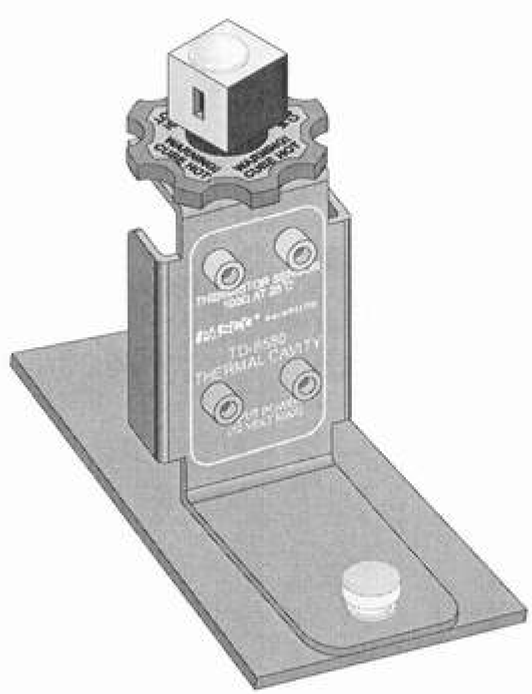
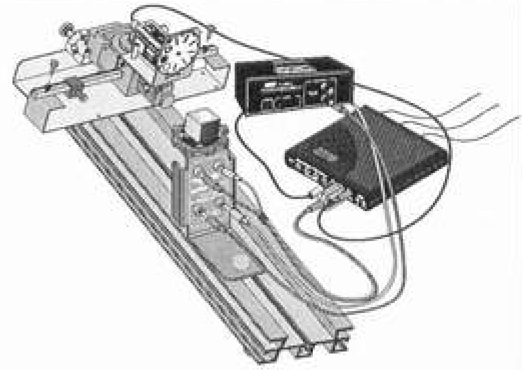
Experiment Guide for the
PASCO scientific
Model TD-8580

021-07510

TD-8580 THERMAL CAVITY





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Introduction

Introduction

This guide contains experiments for studies of thermal radiation from different surfaces, the Steffman-Boltzman law, and for studying the absorption, reflection and emission of light. The Thermal Cavity apparatus is required for all of the experiments. See each individual experiment for a list of additional required equipment. For more detailed information about the Thermal Cavity apparatus, see the *Thermal Cavity Instruction Manual* accompanying the product.

Description of the Thermal Cavity Apparatus

The PASCO TD-8580 Thermal Cavity apparatus can be used in studies of thermal radiation from different surfaces, the Stefan-Boltzmann law, and for studying the absorption, reflection and emission of light from different surfaces.

A heating resistor is mounted to the bottom of the aluminum cube. Using either a direct power supply or a CI-6552A Power Amplifier, the user can directly heat the aluminum cube. A separate power supply is suggested for more rapid results and for users who do not have computers.

A thermistor is contained within the aluminum cube of the apparatus. With a Thermistor Sensor, *ScienceWorkshop*® interface and DataStudio®, the student can observe the direct readout of the temperature. It takes approximately 20 minutes for the cube to reach an equilibrium temperature with the CI-6552A Power Amplifier. If the lab time is less than two hours, teachers are recommended to setup the apparatus and heat the cube before the class laboratory.

The apparatus can be mounted to either a rectangular base or an Optics Bench. With a light sensor, the student can examine light emission and/or reflection from each of the cube's surfaces.

The two upper jacks are for the Thermistor Sensor, and the two lower jacks are for the power input supply. If a Thermistor Sensor is not available, students can use a ohmmeter to measure resistance and calculate the temperature using the Resistance vs. Temperature conversion chart.

Apparatus Setup

Mounting the Thermal Cavity to the Base (Standalone setup for experiments with or without a computer)

1. Place the Thermal Cavity apparatus upright, such that the chassis (horizontal support piece) lies horizontal over the base. (see Figure 1).

2. Align the hole on the outer edge of the chassis with the hole on the base.

3. Insert a thumb screw into the outer hole and rotate clockwise to tighten the support against the base.

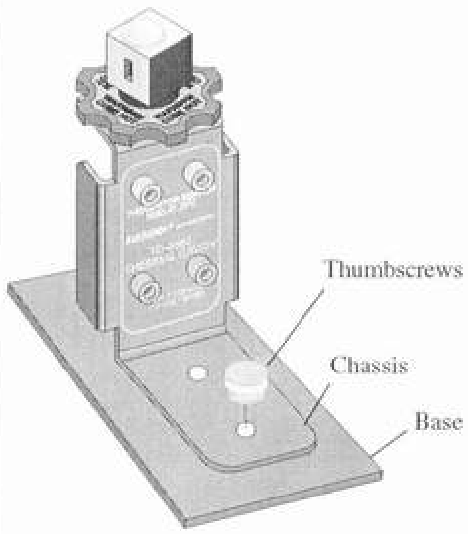

Figure 1: Mounting the Thermal Cavity apparatus to the base

Mounting the Thermal Cavity to an Optics Bench (for experiments measuring light reflected, emitted or absorbed from the cube on the Thermal Cavity apparatus)

1. Slide both nuts into the center groove on the track.

2. Align the holes on the chassis of the Thermal Cavity apparatus over the nuts. (See Figure 2).

3. Move the apparatus to the desired cm position on the bench.

4. Put the thumbscrews into the holes and rotate to tighten.

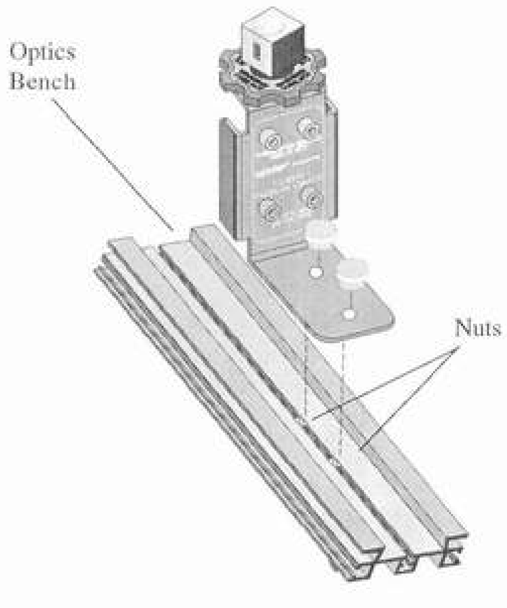

Figure 2: Mounting the Thermal Cavity apparatus to the Optics Bench

Experiment Setup

Basic Setup for Heating the Aluminum Cube (for users who have a computer, *ScienceWorkshop®* interface and DataStudio)

