# PHY 123 Lab 9 - Mechanical Equivalent of Heat

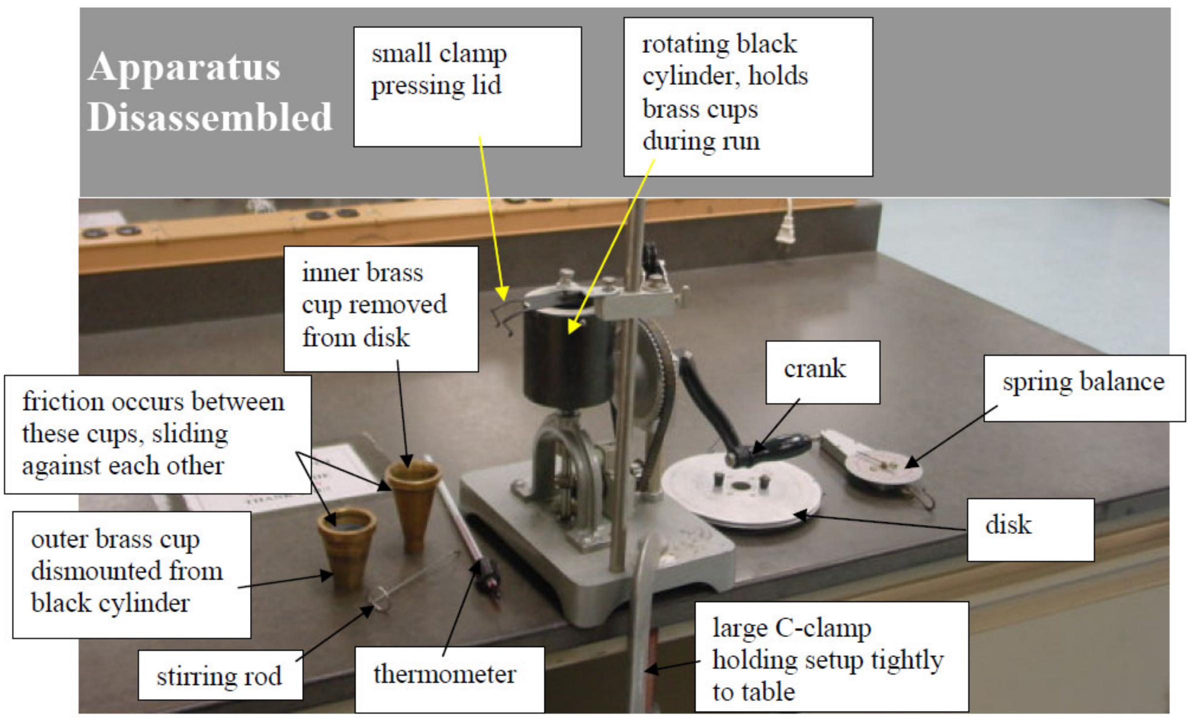
The purpose of this lab is to measure the conversion factor between mechanical energy and heat energy.

