Mechanical Equivalent of Heat

1 Object

To determine the conversion factor between Joules and calories.

2 Apparatus

Balance, calorimeter, Joule apparatus, 5kg mass and 1kg holder, thermometer, vernier calipers.

3 Theory

Energy and heat were not initially seen to be measures of the same physical quantity. Thus the concepts were developed separately and their units are not equivalent. Energy can be measured in Joules (J) and heat in calories (cal). The accepted conversion is that one calorie equals 4.186 Joules. This experiment will attempt to obtain this result.

The apparatus is such that a spinning hub is able to just barely lift a mass, m, off the floor – see figure 1. It does this through the force of friction. Because there is relative motion between the string supporting the mass and the hub there will be work done:

$$W = Fs \tag{1}$$

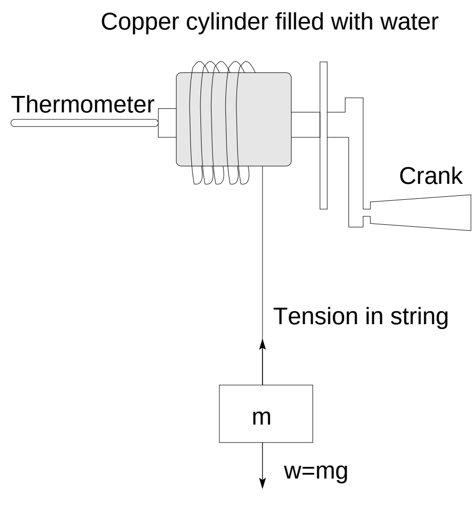

Figure 1: Sketch of apparatus used in this lab.

Here W is the work done, F is the force causing the motion, and s is the distance the object moves. Since the mass is in equilibrium, the tension in the string equals the weight at its end, mg. g is the acceleration due to gravity ($9.80\, m/s^2$). Likewise, the string around the hub is also in equilibrium so that the forces on it cancel. These two forces are a downward tension, T, and a frictional force, f, between the string and the hub.

$$f = T = mg \tag{2}$$

The hub is moving in this experiment but the effect would be the same as if the hub were stationary and the string were moving. Thus F in equation 1 can be equated to f in 2. s is the relative distance moved between the hub and the string. If one counts the number of rotations made by the hub, n, the total distance its outside edge has moved is its circumference, $2\pi r = \pi d$, times the number of revolutions, where d is the diameter of the hub. Thus:

$$S = \pi dn \tag{3}$$

Substituting into equation 1 yields

$$W = \pi dnmg \tag{4}$$

The units of W are Joules if the units of d are meters and m is measured in kilograms.

The work done by friction produces heat and most of this heat is transferred to the hub (which in this experiment is an copper calorimeter). As heat is added to an object its temperature will rise, the more the heat the larger the change in temperature. The appropriate equation is

$$Q = mc\Delta T = m_w c_w \Delta T + m_c c_c \Delta T \tag{5}$$

where Q is the heat added and ΔT is the change in temperature. m is the mass of the object, and c is its specific heat (which is an experimental constant that measures the ability of an object to absorb heat). The subscripts refer to water and calorimeter, respectively. If m is in grams and ΔT in degrees Celsius, then Q will be in calories. For copper, $c_c = 0.0923\, cal/g\,^{\circ}C$, while water's value is $1.00\, cal/g\,,^{\circ}C$.

If one divides equation 4 by equation 5 the result should be $4.186\, J/cal$.

4 Procedure

1. Using the balance determine the mass of the calorimeter. Record room temperature. Record the mass of the attached weight (paint can). Measure the diameter of the calorimeter without the twine wrapped around. This will be d.

2. Fill the calorimeter with cool water from the fountain in the hall so that it is at least ten degrees below room temperature. Measure the mass now so you will know the mass of the water. Set up the apparatus as you have been shown. The string should be wrapped around the calorimeter about five times. CAUTION: the thermometers are VERY FRAGILE. BE CAREFUL!

3. Record the counter value.

4. Record the temperature of the calorimeter. Turn the crank until the temperature is as much above room temperature as it was below when you started. It is best to slow the crank speed about a degree below your desired final temperature. Record the final temperature as well as the final counter number.

5. Repeat the above (starting with the cool water) for five other sets of data using reasonably different starting temperatures.

5 Calculations

Using each set of data evaluate equations (4) and (5). Divide equation (4) by equation (5). This should give the value 4.186 J/cal. Calculate a mean and error for the six results and compare to the accepted value.

Finally, using your results from equations 4 and 5, plot work W in J versus heat Q in cal. This *should* be a linear graph. Find the slope and intercept of this graph, with errors, and explain what each is and why.

6 Questions

1. Estimate how much heat the twine receives in a typical trial.
2. If the mass attached to the twine were $20\,kg$, how would this affect your experiment?
3. The manufacturers of a similar apparatus suggest that the diameter in equation (4) should be $(d_1 + d_2)/2$, where d_1 is the diameter of the calorimeter you measured, and d_2 is the diameter of the calorimeter with the twine wrapped about it. Why would the manufacturer suggest such a thing?