1. Mount the Thermal Cavity apparatus to the base (For instructions, see page 4.)

2. Plug the DIN connector for the Thermistor Sensor into an analog channel on the *ScienceWorkshop®* interface. Plug the red and black cables extending from the Thermistor Sensor into the upper white-colored jacks on the Thermal Cavity apparatus (see Figure 3).

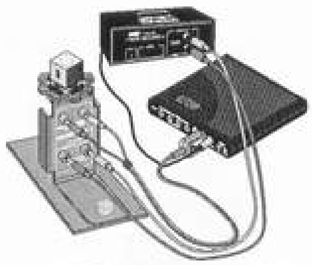

Figure 3: Setup with Power Amplifier, Thermistor Sensor and *ScienceWorkshop®* interface.

3. With the power turned off, plug the DIN connector from the Power Amplifier into analog channel C on the *ScienceWorkshop* interface. Insert the banana jacks into the output channels of the Power Amplifier.

4. Connect the same set of cables from the power source to the lower red plugs on the Thermal Cavity apparatus.

Note: You can use either a SF-9584A Power Supply or a CI-6552A Power Amplifier II to heat the aluminum cube.

5. Open DataStudio. Insert the Thermal Cavity setup diskette into your computer drive and open the desired experiment file.

WARNING: To prevent unnecessary power surges, open DataStudio before turning on the Power Amplifier. Excessive voltage could cause your computer to malfunction.

6. Turn on the Power Amplifier. (The on/off switch is located in the back.) (Note: If you are preheating the cube with a separate power supply, turn on the power supply and set the DC voltage to between 8 and 10 volts.)

WARNING: Do not exceed the 10-volt maximum for the power resistor. Exceeding 10 volts could damage the thermistor and/or power resistor.

7. In DataStudio, open a Digits Display. From the Data list, drag the Temperature icon to the display. Click the **Start** button to begin heating the cube.

WARNING: Never touch the cube while it is heating! Touching the cube may cause burns. Also, do not heat the cube beyond 100 degrees centigrade. Over heating the cube may damage the thermistor, which allows for a 100-degree maximum.

Setup for Heating the Cube (for users who do not have a computer, interface or DataStudio®)

1. Using a thumbscrew, mount the Thermal Cavity apparatus to the base (For instructions, see page 4 of this manual.)

2. With the power supply off, attach the cables to DC section of the power source. Attach the same set of cables to the lower red jacks on the Thermal Cavity apparatus.

3. To begin heating the cube, turn on the power supply and adjust the voltage to between 8 and 10 volts.

WARNING: Do not exceed 10 volts. The apparatus specifications allow for a 10 volt maximum. Exceeding 10 volts could overheat and damage the thermistor or power resistor in the apparatus. Also, do not use both a CI-6552A and a separate power supply simultaneously.

Experiment Setup

4. Plug an ohmmeter or multimeter into the upper white cables on the Thermal Cavity apparatus.

5. From the ohmmeter dial or multimeter read-out, record the resistance. Use the Resistance vs. Temperature conversion table to determine the temperature of the cube.

WARNING: Do not exceed 100 degrees Centigrade. Overheating the cube could damage the thermistor.

Set up with Thermal Cavity Apparatus on the Optics Bench (for Experiments Measuring Light Intensity Absorbed, Reflected or Emitted)

1. Place the base of the Linear Translator perpendicularly over the far edge of the Optics Bench (See Figure 4).

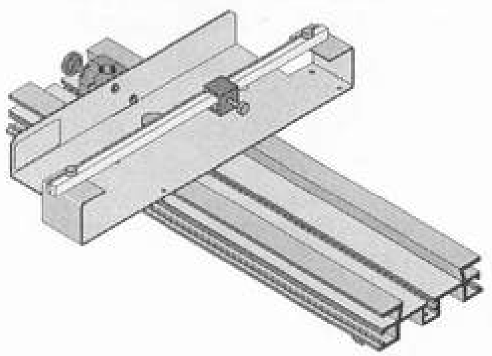

Figure 4: Positioning the Linear Translator perpendicularly over the Optics Bench

2. Insert the rack into the side hole in the Rotary Motion Sensor (RMS) (See Figure 5). The movable stop slides over the rack. Place the rack horizontally over the Linear Translator, such that the holes on the rack align over the Linear Translator. Use the provided thumb screws to mount the rack with RMS to the base of the Linear Translator.

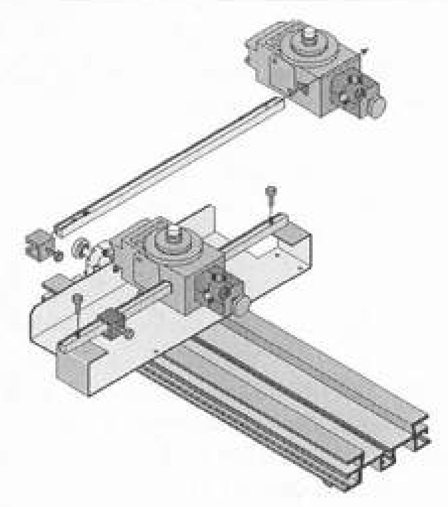

Figure 5: Inserting the Linear Rack into the Rotary Motion Sensor

3. Use the threaded post to secure the Infrared Sensor to the bottom support on the bracket. (see Figure 6) Insert the threaded post into the hole on the underside of the sensor and rotate the post to tighten. Slide the post into the clamp of the RMS and adjust the thumbscrew to anchor the post in the clamp.

