LEOI-65 Experimental Apparatus of

Thermal Radiation and Infrared Thermography

1. Experimental Objectives

1) Study the effect of blackbody temperature on radiative power.
2) Investigate the relationship between radiation intensity and distance.
3) Plot the relationship between radiative energy and wavelength based on **Wien's Displacement Law**.
4) Measure the **transmittance** of thermal radiation through different media.
5) Measure the **emissivity** of different samples and analyze the relationship between surface condition and emissivity.
6) Observe thermal images of various heat sources and study their emissivity and radiation characteristics (extended experiment).

2. Experimental Content

1) System Wiring

Use multi-core cables to connect the "Blackbody Emitter Heating Control" and "Blackbody Emitter Fan" ports on the rear panel of the main unit with the respective "Heating Control" and "Fan" ports on the back of the hemispherical blackbody emitter. Similarly, connect the "Sample Furnace Heating Control" and "Sample Furnace Fan" ports on the main unit to the corresponding ports on the sample furnace (which has four sample slots). Connect the "Thermal Imager" port on the main unit to the rear interface of the infrared thermal imager, and secure all connections using the locking mechanisms.

2) Measuring the Effect of Blackbody Temperature on Radiative Power

a) Remove the lens cap from the thermal imager. Align the hemispherical surface of the blackbody emitter directly facing the imager, leaving about 25 cm between the base sliders. Adjust height so the emitter appears centered in the thermal image.

b) Turn on the main unit. Set the Temperature Control “Switch" on the panel to "Blackbody Emitter" and turn off the blackbody fan (indicator light off).

c) On the touchscreen, tap **"Thermal Radiation Experiment"** to access to the radiation power measurement mode.

d) Tap the temperature box next to **"Target Temperature"**, set a value above room temperature using the up/down arrow buttons, then tap "X" to return. Tick the checkbox left of "Heat" to begin heating control.

e) Once the **"Current Temperature"** stabilizes near the target, tap **"Single Display"** to view the thermal image of the blackbody emitter.

f) Tap **"Area Selection"**, and draw a large rectangular box within the circular image of the emitter (by tapping two diagonal corners). The **"Mean Radiative Power"** field will display the mean received power of the selected area. Record the **current temperature (t)** and **mean radiative power (Pa)**.

   Note: Do not exceed the emitter circle when selecting the area. External background radiation may affect accuracy.

g) Keep the image and area unchanged, but vary the emitter temperature and record multiple sets of **t–Pa** data.

h) Since Pa is proportional to the total emissive power of the blackbody, convert Celsius temperature **t** to thermodynamic temperature **T**, and verify whether **Pa** $\propto$ **T**^{4} to validate the **Stefan–Boltzmann Law**.

3) Plotting Radiation Energy vs Wavelength Using Wien's Displacement Law

Using the data from the previous experiment and Wien's Law (Equation 3), calculate the peak wavelength λ_m corresponding to temperature **T**, then plot the **Pa (x-axis)** vs λ_m **(y-axis)** to obtain the energy-wavelength relationship of the object.

4) Measuring the Relationship Between Radiative Power and Distance

a) Align the blackbody emitter facing the imager at a distance of at least 25 cm. Adjust height so the emitter is fully visible on the imager. Record the imager's slider position x_0, and estimate the correction offset **d** between the emitter center and the imager sensor (reference: d = –7.0 cm) .

b) Power on the main unit, set the control switch to **Blackbody Emitter**, and turn off the fan.

c) On the touchscreen, enter **Thermal Radiation Experiment** mode.

d) Cover the lens (or use a black object at room temp), click **"Single Display"**, and record $\mathbf{P_0}$ as the background radiative power.

e) Remove the lens cover. Set the **Target Temperature** to 90–100 °C and start heating.

f) When stabilized, tap **"Single Display"** to observe the image.

g) Record the position x_1 of the emitter slider and corresponding power reading **P**.

h) Adjust emitter position within a range $25cm \le |x_1 - x_0| \le 60cm$, record multiple set of data x_1-P.

i) Calculate actual distance $D = |x_1 - x_0| + d$. Plot $\frac{1}{D^2}$ **(x-axis)** vs **P (y-axis)**. Fit a line using least squares to validate the inverse-square law.