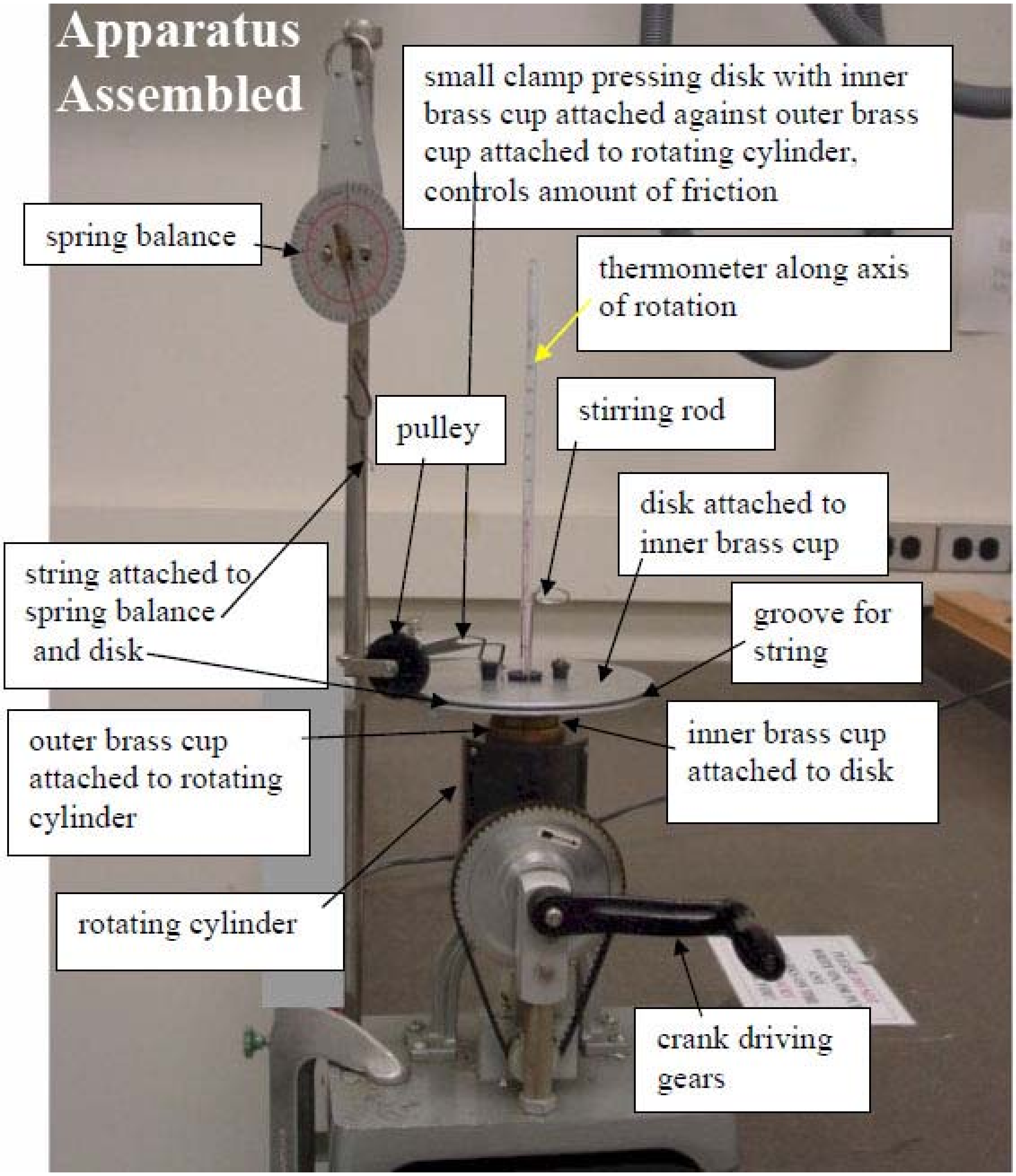
Important! You need to print out the 1 page worksheet you find by clicking on this link and bring it with you to your lab session. [http://www.ic.sunysb.edu/Class/phy122ps/labs/dokuwiki/pdfs/lab9worksheet.pdf]

If you need the .pdf version of these instructions you can get them here [http://www.ic.sunysb.edu/Class/phy122ps/labs/dokuwiki/pdfs/phy123lab9.pdf].

## Equipment

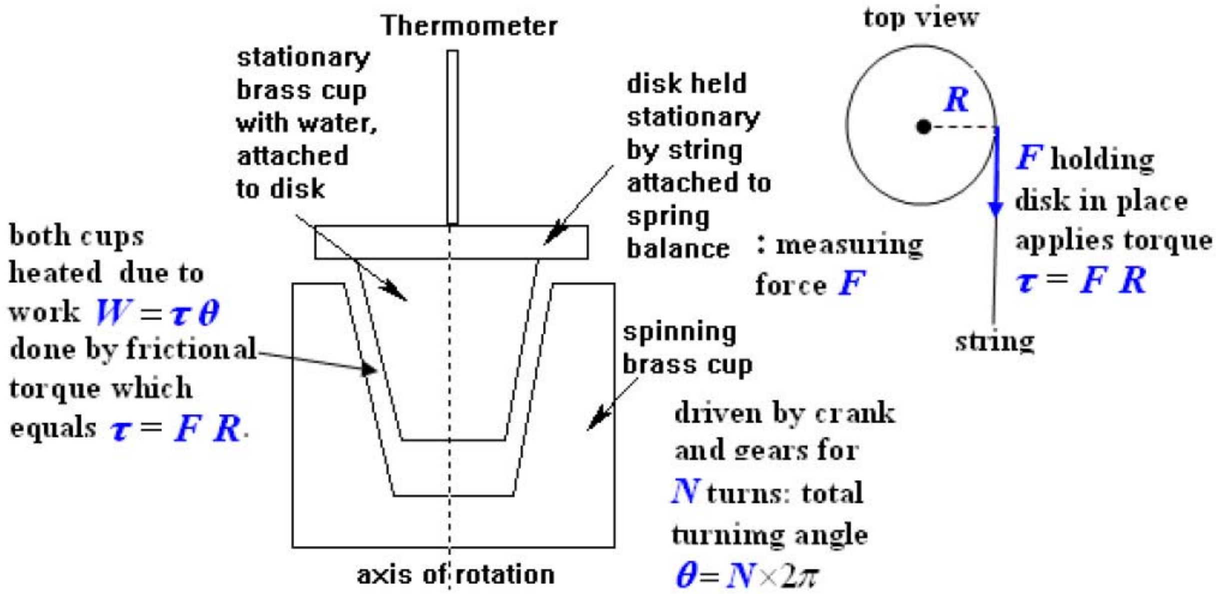
- spring balance
- thermometer
- stirring rod
- inner brass cup
- outer brass cup
- small clamp (check limitation of screw)
- large C-clamp
- pliers to tighten clamp
- crank with gears , turning black cylinder






