(TA INITIALS)

FIRST NAME (PRINT) LAST NAME (PRINT) BROCK ID (AB17CD) (LAB DATE)

Experiment 2

Calorimetry and heat capacity

Liquid nitrogen and safety

In this experiment, you will use liquid nitrogen as a handy source of a large temperature difference. The temperature of liquid nitrogen is 77 K or −196°C, more than 200°C below room temperature. To avoid injury, open-toed footwear will not be permitted in the laboratory, and be sure to:

Always wear gloves and goggles when handling liquid nitrogen!

Procedure and analysis

A computer-connected precise digital weight scale will allow you to monitor the weight of a Styrofoam cup containing liquid nitrogen. As heat is slowly transferred from the room-temperature environment, or as we add a known amount of room-temperature material into the cup, the added heat will turn some of this liquid nitrogen into gas. As a result, the mass reported by the scale will decrease as a function of time. As you analyze the nature of this time dependence, you should be able to extract several relevant physical quantities with considerable precision.

- Turn on the digital weight scale and wait for the display to read zero. Place the empty Styrofoam cup onto the scale. Note the reported mass, how quickly the scale reading settles to a constant value, the precision of the scale. Note what effect vibrations due to your footsteps or leaning on the table have on the readings, and plan the rest of your experiment accordingly.

m_{cup} = ... ± ....

- Fill the Styrofoam cup to about two thirds with liquid nitrogen, then place it on the scale. Close any running Physicalab software, then restart the program and enter your email address. Set the input channel to `Adam`, select `scatter plot`.
- Choose to collect a data point every 5 seconds for at least 20 minutes, then press **Get data** to start the data acquisition. You can click **Draw** at anytime to graph the data set acquired so far.

- Try a simple linear fit, `A*x+B`, and note the resulting χ^2 misfit value. Over short time intervals, a linear function might be appropriate, but as the level of liquid nitrogen in the cup changes, so does the slope of the curve $m(x)$, where x represents time. Label the axes and include the fit equation as part of the title, then press the **Send to:** button to email every member of the group a copy of the graph for inclusion in the lab report.

$\boxed{?}$ What do you note when comparing the curve from fitting equation to the points from your data set?

- Now try an exponential fit, `A*exp(-x/B)` and note again the χ^2 misfit. Your plot should look similar to the one shown in Fig. 2.1.

$\boxed{?}$ Compare once again the curve from the fitting equation to the trend in your data set. What changes do you note from the previous graph?

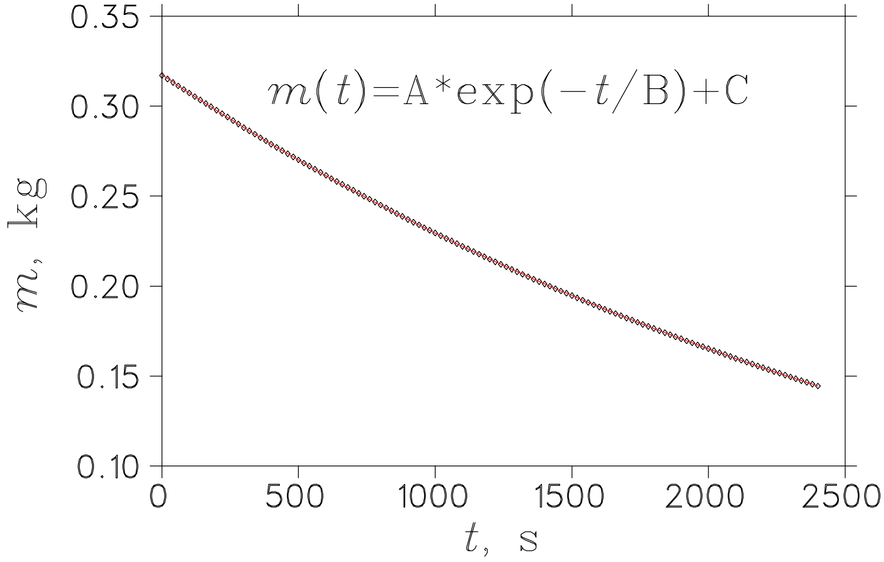

Figure 2.1: Mass of a cup of liquid nitrogen decreases with time due to boil-off

$\boxed{?}$ What is the dimension and the physical meaning of the fit parameter `B` in the exponential fit?

$\boxed{?}$ What value does this fitting equation converge to as time progresses toward infinity? Is this result consistent with what you would expect?

- If the liquid-nitrogen level falls below approximately one-third-full, the exponential function may become insufficient to describe the time dependence you observe, and an additional constant offset parameter may need to be added to the exponential function. Try fitting your data set to `A*exp(-x/B)+C` and make a note of the reported χ^2 values.

$\boxed{?}$ Evaluate the result from this fit. What changes do you note from the previous graph?

$\boxed{?}$ What is the dimension and the physical meaning of the fit parameter `C`?

$\boxed{?}$ What value does this fitting equation converge to as time passes indefinitely (i.e., $t \to \infty$)?

