The Effectiveness of Different Insulators on a Body of Water

Insulators are materials that restrict the flow of heat or electricity. Typical insulators will be able to thermally conduct heat, allowing them to absorb heat as it flows through a given object or system. Insulators are commonly used in housing, appliances, and even space exploration. In fact, insulators were one of the most important factors in mankind reaching the stars. Astronauts needed some way in order to stay warm when exploring the cold vacuum of space, and this solution was presented in the form of insulation. Insulators were used to trap the heat from the astronaut's body within the suit, stopping them from freezing to death. However, In order to be effective, the insulation used had to withstand the extreme temperatures and conditions found in space. NASA engineers had to experiment with different types of insulation in order to create a safe and reliable space suit.

While my investigation will be on a much smaller scale, testing the effectiveness of different insulators has large real-world applications, especially pertaining to one of my largest interests: space exploration. Space exploration has been one of my favorite interests since I was a child, and I have always been fascinated by its possibilities. When we were discussing thermal kinetics in class, my curiosity was sparked when our instructor mentioned how heat transfers differently in space. Further into the unit, my instructor taught our class about insulators and how they can mitigate heat loss, prompting me to think about how insulators were used during the dawn of space exploration in order to keep astronauts alive. The idea of an insulator became more of a thought in my mind, and I decided to look further into insulators in general. While my initial interest in thermal kinetics was due to my enjoyment in space, I found that the modern world relies heavily on insulators on a daily basis. Thus I wondered if there was a correlation between popular insulation and its effectiveness on heat restriction.

To deduce which insulators to use for this experiment, I decided to look at what was commonly available. The first thought to come to mind was fiberglass, as it is the most popular insulating material for houses. Polyethylene foam was also a consideration, as it is commonly used as a "filling" material to seal windows. I was able to find both of these at a local appliance store in sufficient quantities to begin my investigation. The final insulator I decided to test was aluminum foil, as its reflective property stops heat from radiating out into the surrounding environment. This experiment aims to study the effectiveness of different insulating materials, and for this investigation, I will insulate a body of water. I expect the insulation with the highest thermal conductivity (k) to have the highest heat transfer rate, as the more a material can conduct, the more heat it will transfer. A high heat transfer rate encourages heat transfer rather than restricting it, meaning that the material with the highest (k) will be the poorest insulator. I deduced literature values for this experiment from each insulator's thermal conductivity, found on an online data chart (Tools).

Insulation Type	Thermal Conductivity ($W \bullet m^{-1} \bullet K^{-1}$)
Fiberglass	0.045
Aluminum Foil	237
Polyurethane foam	0.030

Since the material with the highest (k) will be the poorest insulator according to the principle of thermal conductivity, I predict that polyurethane foam will be the best insulator, followed by fiberglass, and aluminum foil.

This experiment will be accomplished by comparing the initial and final water temperature in a test tube, with different tubes for each insulator. I will heat four test tubes to 35 degrees Celsius in order to achieve a measurable initial temperature, and then I will wrap three of those test tubes in their respective insulator while using the remaining test tube as a control group. Once the insulators are fixed to the test tubes, they will be submerged in a system of lower temperature for a total of 5 minutes. After that time has passed, the final temperature will be recorded. The thought process in this experiment is that whichever test tube has the highest final temperature has the best insulation. This is because the heat was kept inside the test tube by the insulator rather than dissipating to the surrounding system.

- Dependent Variable: Final Temperature
- Independent: Type of insulator used
- Control: Initial temperature of the body of water

It is important to control the water's initial temperature so that each trial's results are conclusive with one another. If each trial started with drastically different temperatures, the results wouldn't be coherent enough to compare scientifically. Thus I will be as accurate as possible when measuring the initial temperature, heating the water until the temperature probe reads 35 degrees Celsius. The independent variable is also within my control, as I will choose which insulator to use and use the same amount for each trial for accuracy. As for the dependent variable, I will be measuring this to deduce results for this experiment overall. Hence it is not a value controlled by me but rather by the laws of thermal kinetics.

