Latent Heat of Vaporization of Liquid Nitrogen with a Force Sensor

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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 · Measurement of mass ·

1 Conceptual Objectives

In this experiment, we will,

1. understand the concept of latent heat of vaporization,
2. learn how to get meaningful data from experimental graphs,
3. learn calculations of uncertainties from experimental data, and
4. practice error propagation.

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.

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,

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

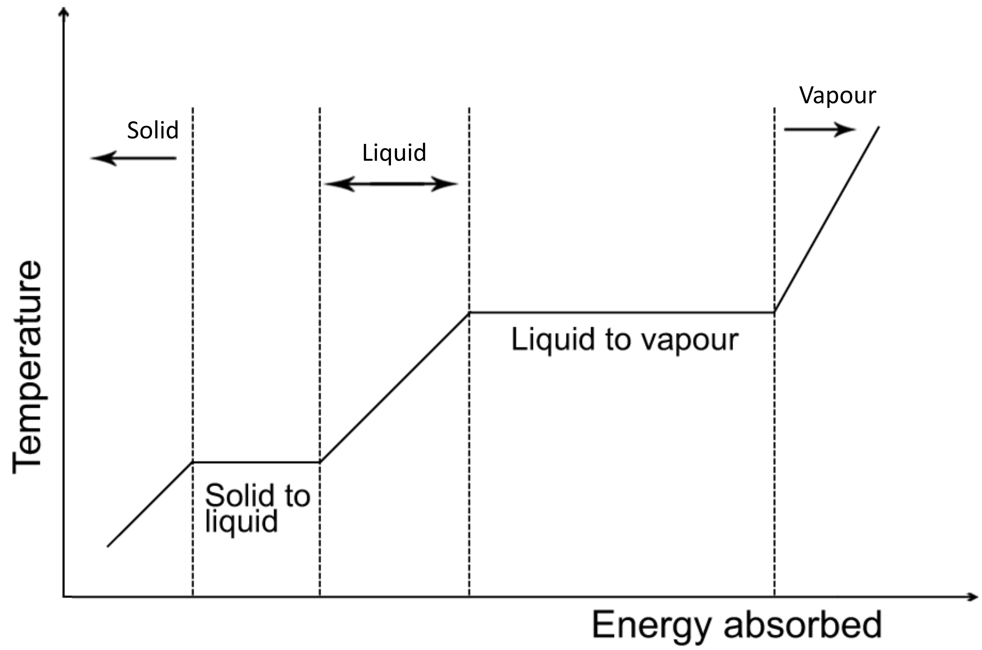

Figure 1: Phase change when heat is added at a constant rate. The temperature remains constant during the phase transition and the heat supplied at these points is called a latent heat.

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 °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 PhysLogger for mass measurement

The mass of liquid nitrogen is gauged using a *Load Sensor* that is connected to *PhysLogger*, a low-cost home built data acquisition device that consists of 4 analog input channels that can be used to acquire differential voltage signals of amplitudes as low as 30 mV with sampling frequencies up to 1 KHz. The data is collected in time domain using the Physlogger application installed on the computer. This can be demonstrated from our website.

3.3 Load sensor

A load sensor is a device capable of measuring weight hung from it and is fabricated in the Physlab. Inside the load cell, two strain-gauges are bonded onto a beam that deforms when weight is applied to it. The working is shown in Figure 4. We use this sensor to measure the rate of change of mass of boiling liquid nitrogen. A glass of liquid nitrogen is hung with the internal beam of the load cell, it deforms, creating strain in the top and bottom strain gauges $G1$ and $G2$ respectively. The strain signal is sent in an electrical form to the Physlogger to be displayed on the computer application. The interevening circuit and the connections with the Physlogger device are shown in the Appendix.

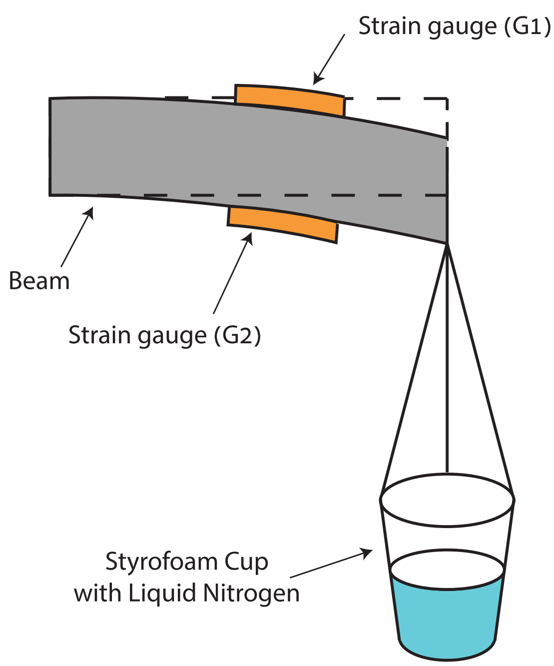

Figure 2: The mechanical structure and application of the load cell. The dashed rectangle shows the undeflected cantilever. The differential signal from the strain gauges G_1 and G_2 which are part of a Wheatstone bridge, is a measure of the weight attached.