$\boxed{?}$ Is the result from the fit consistent with your expectation? Why might this be so?

- Use paper towels to wipe down the frost and accumulated condensation from the Styrofoam cup and the digital scale plate.

- Determine the weight of the provided brass block with the highest possible precision.

$$m_{\text{brass}} = \dots\dots\dots\dots\dots\dots \pm \dots\dots\dots\dots\dots\dots$$

- Use the room thermostat thermometer to determine the "room temperature" which is the initial temperature of the brass block. Handle the block by the attached string to prevent it from absorbing your body heat.

$$T_{\text{room}} = \dots\dots\dots\dots\dots\dots \pm \dots\dots\dots\dots\dots\dots$$

- Refill the Styrofoam cup to two-thirds-full and place *it and the brass block* on the weight scale then start your data acquisition run. Get a point every 5 seconds over approximately 15–20 mins. Five minutes should be enough to establish the initial shape of the mass-as-a-function-of-time curve.

- After five minutes, transfer the brass block into the Styrofoam cup, leaving the string to dangle outside the cup. Be careful to prevent splashing and avoid touching the surface of the liquid nitrogen with anything but the brass block itself. You can expect a significant cloud of cold gas to be generated when the brass is rapidly cooled by the liquid nitrogen to 77 K.

  Try to perform this transfer in between the data points to avoid picking up erratic readings; this is not essential, however.

- Continue the data acquisition and carefully monitor the process to note the rapid boil-off as the brass plug reaches the temperature of the liquid nitrogen, after which the boiling stops. Acquire data for another five minutes, to establish the trailing slope of the curve.

  `Note:` At the end of the run the brass block is at 77 K and is **EXTREMELY DANGEROUS**. Carefully transfer the brass block into the sink and run tap water over it until all traces of ice are gone. Wipe dry and return it to your station.

$\boxed{?}$ What do you suppose might be the cause of this rapid boil-off as the plug reaches 77 K?

- Establish through a visual inspection of the graph the two time points T_1 and T_2 that correspond to the beginning and the end of the rapid boil-off interval.

- Fit your data to `(A*exp(-x/B)+C)*(x<`T_1`)+((A-D)*exp(-x/B)+C)*(x>`T_2`)` using the values of T_1 and T_2 determined above. To get a valid χ^2 value, the constraint equation $(\mathtt{x} < T_1) + (\mathtt{x} > T_2)$ must be entered in the constraint box. Examine the quality of the fit, and note the χ^2 misfit value.

- Repeat several times, changing the values of T_1 and T_2 slightly to move away from the edges of the region of the rapid boil-off. Ideally, the value of `D` reported by the fit should not depend on the precise choice of T_1 and T_2.

T_1, s	T_2, s	`D` ± d`D`	χ^2
	Best D value: (least χ^2)		

`D` = ... ± ....

The fit parameter `D` represents the "extra" liquid nitrogen boiled off to cool down the brass block from T_{room} to 77 K. It takes 208 kJ to boil off 1 kg of liquid nitrogen. Your task is to calculate the *average* specific heat of brass, c_{brass} *i.e.* the amount of heat that is required to raise the temperature of 1 kg of brass by 1 K. Proceed as follows:

- The temperature change experienced by the brass plug in going from room temperature to that of the liquid nitrogen is:

  dT = ... = ... = ...

- The error in this temperature change $\Delta(dT)$, assuming that there is no error associated with the boiling temperature of the liquid nitrogen, is given by:

  $\Delta(dT)$ = ... = ... = ...

- Convert `D` into the total amount of heat discharged by the brass plug dQ

  dQ = ... = ... = ...

- The error in this heat change, $\Delta(dQ)$, is given by:

  $\Delta(dQ)$ = ... = ... = ...

- Calculate the heat capacity of brass c_{brass} and the associated error using $dQ = c_{\text{brass}} m_{\text{brass}} dT$. This result is only an average value because the heat capacity is not constant in brass between 77 K and the room temperature.

  c_{brass} = ... = ... = ...

  $\Delta(c_{\text{brass}})$ = ... = ... = ...

c_{brass} = ... ± ....

- Convert your result to the units of the accepted value, $c_{\text{brass}} = 0.093 \pm 0.002\,\frac{\text{cal}}{\text{g}\,^{\circ}\text{C}}$ at 20°C, so that a direct comparison can be made:

c_{brass} = ... = ... = ...

$\Delta(c_{\text{brass}})$ = ... = ... = ...

c_{brass} = ... ± ....

(!) Important! Be sure to have this printout signed and dated by a TA before you leave at the end of the lab session. All your work needs to be kept for review by the instructor, if so requested.

Lab report

Go to the “Lab Documents” web page to access the online lab report template for this experiment. Complete the template as instructed and submit it to Turnitin before the lab report submission deadline, late in the evening six days following your scheduled lab session. Do not wait until the last minute. Turnitin will not accept overdue submissions. Unsubmitted lab reports are assigned a grade of zero.