Lab 4: Stefan-Boltzmann Law

(Based on Pasco Scientific Radiation Experiments)

Purpose

- to learn about thermal radiation
- to investigate the Stefan-Boltzmann law
- to study radiation rates from different surfaces

Equipment

(The equipment is described in more details in Appendix A)

Stefan-Boltzmann lamp	thermal radiation cube	radiation sensor
power supply (13V max)	reflective heat shield	4 multimeters

IMPORTANT: DO NOT TURN ON THE LAMP UNTIL INSTRUCTED TO DO SO!

Procedure

Part I - Stefan-Boltzmann Law – High Temperature Regime

The Stefan-Boltzmann Law relates $\mathcal{P}$, the power per unit area radiated by an object, to T, the absolute temperature of the object as:

$$\mathcal{P} = \sigma \cdot T^4 \text{ , where } \sigma = 5.6703 \times 10^{-8}\ \mathrm{W/m^2K^4} \text{ is the Stefan-Boltzmann constant}$$

In this experiment, you will make relative measurements of the power per unit area emitted from a hot object, namely the Stefan-Boltzmann Lamp, at various temperatures. From your data you will be able to test whether the radiated power is proportional to the fourth power of the absolute temperature. Most of the thermal energy emitted by the lamp comes from the filament of the lamp.

1. **BEFORE TURNING ON THE LAMP**, follow instructions in Appendix B to measure T_{ref}, the room temperature in kelvin, and R_{ref}, the resistance of the filament of the lamp at T_{ref}. Be VERY PRECISE when measuring R_{ref}, otherwise your results could be significantly off.

   T_{ref} = ______________ R_{ref} = ____________________

2. Set up the equipment as shown in Fig. 1. The voltmeter should be connected directly to the binding posts of the Stefan-Boltzmann Lamp. The Sensor should be at the same height as the filament, with the front face of the Sensor approximately 6 cm away from the filament. The entrance angle of the thermopile should include no close objects other than the lamp.

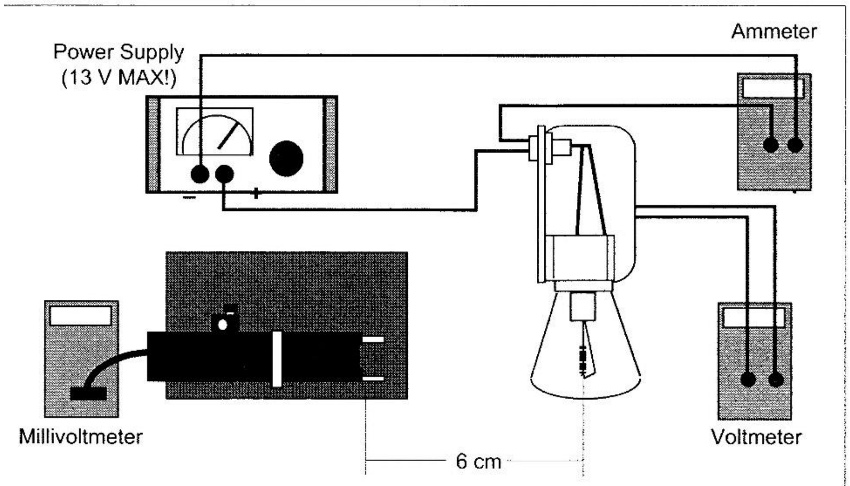

Figure 1

3. Turn on the power supply. Set the voltage V (lamp's voltmeter), to about 1 V. Measure I, the ammeter reading, and *Rad*, the reading on the millivoltmeter. Record in Table 1.

   IMPORTANT: *Make each Sensor reading* **quickly**. *Between readings, place both sheets of insulating foam between the lamp and the Sensor, with the* <u>*silvered*</u> *surface facing the lamp, so that the temperature of the Sensor stays relatively constant.*

4. Repeat step 3 for voltages of about 2 V, 3 V, etc. up to about 12 V (do not let the voltage to the Stefan-Boltzmann lamp exceed 13 V!). Record in Table 1.

   Before proceeding to the next step, and in the interest of time, it is advisable to first do steps 7 and 8, since it may take a long time for the cube's temperature to stabilize.

5. Calculate R, the resistance of the filament at each of the voltage settings. Use the procedure described in Appendix B to determine the temperature, T, of the lamp filament at each voltage setting. Calculate T^4. Record in Table 2.
6. Make graphs of *Rad* versus *T* and *Rad* versus T^4. Perform a power or linear regression on the plots. Do your measurements show that the radiated power is approximately proportional to T^4 ?

   ____

   b) How much is the coefficient next to T^4 in the *Rad* vs. T^4 graph?

   ____

   c) Is this coefficient equal to Stefan-Boltzmann constant, σ? Why do you think this is the case?