5) Measuring Infrared Transmittance of Different Media

a) Align blackbody emitter and imager as before (~25 cm distance).

b) Power on, set control switch to **Blackbody Emitter**, and turn off the fan.

c) Enter **Thermal Radiation Experiment** mode.

d) Cover the lens (or use a room-temperature black object), tap **"Single Display"**, and record $\mathbf{P_0}$ (background radiation). Then remove the cover.

e) Set the target temperature to 90–100 °C, begin heating.

f) After stabilization, tap **"Single Display"** and draw a box on the emitter image. Record average power $\mathbf{P_a}$. Note: Box must stay within emitter circle.

g) Insert a transmission sample (e.g., monocrystalline silicon, CaF_2, or K9 glass) into the slot in front of the imager lens. Let the radiation pass through the sample and record the new power reading $\mathbf{P_b}$.

h) Use the following formula to calculate transmittance τ:

$$\tau = \frac{P_b - P_0}{P_a - P_0} . \qquad (13)$$

6) Measuring Emissivity of Different Samples

a) Open the cover on the sample furnace by removing screws. Insert the sample with the sensing face downward into a slot. Ensure the temperature sensor is in contact with the sample. Reattach the cover.

b) Remove the imager's lens cap. Face the sample side of the furnace to the imager (distance: 20–25 cm). Properly adjust height.

c) Power on the unit. Set control switch to **Sample Furnace** and turn off the fan.

d) Enter **Infrared Temperature Measurement** mode.

e) Without heating, record **ambient temperature** t_u.

f) Set target temperature to 80–100 °C and start heating.

g) Four temperature values t_1–t_4 will appear in real time at lower-left on screen, corresponding to four sample sensors (refer to following diagram).

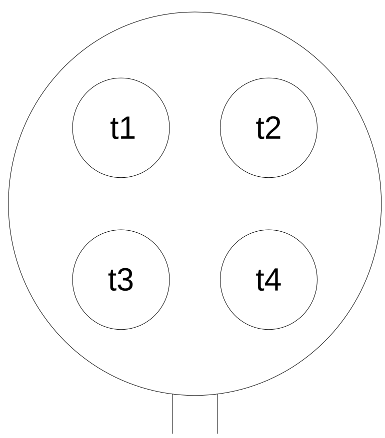

Figure 3. Positions of temperature sensors and their temperature readings

h) Once stabilized, click **Single Display** to see thermal image of the sample furnace.

i) Click **"Area Selection"** and draw a small box on the sample of interest. Record the **radiative temperature t_r** and **actual temperature t_0** of the sample.

j) Convert **t_u, t_r, t_0** to thermodynamic temperatures T_u,T_r,T_0. Use Equation (12) to calculate sample **emissivity ε**.

k) You may enter the calculated emissivity **ε** to the “Surface Emissivity” on the top-right of the touchscreen. Check if the imager now shows actual temperature consistent with sensor temperature value.

7) Observe Thermal Images of Various Radiating Bodies (Extended Experiment)

Use the thermal imager to observe the thermal images of different heat sources such as human body parts, flames, hot water cups, thermos bottles, and ice. Study their color patterns and characteristics, and think about the physical mechanisms involved.

3. An example of data recording and processing

Note: Following data are for reference only, not the criteria for apparatus performance.

1) Measuring the Effect of Blackbody Temperature on Radiative Power

Experimental Conditions: Infrared imager slide position: 5.0 cm; Blackbody emitter slide position: 30.0 cm. Ambient temperature: 26.6 °C.

Table 1 Relationship between blackbody emitter temperature *t*, thermodynamic temperature *T*, T^4, and the average radiative power P_a measured in the selected blackbody emitter region.

T (℃)	T(K)	T^4(×$10^{10}$$K^4$)	P_a(mW)
35.3	308.45	0.905	85.1
39.8	312.95	0.959	91.5
44.9	318.05	1.023	98.7
50.0	323.15	1.090	105.7
54.9	328.05	1.158	112.8
60.0	333.15	1.232	119.8
64.9	338.05	1.306	127.8
70.0	343.15	1.387	136.6
74.9	348.05	1.467	144.3
80.0	353.15	1.555	153.6

85.0	358.15	1.645	163.5
90.0	363.15	1.739	174.2
95.0	368.15	1.837	185.3
100.0	373.15	1.939	195.7

Plot the T^4–P_a graph and perform a linear fitting, as shown in Figure 4:

