Latent Heat of Vaporization of Liquid Nitrogen using Physload

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In this experiment, we present an intuitive setup to measure the latent heat of vaporization of liquid nitrogen. We will learn about the thermal properties of materials, and explore connections between thermodynamics and electricity. Furthermore, we will be exposed to the safe handling of cryogens that are routinely used in physics. This experiment is inspired from previously published articles [1, 2, 3] on the subject.

KEYWORDS Latent Heat of Vaporization · Cryogenics · Wire wound resistors · Ammeter · Voltmeter · Physlogger · Physload · Measurement of mass ·

1   Conceptual Objectives

In this experiment, we will,

1. understand the concept of latent heat of vaporization,

2. understand the transfer of heat in calorimetric experiments, and

3. learn how to get meaningful data from experimental graphs.

2   Experimental Objectives

The experimental objectives attainable from this experiment are,

1. getting familiar with the safe use of cryogens,

2. setup of simple circuits for heating and measurement of current and voltage,

3. data processing, and

4. data acquisition.

2.1 Latent Heat of Vaporization

The amount of energy released or absorbed by any substance during a *phase transition* is called the *latent heat.* If we add heat continuously as in Figure 1, a change of phase from solid to liquid and then from liquid to vapor occurs. In physics, these changes are examples of phase transitions. The latent heat absorbed during the liquid-vapor transition is called the *latent heat of vaporization.* This energy overcomes the inter-molecular forces inside the liquid. Figure 1 illustrates this phenomenon, whereby temperature remains constant as heat is supplied during the phase transition.

The latent heat of vaporization can be mathematically expressed as,

$$L_v = \frac{\Delta Q}{m}, \tag{1}$$

where ΔQ is the heat supplied during phase transition and m is the mass of the liquid vaporized.

In our experiment we will use electrical energy to supply energy to a boiling mass of liquid nitrogen. Current is made to flow through a heater placed inside liquid nitrogen. The heat supplied then becomes, $\Delta Q = VI\Delta t$, where V is the voltage from the source having units in volts, I is the current flowing in amperes and Δt is time interval for which heating remains on.
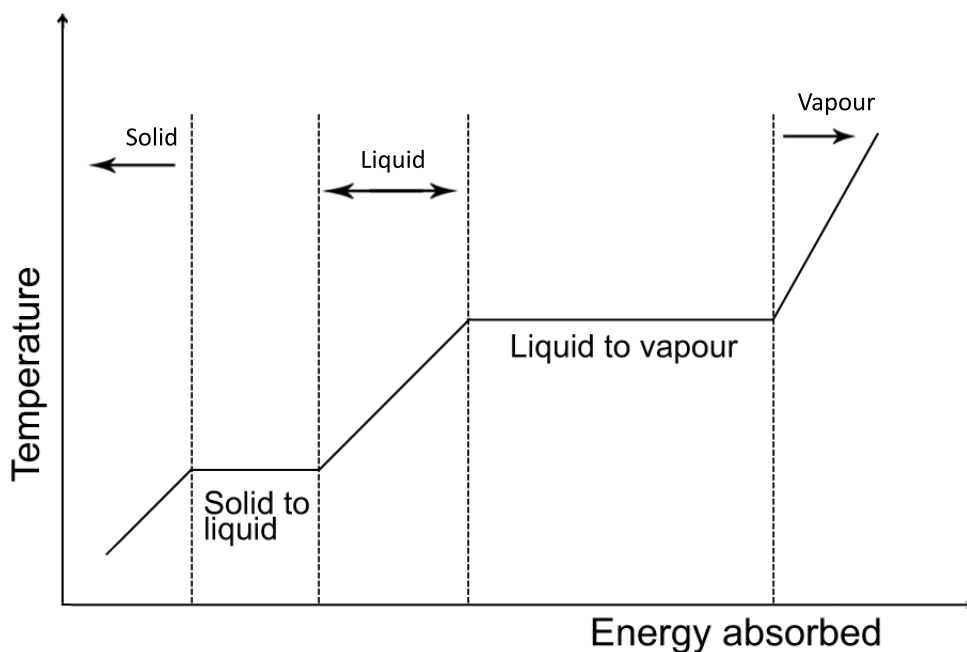

Figure 1: Phase change when heat is added at a constant rate. The temperature remains constant during the phase transition and the heat supplied at these points is called a latent heat.

