# Lab 6 - Latent Heat of Liquid Nitrogen

## Overview

Put a pot of water on a stovetop and heat it up. The more heat added to the water, the higher the temperature the water gets. But, there is at least one temperature that no matter how much heat you add to the water, the water does not increase in temperature. Instead, you may observe bubbles forming in the water. These bubbles are not air bubbles, they are bubbles of water!

The water has begun changing its state from a liquid to a gas. The heat added to the water has increased the energy of the water molecules so much that they now move around like gas instead of a liquid. Because there is no temperature change, the heat is said to be hidden or "latent."

What about other liquids? When we think of boiling water, we think of the water as "hot." Touch boiling water and you will get a very bad burn. But there are other substances that boil at a very low temperature like nitrogen.

Our atmosphere is nearly 80% nitrogen in a gaseous state. But cool nitrogen down to about 77K (-196C) and it will liquify. If you touch liquid nitrogen you would get a severe case of frostbite. Liquid nitrogen boiling point is very cold compared to the boiling point of water

Whether it's water or nitrogen, there is a relationship between the amount of heat $Q$ added and the mass $m$ of the substance changing phase from liquid to gas. The relationship is called the latent heat of vaporization:

$$Q = mL_v \tag{1}$$

In this lab you are going to measure the latent heat of vaporization of liquid nitrogen $L_v$.

## Safety

There are some safety precautions that must be followed at all times during lab:

- Do not touch the liquid nitrogen. Liquid nitrogen is extremely cold. Exposure can cause severe frostbite and blistering. Wear protective safety glasses or goggles at all times.
- During the Power On portion of the lab, the power resistor must be submerged in the liquid nitrogen. If the resistor is exposed to air it can overheat and burn.

- Do not touch the power resistor while power is on. Touching the resistor could cause a burn or electric shock.
- Do not let the power resistor touch the side of the double cup while power is on. It will burn a hole in the cup and the liquid nitrogen will leak out.

## The Experiment

In this experiment, you are going to measure the latent heat of liquid nitrogen (LN2). The experimental setup consists of a double cup containing LN2. The double cup sits on a pan of a balance. A power resistor hangs down into the double cup.


When heat is added to the LN2, the liquid evaporates. The more heat added, the more evaporation. The amount of LN2 decreases over time. If the rate of evaporation $R = dm/dt$ is proportional to the rate of heat (power) transferred $P = dQ/dt$ to the LN2, then the equation of latent heat is:

$$P = RL_v \tag{2}$$

The double cup two thirds full of LN2 is placed on a pan of a balance. The balance can measure the amount of LN2 in the cup. Over time the LN2 will evaporate and the mass of LN2 in the cup will decrease. You will make a series of measurements of the decreasing mass of LN2 over time to determine the evaporation rate.

You will need to record your measurements in a spreadsheet Lab 2 - Latent Heat of Liquid Nitrogen - Student Copy. When you first open the spreadsheet click the men File > Make a copy. Your copy will be in your Google Drive.

Lab 6 - Latent Heat of Liquid Nitrogen - Student Copy

Make sure you select the tab Power Off at the bottom of the spreadsheet.

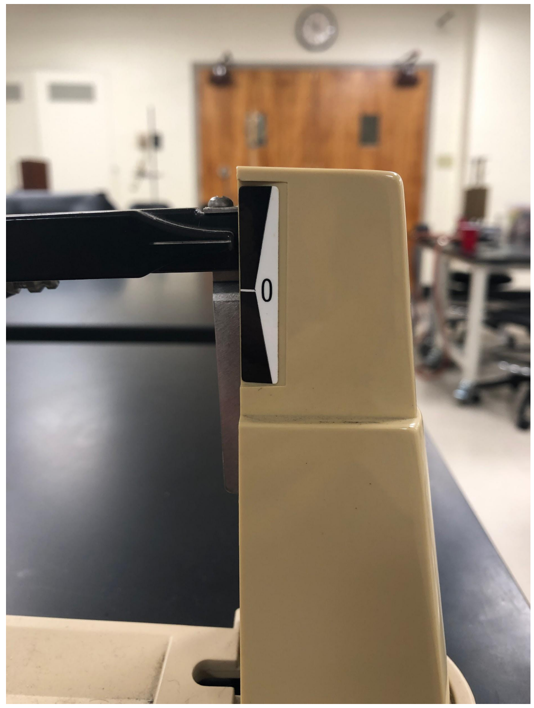
## Evaporation Rate with Power Off

1. Even when there is no power to the resistor, the LN2 will evaporate. Where is the power coming from to evaporate the LN2? Explain your answer.

