Experiment 13: Make-Up Lab for 1408/1420

This is only for those that have approval. Students without approval will not be allowed to perform the lab.

The pre-lab must be turned in at the beginning of lab.

Pre-labs completed during lab will not be accepted.

Students MUST wear closed toe shoes for this experiment.

NO EXCEPTIONS.

Students without closed toe shoes will have to leave the lab room once the experiment is being performed and will not be permitted to "make up" the make up lab.

Report for Make-Up Lab: ***The experiment is abbreviated to allow time for the report to be written during normal laboratory time. The lab report must be written and turned in during lab; late reports will not be accepted.***

All measured values should include uncertainty. However, due to the limited time for the lab report, you will not be required to propagate error in this experiment.

1. **Pre-lab** [15 points]
2. C**ompleted data sheets** [45 points]
3. **Questions [**30 points] Each answer should include at least 3 sentences.
   a. If you would perform the experiment entirely above room temperature, how would this affect the measured value of the mechanical equivalent of heat? Would you expect its value to be larger, smaller, or the same as the accepted value?
   b. What are the heat transfer mechanisms that must be considered in this experiment? Explain.
   c. Discuss sources of error that you feel might have affected your results. Are some of these avoidable? What effect would they have on your calculated value for **J**? Can you estimate the magnitude of the effects?
4. **Conclusion and summary of results.** [10 points]

Name: ________________________ Date:___________

Lab Section: ___________________

Pre-Lab -- Mechanical Equivalent of Heat

1. Make a comprehensive flow chart for the procedure for this experiment (measurements, tasks to perform…).

2. Is it experimentally possible that the heat absorbed by the cylinder could be greater than the work performed on it? Explain.

15 Mechanical Equivalent of Heat

Objectives: In this lab we will investigate the equivalence of mechanical energy (work) and thermal energy (heat), a fundamental concept of thermal physics first experimentally proven by James Joule in the 1840's.

Apparatus: Mechanical Equivalent of Heat Apparatus (TD-8551A) with includes
- aluminum cylinder with embedded thermistor,
- counter with crank and table clamp,
- nylon rope
- rubber band

2 kg masses	beam balance
digital ohmmeter	bubble level
banana-connector cables	calorimeter
thermometer	ice
vernier caliper	paper towels

Explanation:

From the principle of the conservation of energy, we know that if a given amount of work is transformed completely into heat, the resulting thermal energy must be equivalent to the amount of work performed. Of course, since work is normally measured in units of joules and thermal energy is normally 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.

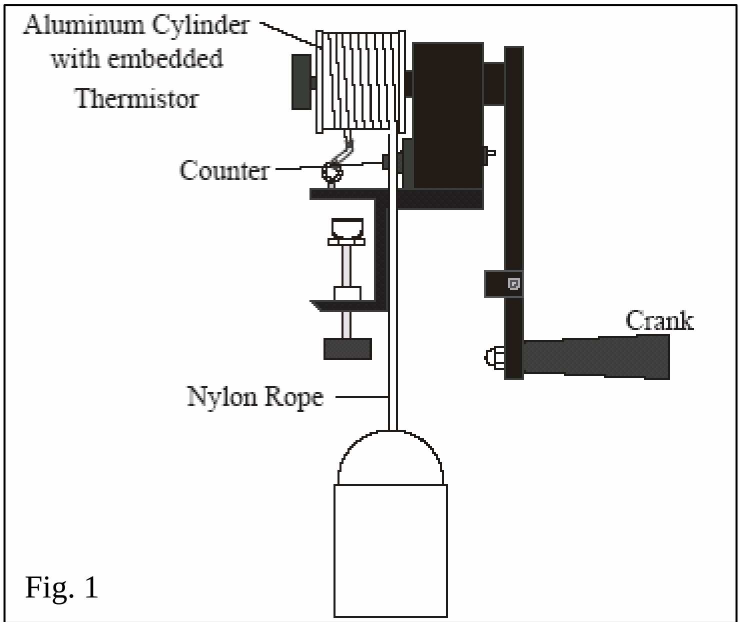
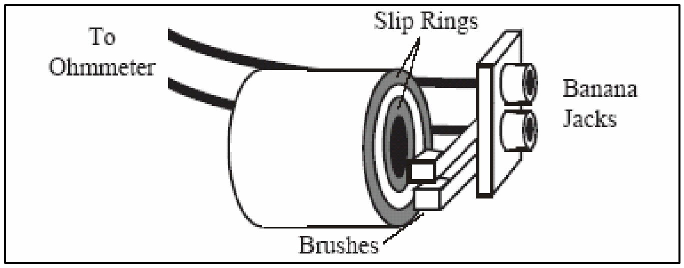


Fig. 1

<u>Mechanical Equivalent of Heat Apparatus:</u> Using this apparatus (Fig. 1), 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. This insures that the torque acting on the cylinder is constant and measurable. A counter keeps track of the number of turns of the crank.