How do we calculate the mass of the nitrogen vaporized *due to the electrical heating alone?* In fact, the mass of liquid nitrogen, for example, when it is measured on a weighing balance,

gradually decreases because the room temperature provides a sufficiently high temperature for the nitrogen to boil off. So, one has to separate out the quantifiable loss in mass due to electrical heating from the loss in mass due to ambient heating, in order to make use of Equation 2. This is done by establishing a background rate of loss of nitrogen *before* the electrical heating is switched on. The heater is then switched on for a fixed duration of time Δt and the differential reduction in mass calculated. In this experiment, you will be required to understand your data and calculate m by comparing against the background loss. This is something for you to figure out on your own.

With electrical heating, Equation (1) becomes,

$$L_v = \frac{VI\Delta t}{m}. \tag{2}$$

3 Experimental preparation and safety measures

3.1 Using Liquid Nitrogen

Liquid nitrogen is a colorless, odorless and tasteless fluid which boils at 77 K ($-196\,^\circ$C), and is formed by cooling and increasing pressure on air which is predominantly N_2. On evaporation, it generates enormous pressure and direct contact with liquid nitrogen can cause cold burns or frost bites. Liquid nitrogen should never be mixed with water and you **must wear goggles** when making solutions. Never ever dip your finger in a container of liquid nitrogen. Some solvents when mixed with dry ice are flammable but most of them are not. Students must not mix any solvent without prior knowledge.

The container of liquid nitrogen, also called a *dewar*, should be handled with care and covered properly after taking out liquid nitrogen. The cylindrical tubes used to take out nitrogen are delicate and no extra pressure should be exerted on them. The container must be refilled when the level of LN_2 is below a certain value.

3.2 Using the Physlogger and Physload

This experiment employs a Physlogger, a home-grown data-logging device, in connection to a Physload balance. Following are the instructions needed to utilize this system for recording the lost mass of liquid nitrogen in this experiment,

1. Connect the provided Physlogger to the PC using the USB cable.

2. Ensure that a cable also connects the Physlogger to the Physload instrument by means of a cable inserted in an analogue channel (e.g. A) of the Physlogger.

3. Locate the PhysLogger Software on your desktop.

4. Once the software is launched, select Physlogger as the connected device and click Continue. **(Do not select Virtual Physlogger.)**

5. Next, click on the **Measure** option.

6. Scroll to the right of the multiple options on the screen and select **Force (kg)**.

7. Before starting the experiment make sure your values are roaming around the zero axis. If not, then click on the **Force** icon and select **Tare**. This will reset the values to around zero.

8. You may also consider to do tare after placing the Styrofoam cup on the Physload so that it only displays the mass of the liquid nitrogen.)

9. Last, before starting you have to define the location where you want to save your data on the drive. For that click on **Options** in the top right corner and click on **Settings**.

10. In the **Save as** field select a folder and a text file where you would like to save your data.

Figure 2: Select "Measure" and scroll right to find "Force (Kg)" and select it.

4 The Experiment: Latent Heat of Vaporization of Liquid Nitrogen

A resistor (e.g., a 10 watts wire wound resistor [1] or a dissembled 30 watts soldering rod) is connected to the variac (*Space Power Electronics, Karachi*) through a digital ammeter in series as shown in the Figure 4. The variac is an AC transformer that can provide variable voltage. The variac voltage must lies between 22-23V. **Note: Do not turn on the variac unless the resistor is immersed in liquid nitrogen and Do not operate it above 25 V**. The Physload is connected to the Physlogger which is then interfaced with the PC. See previous section to understand how to configure the Physload with the Physlogger to measure force.

