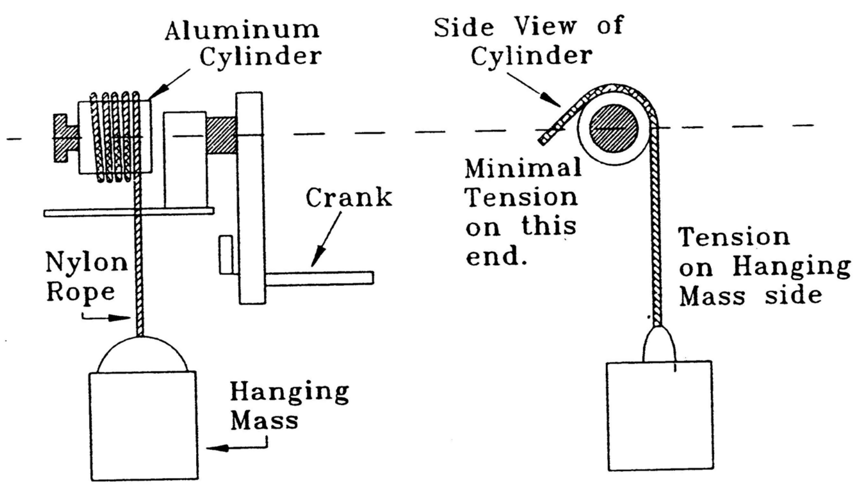
The Mechanical Equivalent of Heat

INTRODUCTION

One of the most famous experiments of the 19th century was Joule's experiment showing that mechanical energy can be converted to heat. This showed that heat was simple the transfer of energy and was a key component in developing the principle of the Conservation of Energy. This conservation law tells us that if a given amount of work is transformed completely into heat the resulting thermal energy must be equivalent to the amount of work that was performed. Since work is commonly measured in units of Joules and thermal energy is commonly measured in units of calories, the equivalence is not immediately obvious. A quantitative relationship is needed that equates Joules and calories. This relationship is called the Mechanical Equivalent of Heat (MEH).

The MEH apparatus allows a fairly accurate determination of the relationship between J and cal. A measurable amount of work is performed by turning the crank, which turns the aluminum cylinder. A nylon rope is wrapped several times around the cylinder so that, as the crank is turned, the friction between the rope and the cylinder is just enough to support a mass hanging from the other end of the rope. (See Figure) This ensures that the torque acting on the cylinder is constant and measurable. A counter keeps track of the number of turns. As the cylinder turns, the friction between the cylinder and rope converts the work into thermal energy, which raises the temperature of the aluminum cylinder. A thermistor, which measures how an electrical resistance changes as the temperature of the cylinder increases, is embedded in the aluminum. A table on the apparatus converts between resistance and temperature for us.



OPERATION

Before performing the experiment spray the surface of the aluminum cylinder lightly with some dry powdered graphite. This ensures the rope slides smoothly on the cylinder making it easier to provide a steady, even torque. When turning the crank never raise the hanging mass higher than about 10 cm off the floor. If the hanging mass is higher than a few cm off the floor and slips while cranking it will be damaged.

You will want to change the temperature of the cylinder over a range that begins below room temperature and increases to above room temperature. (Can you explain why?)

Ask your lab instructor for the room temperature, then pick a starting value about 10^0C below room temperature as your starting temperature, T_i. From the table for your thermistor calibration, determine which resistance corresponds to this temperature. Cool the cylinder until it stabilizes *below* this temperature before beginning to crank.

Before cranking, make sure the rope is looped 3 to 4 times around the cylinder in order to ensure enough thermal contact between the rope and cylinder. Use just enough tension to keep the mass from slipping back to the ground, but not too much or else you will pull the mass up as you crank. While the cylinder is cooler than your starting temperature practice getting the cranking process to work right.

NOTE: In this experiment you want the hanging mass to remain motionless so that you *know* it is not accelerating. Then, by Newton's second law, the net force on the mass, M, must be zero and the tension in the rope is equal at all times to the weight. The torque created by the force of tension is then the lever arm times the forces or $R \times Mg$.

When you reached your desired T_i, zero the rotation counter and start to crank with a steady pace. Don't crank excessively fast or slow, about 40-60 cranks per minute should work well. The final temperature, T_f, you are aiming for is dependent on your starting temperature. If you picked a T_i 10^0C cooler than room temperature then pick a T_f 10^0C *warmer* than room temperature. Keep cranking at the same speed until you reach a temperature of $T_f - 1$ degree. This is because there is a little lag time as the cylinder heats up before it registers on the ohmmeter. Continue to crank *very* slowly until you finally reach T_f. Make sure that the temperature stabilized there and does not go higher after you stop cranking. Record your observations, the mass, M, of the hanging mass, the radius of the cylinder R, the thickness of the rope, x, the initial and final temperatures, T_i and T_f, the number of cranks, N and the mass, m, of the aluminum cylinder.

Questions:

1. Describe exactly how you will determine the torque created by the tension in the rope. Don't neglect the thickness of the rope and describe exactly how to determine the lever arm for the torque. (Assume the force acts through the center of the rope)

2. Show your calculations to determine how much work is done during each turn of the crank?

3. What force is producing the heat that is causing the aluminum cylinder to heat up?

4. You measure a temperature change, but you need to determine the heat produced by friction. What relationship allows you to convert the temperature change to heat? (Note specific heat of aluminum = 0.220 cal/g^{o}C)

Data

	Temperature (ºC)	Corresponding Thermistor Resistance (Ω)
Room Temperature		
Initial Temperature		
Final Temperature (selected value)		
Final Temperature (actual value)		
T_f – 1 ºC (slow crank)		

Mass Hanging from Rope: M = ______________________

Mass of Aluminum Cylinder: m = ______________________

Diameter of Cylinder: D_1 = __________________________

Diameter of Cylinder plus rope: D_2 = _____________________________

Number of turns of crank: N =_____________________________

Work performed on cylinder (W):_________________________

Heat absorbed by cylinder (H):___________________________

Mechanical equivalent of heat J=W/H:_________________________________

Question: How does your value of J compared to the accepted value of 1 calorie = 4.186 Joule. Use statistical arguments when discussing how two measurements agree.

Repeat the experiment with a different hanging mass.

Trial 2 with a different hanging mass

Data

	Temperature (ºC)	Corresponding Thermistor Resistance (Ω)
Room Temperature		
Initial Temperature		
Final Temperature (selected value)		
Final Temperature (actual value)		
T_f – 1 ºC (slow crank)		

Mass Hanging from Rope: M = ______________________

Mass of Aluminum Cylinder: m = ______________________

Diameter of Cylinder: D_1 = __________________________

Diameter of Cylinder plus rope: D_2 = _____________________________

Number of turns of crank: N =_____________________________

Work performed on cylinder (W):_________________________

Heat absorbed by cylinder (H):___________________________

Mechanical Equivalent of heat J=W/H:_________________________________

Question: How does your value of J compared to the accepted value. Use statistical arguments when discussing how two measurements agree.

Question: Do you expect your final result to be independent of the hanging mass? Is this what you experimentally determined?

Question: Which trial gave you a smaller uncertainty in your measurement. Why?