The power is coming from the heat stored in the air, the room temperature donates its heat to evaporate the LN2

$$P_{OFF} = R_{OFF} L_v \tag{3}$$

- Fill the double cup two thirds of the way with LN2, . Make sure the power resistor is completely submerged in the LN2.
- Turn on the timer at your lab station. Set the MODE to CUMULATIVE and set the FORMAT to SECONDS.
- Adjust that balance so that the balance point is pointing *above* balance; approximately 200 grams.



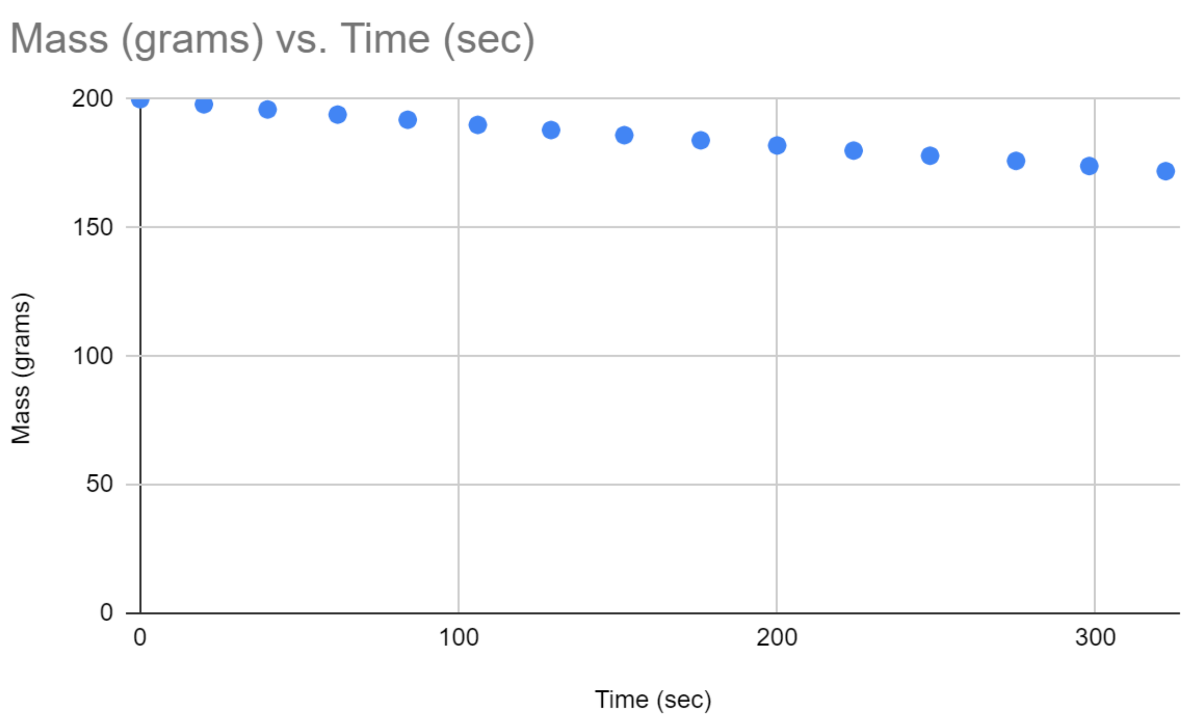

- Wait for some of the NL2 to evaporate. When the balance pointer is pointing to balance, start the timer. Record the mass measured by the balance at time zero.


- Quickly move the slider on the balance beam down 2 grams, so the balance pointer is *above* balance again.

- When more NL2 evaporates the balance point will move back to balance again. When the balance pointer is pointing to balance, hit the START/STOP button on the timer and record the time. NOTE: the timer is still running!
- Move the slider again on the balance beam down 2 grams and wait for the pointer to return to balance again. Hit the START/STOP button again and record the time.
- Continue decreasing the slider on the balance beam by 2 grams and record the time when the balance pointer returns to balance. Continue to record the time and mass decrease of LN2 for about 5 - 6 minutes.