As the cylinder turns, the friction between the cylinder and the rope converts the work into thermal energy, which raises the temperature of the aluminum cylinder. A thermistor is embedded in the aluminum so that, by measuring the resistance of the thermistor, the temperature of the cylinder can be determined. By monitoring the temperature change of the cylinder, the thermal energy transferred into the cylinder can be calculated. Finally, the ratio between the work performed and the thermal energy transferred into the cylinder determines **J**, the mechanical equivalent of heat.



To measure the temperature of the aluminum cylinder, a thermistor is embedded inside. A thermistor is a temperature dependent resistor. If the resistance of the thermistor is known, its temperature can be very accurately and reliably determined. The leads of the thermistor in the cylinder are soldered to the copper slip rings (Fig. 2) on the side of the cylinder. The brushes provide an electrical connection between the slip rings and the banana plug connectors. By plugging an ohmmeter into these connectors, the resistance of the thermistor, and therefore it's temperature, can be monitored, even when the cylinder is turning.

Although the temperature dependence of the thermistor is accurate and reliable, it is not linear. You will therefore need to use the table of Temperature versus Resistance that is affixed to the base of the Mechanical Equivalent of Heat apparatus to convert your resistance measurements into temperature readings. A more complete version of this table, covering a greater temperature range, is given at the end of this experiment.

<u>Calculating the Work Performed</u>: The work performed on the cylinder by turning the crank equals τ, the torque acting on the cylinder, times θ, the total angle through which the torque acts. It would be difficult to directly measure the torque delivered by the crank. However, since the motion of the cylinder is more or less constant through the experiment, we know that the torque provided by the crank must just balance the torque provided by the friction from the rope. The torque provided by the rope friction is

$$\tau = MgR$$

where M is the mass hanging from the rope, g is the acceleration due to gravity, and R is the radius of the cylinder.

Each time that the crank is turned one full turn, this torque is applied to the cylinder through an angle 2π. The total work performed therefore is:

$$W = \tau\theta = MgR\,(2\pi N)$$

where M is the mass hanging from the rope; g is the acceleration due to gravity (9.8 m/s^2); R is the radius of the aluminum cylinder; and N is the total number of times the crank was turned.

Calculating the Heat produced: The heat (Q) produced by friction against the aluminum cylinder can be determined from the measured temperature change that occurred. The calculation is:

$$Q = m\, c\, (Tf - Ti)$$

where m is the mass of the aluminum cylinder; c is the specific heat of aluminum (0.220 cal/g ^{o}C); T_f is the final temperature of the cylinder; and T_i is the initial temperature of the cylinder, just before cranking.

The Mechanical Equivalent of Heat, J, is the ratio of the work performed to the heat produced.

$$J = W/Q$$

When performing the experiment, two general guidelines are useful:

1. *Clamp the mechanical equivalent of heat apparatus on a level table.*
2. ***When turning the crank, never raise the mass higher than about 3 cm from the floor (no higher than you would care to have it fall on your little toe).*** If the mass is raised higher, and is allowed to climb, the rope will likely start overlapping the next turn which makes it climb even higher, producing a dangerous situation.

Procedure:

Read this entire section before attempting the experiment, so that you understand exactly how to do this experiment. *It will keep you from repeating the experiment to obtain good data. If you results are poor due to not following the procedure, then points will be deduced from your lab report.*

1. Clamp the apparatus securely to the edge of a level lab table. If the apparatus is not level, the rope will tend to slip and bunch up on the drum, off towards one side. This will make it difficult to maintain constant tension in the rope.

2. Unscrew the black knob and remove the aluminum cylinder.

3. Fill the outer can of the calorimeter partially with ice water and then insert the inner can. Place the drum into the inner can to reduce its temperature below room temperature. Make sure the cylinder does not get wet. Leave the cylinder in the can for some time to let it cool down to at least 10 ^{o}C below room temperature.

   (Ideally, the temperature of the aluminum drum at the beginning of the experiment should be as much below room temperature as its temperature is above room temperature at the end of the experiment. Then the heat lost to the room while the cylinder is above room temperature will approximately equal the heat absorbed from the room while the drum is below room temperature.)