NOTE: If you are using the CI-6504A Light Sensor to measure reflected light, do not use an aperture bracket. Insert a threaded post into the bottom hole of the sensor and anchor the post with the RMS clamp.

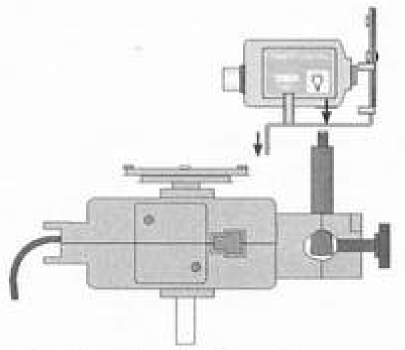

Figure 6: Mounting the Infrared Sensor and Aperture Bracket

4. Plug the black and yellow cables from the Rotary Motion Sensor to channels 1 and 2 of the *ScienceWorkshop* interface.

Experiment Setup

5. Plug the DIN connector cable from the Light Sensor to the analog channel on the *ScienceWorkshop* interface.

6. Mount the Thermal Cavity apparatus to the Optics Bench. (For more detailed instructions, see page 4 of this manual.)

Note: The cavity on matte surface of the cube should be of corresponding height to the aperture slit covering the light sensor. If necessary, loosen the thumbscrew on the RMS clamp and adjust the position of the threaded post until the heights are equivalent.

7. Connect the Thermistor Sensor and power supply to the Thermal Cavity apparatus. (See the instructions for heating the cube on page 5.

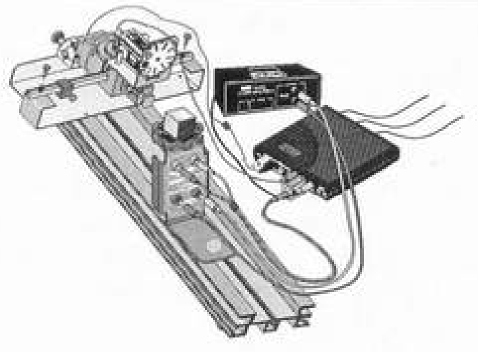

Figure 7: Setup with the Thermal Cavity apparatus and Infrared Light Sensor on the Optics Bench

Optional Setup for Infrared Light Experiments (for users who do not have an Optics Bench, Linear Translator or Rotary Motion Sensor)

1. Connect the DIN connectors from the Infrared Sensor and Thermistor Sensor to analog channels on the *ScienceWorkshop* interface.

2. Attach the black and red cables from the Thermistor Sensor to the upper white jacks on the Thermal Cavity apparatus.

3. With the power turned off, plug the DIN connector from the Power Amplifier into an analog channel C on the *ScienceWorkshop* interface. Insert the banana jacks (black=negative, red=positive) into the output channels of the Power Amplifier.

4. Connect the same set of cables from the power source to the lower red plugs on the Thermal Cavity apparatus.

5. To take a radiation measurement from the cube, position the sensor aproximately 3 cm from the surface. (NOTE: Use the metal shutter as a cover instead of the aperture bracket.)

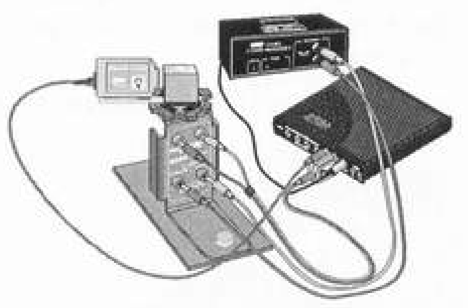

Figure 8: Optional Standalone Setup for Infrared Light Experiments

Experiment 1: Thermal Radiation Emission from Different Surfaces

EQUIPMENT NEEDED:

— Thermal Cavity Apparatus (TD-8580)
— DataStudio®, ver. 1.5.3 or later (CI-6870B)
— Banana jack connectors (SE-9750/9751)*
— Power Amplifier (CI-6552A)
— *ScienceWorkshop*® Interface (700 or 750)
— DIN connector cables, 8-pin (CI-6516)
— Thermistor Sensor (CI-6527)
—Temperature vs. Resistance chart (646-07115)
— Infrared Sensor (CI-6628)
— Base for the Thermal Cavity (648-01081)
— Power Supply (SF-9584A)*
—Thermal Radiation Sensor (TD-8553)*
—Ohmmeter or Multimeter (SB-9631B)*

*Optional equipment required for users who do not have a computer, DataStudio, interface or sensors. The banana jack connectors are required for either setup.

NOTES:

- If lab time is short, it's helpful to preheat the cube at a setting of 5.0 volts for 20 minutes before the laboratory period begins. (A quick method is to preheat the cube at 10 volts for 20-30 minutes, then use a small fan to reduce the temperature quickly as you lower the power input. Just be sure that equilibrium is attained with the fan off.)
- Part 1 and 2 of this experiment can be performed simultaneously. Make the measurements in Part 2 while waiting for the Thermal Cavity to reach thermal equilibrium at each of the settings in Part 1.
- When taking a measurement with the Infrared Sensor, always use the metal shutter to block room light and other interferences from entering the sensor. Always tare the sensor before and between measurements.
- If using the Thermal Radiation Sensor, always shield it from the hot object except for the few seconds it takes to actually make the measurement. This prevents heating of the thermopile which will change the reference temperature and alter the reading.

Radiation Rates from Different Surfaces

Part 1

1. Setup your equipment as shown in Figure 1.1. (See "Experiment Setup" on page 5-6 for instructions.)
2. Insert the Thermal Cavity setup diskette into your computer drive. In DataStudio, open the file "exp1therm."
3. Heat the cube at a power setup of 10 volts (see page 5 for instructions on heating the cube). Watch the temperature reading in a Digits display. When it reaches 50 degrees, reset the voltage to 5.0 and wait for the temperature to equilibrate. (If the cube is preheated, just reset the power to 5.0 volts.)