Now let's analyze the data:

2. Make a scatter plot of Mass vs Time:
    a. Click on the header Time (sec) and drag down the column to select the values of time.
    b. Press and hold the Ctrl key and click on the header Mass (grams) and drag down the column to select the values of mass.
    c. Release Ctrl key and open the Insert menu and select Chart.
    d. The Charter Editor will open. In Setup choose Chart Type > Scatter Chart,
    e. Make sure the X-axis indicates Time (sec).
    f. Make sure the Series indicates Mass (grams). If Time (sec) is in the Series, remove it.
    g. In Customize > Chart & axis titles add axes titles with units to your graph.
    h. Copy and paste your plot into this document below here:



3. Look at your plot of Mass vs. Time. What physical quantity does slope represent? Explain your answer. Hint: look at Eq. (3).

The slope represents rate of evaporation, which in turn represents the rate of change of mass of the liquid nitrogen

We would like to know the value of the slope of Mass vs. Time. In the spreadsheet there is a built-in function called LINEST. LINEST estimates the best fit line $y = mx + b$ (the slope $m$ and intercept $b$) for a set of data. LINEST will return a table with results of the slope and intercept and the uncertainties of slope and intercept of a line that best fits the relationship between Mass and Time. The table of results is organized like this:

| LINEST | |
|---|---|
| Slope | Intercept |
| Uncertainty of Slope | Uncertainty of Intercept |
| Correlation Coefficient R2 | Standard Error |
| F Statistics | Degrees of Freedom |
| Sum of Square Regression | Sum of Square Residuals |

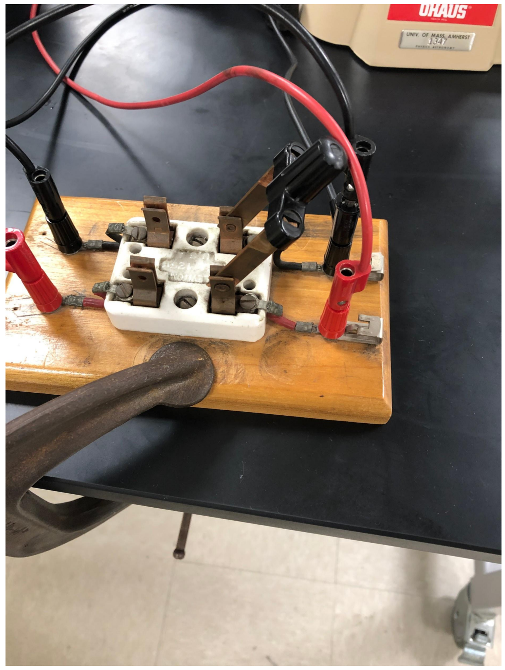
4. Use the built in function LINEST to determine the best slope of Mass vs. Time.
   a. In an empty cell E2 enter =LINEST(range of y,range of x,1,1).
   b. The range of y should be the range of cells with the values of Mass in Column B.
   c. The range of x should be the range of cells with the values of Time in Column A.

5. Record the evaporation rate and its uncertainty (+/-) with power off in table below:

| Evaporate Rate with Power Off (grams/sec) |
|---|
| -0.08612133173 +/- 0.0007528896148 |

## Evaporation with Power On

Now you will repeat the experiment, but this time with power to the resistor ON. IMPORTANT SAFETY: There is a switch you need to close in order to power the resistor. Open the switch when you are NOT taking data or if the resistor is getting too hot!



Now when the power resistor is on, there are two sources of power added to the LN2: the electric power $IV$ and the power from the air in the room:

$$IV + P_{OFF} = R_{ON} L_v \tag{4}$$

6. Will the LN2 evaporate faster or slower when the power resistor is turned on? Explain your answer. The LN2 will evaporate faster because There is now heat being added on top of the ambient temperature

Record your measurements in the spreadsheet Lab 2- Latent Heat of Liquid Nitrogen. Make sure you select the tab Power On at the bottom of the spreadsheet.

