

**PHYS 1001H**  
**Final Lab**

Investigating the Effect of Temperature  
on the Viscosity of Maple Syrup



## Introduction

Ever since I was a child, I loved eating pancakes, regardless if they were warm or cold. Something I quickly noticed was that when I poured the maple syrup over hot steaming pancakes fresh from the pan, the maple syrup would flow faster over the pancakes. However if I was pouring the maple syrup over cold pancakes, the syrup would flow slower. Little did I know this phenomena could be described by a property known as viscosity, something I would learn in my coming years.

After attending physics class in high school, and learning more about molecules and their behaviours in different temperatures, I wondered if it was possible to experimentally determine and calculate the change in viscosity of maple syrup in different temperatures. Therefore the aim of this investigation is to explore the effect of changing the temperature ( $^{\circ}\text{C}$ ) on the viscosity ( $\text{kg} \cdot \text{m} / \text{s}^2$ ) of maple syrup. This is done by dropping a metal sphere into maple syrup at different temperatures, and measuring the time it takes for the sphere to move through the fluid and to reach the bottom of the container. The ball is always dropped from the same height and from rest.

Viscosity is the measure of fluid's resistance to flow, and is represented by the symbol  $\eta$ . It is the ratio of the shearing stress ( $F/A$ ) to the velocity gradient ( $\Delta v_x/\Delta z$  or  $dv_x/dz$ ) in a fluid. (Elert, n.d.)

$$\mu = \frac{F/A}{\Delta v_x/\Delta z}$$

$\mu$  is defined as the viscosity of the fluid

$F$  is defined as the Force that is being applied

$A$  is defined as the cross-sectional area of material with area parallel to the applied force vector

$\Delta v_x$  is defined as the velocity difference

$\Delta z$  is defined as the defined as the distance between the layers

This formula allows us to understand the intricacies of viscosity; when a fluid is moving through a pipe or a solid object is moving through a fluid, the layer of fluid in contact with the sides of the pipe or the surface of the object tends to be in the same state of motion as the object with which it is in contact; that is, the layer of fluid along the side of the pipe is at rest, while that in contact with the moving object is carried along at the same velocity as the object.

## Research Question

What is the effect of temperature on the viscosity of maple syrup?

## Hypothesis

I predict that there will be a negative linear correlation between the variables: an increase of temperature and an increase of the velocity of the steel ball will correlate with a decrease in viscosity of maple syrup. This is due to my understanding of intermolecular forces of fluids; as the temperature increases, the molecules inside the liquids get excited by the energy added, thus resulting in a decrease of the amount of time spent in contact with nearby molecules, and so the average intermolecular forces decreases. This then allows the fluid to flow faster; thus, the viscosity will decrease. (Saylor Academy, 2011)

## Variables

Independent Variable:

- Temperature
  - The experiment was repeated in 5 approximate temperatures: 0°C, 4°C, 21°C, 35°C, 50°C and 70°C

Dependant Variable:

- Viscosity of the fluid
  - Determined experimentally by the velocity of the fall of the ball

Controlled Variables:

- The same setup was used throughout the experiment
  - The ball is always dropped from the same height and from rest
  - Same apparatus
  - Same amount of fluid
  - Five trials at each temperature was conducted
- The same room was used for each trial
  - Acceleration of gravity
  - Atmospheric pressure
  - Room temperature

## Apparatus/ Materials

- |   |  |
|---|--|
| ● Transparent Graduated Cylinders (100 mL)    | ● Heating plate                        |
| ● A steel ball (diameter of 12 mm)            | ● Refrigerator                         |
| ● A camera able to capture slow motion videos | ● Beaker                               |
| ● Electronic Balance                          | ● Thermometer                          |
| ● Various Fluids                              | ● Funnel, with a 1.5 cm diameter spout |
| a) Kirkland© Organic Maple Syrup              | ● Digital Caliper                      |
|   | ● Tongs                                |