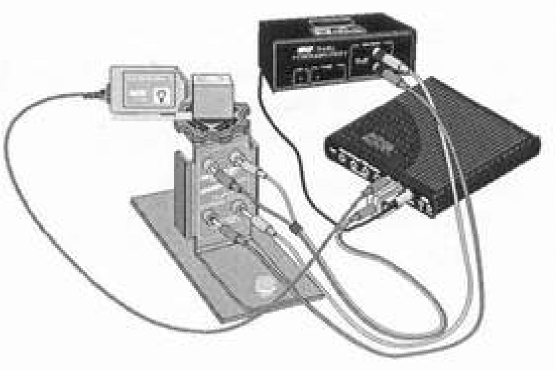

Figure 1.1 Equipment Setup

Experiment 1 (Continued)

Note: In DataStudio, use the Signal Generator box to adjust the voltage. To open the Signal Generator box, go to the Data list and double click on the Output Voltage icon.

OPTIONAL: If you do not have a computer, DataStudio or a *ScienceWorkshop* interface, measure the resistance with an ohmmeter or multimeter and convert to degrees Celsius with the provided Temperature vs. Resistance conversion table. (See page 5 for optional setup instructions.)

4. When the cube reaches thermal equilibrium—the temperature reading will fluctuate around a relatively fixed value—use the Infrared Sensor (or the Thermal Radiation Sensor for optional setup) to measure the radiation emitted from each of the four surfaces of the cube. (Note: The voltage is directly proportional to the heat energy emitted from the cube.)

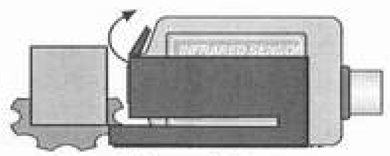

Figure 1.2

5. Slide the Infrared Sensor over the bottom plate of the metal shutter. Set the gain on the sensor to 10. With the metal cover completely blocking the sensor opening, press the **Tare button** to zero the sensor. (Always tare the sensor with the hole blocked.)

6. To take a measurement, place the Infrared Sensor approximately 3 cm from the cube's surface (such that the metal support on the shutter is barely touching the cube) and use your index finger to press the metal shutter inward (see Figure 1.2). The hole on the shutter will align over the sensor opening. (Note: The outside edge of the bottom plate of the shutter should rest against the side of the cube.)

NOTE: Always tare the Infrared Sensor before and between measurements. For consistency, take all measurements with the shutter and from the same distance and position relative to the cube.

WARNING: Do not touch the cube while it is heating! Also, never place the sensor, a metal shutter, or your fingers directly against any of the cube's surface. Touching the cube while it is heating may cause burns. Metal objects contacting the cube's surfaces strip the paint coating and damage the cube on the apparatus. When paint wears off, you may not be able to obtain accurate experimental results.

7. From DataStudio, record the Infrared Sensor's voltage measurements in Tables 1.1-1.4 (page 10). Also measure and record the temperature of the cube. (If you do not have DataStudio, use the Thermal Radiation Sensor with multimeter to measure the voltage and resistance. Use the chart provided with the apparatus to determine the corresponding temperature.)

8. Increase the power voltage, first to 6.5, then to 8.0, then to "10". At each setting, wait for the cube to reach thermal equilibrium, then repeat the measurements of step 1-7 and record your results in the appropriate table.

Part 2

Use the Infrared Sensor (or a Thermal Radiation Sensor) to examine the relative magnitudes of the radiation emitted from various objects around the room. On a separate sheet of paper, make a table summarizing your observations. Make measurements that will help you to answer the questions listed below.

Experiment 1 (Continued)

Absorption and Transmission of Thermal Radiation

- Place the sensor approximately 5 cm from the black surface of the aluminum cube and record the reading. Place a piece of window glass between the sensor and the black surface. Does window glass effectively block thermal radiation?

Data and Calculations

Power Setting 5.0
Temperature ________ °C

Table 1.1

Surface	Sensor Reading (mV)
Black	
White	
Polished	
Matte	
Cavity	

Power Setting 6.5
Temperature ________ °C

Table 1.2

Surface	Sensor Reading (mV)
Black	
White	
Polished	
Matte	
Cavity	

Power Setting 8.0
Temperature ________ °C

Table 1.3

Surface	Sensor Reading (mV)
Black	
White	
Polished	
Matte	
Cavity	

Power Setting 10.0
Temperature ________ °C

Table 1.4

Surface	Sensor Reading (mV)
Black	
White	
Polished	
Matte	
Cavity	

Experiment 2: Stefan-Boltzmann Law (low temperature)

EQUIPMENT NEEDED:

—Thermal Cavity apparatus (TD-8580)*
—Thermal Cavity base (648-01081)*
—*ScienceWorkshop*® interface(700 or 750)
—Power amplifier (CI-6552A)
—Power supply (SF-9584A)*
—DataStudio®, ver. 1.5.3 or later (CI-6870B)
—Thermistor Sensor (CI-6527)
—Infrared Sensor (CI-6628)
—Banana jack connectors (SE-9750/9751)*
—DIN connector cables, 8-pin (CI-6516)
—Multimeter (SB-9631B)*
—Thermal Radiation Sensor (TD-8553)*

*Equipment required for optional experiment setup (for users who do not have a computer, DataStudio or sensors). The banana jack connectors are required for either setup.

Introduction

When investigating the Stefan-Boltzmann Law ($R = sT^4$) for the high temperatures (approximately 1,000 to 3,000 K) attained by an incandescent filament, the ambient temperature is small enough that it can be neglected in the analysis. In this experiment, you will investigate the Stefan-Boltzmann relationship at much lower temperatures using the aluminum cube of the Thermal Cavity apparatus. At these lower temperatures, the ambient temperature cannot be ignored.