The following table lists the materials that will be used in this experiment:

-4 50mL test tubes

-3 rubber bands

-1500mL of water

- 100mL beaker

-Timer

-Water bowl

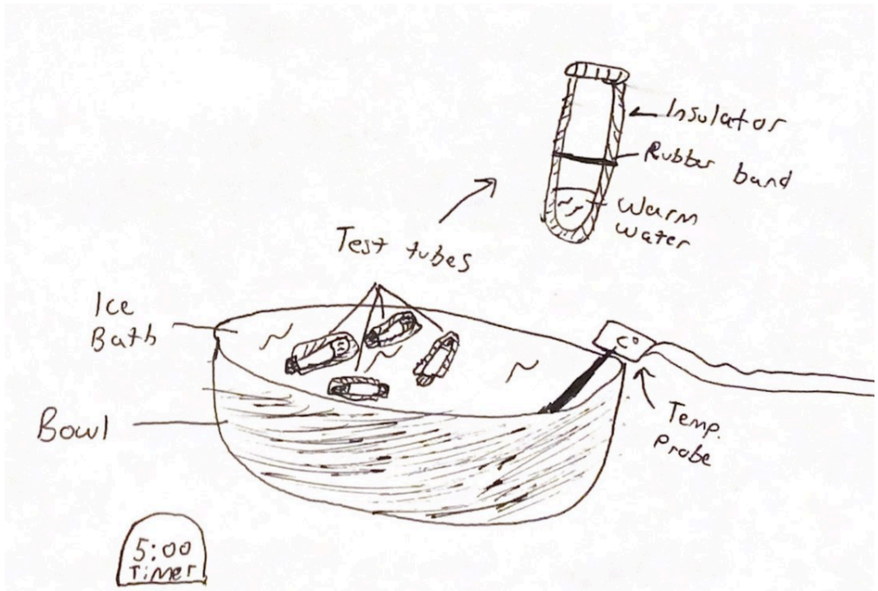
-Ice

-Temperature probe

-Aluminum foil

-Fiberglass

-Polyurethane Foam



The following procedure will be used in this experiment:

1. Pour 40 mL of water into four test tubes.
2. Heat the water to 35 degrees Celsius, make sure this temperature is constant.
3. Wrap one test tube in aluminum foil, one in fiberglass, one in polyurethane foam, and set one aside as a control group. Hold the insulator on the test tube with a rubber band.
4. Submerge the test tubes in a measured ice bath of 1000mL of water. The initial temperature of the ice bath will be recorded and maintained as well, accounting for the heat absorbed by the bath itself.
5. After 5 minutes, remove each test tube and measure their final temperature.
6. Repeat this process a total of 3 times for consistency.

The results will be recorded in tables below, comparing the initial temperature of 35 degrees Celsius to the final temperature of each test tube. Depending on the final temperature, I can deduce which insulator kept the most heat inside the test tube by comparing the change in temperature, or Δ℃. I will also graph each trial in the application “Desmos” to get a visualization of the data. To do so, the following slope formula will be used:

