THE MECHANICAL EQUIVALENT OF HEAT

INTRODUCTION

This is the classic experiment, first performed in 1847 by James Joule, which led to our modern view that mechanical work and heat are but different aspects of the same quantity: *energy*. The classic experiment related the two concepts and provided a connection between the Joule, defined in terms of mechanical variables (work, kinetic energy, potential energy. etc.) and the calorie, defined as the amount of heat that raises the temperature of 1 gram of water by 1 degree Celsius. Contemporary SI units do not distinguish between heat energy and mechanical energy, so that heat is also measured in Joules.

In this experiment, work is done by rubbing two metal cones, which raises the temperature of a known amount of water (along with the cones, stirrer, thermometer, etc,). The ratio of the mechanical work done (W) to the heat which has passed to the water plus parts (Q), determines the constant J (J = W/Q).

THE EXPERIMENT

CAUTION: The apparatus must *not* be operated without oil between the cones. The cones have to be cleaned and a tiny drop of oil put between the rubbing surfaces *(caution!* too much oil will reduce the friction excessively and make the experiment impossible).

The apparatus is shown in Figure 1. The heat generated in the system is absorbed by different parts: the water, the inner and outer cones, the stirrer and the immersed part of the temperature probe. The total increase in heat, including all these contributions, is therefore:

$$\mathbf{Q = (MC_w + M'C_{br} + v\,C_{th})\,\Delta T = constant_1 \times \Delta T} \qquad (1)$$

C_w = specific heat of water = 1.00 cal g^{-1} C^{-1} (by definition of the calorie)
C_{br} = specific heat of brass (cones and stirrer) = 0.089 cal $g^{-1}\,{}^\circ C^{-1}$
C_{th} = heat capacity per unit volume of temperature probe = 0.013 cal $cm^{-3}\,{}^\circ C^{-1}$
M = mass of water (in g)
M′ = mass of cones and stirrer (in g)
v = volume of the immersed part of the temperature probe (in cm^3).
ΔT = increase in temperature

The work provided to the system comes solely from the rotation of the hand wheel; the rate must be so adjusted that the string remains *tangential* to the edge of the disk, and the hanging weight remains stationary. The average power P is given by:

$$P = \frac{W}{\Delta t} = \tau \times \omega \qquad (2)$$

Where: W is the energy, τ is the torque and ω is the angular velocity.
After ΔN revolutions measured in a time Δt:

$$P = mgR \times \frac{2\pi\Delta N}{\Delta t} \quad \text{or:} \quad W = mgR \times 2\pi\Delta N = \text{constant}_2 \times \Delta N \qquad (3)$$

Where: R = radius of the disk (SI units); m = mass of the hanging weight (SI units);
g = gravitational acceleration (listed on the wall in the lab)
ΔN = number of revolutions of the wheel (dimensionless)

Although the height of the weight is *not* needed, it should be kept constant in order that the previous equation applies.

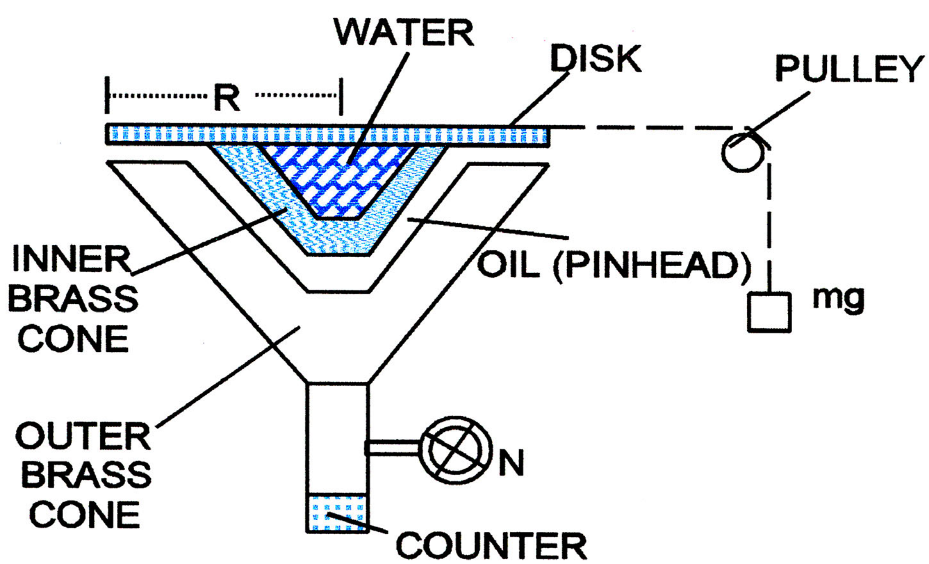

Figure 1. Apparatus

Weigh the cones together with the stirrer. (Aim for an accuracy of one-tenth of a gram.). The operation of the apparatus requires that one person turns the hand wheel at a constant rate in such a way that the string remains tangential to the edge of the disk and the height of the hanging mass remains constant. Select the mass of the hanging weight such that you can get stationary conditions at a relatively slow rotation (in setting the pace, remember that you may have to operate the wheel for a couple of hours). The other person stirs the water and performs the reading (and the logging of the data).

Just before you are ready to start the experiment, take the room temperature. Remove the cones and stirrer from the apparatus. Fill the inner cone to about 1 cm from its edge with water at 6°C to 8°C below the room temperature and weigh again both cones, plus stirrer plus water.
Reassemble the apparatus and proceed with the experiment. Decide how much of the thermo probe you will immerse and determine its volume, v. While the hand wheel is being turned, the other operator stirs the water and notes the temperature at every 100 revolutions of the spindle (note that the counter cannot be reset).
Do not stop turning. The temperature will rise steadily and the experiment should he continued until the temperature is as far above that of the room as it was below at the start (typically after several hundred revolutions). Finally read the temperature of the room again.

ANALYSIS

From Equations (1) and (2) above, we see that: $$J = \frac{W}{Q} = \text{constant} \times \frac{\Delta N}{\Delta T} \quad (4)$$

The 'constant' above is the ratio of constant_2 and constant_1 from equations (3) and (1).
Thus we require a measurement of the slope of the **ΔN** versus **ΔT** curve to obtain **J**. In this experiment, thermal equilibrium is generally not achieved, which means that either some heat is gained from the environment (when the apparatus is cooler than the surrounding air) or lost to it (when it is warmer). However, when the apparatus and the surrounding are at the same temperature, it is neither gaining nor losing heat and its rate of rise of temperature at this instant is wholly due to the heat developed by friction and the equations given above should then adequately describe the experiment. The slope of the curve should therefore be taken at this point.

In Joule's day, when, by definition, the specific heat of water (heat capacity per gram) was defined as unity, the value of J was a conversion factor between calories and joules. However in SI units, Q is defined in joules. You should thus be able to interpret your results to obtain the specific heat of water in **SI** units.

When you have finished the experiment **PLEASE** leave everything clean and tidy, and wipe the cones dry of water and oil. You might find it inspirational to look at the results of Mr. Cappel (a former demonstrator) which are displayed on the North (back) wall in Room 126.

Revised by RMS in 2004. Previous versions: gmg-1970, jv-1989, tk-1995