Vaporization of Liquid Nitrogen

<u>Goals and Introduction</u>

As a system exchanges thermal energy with its surroundings, the temperature of the system will usually increase or decrease, depending on the direction of the flow of thermal energy. The exceptions to this occur at particular temperatures of a system where the flow of thermal energy causes a change in phase of the system, rather than a temperature change. These particular temperatures are often referred to as the *melting point* (when the system changes from solid to liquid or vice-versa) and the *boiling point* (when the system changes from liquid to gas or vice-versa). In this lab, you will investigate the phase change of a substance and compare the thermal energy flow rate into the system to the rate at which the mass of the substance undergoes the phase change.

In thermodynamics, the system with which we are often concerned is a substance in a particular phase (solid, liquid, or gas). When the temperature of a liquid substance is raised to its boiling point, the further addition of thermal energy (Q) will cause the liquid to start vaporizing, changing phase from liquid to gas. Just as you have probably observed with a boiling pot of water though, the entire substance does not undergo the phase change instantly. Rather, some portion of the liquid is converted to gas while thermal energy continues to flow into the substance. In other words, it takes a certain amount of thermal energy (Q) to transform a certain mass of the substance (Δm). The ratio of these quantities is referred to as the *latent heat* of the material. When examining the phase transition that occurs at the boiling point, the property is called the *latent heat of vaporization* (L_v). The relationship between this property, the thermal energy flow, and the mass of the substance is shown in Eq. 1.

$$L_v = \frac{|Q|}{\Delta m} \qquad \text{(Eq. 1)}$$

The absolute value symbol surrounding Q is required because the same equation governs the phase change whether the heat flow is into (+) or out of (-) the system. In other words, the same equation governs the change from gas to liquid and the change from liquid to gas.

Different materials have different values for their latent heats, because the quantity is really a measure of the energy necessary to break intermolecular bonds and allow the substance’s phase to change. Today, you will be working with liquid nitrogen, which has a boiling point temperature of 77 K. The difficulty is that the liquid nitrogen will already be undergoing a phase change when you start the lab because the room temperature is closer to 300K! You will be using a thermal container (or thermos) to limit the interaction between the liquid nitrogen and the room, but some thermal energy is going to flow from the room into the liquid regardless. By observing for some amount of time and watching how the mass of the liquid changes, we can quantify the effect of the thermal energy from the room on the liquid.

Knowing the rate of mass conversion (from liquid to gas), due to the thermal energy from the room, we can apply a controlled flow of energy and observe its effect on the rate of mass conversion. This is accomplished by running an electric current through a coil that is immersed in the liquid. Electrical energy from the current will be converted to thermal energy in the coil, which then becomes thermal energy in the liquid. Because you have not yet dealt with modeling electric current, we will have to provide briefly the required knowledge here.

When a current (I), measured in amperes (A), flows through a wire (coil) with a potential difference (ΔV), measured in volts (V), the power (P) delivered to the coil is given by Eq. 2.

$$P = I\Delta V \qquad \text{(Eq. 2)}$$

Recall that power is the rate at which energy is delivered. While its units are normally expressed in watts (W), an equivalent unit expression is joules per second (J/s). When the current is measured in amperes and the potential difference in volts, the power will have units of joules per second. By observing how the mass of the liquid nitrogen in our experiment changes as time goes on (the mass is being converted to gas and leaves the container), we can find a rate of change of the mass of the liquid nitrogen, symbolized as $\Delta m/\Delta t$.

Looking back at Eq. 1, we find a useful result if we divide both the numerator and denominator by Δt.

$$L_v = \frac{|Q|/\Delta t}{\Delta m/\Delta t}$$

Now the numerator is the rate of change of energy, that is the power, and the denominator is the rate of change of mass, as shown in Eq. 4.

$$L_v = \frac{P}{\Delta m/\Delta t} \qquad \text{(Eq. 4)}$$

The accepted value of the latent heat of vaporization for liquid nitrogen is 1.992×10^5 J/kg. Today, you will perform measurements in an effort to confirm this value. This will be accomplished by measuring the rate of liquid mass loss due to the room itself, and then measuring the rate of liquid mass loss when the electric current is applied.

Goals: (1) Become more familiar with the concept of the material property *latent heat of vaporization*.

(2) Use the rate of mass loss and the power delivered to measure the latent heat of vaporization of liquid nitrogen.

Procedure

Equipment – stopwatch, liquid nitrogen, thermal container, balance, ammeter, voltmeter, coil heating element, power supply

WARNING: During the experiment, never allow the electric current to exceed 0.5 A!

1. Place the thermal container on the balance and suspend the heating element within it in such a way that it is not contacting the bottom or inner walls of the container.