## Procedure

1. All the necessary materials were gathered. The mass of the empty 100 mL graduated cylinder was measured.
2. 100 mL of room temperature maple syrup was poured into the 100 mL graduated cylinder.
3. It was left to set for 2 hours, to eliminate air bubbles.
4. The temperature of the maple syrup was made sure to be 21°C, and then a funnel was placed on top.
5. The camera was placed in a position where the entire graduated cylinder is visible. The camera was pressed to start recording.
6. A steel ball was placed above the funnel, and dropped.
7. Once the ball hit the bottom of the graduated cylinder, the camera was stopped.
8. Steps 2-7 were repeated 4 more times, for a total of 5 trials.
9. Steps 4-8 were repeated, but with different temperatures of maple syrup
  - a. 100 mL of maple syrup in a 100 mL graduated cylinder was placed in a freezer of (0°C) for 2 hours.
  - b. 100 mL of maple syrup in a 100 mL graduated cylinder was placed in a refrigerator (4°C) for 2 hours.
  - c. 100 mL of maple syrup in a beaker was placed on a heating plate. It was heated to 35°C, then poured into a graduated cylinder.
  - d. 100 mL of maple syrup in a beaker was placed on a heating plate. It was heated to 50°C, then poured into a graduated cylinder.
10. A time stamp was placed on the video in slow motion to determine the amount of time the fall took.

## Safety Measures

Safety goggles were used throughout this experiment. Heating plates were handled with caution, and hair, clothes, and other loose objects were kept away from the plate. Tongs were used to remove the beaker from the heating plate, to prevent the burning of hands. No harmful or toxic chemicals were used, and all waste was disposed of in the appropriate waste disposal site.

## Data Collection

*Table 1: Quantitative Observations: Lengths of apparatus*

	<i>Length (<math>\pm 0.05</math> cm) (cm)</i>
<i>Diameter of Ball</i>	1.20
<i>Height of Graduated Cylinder</i>	26.40

Table 2: Quantitative Observations: Mass determined by the electronic balance

	Mass ( $\pm 0.01\text{g}$ ) (g)
Graduated Cylinder	96.71
Graduated Cylinder and Maple Syrup	236.87
Mass of Steel ball	8.51

Table 3: Time taken for metal sphere to reach the bottom of the cylinder

Temperature of Maple Syrup ( $\pm 1^\circ\text{C}$ ) ( $^\circ\text{C}$ )	Time ( $\pm 0.1\text{s}$ ) (s)					Average Time ( $\pm 0.1\text{s}$ ) (s)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
$0^\circ\text{C}$	130.47	131.48	129.99	129.23	132.65	$Avg_{time} = (130.47 + 131.48 + 129.99 + 129.23 + 132.65) / 5$ $= 130.76$
$4^\circ\text{C}$	88.32	90.67	89.65	75.97	72.91	$Avg_{time} = (88.32 + 90.67 + 89.65 + 75.97 + 72.91) / 5$ $= 83.51$
$21^\circ\text{C}$	6.52	6.34	6.58	6.54	6.42	$Avg_{time} = (6.52 + 6.34 + 6.58 + 6.54 + 6.42) / 5$ $= 6.48$
$35^\circ\text{C}$	2.01	2.08	1.90	2.03	1.98	$Avg_{time} = (2.01 + 2.08 + 1.90 + 2.03 + 1.98) / 5$ $= 2.02$
$50^\circ\text{C}$	0.49	0.48	0.49	0.53	0.44	$Avg_{time} = (0.49 + 0.48 + 0.49 + 0.53 + 0.44) / 5$ $= 0.49$

## Data Processing

In terms of this investigation, the viscosity will be calculated not through the previously mentioned equation, but through the use of the drag force, the force of buoyancy and the force of gravity, which take into account the shear forces between the layers of the fluid, or in other words, the viscosity. (Stanford University, n.d.)

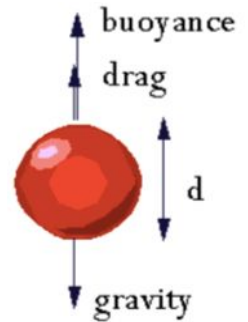
Beginning with the gravity, this can simply be considered as the force that is acting down on the sphere, determined by its mass and the gravitational content. In other words, it is the weight of the ball, expressed in the equation:

$$\mathbf{Fg} = \mathbf{mg}$$

**Fg** is defined as the force of gravity acting on the mass

**m** is defined as the mass of the mass

**g** is defined as the gravitational acceleration constant - 9.81 m/s<sup>2</sup>



Buoyancy is essentially, akin to the force of gravity on the sphere (the weight of the sphere), the weight of the fluid that is displaced by the sphere. As a result, it is simply determined through the use of its mass, which in this case will be determined by its volume, and the gravitational acceleration constant.

$$\mathbf{Fb} = (4/3)\pi r^3 D_{fluid} g$$

**Fb** is defined as the force of buoyancy

$(4/3)\pi r^3$  is defined as the radius of the liquid in terms of the graduated cylinder.