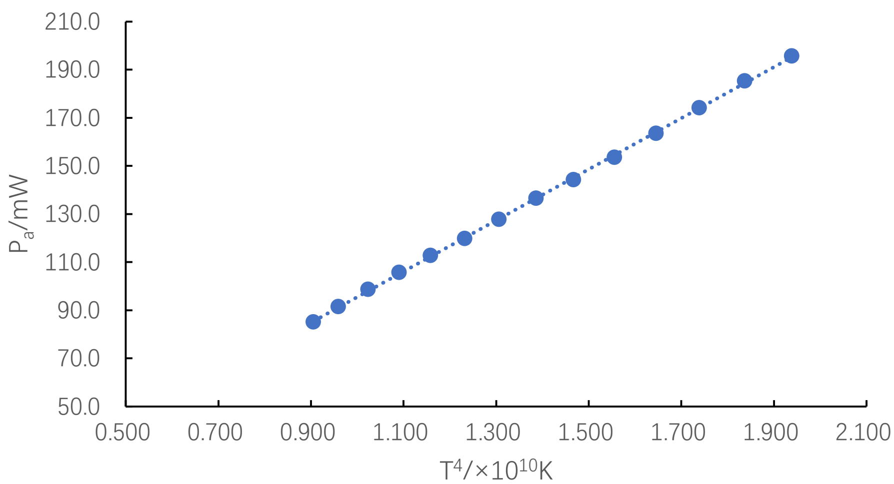

Figure 4. Relationship Graph Between Blackbody Emitter Temperature T^4 and Radiant Power P_a

The linear fit yields $R^2 = 0.9997$, indicating an excellent degree of fit, which verifies the Stefan–Boltzmann Law.

2) Plotting the Relationship Between Radiant Energy and Wavelength Based on Wien's Displacement Law

Using the temperature data from Table 1 and Equation (3), the peak wavelength λ_m corresponding to the blackbody radiation energy is calculated. By pairing these values with the average radiant power P_a measured from the selected blackbody emitter region, the results are shown in Table 2:

Table 2. Data Relationship Between Radiant Power P_a, Blackbody Emitter Temperature T, and Peak Wavelength λ_m .

P_a(mW)	T(K)	λ_m (μm)
85.1	358.25	9.395
91.5	364.65	9.260
98.7	371.85	9.112
105.7	378.85	8.968
112.8	385.95	8.834
119.8	392.95	8.699
127.8	400.95	8.573
136.6	409.75	8.445
144.3	417.45	8.326
153.6	426.75	8.206
163.5	436.65	8.092
174.2	447.35	7.980
185.3	458.45	7.872
195.7	468.85	7.766

By using P_a as the horizontal axis and the peak wavelength λ_m as the vertical axis, the relationship graph between radiant energy and wavelength can be plotted, as shown in Figure 5**:**

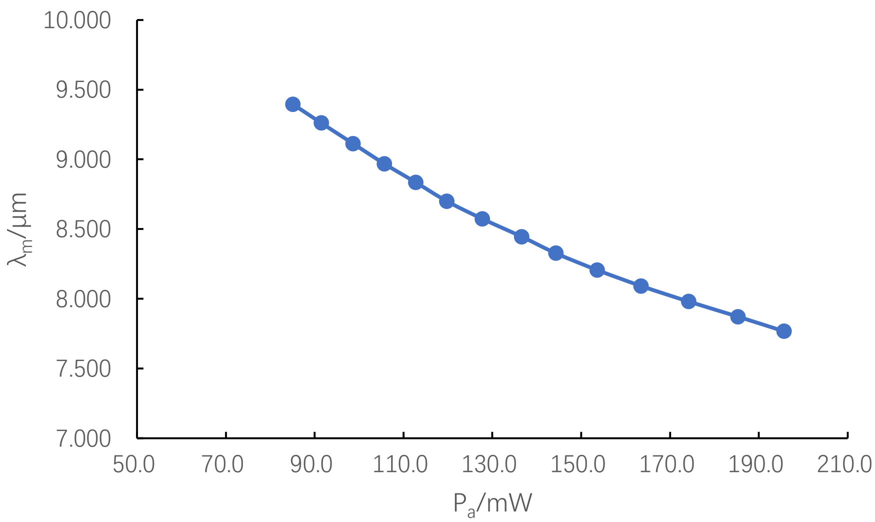

Figure 5. Relationship Between Radiant Power P_a and Peak Wavelength λ_m

3) Measuring the Relationship Between Radiation Intensity and Distance

Experimental Conditions: Blackbody emiiter temperature = 90.1 °C; Thermal imager slider position x_0=5.0 cm, distance correction value d=−7.0cm, environmental background radiation power P_0=69.6 mW

