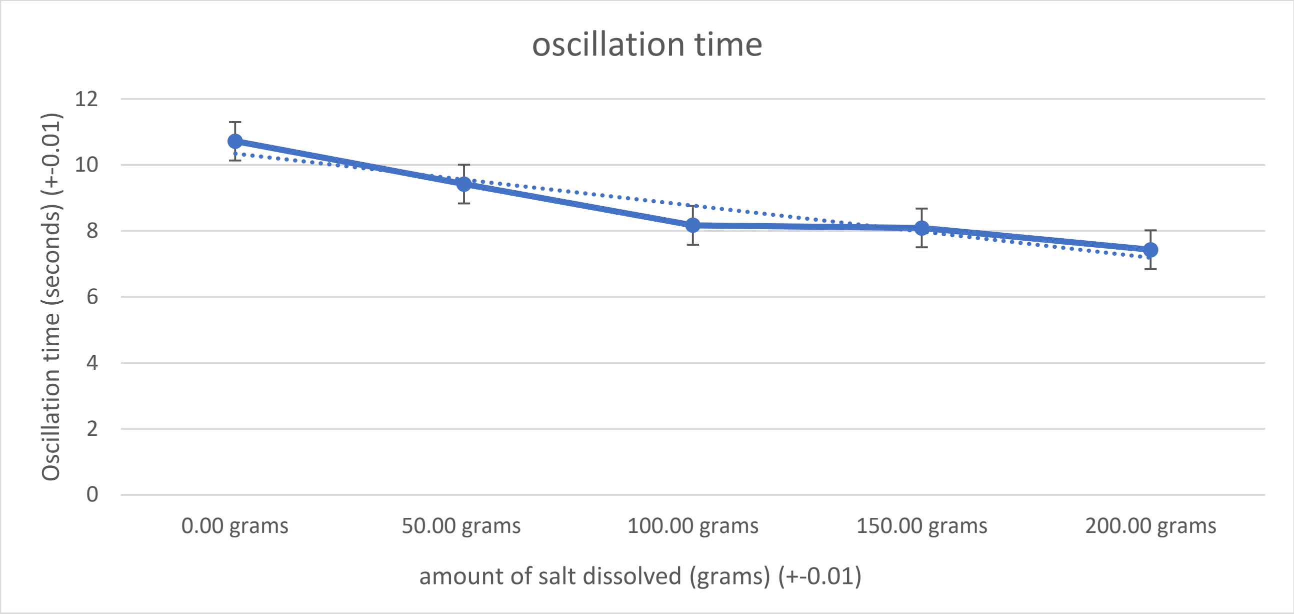


Figure 9: Graph of Mean of Data for each salt amount

amount of salt dissolved in water ($\pm$0.01)	Mean of data from each trial	Standard deviation	Standard Error
0.00 grams of salt dissolved	10.720	0.537	0.240
50.00 grams of salt dissolved	9.424	0.372	0.166
100.00 grams of salt dissolved	8.169	0.353	0.158
150.00 grams of salt dissolved	8.094	0.344	0.154
200.00 grams of salt dissolved	7.426	0.397	0.178

Figure 10: Table of Processed Data

Figure 9 shows the processed oscillation time values for each salt amount added. The mean of oscillating time is shown to decrease within the increasing salt amount in water, which supports the hypothesis. The standard deviation and standard error being low is a good indication as that expresses the values to have a good correlation and accuracy. When looked at the mean values of 0 grams of salt and 200 grams of salt, it is seen that the oscillation time was decreased by almost 3 seconds which is a huge value for a spring period.

Qualitative Observations

- The spring almost travelled the same distance, but with different times of cycles. One could say that the oscillation distance does not depend on the medium density but other factors like the weight spring carries, spring constant, which is a dependable of spring type, etc.
- It became harder and harder for the spring to travel with changing dissolved salt amounts.
- The salt took some time to dissolve, even though was mixed for minutes because of col water usage, so it could be suggested to use water with greater temperature value.

Evaluation

When looked at the essay, the experiment was a success. The hypothesis was supported, and the data collected was correlated. Repeating each data set eight time, the error rate was reduced, and the conclusion was more accurate. The actual values cannot be found on the internet to support the values, but the aim was to prove the decrease in the period time when the water got denser. There is no actual formula that contains both the period, and the drag force so theoretical values are not used, but the empirical data was compared with itself. the accuracy of the result, though, can be obtain through the internet. Performing the experiment, a lot of limitations were faced. These were:

1. One spring with a more sensitive properties were harmed irreversible as the weight it carried was too much. When the experiment is to be repeated, a spring and a weight should be put delicately and one by one to prevent any other harms on springs

2. The usage of camera and chronometer was not used perfectly accurate. The camera had fewer frames than expected. Usage of a better camera and software to measure the time can be used. There might be humanly mistakes when measuring and to reduce it, there is no better solution to use technology.

