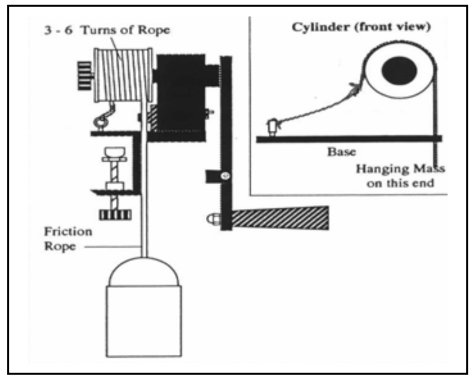
Mechanical Equivalent of Heat

The purpose of this experiment is to verify the relationship between mechanical energy, or energy associated with motion, and heat, associated with the transfer of energy between objects because of a temperature difference. In 1850 James Joule experimentally determined a conversion factor between the calorie, a common unit for heat, and the joule, a unit of mechanical energy or work. He found that heat was not a substance or a form of energy, but rather experiments showed that a given amount of work always produced a particular amount of heat. Heat was then defined as a transfer of energy due to a temperature difference whereas work is a transfer of energy that is not due to a temperature difference. In this experiment we will determine the conversion factor between mechanical energy due to some work and heat, referred to as the mechanical equivalent of heat.



The work, measured in joules, to be done in this experiment is on an aluminum cylinder. This work increases the internal energy of the cylinder, thereby increasing its temperature. We can also determine the amount of heat, measured in calories, required to produce the same change in temperature of the cylinder.
The ratio of these two quantities is the mechanical equivalent of heat. The work is performed by exerting a frictional torque on the cylinder. A nylon cord is wrapped around the cylinder several times with one end of the cord attached to a heavy weight. The cylinder is then rotated in a direction such that the frictional force of the cylinder on the cord will lift the heavy weight, ideally keeping the weight in an equilibrium position several centimeters above the floor. The work done on the cylinder is equal to

$$W = \tau\theta$$

where τ is the torque exerted by the nylon cord and θ is the angle through which the cylinder is rotated. In the equilibrium situation, with the hanging mass above the floor, the tension is equal to the weight of the hanging mass. The torque is then given by

$$\tau = RMg$$

where R is the radius of the cylinder and Mg is the weight of the hanging mass. If the cylinder rotates a total of N times, then θ in radians is given by

$$\theta = 2\pi N$$

Thus the total amount of mechanical work done on the cylinder is

$$W = RMg2\pi N$$

The amount of heat, Q, required to produce the same change in temperature as the work done on the cylinder can be calculated since the specific heat of aluminum is known. Since the specific heat of a material is the amount of heat required to raise the temperature of a unit mass of the material one degree, the amount of heat required to raise the temperature by an amount $T_f - T_i$ will be

$$Q = mc(T_f - T_i)$$

where m is the mass of the cylinder, c is the specific heat of aluminum [0.220kcal/(kg · C°)], and T_i and T_f are the initial and final temperatures respectively of the aluminum cylinder. The mechanical equivalent of heat, J, is then given by

$$J = W/Q$$

Procedure

1. A possible source of error in the experiment is the exchange of heat between the cylinder and its surroundings. This error can be minimized by choosing the initial and final temperatures of the cylinder so that approximately half of the time heat flows from the room to the cylinder and the other half of the time the heat flows from the cylinder to the room. Since the direction of heat flow is from warmer to colder, one starts out with the temperature of the cylinder below room temperature and ends up with the final temperature above room temperature. Therefore, record the room temperature, in Celsius, from the thermometer mounted on the wall and subtract 8.0 C° for your initial temperature T_i, also record this in the appropriate column. Next, add 8.0 C° to the room temperature. This will be your target temperature, T_f. All temperatures should be determined to within 0.1 C°.
2. The temperature of the cylinder is monitored with a temperature dependent resistor, called a thermistor. There is a conversion chart attached to the side of your apparatus that converts the measured resistance of the thermistor, in ohms, to the corresponding temperature of the thermistor, in Celsius. Using the chart, determine the resistance of the thermistor which corresponds to T_i and T_f , record these numbers in the space provided.
3. Get the cooled cylinder from your lab instructor. You will have to work efficiently in order to get everything ready before the cylinder heats up above your T_i. Slide the cylinder onto the crank shaft making certain that the copper plated board is facing toward the crank. Also make certain that the pins on the drive shaft fit into the slots on the plastic ring on the cylinder. Replace the black retaining knob and tighten securely.
4. Using a multimeter as an ohmmeter, choose the 2000kΩ scale. Monitor the temperature of the cylinder by observing the resistance as you wrap the cord attached to the hanging mass 4-6 times around the cylinder. Be sure that the cord lies flat against the cylinder.
5. Turn on the Smart Timer. Set it to 1. **Count** and 2. **Manual**. Rotate the crank (10-20 times) to test the system. Ideally, the mass should raise a few centimeters off the floor and remain there, while the end of the cord by the cylinder should be somewhat slack. If this does not happen, dry the cylinder if condensation appears and adjust the number of loops around the cylinder and try again. Once the system in functioning correctly, reset the Smart Timer to zero.
6. Watch the resistance carefully, when it falls below 200kΩ, change the scale on the ohmmeter to 200kΩ. When the resistance reaches the value corresponding to your starting temperature, start cranking. Stop cranking when your ohmmeter reads the resistance that corresponds to your final, target temperature. Continue to monitor the thermistor and record the lowest resistance reached. Use this lowest resistance as your actual final value for T_f, even if it does not match your target temperature exactly. Consult the graph posted in the room to convert your reading from ohms to T_f in Celsius within 0.1 C°. Return the aluminum cylinder to your lab instructor.
7. Record N, the number of rotations on the Smart Timer.
8. Measure and record m, the mass of the cylinder.
9. Measure and record the radius R, of the cylinder.
10. Record M, the hanging mass.
11. Calculate the mechanical work performed on the cylinder.
12. Calculate the heat added to the cylinder.
13. Calculate the mechanical equivalent of heat.
14. Calculate the percent difference from the accepted value of 4186 joules/kcal.

Name_______________________________ Partner______________________________

Lab Section________ Lecture Section________

	Temperature	**Thermistor reading**
Room Temperature		____________________________ ____________________________
Initial Temperature (T_i)		
Target Temperature "T_f"		
Actual Final Temperature (T_f)		

Mass of Hanging Object (M)	
Mass of cylinder (m)	
Radius of cylinder (R)	
Number of rotations (N)	

Work performed on cylinder:

W = ___________________________

Heat required to produce the same change in temperature:

Q = ___________________________

Mechanical Equivalent of heat:

J = ____________________________

Percent Difference: ______________

1. Heat is best defined as

A) avg. kinetic energy of individual molecules

B) amount of energy transfer from one body to another

C) total energy of all the molecules in an object

D) the temperature of an object

2. **Which of the four definitions above best defines temperature?**