- Refill the double cup two thirds of the way with LN2, . Make sure the power resistor is completely submerged in the LN2.
- Turn on the timer at your lab station. Set the MODE to CUMULATIVE and set the FORMAT to SECONDS.
- Adjust that balance so that the balance point is pointing *above* balance; approximately 200 grams.
- Close the switch and record the values of Voltage $V$ and Current $I$ supplied to the resistor. Estimate the uncertainty for current and voltage and record the uncertainty in the spreadsheet.
- Wait for some of the NL2 to evaporate. When the balance pointer is pointing to balance, start the timer. Record the mass measured by the balance at time zero.
- Quickly move the slider on the balance beam down 2 grams, so the balance pointer is *above* balance again.

- When more NL2 evaporates the balance point will move back to balance again. When the balance pointer is pointing to balance, hit the START/STOP button on the timer and record the time. NOTE: the timer is still running!
- Move the slider again on the balance beam down 2 grams and wait for the pointer to return to balance again. Hit the START/STOP button again and record the time.
- Continue decreasing the slider on the balance beam by 2 grams and record the time when the balance pointer returns to balance. Continue to record the time and mass decrease of LN2 for about 2 - 3 minutes.
- IMPORTANt: Open the switch to turn off the power to the resistor.

Now analyze the data with power on:

7. Make a scatter plot of Mass vs Time:
    a. Click on the header Time (sec) and drag down the column to select the values of time.
    b. Press and hold the Ctrl key and click on the header Mass (grams) and drag down the column to select the values of mass.
    c. Release Ctrl key and open the Insert menu and select Chart.
    d. The Charter Editor will open. In Setup choose Chart Type > Scatter Chart,
    e. Make sure the X-axis indicates Time (sec).
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    g. In Customize > Chart & axis titles add axes titles with units to your graph.
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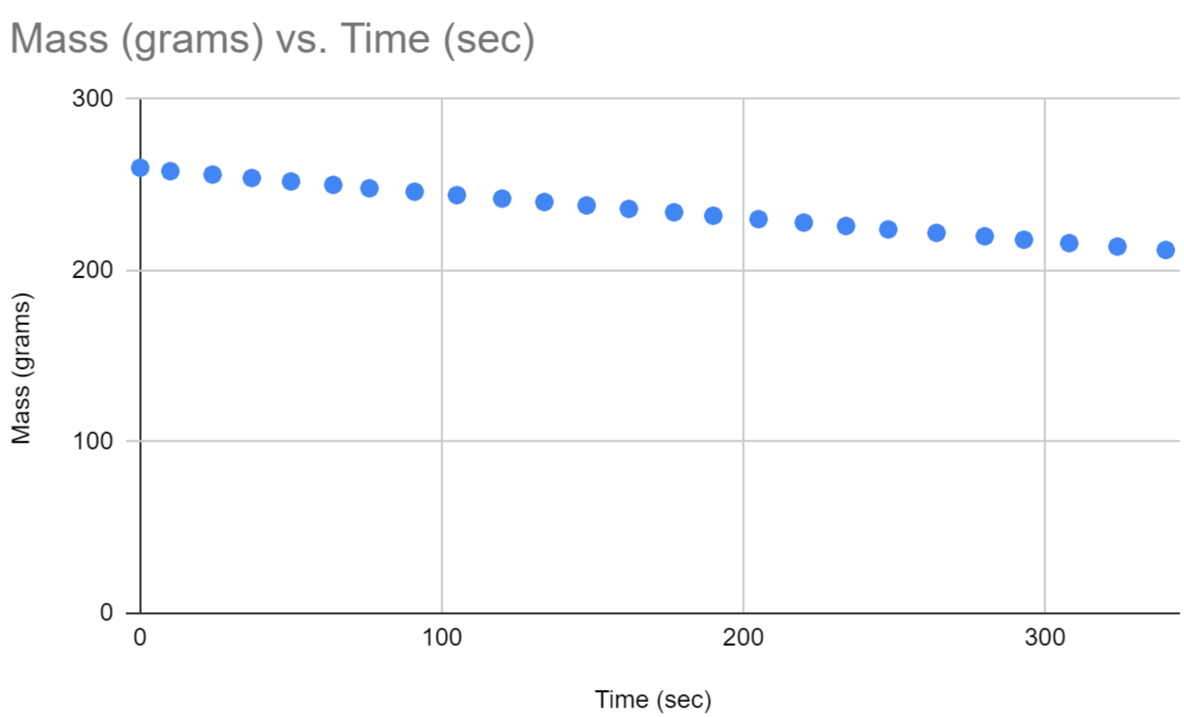


8. Use the built in function LINEST to determine the best slope of Mas vs. Time.
    a. In an empty cell E2 enter =LINEST(range of y,range of x,1,1).
    b. The range of y should be the range of cells with the values of Mass in Column B.
    c. The range of x should be the range of cells with the values of Time in Column A.