Table 3. Relationship Between Blackbody emitter, Slider Position x_1, Distance D (Between the Emitter and Thermal Imager), and Average Radiation Power P Received by the Imager

x_1(mm)	D(cm)	D^{-2}(cm^{-2})	P(mW)
30.0	18.0	0.003086	122.1
32.0	20.0	0.002500	111.3
34.0	22.0	0.002066	103.5
36.0	24.0	0.001736	97.8
38.0	26.0	0.001479	93.3
40.0	28.0	0.001276	89.7
44.0	32.0	0.000977	84.6
48.0	36.0	0.000772	81.4
52.0	40.0	0.000625	78.9
56.0	44.0	0.000517	77.0
60.0	48.0	0.000434	75.6

Using the inverse square of the distance D^{-2} as the horizontal axis and the average radiation power P as the vertical axis, perform a linear fit using the least squares method, as shown in Figure 6:

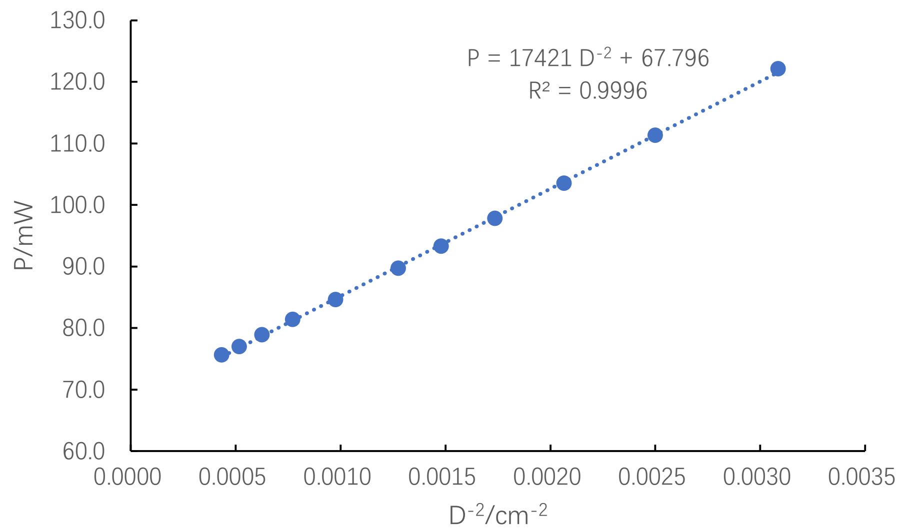

Figure 6 Relationship between the inverse square of distance D^{-2} and average radiation power P

The linear fit shows a good degree of linearity. The intercept of the fitted line is 67.796 mW, which is very close to the measured environmental background radiation power P_0=69.6 mW. This indicates that when the distance D between the blackbody emitter and the thermal imager approaches infinity, the thermal imager receives only the environmental background radiation power.

4) Measurement of Thermal Radiation Transmittance of Different Media

Experimental conditions: Thermal imager slider position: 5.0 cm; Blackbody emitter slider position: 30.0 cm; Blackbody emitter temperature: 94.9 ℃

At this temperature, the peak wavelength of the blackbody radiation energy is approximately 8 μm (in theory).

Measured values:

Environmental background radiation power P_0=75.8 mW

Blackbody emitter region average radiation power P_a=186.7 mW

- When inserting a single crystal silicon sample, P_b=127.7 mW. Using equation (13), the thermal radiation transmittance of single crystal silicon is calculated as $\tau_{si} = 0.468$.

• When inserting a calcium fluoride (CaF_2) sample, P_b=142.5 mW. Using equation (13), the thermal radiation transmittance of calcium fluoride is calculated as $\tau_{CaF_2} = 0.601$.

• When inserting a K9 glass sample, P_b=75.3 mW, which is almost the same as the environmental background radiation power P_0. This shows that K9 glass almost completely blocks thermal radiation at this wavelength.

5. Measurement of Thermal Radiation Emissivity of Different Samples

Experimental samples: Aluminum alloy, one with a black matte surface and another with a white matte surface

Experimental conditions: Thermal imager slider position: 5.0 cm; Sample furnace slider position: 26.0 cm; Sample furnace temperature: 90.0 ℃; Environmental temperature t_u=20.9 ℃

- For the black matte aluminum alloy sample:
  Radiation temperature t_r=87.1 ℃, actual sample temperature t_0=89.0 ℃
  Using equation (12), the emissivity ε is calculated as 0.96.
- For the white matte aluminum alloy sample:
  Radiation temperature t_r=73.8 ℃, actual sample temperature t0=89.0 ℃
  Using equation (12), the emissivity ε is calculated as 0.72.