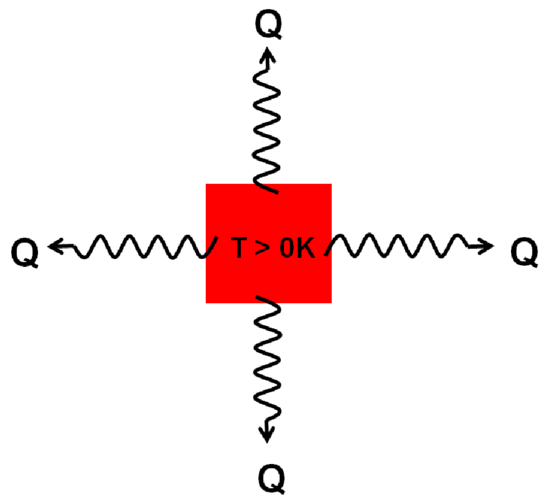
Stefan-Boltzmann Radiation Law

1 Purpose

The objectives of this experiment are to verify that the intensity of thermal radiation from a point source is inversely proportional to the square of the distance and that the intensity of thermal radiation increases with temperature to the fourth power.

2 Theory

All bodies above absolute zero emit thermal radiation in the form of electromagnetic waves.



The thermal radiation emission rate is given by the Stefan-Boltzmann radiation law,

$$P_{rad} = \epsilon \sigma A T^4$$

where ϵ is the emissivity of the surface, and is assumed to be equal to one, i.e. that of black body. σ is the Stefan-Boltzmann constant and is equal to $5.6704 \times 10^{-8} \frac{\mathrm{W}}{\mathrm{m^2 K^4}}$, A is the surface area of the radiating body, and T is the absolute temperature.

A point source emits thermal radiation isotropically (equally) in all directions. For a point source, the intensity I, that is the energy impacting a 1 m^2 area per second of the thermal radiation is,

$$I = \frac{P_{rad}}{4\pi r^2} = \frac{\epsilon \sigma A T^4}{4\pi r^2}$$

$$I \propto \frac{1}{r^2}$$

where r is the distance between the radiating object and the point where the intensity is measured. The radiation sensor used in this experiment measures the radiation intensity in $[\frac{\text{mW}}{\text{cm}^2}]$.

The solar constant gives the intensity of the thermal radiation emitted by the sun incident on the top of the Earth's atmosphere, and is equal to,

$$I_{SC} = 1361 \frac{\text{W}}{\text{m}^2} = 136.1 \frac{\text{mW}}{\text{cm}^2}$$

3 Procedure

1. Assemble the equipment as shown by your instructor. The radiation sensor should be connected to a voltmeter set on the mV scale. The ammeter connected to the bulb should be connected to the mA plug and set to the 2mA (or 20mA) scale while the voltmeter connected to the bulb should be set to the mV scale. The rheostat (variable electrical resistance) black knob should be fully CW.

2. Draw a diagram (or take pictures) showing the geometry of the filament with respect to the longitudinal axis of the bulb. Show a front and side view.

3. Connect the bulb to the 1 kΩ resistor alligator clip and determine the current i in [mA] of the bulb filament at room temperature when varying the voltage V across the filament from 1.0 mV to 1.9 mV.

4. Remove the bulb connection to the 1 kΩ resistor alligator clip and connect the wire from the bulb to the red banana plug. Disconnect the wire to the mA plug of the ammeter and connect to the 10A plug. The rheostat black knob should be set half way (pointing down). Set the scale of the bulb voltmeter to 20V.

5. Measure the radiation intensity in $[\frac{mW}{cm^2}]$ $(1mV = 1\frac{mW}{cm^2})$ at a distance of 10 cm from the filament and the bulb set at 8 V from an angle of -120° to +120° at every 10° from the longitudinal axis of the bulb. Turn the bulb off and block the radiation with insulation after each measurement. Adjust the bulb voltage to 8 V for each reading.