   ____

If you already did steps 7 and 8, continue to step 9.

Table 1

Data		
V (V)	I (A)	*Rad* (mV)

Table 2

Calculations and Analysis		
R (=V/I) (Ω)	T (K)	T^4 (K^4)

Do not increase the voltage over 13 V

Part II - Radiation Rates from Different Surfaces

7. Connect the Ohmmeter and voltmeter as shown in Fig. 2.
8. Turn on the Thermal Radiation Cube and set the power switch to "HIGH". When the Ohmmeter reading gets down to about 40 kΩ, reset the power switch to 5.0. (Go back to steps 5 and 6, if you previously skipped them).

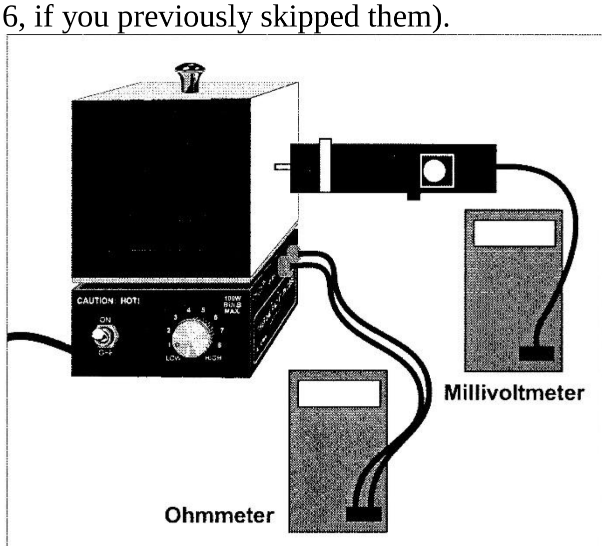

Figure 2

9. When the cube reaches thermal equilibrium, the ohmmeter reading will fluctuate around a relatively fixed value. Use the Radiation Sensor to measure the radiation

emitted from each of the four surfaces of the cube. Place the Sensor so that the posts on its end are in contact with the cube surface (this ensures that the distance of the measurement is the same for all surfaces). Record your measurements in Table 3. Also measure and record the resistance of the thermistor. Use the table on the base of the Cube (or Table 4) to determine the corresponding temperature.

10. Repeat the previous step with the power switch set to 8.0. Again, wait for the cube to reach thermal equilibrium. Record your results in Table 3. It may take a long time for the temperature to stabilize. Use your best judgment to decide when the temperature changes are small enough that you can take reliable measurements.

Table 3

Power Setting	5.0	8.0
Thermistor Resistance (kΩ)		
Temperature (^{o}C)		
Surface	Sensor Reading (mV)	
Polished Aluminum		
White		
Black		
Dull Aluminum		

Table 4 - Use for the Radiation Cube

Resistance versus Temperature for the Thermal Radiation Cube

Therm. Res. (Ω)	Temp. (°C)	Therm. Res. (Ω)	Temp. (°C)	Therm. Res. (Ω)	Temp. (°C)	Therm. Res. (Ω)	Temp. (°C)	Therm. Res. (Ω)	Temp. (°C)	Therm. Res. (Ω)	Temp. (°C)
207,850	10	66,356	34	24,415	58	10,110	82	4,615.1	106	2,281.0	130
197,560	11	63,480	35	23,483	59	9,767.2	83	4,475.0	107	2,218.3	131
187,840	12	60,743	36	22,590	60	9,437.7	84	4,339.7	108	2,157.6	132
178,650	13	58,138	37	21,736	61	9,120.8	85	4,209.1	109	2,098.7	133
169,950	14	55,658	38	20,919	62	8,816.0	86	4,082.9	110	2,041.7	134
161,730	15	53,297	39	20,136	63	8,522.7	87	3,961.1	111	1,986.4	135
153,950	16	51,048	40	19,386	64	8,240.6	88	3,843.4	112	1,932.8	136
146,580	17	48,905	41	18,668	65	7,969.1	89	3,729.7	113	1,880.9	137
139,610	18	46,863	42	17,980	66	7,707.7	90	3,619.8	114	1,830.5	138
133,000	19	44,917	43	17,321	67	7,456.2	91	3,513.6	115	1,781.7	139
126,740	20	43,062	44	16,689	68	7,214.0	92	3,411.0	116	1,734.3	140
120,810	21	41,292	45	16,083	69	6,980.6	93	3,311.8	117	1,688.4	141
115,190	22	39,605	46	15,502	70	6,755.9	94	3,215.8	118	1,643.9	142
109,850	23	37,995	47	14,945	71	6,539.4	95	3,123.0	119	1,600.6	143
104,800	24	36,458	48	14,410	72	6,330.8	96	3,033.3	120	1,558.7	144
100,000	25	34,991	49	13,897	73	6,129.8	97	2,946.5	121	1,518.0	145
95,447	26	33,591	50	13,405	74	5,936.1	98	2,862.5	122	1,478.6	146
91,126	27	32,253	51	12,932	75	5,749.3	99	2,781.3	123	1,440.2	147
87,022	28	30,976	52	12,479	76	5,569.3	100	2,702.7	124	1,403.0	148
83,124	29	29,756	53	12,043	77	5,395.6	101	2,626.6	125	1,366.9	149
79,422	30	28,590	54	11,625	78	5,228.1	102	2,553.0	126	1,331.9	150
75,903	31	27,475	55	11,223	79	5,066.6	103	2,481.7	127		
72,560	32	26,409	56	10,837	80	4,910.7	104	2,412.6	128		
69,380	33	25,390	57	10,467	81	4,760.3	105	2,345.8	129		