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[1] Wire wound resistors consist of a cylindrical core which is wrapped with a wire. This core is typically made up of a ceramic material and the wire is a type of resistance wire.
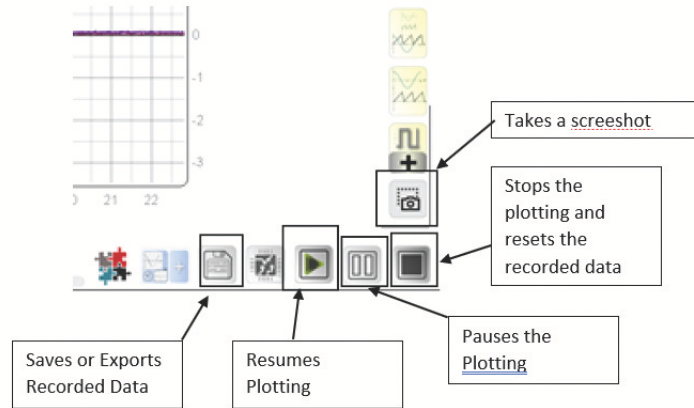
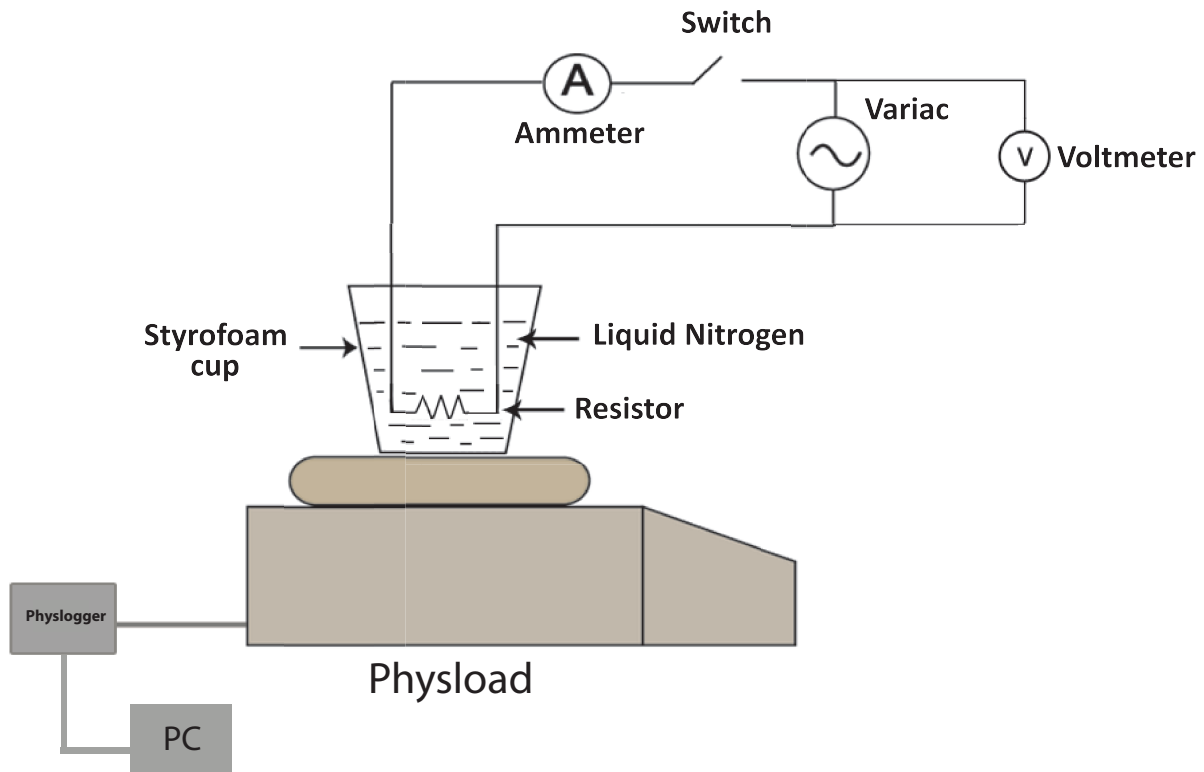Figure 3: Description and functions of some icons in the Physlogger software.

Figure 4: Set up of the Experiment.

Step 1 Make sure the apparatus is set up as shown in Figure (4).

Step 2 Place the styrofoam cup on the mass balance with resistor inside and pour safely liquid nitrogen from the cryogenic container into the provided styrofoam cup. Wait for a few seconds until the system establishes a state of thermal equilibrium and the sizzling sound of

nitrogen settles.

Step 3 Press the **Play** button or the **Clean up** button in the Physlogger Desktop to begin or restart collecting the force values respectively.

Step 4 After having the background loss for ≈ 30 seconds, the switch is closed to turn on the heater. Now the rate of mass loss will be faster and is again recorded as a function of time for ≈ 30 seconds. The heater is then switched off to re-establish the background loss rate and take data for an additional ≈ 30 seconds once again.

Step 5 Plot the data points using Matlab.

Step 6 From the data, find the change in mass m **only** due to electrical heating.

Q 1. Calculate the latent heat of vaporization of liquid nitrogen L_v, also find the uncertainty.

Q 2. Why does the mass of the liquid nitrogen decrease and at what rate? Can this rate be controlled?

Q 3. What would happen if we repeat the experiment varying the heating time (to say 40, 50s) and calculate the latent heat?

References

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