$D_{fluid}$  is defined as the density of the fluid

**g** is defined as the gravitational acceleration constant

In terms of Stoke's Law, the drag force can be determined. This can be used in this investigation as Stoke's Law is only applicable to spherical objects in a fluid that are flowing in a steady manner (not turbulent). Drag serves to oppose the downward force of gravity and is dependent on the viscosity, which finally allows for an equation that can be used to determine the viscosity of a fluid.

$$\mathbf{Fd} = 6\pi\mu Vd$$

**Fd** is defined as the force of drag

**$\mu$**  is defined as the viscosity of the fluid

**V** is defined as the sphere's velocity

**d** is defined as the diameter of the sphere

**$6\pi$**  is defined as a constant utilized in accordance with the size of the sphere

It can be assumed that the steel ball is falling at a constant velocity in a calm fluid, and thus, the force of drag and buoyancy must be equal to the force of gravity (the downward forces must equal the upward forces).

$$\mathbf{F_b + F_d = F_g}$$

$$\mathbf{(4/3)\pi r^3 D_{fluid} g + 6\pi\mu Vd = mg}$$

In terms of units, the SI unit for viscosity is  $kg \cdot m / s^2$ , however since the experiment was done in such a small scale, the viscosity will be instead measured in  $kg \cdot cm / s^2$ .

*Table 4: Sample Calculation of Mass and Density of Maple Syrup at 21°C*

<p><i>Mass of Maple Syrup Used:</i></p> $m_{\text{maple syrup}} = m_{\text{maple syrup and graduated cylinder}} - m_{\text{graduated cylinder}}$ $= [(236.87 \pm 0.01) - (96.71 \pm 0.01)] \text{ g}$ $= (140.16 \pm 0.02) \text{ g}$	<p><i>Density of Maple Syrup Used:</i></p> $D_{\text{maple syrup}} = m_{\text{maple syrup}} \div V_{\text{maple syrup}}$ $= (140.16 \pm 0.02) \text{ g} \div (100.00 \pm 0.1) \text{ mL}$ $= \mathbf{(1.402 \pm 0.002) \text{ g/ml}}$
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*Table 5: Calculation of Conversions Needed for Final Calculation*

<p><i>Converting the mass of the steel ball from g to kg</i></p> $m_{\text{steel ball(g)}} = 8.51 \text{ g} \pm 0.01 \text{ g}$ $m_{\text{steel ball(kg)}} = 8.51 \text{ g} / 1000 \pm 0.01 \text{ g}$ $m_{\text{steel ball(kg)}} = \mathbf{(8.51 \times 10^{-3} \pm 1 \times 10^{-5}) \text{ kg}}$	<p><i>Converting the value of gravitational acceleration constant from m to cm</i></p> $g = 9.8 \text{ m/s}^2$ $g = 980 \text{ cm/s}^2$
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*Table 6: Sample Calculation of Velocity of Steel Ball during Fall through 21°C Maple Syrup*

<p><i>Velocity of Ball:</i></p> <p>Velocity = distance / time</p> $V_{\text{ball}} = d_{\text{travelled by ball}} / t_{\text{of fall}}$ $= (26.4 \pm 0.05) \text{ cm} / (6.48 \pm 0.01) \text{ s}$ $= \mathbf{(4.07 \pm 0.07) \text{ cm/s}}$
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*Sample Calculation of the Viscosity of 21°C Maple Syrup, using the equation derived above*