11. a) List the Cube surfaces in order of <u>decreasing</u> amount of radiation they emit.

____

b) Does the order depend on temperature? __________________________

c) According to your measurements:

The poorer absorbers (better reflectors) are ___________________ emitters.
(better/poorer)

APPENDIX A - Equipment Description

The **TD-8554A Radiation Cube** provides four surfaces that can be heated from room temperature to approximately 120 °C. The cube is heated by a 100-W light bulb. Just plug in the power cord, flip the toggle switch to "ON", then turn the knob clockwise to vary the power. Measure the cube temperature by plugging your ohmmeter into the banana plug connectors labeled THERMISTOR. The thermistor is embedded in one corner of the cube. Measure the resistance and then use Table 4 to translate the resistance into a temperature measurement. An abbreviated version of this table is printed on the base of the Cube.

The **TD-8555 Stefan-Boltzmann Lamp** is a high temperature source of thermal radiation. The lamp can be used for high temperature investigations of the Stefan-Boltzmann Law. The high temperature simplifies the analysis because the fourth power of the ambient temperature is negligibly small compared to the fourth power of the high temperature of the lamp filament. By adjusting the power into the lamp, filament temperatures up to approximately 3000 °C can be obtained. The filament temperature is determined by carefully measuring the voltage and current into the lamp.

The PASCO **TD-8553 Radiation Sensor** (Fig. 3) measures the relative intensities of incident thermal radiation. The sensing element, a miniature thermopile, produces a voltage proportional to the intensity of the radiation. The Sensor can be hand held or mounted on its stand for more accurate positioning. A spring-clip shutter is opened and closed by sliding the shutter ring forward or back. During experiments, the shutter should be closed when measurements are not actively being taken. This helps reduce temperature shifts in the thermopile reference junction which can cause the sensor response to drift. The two posts extending from the front end of the Sensor protect the thermopile and also provide a reference for positioning the sensor a repeatable distance from a radiation source.

<u>Specifications</u>

Temperature Range: -65 to 85 °C.
Maximum Incident Power: 0.1 Watts/cm^2.
Spectral Response: 0.6 to 30mm.
Output: Linear from 10^{-6} to 10^{-1} Watts/cm^2.

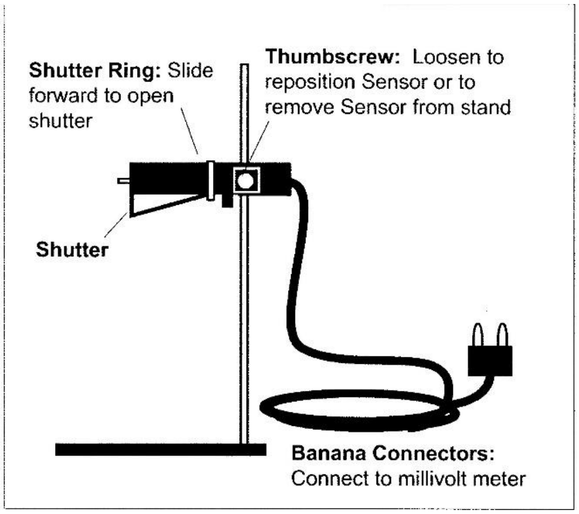

Figure 3

APPENDIX B - Determination of Filament Temperature

1. Accurately measure the resistance (R_{ref}) of the tungsten filament at room temperature (about 300 K). Accuracy is important here. A small error in R_{ref} will result in a large error in your result for the filament temperature.
2. When the filament is hot, measure the voltage and current into the filament and divide the voltage by the current to find the resistance (R_T). Divide R_T by R_{ref} to obtain the relative resistance (R_T/R_{ref}).
3. Use your value for the relative resistance of the filament at temperature T and Table 5 to find the temperature of the filament. Linearly interpolate values when needed.

Use for the Filament Temperature

Table 5 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			