## Introduction

Historically, the relationship between heat flow into a material and its resulting temperature change was deduced prior to mankind's understanding of heat as a form of energy. A unit of heat (the calorie) was invented to quantify heat flow. A calorie is defined as the amount of heat necessary to raise the temperature of one gram of water by one degree Celsius. The equivalence of heat energy and mechanical energy can be deduced by measuring for example the amount of heat created when an object undergoes a known amount of work due to a frictional force. We will use this technique to measure the proportionality constant between the heat unit calorie and the energy unit Joule.




A simple schematic diagram of the apparatus is shown above. The inner brass cup is partly filled with water. The outer brass cup is connected to a crank handle and turned about the axis of rotation shown. The inner cup is stationary. Thus, with the inner cup lowered into the outer cup, there is friction. The work done by the frictional force is converted to heat. You will measure the mechanical work done (in Joules) and the heat generated (in calories) and thus determine the conversion factor between the 2 units.

If you apply a constant torque $\tau$ to a disk with radius R by applying a constant force F tangentially to the disk, the torque is given by $\tau = FR$. The work W done by turning the disk through an angle $\theta$ is given by $W = \tau\theta$. If N turns were made this angle is (N $2\pi$) radians. Thus the work done in N turns is

$$W = 2\pi NFR$$
(9.1)

In your experiment you don't turn the disk holding the inner brass cup, but you turn the outer cup with a crank and hold the disk stationary with a string exerting a force, which is measured by a spring balance attached to the string. The frictional force between the two cups does not set the inner cup and disk in motion, but is balanced by the force in the string. Thus the formula (9.1) above is valid for the way you execute the experiment.

The amount of heat input to the system can be analyzed by measuring the change in the temperature of the system. In general, the amount of heat absorbed or released by a single material, which does not undergo a phase change , can be calculated by using the equation

$$Q = mc\delta T$$
(9.2)

In this lab, we will use the Greek letter $\delta$ to denote 'change', not $\Delta$ which will be used to denote errors (as we have done for the other labs).

When you begin the experiment (generating heat by friction turning the crank) you will start with water at a temperature $T_i$ a few degrees C below room temperature $T_{room}$ and end the experiment at a temperature $T_f$ which should be about the same amount above room temperature. This is done so that the heat gain from the environment (the room) when the water temperature is below $T_{room}$ is roughly canceled by the heat loss when the water temperature is above $T_{room}$.

## Procedure

- Disassemble the apparatus by moving the small clamp pressing against the disk off the top of the aluminum disk.
- The stopper in the middle of the aluminum disk contains a thermometer and a stirring rod; remove the stopper from the middle.
- Gently remove the thermometer and the stirring rod from the stopper.
- Unscrew the two screws on top of the aluminum disk. Pull out the inner and outer brass cups.
- Using a scale, obtain the following mass values:

$m_b$ = mass of inner brass cup and outer brass cup combined

$m_s$ = mass of stirring rod

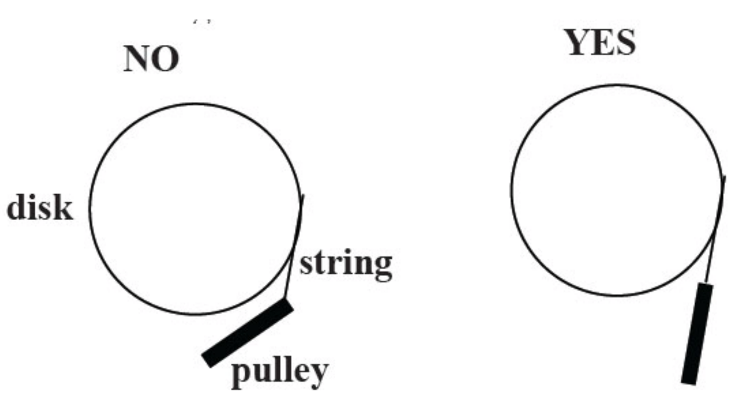
$m_{th}$ = mass of thermometer

- Assume that each mass measurement has an absolute error of 0.2 grams and enter all the mass values on your worksheet.