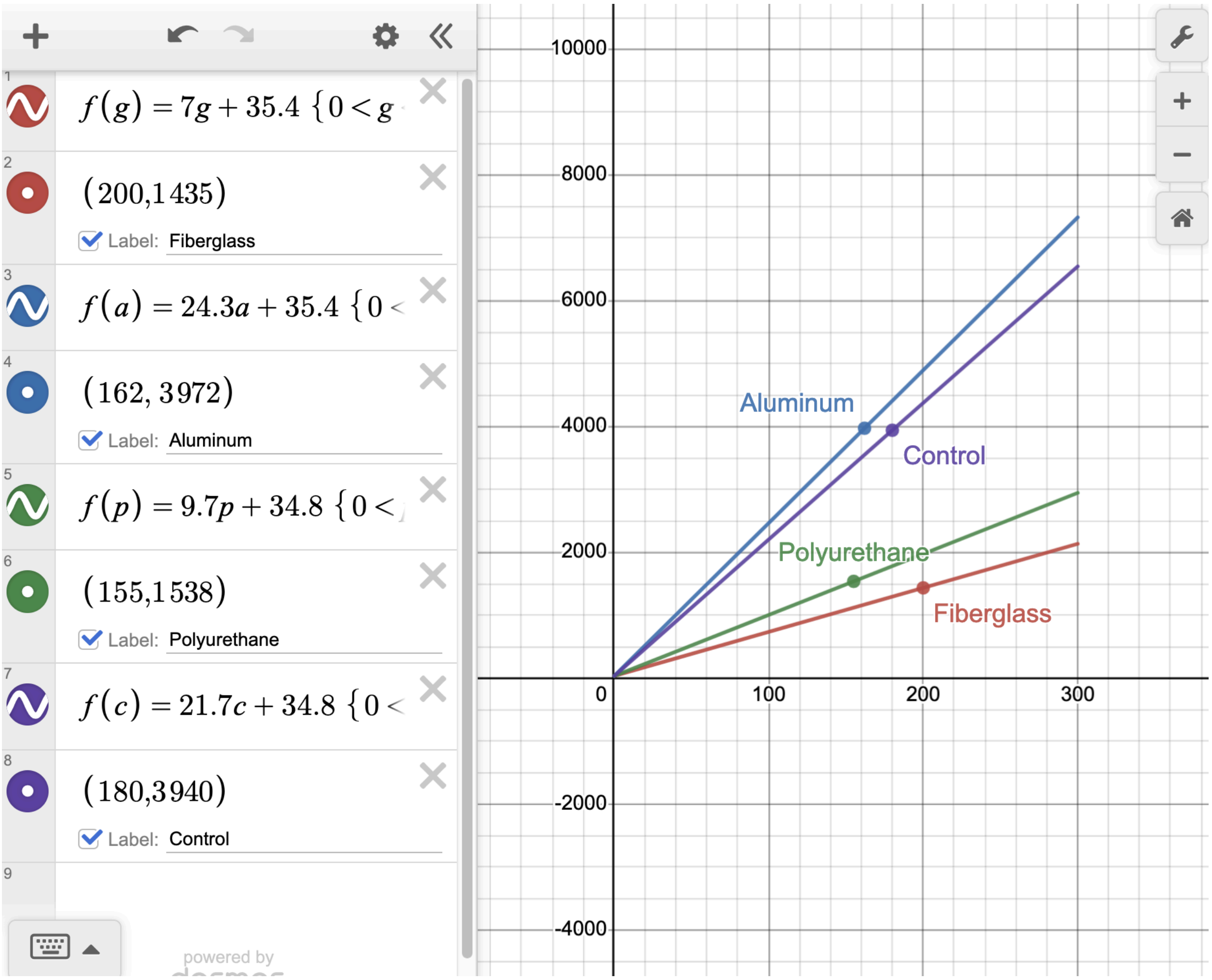
$$y = mx + b$$

$$m = T_I - T_F = \Delta T = \Delta ℃$$

$$b = Initial\,Temperature$$

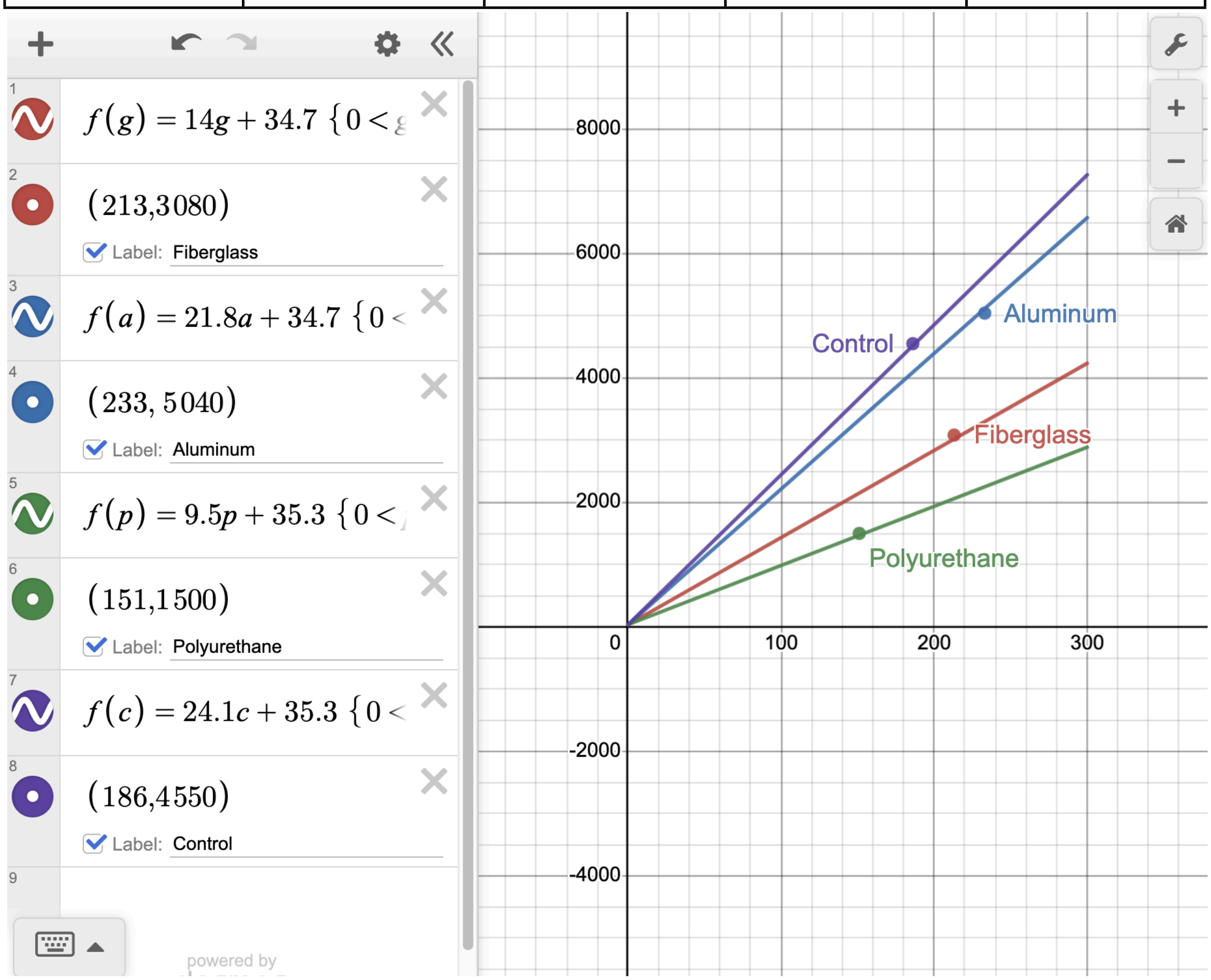
One thing to note is that the graph for these trials is just for visualization purposes, and does not show the proper trend for the change in temperature. Rather the graph shows which insulator lost the most amount of heat, which is represented by a high Δ℃, or a steep slope.