3.4 Calibrating the load sensor

Before we start collecting data, the load sensor has to be calibrated. The calibration can be done by hanging a glass of water with known mass, say 50 g with the load sensor and let it run for about 2 minutes until the load displayed on the Physlogger application stabilizes. After the value becomes stable, remove the cup of water and let the sensor stabilize around the zero value again. This will typically take about 2 minutes again. You can also use the provided set of weights for calibration instead of a glass of water. If you would like to zero your reading at some baseline, click the "Set to Zero" button.

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 a DC Power Supply. The output current and voltage of the supply is measured through a digital ammeter in series and a digital voltmeter in parallel as shown in Figure 3. The power supply can provide variable DC voltage. The voltage must lie between 10–15 V. **Note: Do not turn on the power supply unless the resistor is immersed in liquid nitrogen and do not operate it above 15 V**. The load sensor is connected to the computer through the PhysLogger via a USB cable. Refer to the Appendix for the circuit diagram, the amplifier circuit for the load cell and the cable pins connecting to the PhysLogger.

Q 1. Set up the apparatus as shown in Figure 3. Refer to the Appendix ensuring that all connections to Physlogger are properly made. Open the Physlogger application.

Q 2. Hang the styrofoam cup using threads with the load cell and safely pour liquid nitrogen from the dewar into the provided styrofoam cup.

Q 3. The load cell will record the loss in the mass of liquid nitrogen through the PhysLogger on the computer.

Q 4. Set the channel type inside the PhysLogger to **PhysLab K-Type thermocouple amplifier**. Also, rename the channel accordingly.

Q 5. After having the background loss for $\approx$ 30 seconds, turn on the power supply to switch on the heater. Now the rate of mass loss will be faster and is again recorded as a function of time for $\approx$ 30 seconds. The heater is then switched off to reestablish the background loss rate and take data for an additional $\approx$ 30 seconds once again. You can save data for analysis from the `Project` menu.

Q 6. Why does the mass of the liquid nitrogen decrease and at what rate? Can this rate be controlled?

[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.

