Thermodynamics Laboratory

Bolometric determination of the blackbody power-temperature relation

OBJECTIVE: We use a bolometer (a device that that can record minute temperature changes) to determine the total power of a thermal source. In doing so we are able to determine a power law relation between power and temperature.

EQUIPMENT: The black body source, bolometer (made of a bridge circuit containing two matched thermistors and an isolation horn) a differential amplifier, voltage controlled oscillator, computer, insulated beam blocker.

THEORY: The Stefan-Boltzmann relation indicates that the total thermal radiant power goes as $P = \sigma T^4$. This relation is actually somewhat difficult to measure for at least two reasons;

1) Huge spectral range: The blackbody spectrum at typical temperatures has a huge band-width, that is, the light that is emitted covers the entire spectrum. Typically detectors (such as the TSL337 sensor used in the previous black-body radiation laboratory) have a relatively narrow spectral response. This means that with such a detector we cannot unambiguously test for the temperature dependence of the total power; as in the previous laboratory, there the intensities in narrow bands increased exponentially with the temperature.

The bolometer solves this problem by having a huge spectral range…essentially all the light that hits it is converted to temperature rise. In our bolometer only the most modest attempt was made to make the bolometer actually "black" (i.e. absorbing) at all frequencies. The black coating on it is courtesy of a permanent marker! In the experimental runs we've certified that the overall wavelength dependence of the absorption is minimal.

The fact that we really don't know what the spectral response function of the bolometer is means that we will not really be able to determine the Stefan-Boltzmann coefficient; instead we focus in the lab at determining the exponent.

2) Large dynamic range: it is actually experimentally problematic to measure the total power vary over an appreciable range of temperatures, essentially due to the fact that the power depends so steeply on the temperature change. Drifts in our bolometer simply limit our dynamic range to about a factor of a few hundred, which would be associated with a pretty modest temperature change. This means that this experiment is somewhat limited in that it can only explore the power-temperature relation over a rather narrow temperature range. This in turn increases the overall error in our determination in the exponent of the power law.

PROCEDURE: First turn of the blackbody radiator and set it to about 998°C…you need to do this first because it takes about 30 minutes to warm up.

Line up the bolometer with the light beam from the blackbody source. Now block the beam with the beam blocker and turn on the bolometer, trimming it if necessary have output from the amplifier near zero.

Once the black body source is up to temperature, with the data logger program running continuously, remove the beam blocker for about 20 seconds. Do this a few times, in between waiting about 100 seconds or so for the bolometer to return to (at least near) is pre-measurement state. This opening and closing a detector is called "chopping" and reduces the noise very significantly.

Then reduce the temperature of the black-body source and wait until it comes to that target temperature and again chop the beam a few times while recording the bolometer excursions over a 20 second period beam on -vs- 100 seconds beam blocked

Repeat this procedure again for several temperatures of your choosing (at least 6) between 980°K and 450°K. Make sure that you take your data file with you!

ANALYSIS: The analysis consists of comparing the power received by the bolometer -versus- the temperature of the black body source. As a stand-in for the power received, we determine that the best fit line during the *beginning* of each heating phase. The rationale for this is that the change in the voltage is proportional to the change in resistance, which is roughly linear. Also, since the thermistor has some fixed heat capacity, the change in voltage is proportional to the heat received.

One remark; you need to fit only the first few (maybe 10 or less) points of each heating cycle. If you take too many points, the detector will start saturating (as the detector in the dark heats up…that IR bounces around much inside the bolometer) and you will not get an accurate measurement of the heat power.

Once you fit the beginning of each heating cycle, the slope of the fit is proportional to the total thermal power received. Make a plot of the log of this thermal power as a function of the log of the absolute temperature and extract an exponent (we are assuming that there is a power law relation between the total power radiated and the temperature!) by finding the slope of that graph. Don't forget to report your errors in the determination of that slope. Is your result consistent with the Stefan-Boltzmann law?