Trial 1	Initial Temperature ℃	Final Temperature ℃	Temperature Change Δ°C	Temperature of ice bath ℃
Fiberglass	35.4℃	28.4℃	7℃	7.8℃
Aluminum Foil	35.4℃	11.1℃	24.3℃	7.8℃
Polyurethane foam	34.8℃	25.1℃	9.7℃	7.0℃
Control	34.8℃	13.1℃	21.7℃	7.0℃



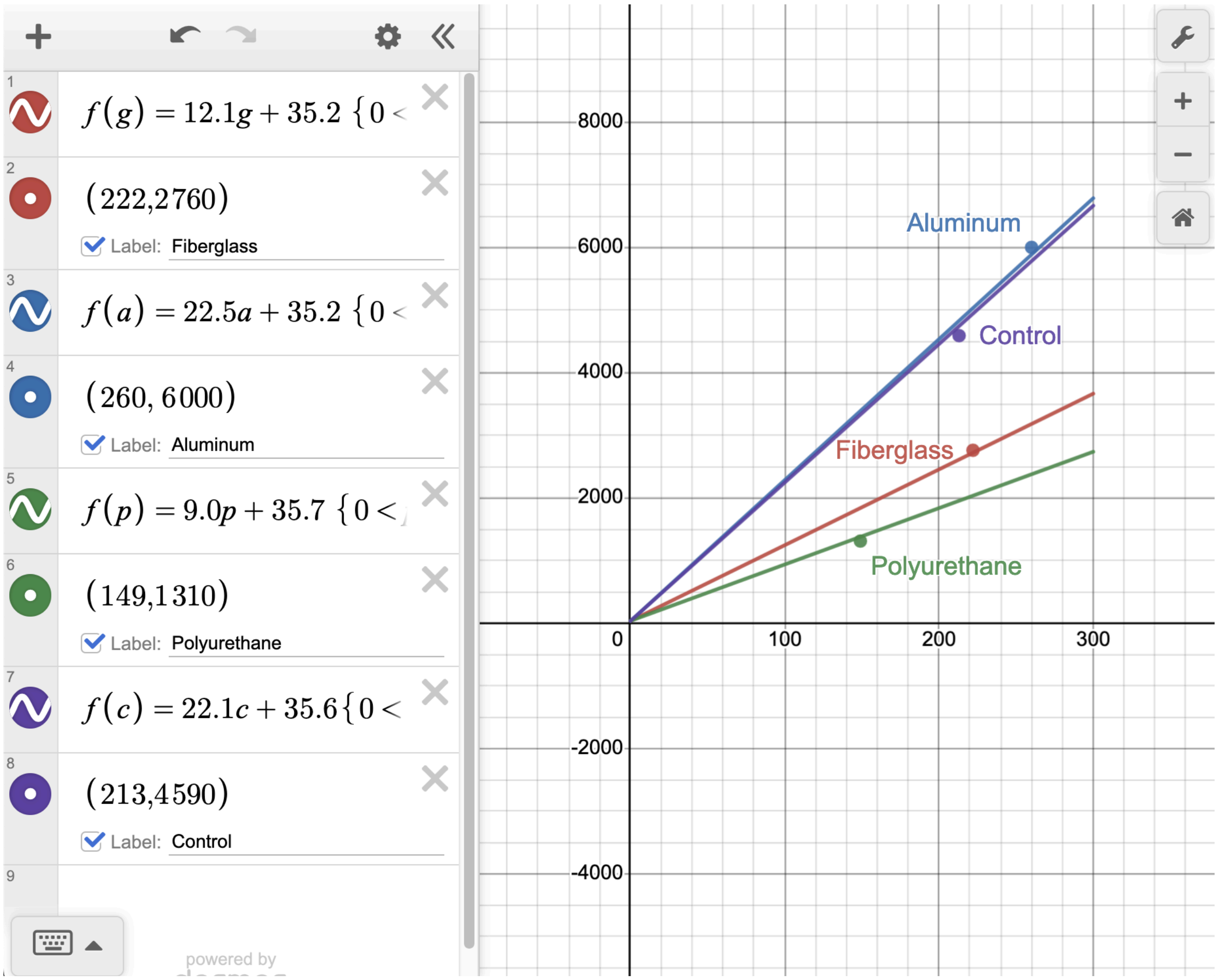
For the first trial, fiberglass had the lowest change in temperature. With a Δ°C of 7 degrees, fiberglass was the best at insulating heat during this trial. This is also seen in the visual representation above, as fiberglass has a much lower curve. In terms of qualitative data for this trial, I noticed the test tubes tended to float above the water, not being fully submerged. However, for the most part, the water in the test tubes was submerged, and it was the remaining pocket of air that didn't go fully into the water. Upon further analysis, I'll see how this affects the results of my experiment. I also noticed that the fiberglass was coming apart in the water, and to solve this problem; I put a plastic bag over the fiberglass test tube.