2. The ammeter measures current in amps (A), while the voltmeter measures the potential difference across the heating element in volts (V). Check and verify that the heating element, voltmeter, ammeter, and power supply are connected as shown in Figure 17.1. Note that you should be connected to the 1 A scale on the ammeter and the 30 V scale on the voltmeter. This should be done for you ahead of time. Note! The voltage knob on the power supply (knob on the wall unit) should be turned all the way counter-clockwise (i.e. all the way off) before you turn on any of the equipment. Have your TA check your setup if you are unsure.

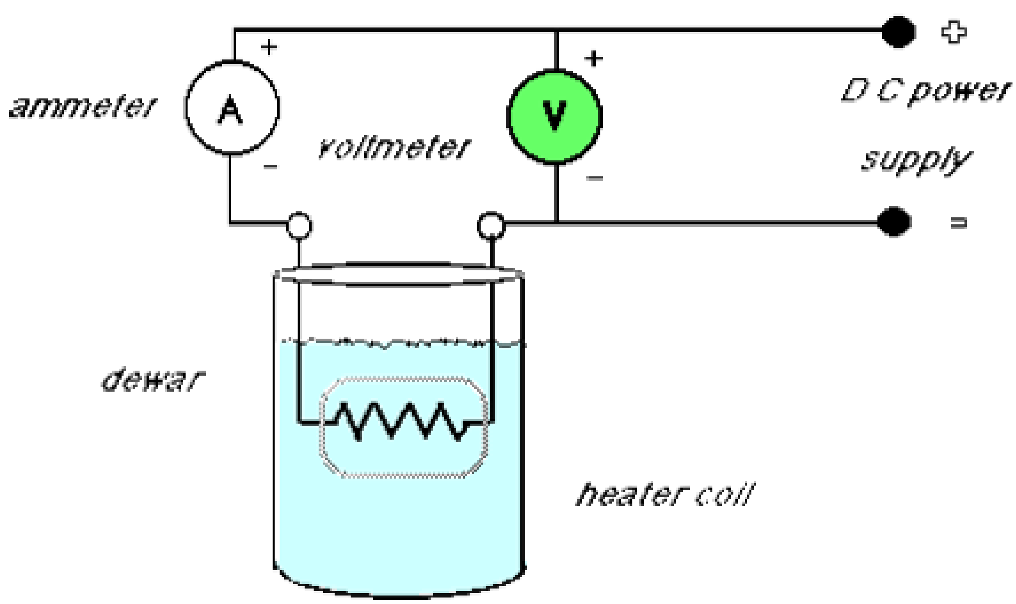

Figure 17.1

3. Turn on the power supply, slowly turn the voltage knob, and verify that both meters register a change in electrical behavior. Turn the knob until the ammeter shows a current of 0.5 A and then turn off the power supply. This will ensure the heating coil will experience the proper current during the experiment.

In the steps 4 through 6, you will practice the procedure for taking data in this lab exercise. Read steps 4 through 6 before initialing your practice run. Be sure you understand the measurement process before actually starting the experiment (step 7) where you need to record timed results.

4. Fill the container with liquid nitrogen and wait for 3-5 minutes while the nitrogen cools the container and the heating element. Have one lab partner prepare the stopwatch, while the other prepares to operate the balance and record the mass and time during the experiment. Once it appears most of the liquid nitrogen has boiled off, note the mass of the container with the liquid nitrogen. At that same moment, start the stopwatch and then set the balance for 2 g less than your recorded mass. The system will eventually be balanced again as the liquid nitrogen slowly vaporizes. Once it is, you would record the time and set the balance for 2 g less than the current mass. This process could then be repeated when taking data later.

5. To practice with the heating element turned on, repeat the last step of the procedure, but turn the power supply on when you start the stopwatch. Note that the liquid nitrogen is vaporizing faster and that you will need to reduce the balance by 2 g more often, as it comes into balance more quickly.

6. Turn off the power supply and note the mass at that moment. Restart the stopwatch and again set the balance for 2 g less than the current mass. Observe the time when the system comes into balance and set the balance for 2 g less than the current mass again.

You are now done with practicing unless you would like to try again. Check with your TA if there is any confusion. Be sure you understand how to turn the power supply on and off and know how to adjust the voltage on the supply so that the current on the ammeter remains at 0.5 A.

During this experiment, you will record the time each time the mass of the container has dropped by 2 g. You should prepare to record your data by making three tables, where each table has two columns: one labeled *mass* and the other labeled *time*. You will now proceed with steps similar to what you practiced to fill in each table. Be sure the heating element is off at the start.

WARNING: Read the entire rest of the procedure before beginning to take data, so that you are prepared for each step and understand the process.

7. Refill the thermal container with liquid nitrogen and wait for it to settle down after the initial boil-off. When you are ready to begin, **record** the mass and start the stopwatch. You should record the *mass* in your first table with the corresponding *time* as 0. Set the balance for 2 g less than the initial mass. Then, each time the mass drops by 2 g (so that the system is balanced again), **record** the new mass and the time that has elapsed since the beginning. Do this for ten minutes.