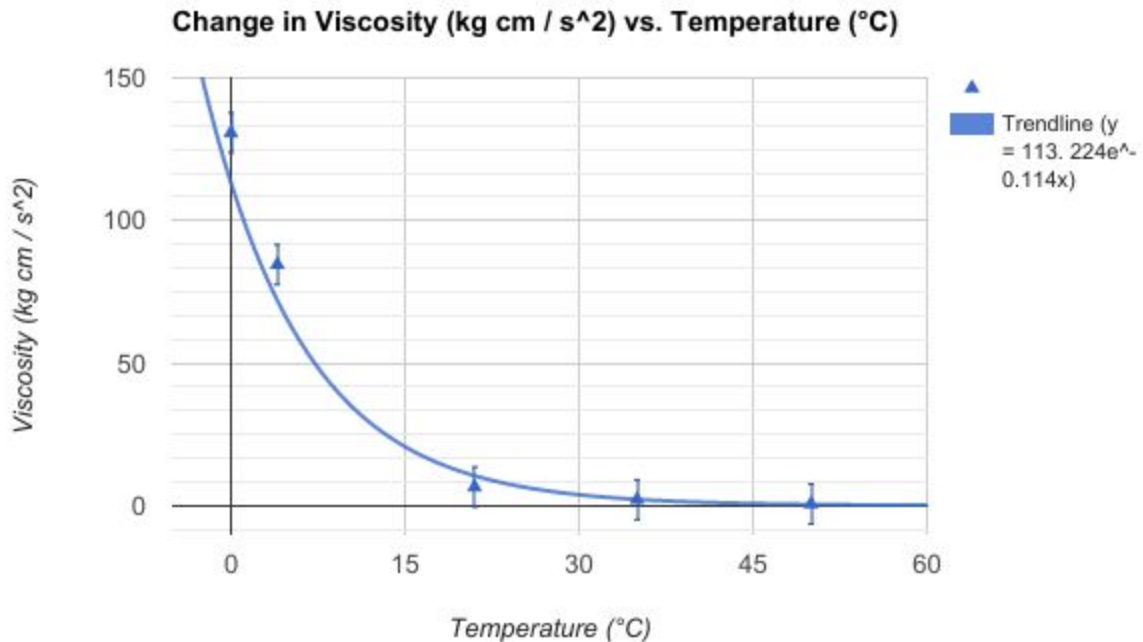
$$\begin{aligned}
 (4/3)\pi r^3 D_{fluid} g + 6\pi \mu V d &= mg \\
 \mu &= [mg - (4/3)\pi r^3 D_{fluid} g] / [6\pi V d] \\
 &= \frac{[(8.51 \times 10^{-3} \pm 1 \times 10^{-5}) \text{kg} (980 \text{ cm/s}^2) - (4/3)(\pi)(0.6 \pm 0.05)^3 \text{cm} (1.402 \pm 0.002) \text{g/ml} (980 \text{ cm/s}^2)]}{(6\pi) \times (4.07 \pm 0.07) \text{cm/s} \times (1.2 \pm 0.05) \text{cm}} \\
 &= \frac{[(8.51 \times 10^{-3} \text{kg} \pm 0.12\%) - (4/3)(\pi)(0.216 \pm 0.15) \text{cm} (1.402 \text{g/ml} \pm 0.14\%)]}{(6\pi) \times (4.07 \text{cm/s} \pm 0.07\%) \times (1.2 \text{cm} \pm 1.71\%)} \\
 &= \frac{[(8.51 \times 10^{-3} \text{kg} \pm 0.12\%) - (4/3)(\pi)(0.216 \text{cm} \pm 69.44\%)(1.402 \text{g/ml} \pm 0.14\%)]}{(6\pi) \times (4.07 \text{cm/s} \pm 0.07\%) \times (1.2 \text{cm} \pm 1.71\%)} \\
 &= \frac{1234.79 \pm 0.88\%}{92.06 \pm 1.78\%} \\
 &= 13.41 \pm 0.49\% \\
 &= (13.41 \pm 0.07) \text{kg} \cdot \text{cm} / \text{s}^2 \\
 &= (0.13 \pm 0.01) \text{kg} \cdot \text{m} / \text{s}^2
 \end{aligned}$$

*Table 7: Average Calculated Viscosities for Maple Syrup at all Temperatures °C*

Temperature of Maple Syrup (±1°C) (°C)	Calculated Viscosity ( $\text{kg} \cdot \text{cm} / \text{s}^2$ ) (±0.07)
0°C	270.4
4°C	172.7
21°C	13.41
35°C	4.176
50°C	1.013

## Data Analysis

Using the calculated viscosity values above, I decided to represent it graphically, in order to obtain a greater understanding of the relationship between temperature and the viscosity of maple syrup.