Trial 2	Initial Temperature ℃	Final Temperature ℃	Temperature Change Δ°C	Temperature of ice bath ℃
Fiberglass	34.7℃	20.7℃	14℃	10.8℃
Aluminum Foil	34.7℃	12.9℃	21.8℃	10.8℃
Polyurethane foam	35.3℃	25.8℃	9.5℃	6.9℃
Control	35.3℃	11.2℃	24.1℃	6.9℃



For trial 2, there were interesting results. The polyurethane foam was the best insulator, with a Δ°C of 9.5 degrees Celsius. This result agrees with my initial hypothesis, as the thermal conductivity for the foam was lower when compared to the fiberglass. However, I believe there is a source of error in this trial. The recorded value of the ice bath was 10.8℃ for the fiberglass, but it was 6.9℃ for the foam. In theory, the temperature of the ice bath has to be the same for both, even if it is higher or lower than in other trials. However, the fact that it differs introduces a source of error in this trial. This is largely because I only had two test tubes available, so I had to record the values in pairs rather than in a group of four. There was also a lack of control over the ice bath temperature, as I had to rely on adding ice cubes to lower the temperature, which has proven to be an unreliable strategy. For the next trial, I will attempt to keep the temperature of the ice bath the same or far closer than I did in this trial, which will help me figure out which trial was the outlier value. Of course, my hypothesis can also be wrong, or other factors I haven't considered impacted the results.

Trial 3	Initial Temperature ℃	Final Temperature ℃	Temperature Change Δ°C	Temperature of ice bath ℃
Fiberglass	35.2℃	23.1℃	12.1℃	7.5℃
Aluminum Foil	35.2℃	12.7℃	22.5℃	7.5℃
Polyurethane foam	35.7℃	26.7℃	9.0℃	6.8℃
Control	35.6℃	13.5℃	22.1℃	6.8℃



For the final trial, polyurethane foam was once again the best insulator with a Δ°C of 9.0 degrees Celsius. For this trial, the ice bath temperature was 6.8℃ for the foam and 7.5℃ for the fiberglass. This is considerably less of a difference than in trial 2; however, the results were the same. However, one qualitative factor I noticed in this trial that I overlooked before was the fact that the layer of the foam insulator was so thick the water inside the test tube did not come into contact with the ice bath, despite my previous observations. In fact, the test tube was not being insulated from the ice bath, but rather it was prevented from coming into contact with the water.