If the detector in the Infrared Sensor (or Thermal Radiation Sensor) were operating at absolute zero temperature, it would produce a voltage directly proportional to the intensity of the radiation that strikes it. However, the detector is not at absolute zero temperature, so it is also radiating thermal energy. According to the Stefan-Boltzmann law, it radiates at a rate, $R= sT^4$, where s is a constant, (5.67×10^{-8} watt/m^{2}k^4)and T is the temperature in degrees Kelvin. The voltage produced by the sensor is proportional to the radiation striking the detector minus the radiation leaving it. Mathematically, the sensor voltage is proportional to $R_{net} = R_{rad} - R_{det} = s(T^4 - T_{det}^4)$. If you are careful to shield the Infrared Sensor from the cube when measurements are not being taken, T_{det} will be close to room temperature (T_{rm}).

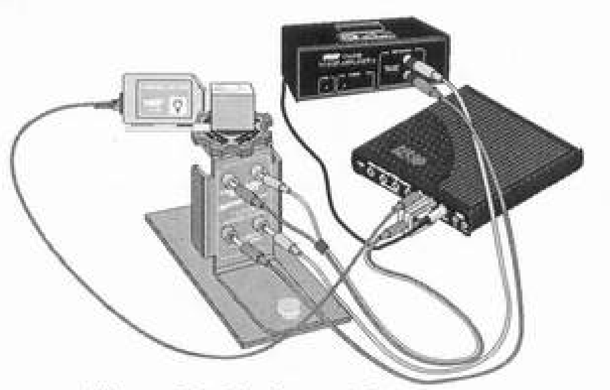

Figure 2.1: Equipment Setup

Procedure

1. Set up the equipment as shown in Figure 2.1. (For instructions, see "Experiment Setup" on page 7.)

> **OPTIONAL:** If you do not have DataStudio or a *ScienceWorkshop* interface, plug the leads from a Thermal Radiation sensor to a multimeter. Plug the black (-) lead into the "COM" port and the red (+) lead into the "V" port on the multimeter.

2. With the power supply to the Thermal Cavity off, insert the Thermal Cavity setup diskette into your computer drive. Open the file "exp2therm." Click the **Start** button to measure R_{rm}, the resistance of the thermistor at room temperature. Also note the room temperature in degrees centigrade. Enter this data in Table 2.1 on page 11.

3. If using the Infrared Sensor, set the gain on the Infrared Sensor to 10. Tare the Infrared Sensor with

Experiment 2 (Continued)

the metal shutter blocking the sensor's opening.

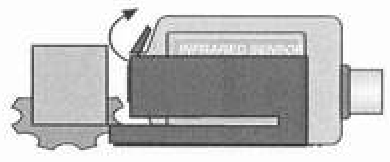

Figure 1.2

4. With the Infrared Sensor (or Thermal Radiation Sensor), take a measurement of the radiation emitted from the black surface at room temperature. To take a measurement, place the Infrared Sensor approximately 3 cm from the cube's surface (such that the metal support on the shutter is barely touching the cube) and use your index finger to press the metal shutter inward (see Figure 1.2). The hole on the shutter will align over the sensor opening.) (Note: The outside edge of the bottom plate of the shutter should rest against the side of the cube.) In Table 2.1, record the voltage reading in millivolts (mv).

   IMPORTANT: Always tare the Infrared Sensor before and between measurements. Take each reading quickly, pressing the shutter only as long as it takes to make the measurement. For consistency, before each measurement, ensure that the sensor is the same distance and position relative to the cube. Take all measurements with the shutter.

WARNING: Do not touch the cube while it is heating! Also, never place the sensor or metal shutter directly against any of the cube's surface. Touching the cube with your fingers may cause injury or burns. Metal objects contacting the cube's surfaces strip the paint coating and damage the cube on the apparatus. When paint wears off, you may not be able to obtain accurate experimental results.

5. Turn on the power amplifier (or power supply) and Signal Generator to heat the cube to about 15 degrees above room temperature. Record the cube temperature, thermistor resistance, and radiation (mv). The readings should be taken at or nearly the same instant and on the same color surface each time. If necessary, click the **Stop** button to freeze the measurement readings. Then record the measurements in Table 2.1.

6. When the temperature rises an additional 15 degrees, take another resistance, temperature and thermal radiation measurement (mv) and record in Table 2.1. Repeat these measurements at 15° intervals until you reach 100 degrees centigrade.

Experiment 2 (Continued)

Data and Calculations

Room Temperature: R_{rm} = ________ Ω

T_{rm} = ____ °C = _____ K

Table 2.1

Data			Calculations		
Resistance (ohms)	Radiation (mV)	T_c (°C)	T_k (K)	T_k^4 (K^4)	$T_k^4 - T_{rm}^4$ (K^4)

1. Using the Resistance vs. Temperature table provided, determine T_c, the temperature in degrees Centigrade corresponding to each of your thermistor resistance measurements. For each value of T_c, determine T_k, the corresponding value in degrees Kelvin (K = °C + 273). Enter both sets of values in Table 2.1. In the same manner, determine the room temperature, T_{rm}.
2. CalculateT_k^4 for each value of T_k and record the values in the table.
3. Calculate $T_k^4 - T_{rm}^4$ for each value of T_k and record your results in the table.
4. On separate sheet of paper, construct a graph of Radiation versus $T_k^4 - T_{rm}^4$. Use Radiation as the dependent variable (y-axis).

Questions

1. What does your graph indicate about the Stefan-Boltzmann law at low temperatures?

2. Is your graph a straight line? Discuss any deviations that exist.

Experiment 3: Reflection of Visible Light

EQUIPMENT REQUIRED:

—Light Sensor (CI-6504A)*
—Thermistor Sensor (CI-6527)*
—Rotary Motion Sensor (CI-6538)
—Banana Plug connectors (SE-9750/9751)*
—Power Supply* or CI-6552 Power Amplifier
—Base for the Thermal Cavity (648-01081)*
—DIN connector cables, 8-pin (CI-6516)
—Linear Translator (OS-8535)
—Optics Bench (OS-8541)
—Threaded Post
—*ScienceWorkshop®* Interface (700 or 750)*
—DataStudio, ver. 1.5.3 or later (CI-6870B)*
—Thermal Cavity apparatus (TD-8580)*

*Equipment required for optional experiment setup (for users who do not have a Linear Translator, Optics Bench or Rotary Motion Sensor). The banana plug connectors are required for either setup.