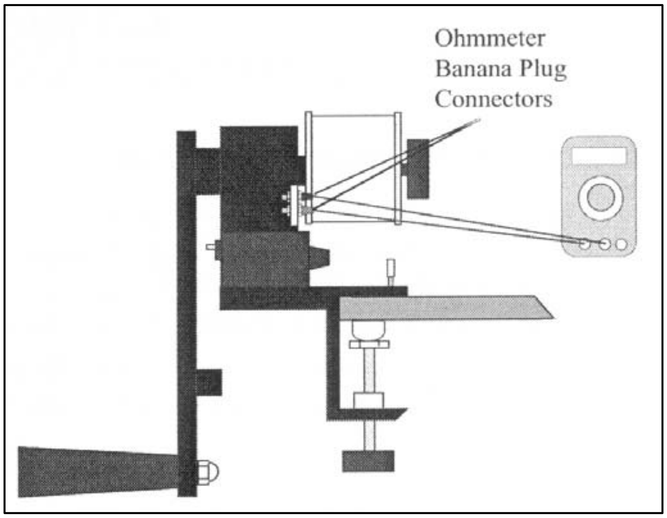
4. While you are waiting for the cylinder to cool, plan the rest of the experiment. Ideally, the temperature variation of the cylinder should be from 6 or 7 ^{o}C below room temperature to the same amount above room temperature. Therefore, measure the room temperature, using the thermometer, and then determine the ideal initial and final temperatures you would like to start and finish with (in a perfect world, it might be plus or minus 6 ^{o}C). Record these values in Table 2

5. Using the table of Resistance versus Temperature for the thermistor, determine the approximate resistance values which will correspond to each of your ideal temperatures. Also determine the resistance measurement which corresponds to 1 ^{o}C below the final temperature. You will want to start cranking more slowly as the temperature approaches this point, so that the final, equilibrium temperature will be close to your chosen final temperature. Record these values in Table 2.

6. When the drum has cooled down wipe off any moisture that may have condensed on the drum and place it back onto the shaft. (Note: It is often helpful to cool the cylinder down to several degrees *below* the desired starting temperature. This allows you time to set everything up and determine the number of turns of rope needed to lift the mass before you actually start taking data.) Be sure that the copper plated board is facing toward the crank. Also make sure that the pins on the drive shaft fit into the slots on the plastic ring on the cylinder, then replace the black knob and tighten securely.

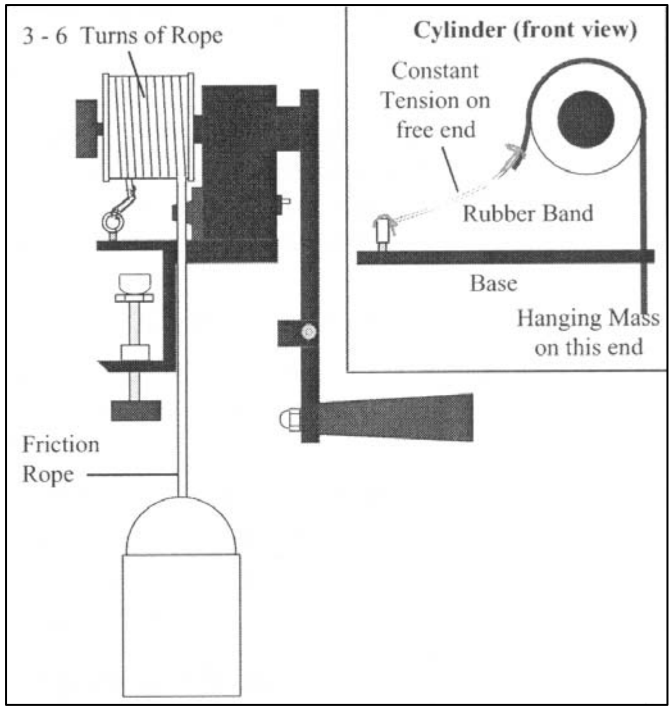
7. Plug the leads of the ohmmeter into the banana plug connectors. Set the ohmmeter to a range that is appropriate to the thermistor resistances that correspond to your chosen temperature range.

   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 heating the cylinder and not into evaporating the condensed water.



8. Wrap the nylon rope several turns around the aluminum cylinder (3-6 turns should work well.) Be sure that the rope lies flat against the cylinder and hangs down the slot provided in the base plate. Tie one end of the rope, the end nearest to the crank, to the 5 kg mass as shown.