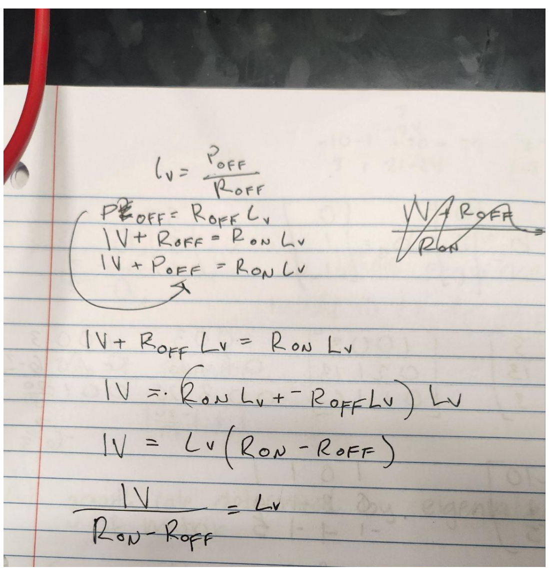
9. Record the evaporation rate and its uncertainty (+/-) with power on in table below:

| Evaporate Rate with Power On (grams/sec) |
|---|
| -0.1450213956 +/- 0.001023579859 |

## Determine the Latent Heat

Now you want to determine the latent heat of LN2 using the measurements you made. Looking at both Eqs. (3) and (4) you can see they both depend on $L_v$.

10. Combine Eqs. (3) and (4) and solve for $L_v$ *algebraically* as a function of $IV$, $R_{ON}$, and $R_{OFF}$. Show your work.




11. Using your equation from question 10 and calculate the latent heat of liquid nitrogen. Record you value of $L_v$ in table below:

| Latent Heat of LN2 (J/g) |
|---|
| -106.9608348 |

Finally you are going to determine the uncertainty of your value of $L_v$. Whenever you make any kind of measurement, there is always a limit to how well you know the value of the measurement. No measurement is exact. That means any value you determine with measured quantities will have an uncertainty too.

One method for determining the uncertainty in a value is called the Monte Carlo method. This method gets its name from the city of Monte Carlo which is famous for its casinos. Many of the games played in casinos are based on random actions like dealing shuffled cards or rolling of dice. The Monte Carlo method uses random numbers to simulate the statistical variability of making measurements.

For your lab, you will generate values you measured ($I$, $V$, $R_{OFF}$, $R_{ON}$) with very small random variations and calculate $L_v$ with these randomly generated values. You will do this hundreds of times, each time randomly varying your measured values, then calculating the hundreds of new $L_v$.

Now you do not have to do all the calculations yourself. Let the spreadsheet do it for you! First click the tab Monte Carlo at the bottom of the Google Sheet spreadsheet. At the top of the spreadsheet enter the values (best) of $I$, $V$, $R_{OFF}$, and $R_{ON}$. Enter the uncertainties of these values in the row Uncertainty. The uncertainties for $V$ and $I$ are your estimates from reading voltmeter and ammeter gauges. The uncertainties of $R_{OFF}$ and $R_{ON}$ are calculated from LINEST().

The spreadsheet will generate randomized values of the $I$, $V$, $R_{OFF}$, and $R_{ON}$ and calculate random values of the latent heat $L_v$ 1000 times!

12. Calculate the average value of $L_v$ using the function =AVERAGE() in the spreadsheet.

13. Calculate the uncertainty of $L_v$ using the function =STDEV() in the spreadsheet. Record the average +/- uncertainty of $L_v$ in the table below:

| Latent Heat of LN2 (J/g) |
|---|
| -106.5583373+/-9.13182301 |