Introduction

A given object, such as an aluminum cube, can absorb, emit, and/or reflect light. The ability of any object to absorb or reflect light depends upon factors such as the chemical makeup or color of the object. Light that is not absorbed by an object is "reflected" or bounced off of its surface. The capacity of an object to absorb light relates to the capacity of an object to emit light; the more light the object absorbs, the more light the object emits, minus interferences from the surrounding environment. In this experiment, you will examine how different surface types on an aluminum cube affect the reflection of visible light.

Procedure

1. Follow the instructions for setting up the Thermal Cavity apparatus on the Optics Bench (pages 4-5 of this manual). The recommended gain setting for the light sensor is 10.

Note: Do not use the Aperture Bracket or light filters in this experiment.

2. Insert the provided Thermal Cavity setup diskette. In DataStudio, open the file "exp3therm."

3. Open the Signal Generator box to review the settings: Voltage = 8, Sample Rate = 20 Hz, DC voltage. As needed, you can change the voltage and sample rate during the experiment. (Keep within the maximum voltage and power specifications, as described on pages 5-6 of this manual.)

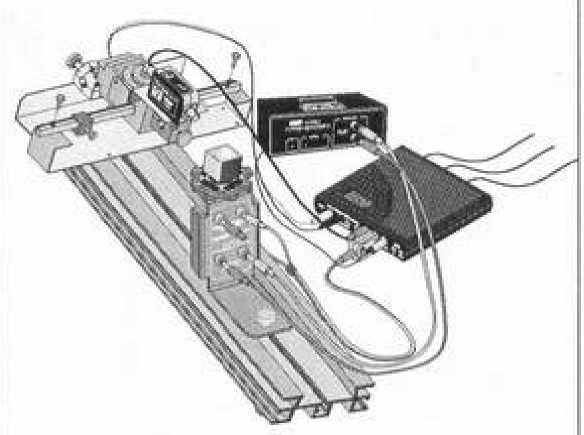

Figure 3.1: Experiment Setup

Note: You do not need to heat the aluminum cube for this experiment. The temperature of the cube does not affect the amount of reflected light.

4. Click the **Start** button. With the Rotary Motion Sensor (RMS) resting at the stop, slowly rotate the pulley on the RMS to move the sensor past the cube and back toward the stop. In DataStudio, click the **Stop** button. This constitutes one run of data collection.

Note: Use the **On** and **Off** buttons in DataStudio's Signal Generator box to toggle the voltage on or off between runs. Do not keep the Signal Generator in Auto mode.

Experiment 3 (Continued)

5. When you finish a run, turn the scalloped knob until the next surface type directly faces the sensor. Perform another run, as in step 4. Repeat step 4 for each of the cube's surfaces.

6. When you finish, save your experiment in DataStudio and record your results in Table 3.1.

7. If you have time, also measure the reflection from the cavity with the cap to the cube removed. Move the Thermal Cavity another 10-15 cm away from its position on the track. Take another set of measurements and record them in Table 3.2.

Data and Calculations

1. For each surface, enter the highest light intensity recorded in DataStudio in Table 3.1. Also record the gain setting and voltage measurement for the Light Sensor and the distance between the Thermal Cavity and the Light Sensor.

2. Save your DataStudio file. Use the **Text Tool** to label each of the surfaces on the graph. Give your experiment a title. Print your graph and put a copy in your lab notebook.

Table 3.1

gain setting=______ voltage=______
distance to light sensor=________

Surface	Light Intensity (Peak value)
Black	
White	
Polished	
Matte	
Cavity (cap on)	
Cavity (cap off)	

Table 3.2

gain setting=______voltage=______
distance to light sensor=_____

Surface	Light Intensity (Peak value)
Black	
White	
Polished	
Matte	
Cavity (cap on)	
Cavity (cap off)	

Questions:

1. Did the matte surface reflect more or less light than the cavity? Does the cavity appear to be a better absorber or reflector? Why might the cavity absorb more or less light than the matte surface?

2. Which surface reflected the most light? Why? How does the type of surface affect the amount of light reflected?

3. Is a good reflector a good absorber or emitter? Explain.

4. How might you change the experimental conditions to obtain different results?

Experiment 4: Emission of Infrared Light

EQUIPMENT REQUIRED:

—Thermal Cavity apparatus (TD-8580)
—Infrared Sensor (CI-6628)*
—Thermistor Sensor (CI-6527)*
—Banana Plug connectors (SE-9750/9751)*
—Power Supply or CI-6552A Power Amplifier*
—Base for the Thermal Cavity (648-01081)*
—Aperture Bracket (OS-8534)
—Metal shutter for the Infrared Sensor*
—Linear Translator (OS-8535)
—Optics Bench (OS-8541)
—Threaded Post
—Rotary Motion Sensor (CI-6538)
—*ScienceWorkshop*® Interface (700 or 750)*
—DataStudio, ver. 1.5.3 or later (CI-6870B)*
—Thermal Cavity apparatus (TD-8580)*
—DIN connector cables, 8-pin (CI-6516)*

*Equipment required for optional experiment setup (for users who do not have a Linear Translator, Optics Bench or Rotary Motion Sensor). The banana plug connectors are required for either setup.

Introduction

Infrared light is invisible to the human eye and lies next to visible light in the electromagnetic spectrum. A hot object emits infrared light. An established relationship between temperature and infrared light exists; we can predict the temperature or heat emitted from an object by measuring the intensity of the infrared light emitted. Sir Frederick William Herschel first discovered the presence of infrared light in 1800, using a glass prism and thermometers. He found that shining sunlight through a prism revealed a spectrum of visible and invisible colors.

