

# Mechanical Equivalent of Heat

- Purpose:**
1. To gain experience at doing heat and energy calculations
  2. To measure the mechanical equivalent of heat

**Equipment:** Mechanical equivalent of Heat Apparatus, one ohmmeter, one clamp, masses (10 Kg), mass container, ice, calipers.

## Introduction:

The original development of the law of conservation of energy proceeded slowly. One of the last important ideas that was needed for a complete, consistent theory was the development of the science of thermodynamics. Finding the connection between mechanical energy and heat (thermal energy) was a crucial step in this understanding. Joule did the original experiment to find an equivalence between the units of mechanical energy (in Joules!) and units of heat (calories). His experiment dealt with a system of falling weights that converted the lost potential energy of the system into thermal energy in a container of water that was being stirred by a paddle driven by the falling weights. Our experiment is similar in nature. We will do work on our system by turning a handle against the force of friction and using this energy to warm an aluminum cylinder.

Thus the mechanical energy introduced into our system will be the work done by friction. The work (in Joules) done by a friction force can be calculated by

$$1) \quad W_f = f \Delta s = f (2 \pi r) N,$$

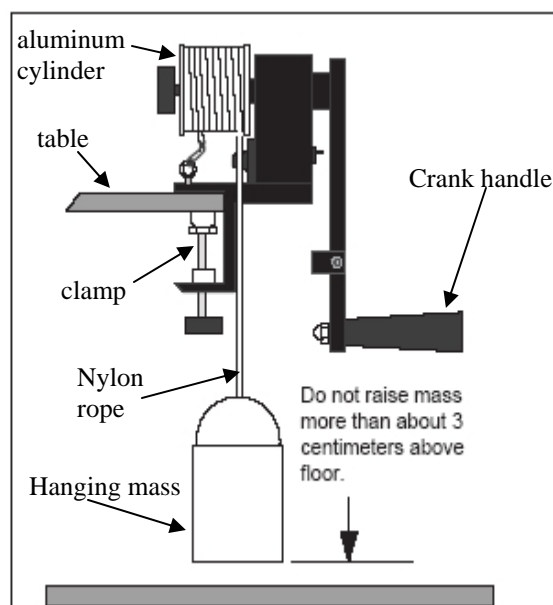
where  $f$  is the friction force,  $r$  is the radius of the cylinder and  $N$  is the number of turns through which the cylinder rotates. The heat energy,  $\Delta Q$ , (in calories) transferred into the aluminum cylinder can be calculated by observing the temperature,  $\Delta T$ , rise of the aluminum and calculating the following:

$$2) \quad \Delta Q = m C \Delta T$$

where  $m$  is the mass of the aluminum cylinder and  $C$  is the specific heat of aluminum. If we assume that 100 percent of the work done on the system is converted into heat energy, we can equate 1) and 2) to see how many joules of mechanical energy are equivalent to the same amount of energy expressed in calories. The number of Joules/calorie is called the mechanical equivalent of heat.

## Procedure:

1. Use the C-clamp to clamp the apparatus securely to the corner of a level table. The edges of the base should hang over the table surface by about a centimeter to ensure that the crank will turn freely and the edge of the table will not interfere with the hanging rope.



2. Unscrew the black knob and remove the aluminum cylinder. Place the cylinder in ice to bring the temperature down to at least 10 °C below room temperature. The cylinder is cooled so that, when it is heated by friction, the midpoint of the high and low temperatures will be at room temperatures.
3. While the cylinder is cooling, plan the desired temperature variation of the experiment. Ideally, the temperature variation of the cylinder should be from 7-9 °C below room temperature to the same amount above room temperature. Therefore, measure and record the room temperature, and determine and record the initial and final temperatures you wish the cylinder to reach during the experiment. Record your data in the table.
4. Using the table of resistance versus temperature for the thermistor, determine the resistance value which will correspond to each of your recorded temperatures. (A table that will cover most temperatures ranges is listed on the apparatus.) Also determine the resistance measurement which corresponds to 1°C below the final temperature. You will want start cranking more slowly as the temperature approaches this point, so the final, equilibrium temperature will be close to your chosen final temperature.
5. When the cylinder is sufficiently cool, slide it back on the crank shaft. Be sure that the copper plated end is facing toward the crank.
6. Plug the leads of the ohmmeter into the banana plug connectors. Set the ohmmeter to a range that is appropriate to the thermistor resistances that correspond to your chosen temperature range.
7. Wrap the nylon rope several turns around the aluminum cylinder (2-4 turns should work well). Be sure that the rope lies flat against the cylinder. Tie one end of the rope, the end nearest to the crank, to the 10 kg mass as shown.  
**Note:** When the cylinder is cold, water may condense on its surface. Dry the cylinder thoroughly with a cloth or paper towel before wrapping the rope, so that all of the heat goes into warming the cylinder and not evaporating the condensed water.
8. Set the counter to zero by turning the black knob on the counter.
9. Watch the ohmmeter carefully. When the resistance reaches the value corresponding to your starting temperature, start cranking (clockwise, facing the crank side of the apparatus). Crank rapidly until the temperature indicated by the thermistor is 1 °C less than your designated stopping temperature, then crank very slowly while watching the ohmmeter. When the temperature reaches your stopping value, stop cranking. Continue watching the ohmmeter until the thermistor temperature reaches a maximum (the resistance will be minimum) and starts to drop. Record the highest temperature attained as your final temperature.
10. Record N, the number on the counter-the number of full turns of crank.
11. Measure and record m, the mass of the aluminum cylinder.
12. With a pair of calipers, measure  $D_1$ , the diameter of the aluminum cylinder. Then wrap the nylon rope tightly around the cylinder, as in the experiment, and measure  $D_2$ , the diameter of the cylinder including the additional thickness of the rope.
13. From equation 1 calculate the mechanical energy in Joules introduced into the system in the form of work. From equation 2 find the heat energy absorbed by the aluminum in calories. By equating the two, find the mechanical equivalent of heat in J/cal. Find the percent difference between your value and the accepted value.
14. Repeat for at least one more trial.
15. Be sure that all of your data are recorded in neat tables and that you have carefully explained all calculations.