- Add cold water (roughly 6-8$^o$C below room temperature) to the inner brass cup so that it is 90% full. After you have added the water, put the inner and outer brass cup on a scale and get the total mass of the cups plus water. To get the mass of the water, $m_w$, subtract $m_b$ from this total mass. Assume this measurement has an absolute error of 0.2 grams and enter it on your worksheet.

- Measure the diameter d of the aluminum disk with a ruler and assume that it has an absolute error of 2 mm. Make sure your measurement does not include the depth of the grove where the string sits (on both ends of the diameter). Write your values on your worksheet.

- Reassemble the device with the inner cup filled with the water. Make sure that there is a piece of paper between the inner and outer cup during reassembly so that the crank will turn smoothly. Make sure that the string is sitting in the grooves of the aluminum disk and of the pulley. The pulley should be aligned as shown.



- There should be a slight torque on the spring, i.e. the arrow should be pointing to a value higher than 0, when the string is hooked up to the spring balance. In order to increase friction clamp the aluminum disk down tight with the black clamp by tightening the screws. (You want the frictional force shown to be 2 - 3 N when turning the crank.)

- Insert the stirring rod into the slit of the stopper so that you can stir the water effectively. Stir the water in order to have a uniform temperature and measure the starting temperature, $T_i$. Also obtain the room temperature from your lab instructor. Assume that the starting temperature measurement has an absolute error of 0.5$^o$C and write the temperature values on your worksheet.

- The crank handle is attached to a counter so that the number of turns can be measured. Record the starting value of the counter on your worksheet. When the crank handle is turned, the spring balance registers the force necessary to keep the inner cup stationary. Try to keep the force steady by turning the crank smoothly and continuously.

- While one partner cranks, the other should “spot-check” the temperature of the water and record the value of the force, F, on the spring balance. You will notice that the arrow of the spring balance jitters between two values. Take the average of them. The smallest subdivision of the spring balance scale of 0.1 N is not a good estimate for the error of F. The accuracy of the spring balances checked with weights is not better than ~ 15%. Thus assign a 15% error to the force measurement. Record the average of the force values you wrote down and its absolute error on your worksheet.

- DO NOT stop cranking the device during the “spot-check” temperature measurements. If the person turning gets tired, they should switch with their lab partner.

- Continue to crank the apparatus until the final temperature $T_f$ is roughly as far above room temperature as $T_i$ was below it. (You want to be symmetric about room temperature.) (i.e. if $T_i$ was 6$^o$C below room temperature, then you should stop cranking at around 6$^o$C above room temperature.)

- After you have stopped cranking, continue to monitor and take several temperature measurements because the temperature value will continue to rise for a short time (don’t forget to stir the water before you take the measurement). Your highest temperature value will be the final temperature value, $T_f$. Assume that it has an absolute error of 0.5$^o$C. Record your values on your worksheet. Also record the final counter value. Calculate N, the number of turns of the outer cup by subtracting the initial counter value from the final counter value and enter it on your worksheet.

## Analysis

Calculate the work W done by turning the outer brass cup using equation 9.1. Calculate its error according to expression 1.3 and 1.7 in Lab1 from the errors of the effective diameter d of the disk and the force F. Calculate the temperature rise $\delta T$ of the system and its absolute error according to expression (1.6) from Lab 1.

In this experiment, the generated heat is absorbed not just by one single material, it is absorbed by 4 different elements: the water, the brass cups, the stirring rod, and the thermometer. In order to calculate the total heat generated in this system, you use equation 8.2 for each of the elements. Assume that the stirring rod is made of aluminum and the thermometer is made of glass. The specific heats *c* of these materials are provided in the table below.

| Material | Specific Heat *c* [cal $g^{-1}$ $^{o}C^{-1}$] |
|---|---|
| water | 1.000 |
| brass | 0.092 |
| aluminum (stir rod) | 0.215 |
| glass (thermometer) | 0.200 |

Calculate the heat absorbed by the water, $Q_W$ , using equation 9.2. Repeat the calculations for the brass cups, stirring rod, and the thermometer. Record these values on your worksheet. Calculate the total heat Q by taking the sum of the heat absorbed by each of the four elements. You should see that the main contributions to the overall absorbed heat are from the brass cups and the water. The relative errors in the masses of both the brass cups and the water are fairly small, so we can consider only the error in our change of temperature ($\delta T$) when calculating the error in Q. Therefore, we can find the absolute error in Q simply by mutliplying it by the relative error in $\delta T$.

Calculate your experimental proportionality constant between the heat unit of the calorie and the energy unit of the Joule by calculating $\frac{W}{Q}$. Calculate the error for this ratio according to equations (1.3) and (1.7) from Lab1. Compare your measured value of $\frac{W}{Q}$ with the accepted value of 4.187 J/cal and check whether your measurement is consistent with it within expermental error.

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