The detection and measurement of infrared light requires specialized equipment, such as an infrared light sensor. The wavelength of infrared light lies between 10^3 and 10^6 nanometers (nm). The amount of infrared light emitted by an object's surface depends on several factors: the inherent properties of the surface, the color of the surface, and the temperature of the object. In this experiment, you will use a Infrared Light Sensor to measure infrared light emitted from four surfaces (black, white, matte and polished) after heating an aluminum cube to a temperature equilibrium.

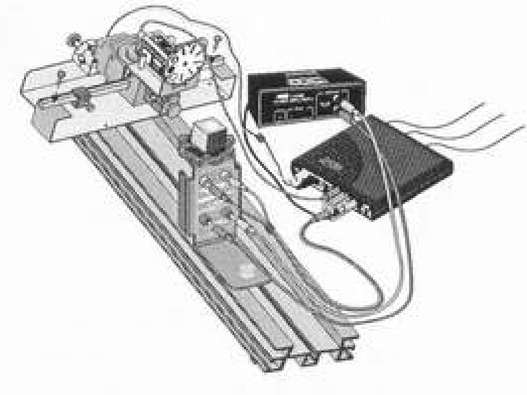

Figure 4.1: Experiment Setup

Procedure

1. Follow the instructions for setting up the Thermal Cavity apparatus on the Optics Bench (pages 6-7 of this manual). The recommended gain setting for the Infrared Sensor is 10.

OPTIONAL: If you do not have an Optics Bench, Linear Translator or Rotary Motion Sensor, follow the optional setup instructions on page 7.

Note: For the setup on the Optics Bench, the Infrared Sensor requires an Aperture Bracket instead of a metal shutter. You do not need an infrared light filter for either setup.

2. Insert the provided Thermal Cavity setup diskette. In DataStudio, open the file "exp4therm." In the Signal Generator box, review the recommended settings: voltage = 8, sample rate = 20 Hz, DC voltage. As needed, you can change the voltage or sample rate during the experiment.

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Experiment 4 (continued)

IMPORTANT: Keep within the maximum power, voltage, and temperature specifications, as described on pages 5-6 of this manual.

3. Open a Digits display. Turn on the power source from the Signal Generator box. From the Experiment menu, select Monitor Data to begin heating the aluminum cube to approximately 90 degrees centigrade. The cube takes approximately 20 minutes to heat at a voltage setting of 10 volts.

4. Turn off the room lights and reduce the lighting on your computer screen.

NOTE: This experiment must be performed in a dark room. Room lighting, from any source, will affect the accuracy of your results.

5. With the Infrared Light Sensor blocked from room light, press the **Tare button** to zero the sensor.

IMPORTANT: Always tare the Infrared Sensor before and between measurements. (Note: For the optional setup, you must use the metal shutter covering when taking a measurement. For consistency, take all measurements with the shutter and ensure that the sensor is the same distance and position relative to the cube.)

6. After the temperature reaches equilibrium (approximately 90 °C), reduce the voltage to 8 or 9 volts, and click the **Start** button. With the Rotary Motion Sensor (RMS) at the stop, rotate the pulley to move the sensor past the cube. Click the Stop button before moving back toward the stop. This constitutes one run of data collection. (Note: For the optional setup, one run is a reading from any surface.)

WARNING: To avoid burns or injury, do not touch the cube while it is heating!

7. When you finish a run, click the **Stop** button. Turn the scalloped knob until the next surface type directly faces the sensor. Perform another run, as in step 6. Perform a run for each of the cube's surfaces and then the cavity.

Note: Perform all runs at the same temperature. If the temperature falls out of equilibrium, use the **On** and **Off** buttons in DataStudio's Signal Generator box. Turn the signal off to lower the temperature and on to raise the temperature. Do not keep the Signal Generator in **Auto** mode.

8. When you finish, save your experiment in DataStudio.

Experiment 4 (continued)

Data and Calculations

1. For each surface, enter the highest light intensity (recorded in DataStudio) in Table 4.1 to 4.2. Also record the voltage for the power supply, gain setting for the Infrared Light Sensor, and temperature of the cube.

2. Save your DataStudio file. Use the **Text Tool** to label each of the surfaces on the graph. Print your graph and put a copy in your lab notebook.

Table 4.1

voltage setting=_____ gain setting=______
cube temperature=_______

Surface	Light Intensity (Peak value)
Black	
White	
Polished Aluminum	
Matte	
Cavity	

Table 4.2

voltage setting=______ gain setting=_____
cube temperature=_________

Surface	Light Intensity (Peak value)
Black	
White	
Polished Aluminum	
Matte	
Cavity	

Questions

1. How does temperature affect the amount of infrared light emitted?

2. From the data, can you tell which surface emits the most amount of infrared radiation? Why? How does the cavity compare to the matte surface in radiation emitted?

3. How could you change your experimental conditions to cause the absorption of more or less infrared light?

Teacher's Guide

Experiment 1: Introduction to Thermal Radiation

Notes on Questions

Part 1

- In order of decreasing emissivity, the surfaces are Black, White, Matte (Dull), and Polished Aluminum. This order is independent of temperature; and within the temperature range tested, the ratio of emissions between sides is almost constant. The normalized percentages are as follows: (Black is defined as 100%).

Surface	Normalized Emissions	Standard Error
Black	100	
White	96.86	±1.21%
Dull	20.23	±2.17%
Polished	7.38	±1.82%

- Measurements are consistent with the rule. The better reflectors (poorer absorbers) are poor emitters.

Notes on Questions

Part 2

- Yes. All sides of the aluminum cube are at the same temperature, but the polished side emits less than 10% as much radiation as the black side.
- Materials that block thermal radiation well include aluminum foil, styrofoam, etc. Materials that do not block radiation as well include air, clothing, etc. All materials will block radiation to some degree, but there are strong differences in how much is blocked.