We can see that there is a negative exponential correlation between the viscosity and the temperature of the maple syrup, and it is also confirmed with the trendline created, that shows an equation of  $y = 113.224e^{-0.114x}$ .

## Conclusion

This investigation successfully concluded that as the temperature (°C) of the maple syrup increased, the viscosity ( $kg \cdot cm / s^2$ ) of the maple syrup also decreased, in an exponential relationship. The line of best fit of this relationship was found to be  $y = 113.224e^{-0.114x}$ , where x represented the temperature (°C). Although I predicted the negative correlation in my hypothesis, I was unable to foresee the exponential relationship. Due to the low uncertainty value ( $\pm 0.07$ ) for all of my calculated values for viscosity, I believe the calculated viscosities are very reliable.

## **Evaluation**

There are various strengths and limitations that have affected the execution of this investigation, as well as the accuracy and precision of the final results of this exploration. In terms of strengths of the design, the use of a funnel on top of the graduated cylinder in order to focus and center the position of the fall of the steel ball allowed the ball to be dropped in a consistent manner for every trial. Moreover, it allowed the sphere to fall without making contact with the sides of the graduated cylinder, which would ultimately exert more friction on the ball, leading to inaccurate final results. The choice of the spherical shape of the object allowed the overall drag to be minimized, which permitted the investigation to be more focused on the property of viscosity of the maple syrup. As for the fluid, the maple syrup was left to set for two hours prior to each trial in order to eliminate air bubbles, which would affect the consistency of the fall of the ball. Next, to capture and measure the amount of time taken for the fall of the ball, a video camera was used and the time take was later determined using time stamps. This eliminated the human error which would exist if the time was measured instead with a stopwatch, which relies on human reaction time. Finally another strength of this exploration was the execution of 5 trials for each temperature of maple syrup, which eliminated random error.

However, there were also some limitations that hindered the accuracy of the final results obtained. The most prominent limitation I realized only after conducting the experiment and the calculating the final viscosities of the different temperature of maple syrup, is the assumption that the density of the maple syrup was constant throughout all the trials. The density of the maple syrup should be constant for the room temperature and the colder samples, as they were all room temperature prior to the tampering of the temperature. However, the maple syrup samples that were heated to 35°C and then 50°C definitely had a change in density, since as the sample was being heated, the water content in the maple syrup was being evaporated, leaving behind the sugar. This would produce a different density from the sample at room temperature. A solution to this would be to finding the mass of the maple syrup sample, figuring out the density and plugging each different value of density, for each trial calculation.

Another limitation is the assumption that the velocity of the ball during the fall is constant. However a qualitative observation that was observed, especially during the trials of the 0°C maple syrup, the ball would sometimes get stuck along the graduated cylinder, and would have to wait until the fluid melted a little bit more, for it to continue along its trajectory. Although there is no solution for this limitation in a high school lab environment, this limitation should still be considered when evaluating the accuracy of the final results of this investigation.

Finally, another possible source of error is the width of the graduated cylinder containing the maple syrup, that was not considered in the final calculation of the viscosity. It is possible that since the width of the graduated cylinder was only around 3 times the diameter of the steel ball, that it exerted some friction and drag from the walls of the container. In order to minimize this, the experiment should be conducted in a cylindrical container with a wider diameter, such as a vase or a small bucket, in order to minimise unforeseen friction and drag.

**Extension:**

This investigation allowed me to further understand the concepts of viscosity and the frictional drag force exerted on spherical objects in fluid flow. Although there are limitations to executing this investigation in a high school environment, I realized that there are some slight changes that could be made to my homemade viscometer, in order to prevent unwanted extra sources of friction and drag, in order to improve the accuracy of the final results. After this exploration, my determination to build a more accurate and precise viscometer grew, as it would be interesting to investigate this topic further with more temperature points, and with different Newtonian fluids.

**Citations**

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