8. Turn on the power supply and adjust the voltage knob on the power supply if necessary so that the current measured by the ammeter is about 0.5 A. **Record** the current in amperes (on the ammeter) and the potential difference in volts (on the voltmeter). Also, restart the stopwatch and **record** the current *mass* in your second table with the corresponding *time* as 0. Set the balance for 2 g less than the initial mass. Then, each time the mass drops by 2 g (so that the system is balanced again), **record** the new mass and the time that has elapsed during this step. Do this for ten minutes.

9. Turn off the power supply. Restart the stopwatch and **record** the current *mass* in your third table with the corresponding *time* as 0. Set the balance for 2 g less than the initial mass. Then, each time the mass drops by 2 g (so that the system is balanced again), **record** the new mass and the time that has elapsed during this step. Do this for ten minutes.

As always, be sure to organize your data records for presentation in your lab report, using tables and labels where appropriate.

Data Analysis

HINT: You may have recorded the mass in grams (g). Be sure to convert to kilograms (kg) before performing any further analyses.

If we graph the mass as a function of time from each table (mass on the *y* axis and time on the *x* axis), a best-fit trendline can be found. The slope of this line would have units of kg/s and would be equal to $\Delta m/\Delta t$. By comparing the slope when the heating element was on to the slope when the heating element was off, we can determine the effect of the heating element itself, as opposed to the effect of the environment.

Take your data from table 1 (before you had turned on the heating element) and create a scatter plot in Excel. Then, find a trendline and display the equation of the trendline on your plot. Note the slope of your trendline.

HINT: If you are unsure how to create a scatter plot and find the best-fit trendline in Excel, review steps 26 through 32 in the Introduction to Excel lab from the beginning of the semester.

Take your data from table 3 (after you had turned off the heating element) and create a scatter plot in Excel. Then, find a trendline and display the equation of the trendline on your plot. Note the slope of your trendline.

Find the average of the slopes you found for these two trendlines. This average slope represents the rate of mass conversion, $\Delta m/\Delta t$, due to the environment (with the heating element turned off).

Take your data from table 2 (when the heating element was on) and create a scatter plot in Excel. Then, find a trendline and display the equation of the trendline on your plot. Note the slope of your trendline.

Subtract the average slope due to the environment from the slope of the data from table 2. This result represents the rate of mass conversion due to the heating element alone.

Use your rate of mass conversion due to the heating element and Eq. 4 to compute the latent heat of vaporization for the liquid nitrogen.

Question 1: Had we not attempted to account for the rate of mass conversion due to the environment, would we have overestimated or underestimated the latent heat of vaporization? Explain your answer.

Question 2: Suppose that we used a heating element that caused the power delivered to be greater. Would this have caused us to arrive at a significantly different result for the latent heat of vaporization of liquid nitrogen, or would the final result turn out to more or less be the same? Explain your answer.

Error Analysis

Compare your result for the latent heat of vaporization to the accepted value by computing the percent error for your result. The accepted value of the latent heat of vaporization for liquid nitrogen is 1.992×10^5 J/kg.

Questions and Conclusions

Be sure to address Questions 1 and 2, and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for "Vaporization of Liquid Nitrogen," and submit it before the start of your lab section on the day this experiment is to be run.

PL-1) The latent heat of vaporization, L_v, has units of

(A) joules/degrees Celsius.
(B) newtons.
(C) watts.
(D) joules/kilogram.
(E) joules.

PL-2) The accepted value for the latent heat of vaporization of liquid nitrogen is 199,200 J/kg. How much energy, in Joules is required to completely vaporize 2.0 kg of liquid nitrogen?

PL-3) The accepted value for the latent heat of vaporization of liquid nitrogen is 199,200 J/kg. If the rate of mass conversion is entirely due to a heating element that delivers 150 J/s (or 150 W), how long will it take, in seconds, for the heating element to completely vaporize 2.0 kg of liquid nitrogen?

PL-4) Patrick and Domonique are performing the Vaporization of Liquid Nitrogen lab. They notice that when they turn on the power supply the ammeter says the current in the electrical circuit is 0.75 A. They should

(A) adjust the power supply so that the current is decreased to 0.5 A.
(B) adjust the power supply so that the current is increased to 1.0 A.
(C) panic.
(D) be thankful that the previous lab group had left the power supply set exactly where it should be for this experiment.

PL-5) Patrick and Domonique are performing the Vaporization of Liquid Nitrogen lab and they determine that the rate of mass conversion due to the heating element is 15 g/s. By what factor would this rate change if the power of the heating element were tripled?

(A) It would double.
(B) It would triple.
(C) It would be one-third as much.
(D) It would be one-half as much
(E) It would be about six times greater.
(F) It would be about one-sixth as much.