   IMPORTANT: There should be only enough turns of rope around the cylinder so that the frictional pull on the rope is just enough to lift the hanging mass **about 3 cm off the floor – no higher!** To accomplish this, wrap the rope three or four turns and crank. Add turns as needed to support the mass while cranking with only very slight tension on the free end. Attach the rubber band to the free end of the rope. Now, without cranking and while keeping the rope taught by the rubber band, tie the other end of the rubber band to the eyebolt on the baseplate. If you find that the large hanging mass continues to rise more than 3 cm as you turn the crank, remove one turn from the cylinder nearest the free end. If the large hanging mass continues to rest on the floor, add another turn of rope around the cylinder at the free end.



9. Set the counter to zero by turning the black knob on the counter.

10. Watch the ohmmeter carefully. When the resistance reaches the value corresponding to your desired 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 a minimum) and starts to drop. Record the highest temperature attained as your final temperature, T_f.

11. Record *N*, the number on the counter – the number of full turns of the crank.

12. Use the vernier calipers to measure the diameter of the cylinder. Record the diameter, *D*, in Table 2. Calculate the radius, R.

13. Measure and record *m*, the mass of the aluminum cylinder.

14. Complete the sample calculations in Table 3.

Name: ______________________ Date:_______________
Partner: _____________________

Mechanical Equivalent of Heat Data Sheet

Table 1: Planning the experiment

Room Temperature	T_{room} =
Desired Initial Temperature	$T_{i,\ desired}$ =
Desired Initial Resistance	$R_{i,\ desired}$ =
Desired Final Temperature	$T_{f,\ desired}$ =
Desired Final Resistance	$R_{f,\ desired}$ =
Resistance at which to slow cranking	$R\ (temp = T_{f,\ desired}-1)$ =

Table 2: Measurements

Actual initial resistance (kΩ)	R_i =
Actual initial Temperature	Ti =
Actual final minimum resistance (kΩ)	R_{min} =
Actual final maximum temperature	T_{max} =
Actual change in temperature	$\Delta T = T_{max}-T_i$ =
Number of turns of the crank	N =
Mass of Aluminum Cylinder	m =
Diameter of Cylinder	D =
Radius of the Cylinder	R =
Mass of Hanging Mass	M =

Remember to include units and uncertainty of measurements

Work Safely

Table 3: Final Calculations

Show your calculations. Include the equation that you are using, the values plugged into the equation with units. Be neat.

Work performed on cylinder: Q = ________________
Heat absorbed by Cylinder: W = ________________
Percent Difference between Heat Absorbed and Work Performed.   Percentage Difference = ________________
Mechanical Equivalent of Heat   J = ________________

Work Safely

Thermistor Properties
Temperature Versus Resistance

Resistance (Ohms)	Temp (^oC)	Resistance (Ohms)	Temp (^oC)	Resistance (Ohms)	Temp (^oC)
351,020	0	66,356	34	16,689	68
332,640	1	63,480	35	16,083	69
315,320	2	60,743	36	15,502	70
298,990	3	58,138	37	14,945	71
283,600	4	55,658	38	14,410	72
269,080	5	53,297	39	13,897	73
255,380	6	51,048	40	13,405	74
242,460	7	48,905	41	12,932	75
230,260	8	46,863	42	12,479	76
218,730	9	44,917	43	12,043	77
207,850	10	43,062	44	11,625	78
197,560	11	41,292	45	11,223	79
187,840	12	39,605	46	10,837	80
178,650	13	37,995	47	10,467	81
169,950	14	36,458	48	10,110	82
161,730	15	34,991	49	9,767.2	83
153,950	16	33,591	50	9,437.7	84
146,580	17	32,253	51	9,120.8	85
139,610	18	30,976	52	8,816.0	86
133,000	19	29,756	53	8,522.7	87
126,740	20	28,590	54	8,240.6	88
120,810	21	27,475	55	7,969.1	89
115,190	22	26,409	56	7,707.7	90
109,850	23	25,390	57	7,456.2	91
104,800	24	24,415	58	7,214.0	92
100,000	25	23,483	59	6,980.6	93
95,447	26	22,590	60	6,755.9	94
91,126	27	21,736	61	6,539.4	95
87,022	28	20,919	62	6,330.8	96
83,124	29	20,136	63	6,129.8	97
79,422	30	19,386	64	5,936.1	98
75,903	31	18,668	65	5,749.3	99
72,560	32	17,980	66	5,569.3	100
69,380	33	17,321	67		