Likewise, this means the results of this experiment are considered inconclusive due to this considerable error in the experimentation process. Polyurethane foam, according to the results of the flawed experiment, would be the best insulator; however, in the experiment, the foam was only insulating the water from the air. This error is consistent with all three trials as the Δ°C for the polyurethane foam has an average value of 9.4℃. For future reference, this can be mitigated by cutting back on the thickness of the foam or finding a method to submerge the tube without relying upon buoyancy. It is essential to do so, as the hypothesis cannot be correctly tested if the insulator is not within the controlled environment. Despite the results of this experiment matching my hypothesis, the results cannot be considered reliable because of the unconsidered buoyant nature of the polyurethane insulator. As for the results of the outlier trial, or trial 1, this can be explained by my attempt to fix another error that arose. I mentioned earlier that the fiberglass was 'dissolving' in the water, and I briefly removed the fiberglass insulator to put it in a plastic bag to prevent it from breaking apart. The fact that I performed this during the experiment can account for the outlier value. I was not only introducing a new variable, the plastic bag, but I was also temporarily removing the insulator. This accounts for the significant difference in Δ°C for the fiberglass when compared to the other two trials, in which I began with the plastic bag already around the fiberglass insulator.

Another important thing to note for this experiment is the precision of the tools I used to make my measurements. This is an important factor when considering the absolute, relative, and percent error for the investigation. The formula for absolute uncertainty is given as:

$$\Delta x = \sqrt{(\Delta A)^2 + (\Delta B)^2}$$

The tools used to make measurements were the temperature probe, with a digital reading error of $\pm\ 0.1$, and the 100mL beaker with a reading error or $\pm\ 0.5$. Both these values will be my A and B, which when plugged into the formula yields:

$$\Delta x = \sqrt{(0.1)^2 + (0.5)^2} = 0.511$$

In order to calculate the relative and percent uncertainty I must divide the reading error by the best estimate of the measurement made.

$$\frac{reading\ error}{measurement} = relative\ uncertainty \bullet 100\% = percent\ uncertainty$$

$A = Probe\ measurement = 35℃ \pm 0.1$

$\frac{0.100}{35.0}(100\%) = 0.286\%$

$B = Beaker\ measurement = 40mL \pm 0.5$

$\frac{0.500}{40.0}(100\%) = 1.25\%$

Overall the precision of the experiment was as expected, despite the inaccurate results and methods during the process. Ultimately if this procedure were to be repeated, I recommend that all of the required materials are available. The biggest limitation during this experiment was only having two test tubes, which can be seen in my trials as the temperature of the water bath changed over time and wasn't accurately maintained. The inability to control a constant temperature for the initial test tube water and the ice bath was also a major weakness. I'd recommend using a hot plate or something similar to solve this issue. Absolving the random error in this experiment is also extremely important, and a large portion of that can be accomplished by ensuring each test tube and its respective insulator are fully submerged in the ice bath. This can be accomplished by tying a weight to each insulated test tube, forcing it to sink into the water. These can be small weights fixed by a string, and they would have to be added to the list of materials for the experiment. The effect of the plastic bag on the fiberglass insulator is another important angle to look at. I am unaware if there was a significant impact; however, for the sake of consistency, I suggest putting plastic bags on all of the insulated test tubes. Systematic error is another aspect to reflect upon, specifically in the time taken to measure the temperature of the test tube water to when it is submerged in the ice bath. Combined with some random error, having to measure the temperature, then immediately seal the test tube and fix a weight can consume time, especially when this has to be done for all four insulators back to back. However, this can be resolved by having a weight prefixed to the test tube and the water heated on a hot plate. This removes using the temperature probe to measure the initial temperature, saving some time. Having the water premeasured for the test tubes will also help save time and mitigate error since the water is losing heat while carefully being measured in 50mL increments. An additional four 50mL test tubes heated to 35℃ on the hot plate solves this problem, as once they are heated, they can immediately be poured into the four 50mL insulated test tubes, which are then submerged. With all of these realistic improvements, this experiment can be reciprocated without the large margin of error I experienced. Increasing the reliability of the methods will produce greater results overall, allowing for trustworthy data. Only then can the hypothesis be tested to see if the observed outcome differs from the expected outcome. The error encountered during this experiment serves as a stepping stone for future research, as error is necessary to make improvements. For that is what the scientific method encourages, as we are meant to build upon previous knowledge to develop a better understanding of our world overall.

Works Cited

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