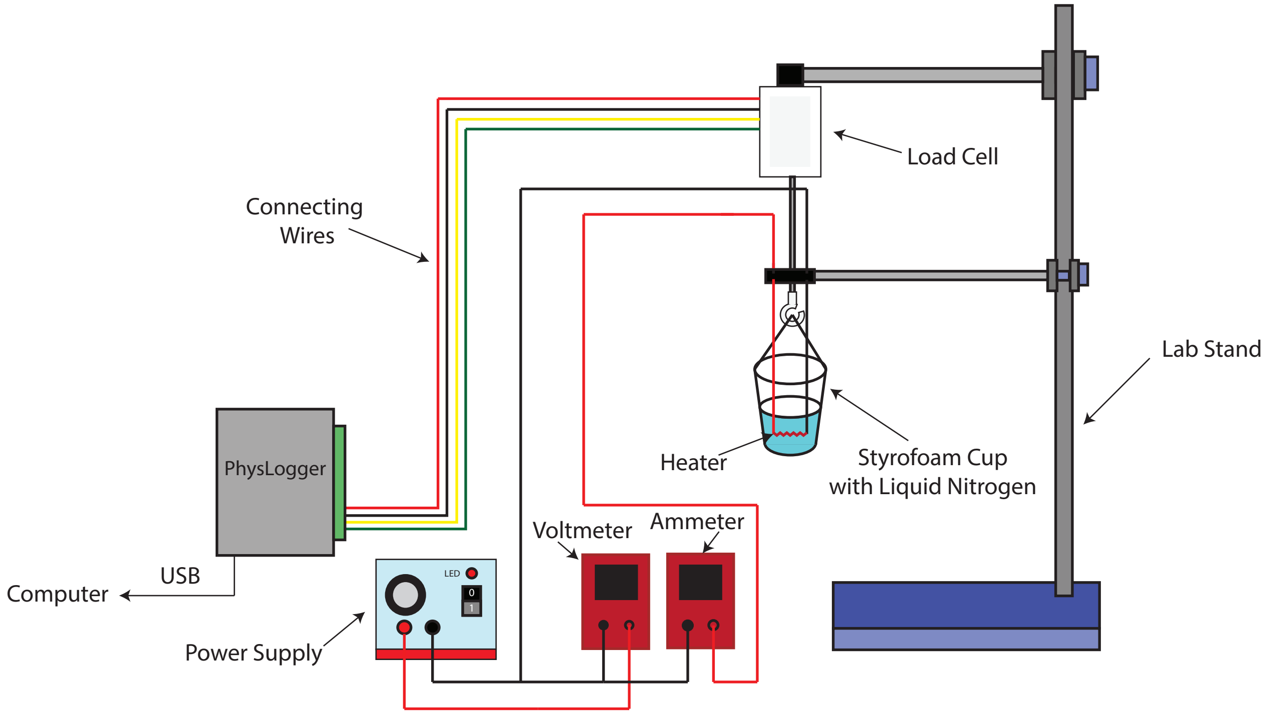

Figure 3: Schematic of the experimental used to measure the latent heat of vaporization of liquid nitrogen.

Q 7. Plot the data points and find the change in mass m **only** due to electrical heating.

Q 8. Calculate the latent heat of vaporization of liquid nitrogen L_v, also find the uncertainty.

Q 9. What would happen if we repeat the experiment varying the heating time (to say 40,50 s) and calculate the latent heat? What would the graphs look like?

References

[1] C. G. Deacon, J. R. de Bruyn, J. P. Whitehead "A simple method of determining Debye temperatures", Am. J. Phys. **60**(5), 422-25 (1991).

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A Appendix

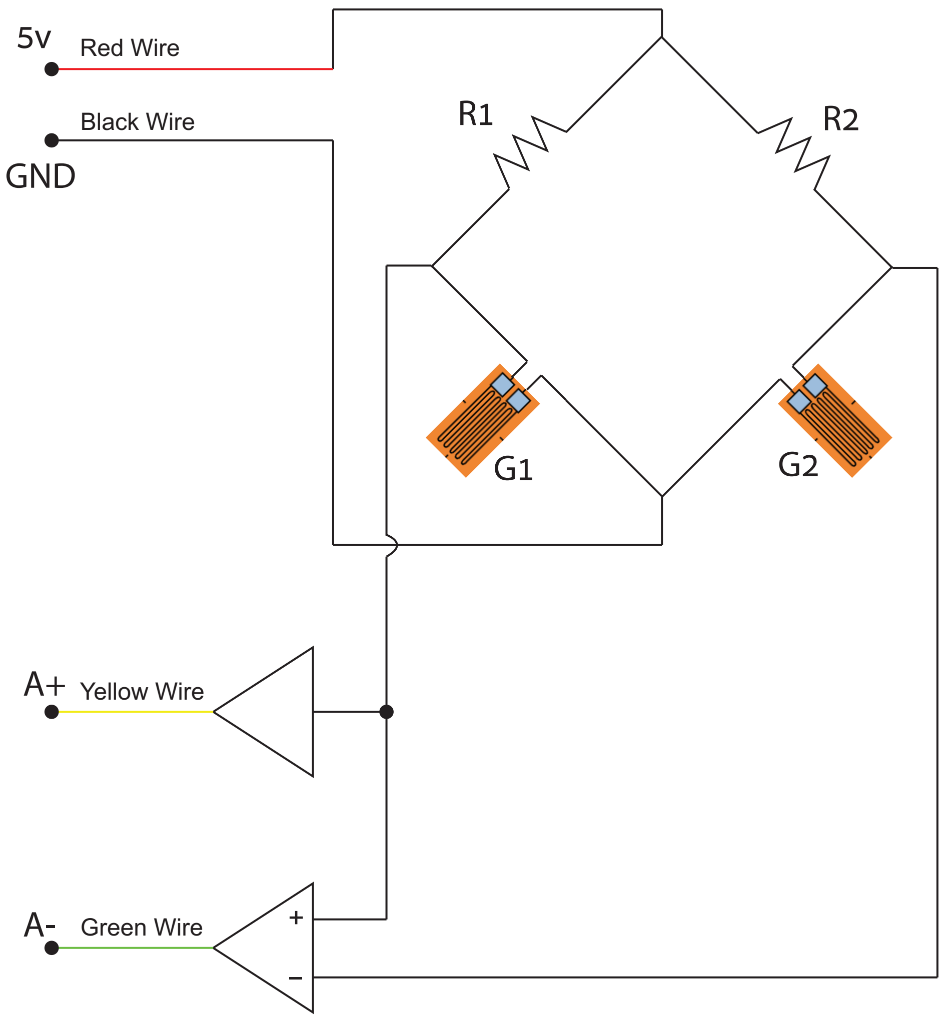

Figure 4: The load sensor signal amplifier circuit and pin diagram showing connections between the load cell and the Physlogger. The 5 V, GND, A+ and A- pins are physically situated on the Physlogger unit. Also note that $R_1 = R_2 = 1\ \text{k}\Omega$ and G_1 and G_2 are nominally $350\ \Omega$.