6. Measure the radiation intensity in $[\frac{mW}{cm^2}]$ of the bulb pointing forward at 10 V from 5 cm to 15 cm at every cm. Turn the bulb off and block the radiation with insulation after each measurement. Adjust the bulb voltage to 10 V for each reading.

7. Measure the radiation intensity in $[\frac{mW}{cm^2}]$, the voltage [V] and current [A] through the filament from 5 V to 12 V at 0.5 V interval at a bulb-sensor distance of 10 cm. Turn the bulb off and block the radiation with insulation after each measurement.

4 Interpretation of Results

1. Plot a graph of V [mV] versus current i [mA] for the bulb at room temperature. Perform a linear regression analysis to obtain the slope. The slope gives the resistance R_{300K} in [ohms or Ω] of your bulb at room temperature.

2. Plot a graph of radiation intensity in $[\frac{mW}{cm^2}]$ versus angle [deg]. According to this graph, is the filament radiating isotropically in all directions? According to your filament diagrams or pictures explain why is the radiation intensities at two side angles greatest.

3. According to your filament diagrams or pictures, in which direction relative to the longitudinal axis of the bulb, the filament most resembles a point source? Plot a graph of radiation intensity in $[\frac{mW}{cm^2}]$ vs. $\frac{1}{r^2}$ in [cm^{-2}]. According to a linear regression analysis and your R^2 correlation value, does your graph show that radiation intensity along the longitudinal direction is inversely proportional to the distance squared, as expected for a point source?

4. Plot a graph of temperature T (K) versus R/R_{300K} using the values from the following PASCO table. Perform a power regression and include on the graph the regression equation and R^2 value. The last value of $\text{R}/\text{R}_{300K} = 26.35$ of the PASCO table is incorrect, it should read 20.35 .

Table 2 Temperature and Resistivity for Tungsten

R/R_{300K}	Temp °K	Resistivity μΩ cm	R/R_{300K}	Temp °K	Resistivity μΩ cm	R/R_{300K}	Temp °K	Resistivity μΩ cm	R/R_{300K}	Temp °K	Resistivity μΩ cm
1.0	300	5.65	5.48	1200	30.98	10.63	2100	60.06	16.29	3000	92.04
1.43	400	8.06	6.03	1300	34.08	11.24	2200	63.48	16.95	3100	95.76
1.87	500	10.56	6.58	1400	37.19	11.84	2300	66.91	17.62	3200	99.54
2.34	600	13.23	7.14	1500	40.36	12.46	2400	70.39	18.28	3300	103.3
2.85	700	16.09	7.71	1600	43.55	13.08	2500	73.91	18.97	3400	107.2
3.36	800	19.00	8.28	1700	46.78	13.72	2600	77.49	19.66	3500	111.1
3.88	900	21.94	8.86	1800	50.05	14.34	2700	81.04	26.35	3600	115.0
4.41	1000	24.93	9.44	1900	53.35	14.99	2800	84.70			
4.95	1100	27.94	10.03	2000	56.67	15.63	2900	88.33			

5. For each of your pair of voltages and currents from procedure 7, obtain the resistance $R = \frac{V}{i}\left[\frac{V}{A}\right]$ and ratio $\frac{R}{R_{300K}}$ and determine the temperature of the tungsten filament using the power regression equation obtained in the previous interpretation. Include a table of values summarizing these calculations and give an example of your calculation.

6. Plot a graph of radiation intensity in $[\frac{mW}{cm^2}]$ vs. absolute temperature in $[K]$. Perform a power regression. You may eliminate some data points to increase the R^2 correlation. Compare using the percentage difference, the obtained exponent of the temperature to the accepted value of 4.

7. Use the power regression analysis of the previous interpretation to obtain an estimate of the bulb filament area. Hint: Compare your numerical coefficient of T to the coefficient of T in $I_{rad} = \frac{\epsilon\sigma A}{4\pi r^2}\,T^4$