Systematic Errors:

1. The salt was not completely separated from other particles that might have come with it. This would pollute the water and might have changed the result. Only clear salt particles should be used, and the water should be mixed until complete dissolvement process happens.
2. The force applied on the spring while pulling upwards was not measured with a dynamometer but was made by the rule of thumb so it could have affected the result. While one trial was pulled more delicately the other could have been a little harsher which have affected the period time. Pulling with a dynamometer or repeating the process more times would reduce the error rate caused by this reason.

Random Error:

1. The chronometer could have started earlier or later than how it should have supposed to work. A better system should be used for the measure of time, for example a software would have a more accurate time measure.
2. As mentioned above the force applied on the spring upwards in order to start the oscillation movement, was not directly measure but was a rule of thumb. The spring holding the weight was moved upwards, but as humans are very prone to making mistakes, instead of directly pulling the spring upwards, with 90 degrees angle to the ground, a force with a higher or lower degree angle to the ground could be applied which might increase or decrease the period time. Amount of force applied is also the same. As a measurement device like a dynamometer was not used, could not be used in

this type of experiment due to lack of space, an estimated force was applied and that could also be the cause of the standard error.

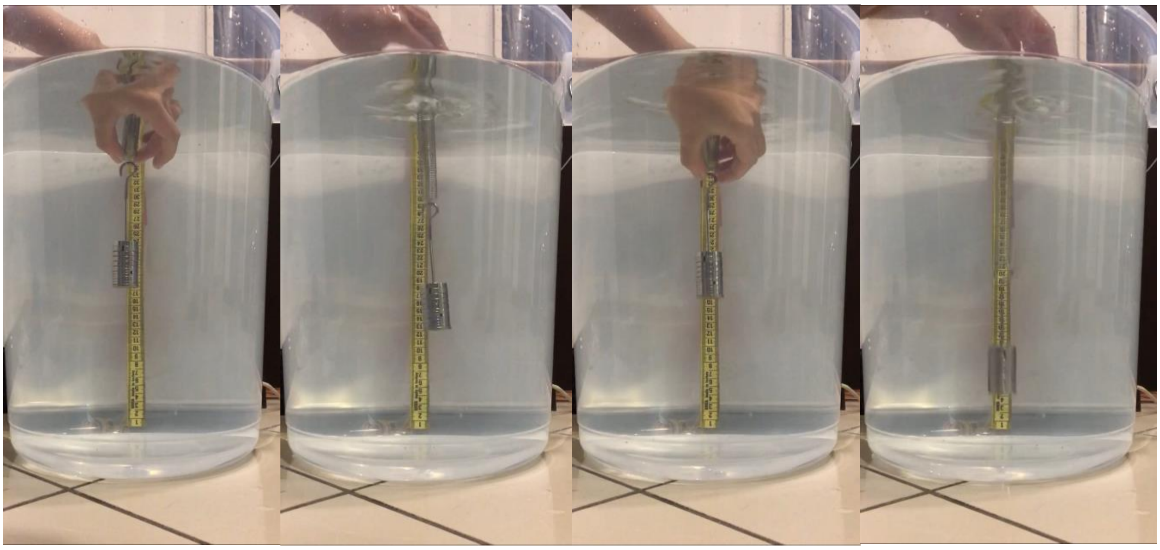


Figure 11: pulling the spring with slope and pulling the spring perpendicular to the surface

The situation could be given example with the figures above. The pictures were taken from the filmed experiment of this essay. In figure 11, the first two figures, the spring was pulled up with a slight slope and resulted in the oscillation with a slope as well. In the last two figures in figure 8, how the spring should have been pulled is shown, directly upwards without any slope and resulted in the oscillation movement directly downwards, also without any slope. These mistakes could be made in the experimentation process, that is the reason for different trials being made. One mistake in one trial could be corrected in different trials, so by looking at the standard deviation and error amount, the accuracy and the correlation of the data collected could be interpreted more accurately.

Conclusion

This experiment investigated the effect of medium density, simulated by dissolving salt in water, to spring period. The raw data graph shown on figure 7 demonstrates the data found after experimentation. As the salt amount increased in water, the oscillation time decreased, therefore the results support the hypothesis as in the hypothesis it was mentioned that the increasing dissolved salt amount will affect the spring period to decrease. This experiment was repeated through each 8 trials and in all of them the oscillation was affected by the increasing salt amount, as shown in the raw data table. The standard error and deviation values being minor numbers indicate the experiment to be precise and very close to accuracy, shown in figure 10. Systematic errors such as humanly mistakes caused the standard error rates between different trials. However, the experiment was successful to measure the effect of medium density to the spring oscillation time because of great precision and accuracy.

Springs are used in many fields depending on their ability to resist force, elasticity, or their ability to store energy. This experiment proved their usage in different densities. This quality can be very useful in vehicle systems. As strings move harder in denser mediums, they can be used in denser mediums to hold heavier weights. The weights are held both by the water and the spring so the spring would do less work and therefore, cheaper materials can be used. Or spring used in less denser mediums would oscillate more so more work would be done as more distance is travelled.

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