Notes on Questions

Absorption and Transmission of Thermal Radiation

- Heat loss through (closed) windows is primarily conductive. Although the glass tested transmitted some infrared, most was blocked.
- A greenhouse allows light in, but does not allow much heat to escape. This phenomenon is used to grow tropical plants in cold climates.

Sample Data

Power	5.0	6.5	8.0	10
Temp. (°C)	48.6	64.2	80.3	96.6
Surface	**Sensor Reading (mV)**	**Sensor Reading (mV)**	**Sensor Reading (mV)**	**Sensor Reading (mV)**
Black	1.001 mV (20.0 %)	2.149 mV (43.0 %)	3.682 mV (73.6%)	5.630 mV (112.6%)
White	0.874 mV (17.5%)	1.636 mV (32.7%)	3.027 mV (60.5%)	5.039 mV (100.8%)
Polished	-0.044 mV (-0.9%)	0.078 mV (1.6%)	0.239 mV (4.8%)	0.381 mV (7.6%)
Matte	0.264 mV (5.3%)	0.645 mV (12.9%)	0.928 mV (18.6%)	1.641 mV (32.8%)
Cavity	0.430mV (8.6%)	1.167 mV (23.3%)	2.090 mV (41.8%)	3.218 mV (64.4%)

Teacher's Guide

Experiment 2: Stefan-Boltzmann Law (at low temperatures)

Notes on Procedure

- Make sure that the thermal cube has been off for enough time to be at equilibrium with the room before making this measurement.

Notes on Questions

- The graph should be a straight line, with some statistical variations. The linearity of this graph indicates that the Stefan-Boltzmann equation is correct, even at low temperatures.

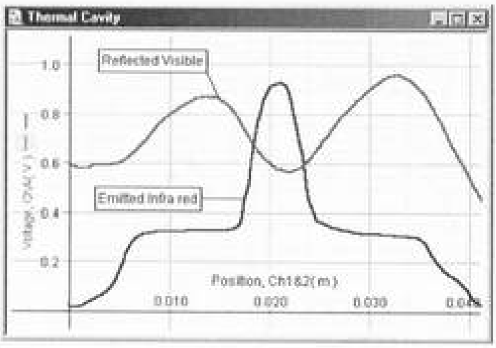
Sample Data

Temperature	Radiation	Resistance
22.7	0.020 (0.4%)	110,746
37.8	0.757 (15.1%)	57,131
52.7	1.504 (30.1%)	31,290
67.8	2.622 (52.4%)	17,754
82.6	4.922 (98.4%)	10,547

Experiment 3: Reflection of Visible Light

Data and Calculations

Sample Data: Reflected light vs. Absorbed Infrared for the Matte Surface and Thermal Cavity



Notes on Questions

1. The matte surface relected more light and absorbed less light than the cavity. The cavity is a better absorber (poor reflector) because it is a black body. By definition, a black body absorbs and emits light from all wavelengths in the electromagnetic spectrum.

2. The polished surface reflected the most light.

3. A good light absorber is a good light emitter and poor light reflector. An object must absorb light before it can emit it. Reflected light is that light which is not absorbed.

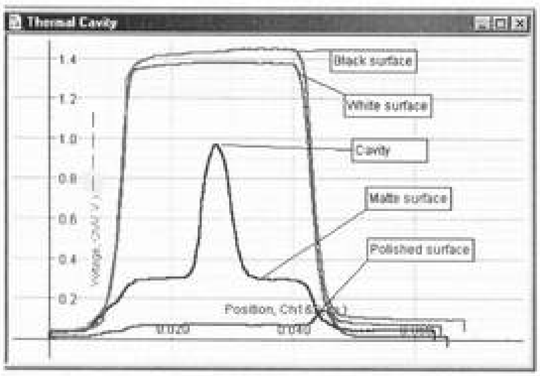
4. Changing any of the following experimental conditions could alter your measurements:
• Increasing the distance between the light sensor and the apparatus
• Changing the angle or height of the cube relative to the light sensor
• Changing the intensity of or moving the light sources present in the room.

Teacher's Guide

Experiment 4: Emission of Infrared Light

Data and Calculations

Sample Data: Emission of Infrared Light from Different Surfaces



Notes on Questions

1. The amount of light emitted depends both on the property of the surface and the temperature of the cube. As temperature increases, more thermal energy and light are emitted. Beyond a certain temperature increase, light becomes more visible and less infrared.

2. The black surface emits the most amount of infrared radiation. Black colors are good absorbers (reflect light poorly).

   The cavity is both a better absorber and emitter than the matte surface. Therefore, the cavity emits more infrared heat than the matte surface. The emission of light from the cavity is also known as "blackbody radiation." Black bodies are perfect emitters and absorb light in all regions of the electromagnetic spectrum.

3. Changing any of the following conditions would alter your experimental results:

   - Changing the slit width on the Aperture Bracket would allow less light to enter the Infrared Sensor.
   - Reducing the light on your computer screen would reduce interference from visible light and give you more accurate measurements of light in the invisible region of the spectrum.
   - Lowering the temperature of the cube would reduce the amount of heat and infrared light/radiation emitted.
   - Placing the cube at an angle relative to the aperture slit will also change the amount of infrared light entering the slit and received by the sensor.
   - Adjusting the gain on the Infrared Light Sensor would alter the resolution of your sample data, but should not change the absolute or relative amount of light intensity read by the sensor.
   - Altering the rate at which you move the pulley on the Rotary Motion Sensor back and forth across the Linear Translator may change the rate at which the light enters the sensor, but will not affect the amount of the light intensity received from a given surface.

Troubleshooting

Problem: *The thermal cube is not heating up.*

Solution(s): Chech the following: a) Ensure you have correctly inserted the banana plugs to either the power supply or the power amplifier. b) In the Signal Generator box, check that the **On** button is depressed and the signal is set for DC current. c) Check that the power supply inputs plug into the lower red jacks on the Thermal Cavity Apparatus. d) Ensure that you have correctly inserted the plugs for the Thermistor into the upper white-colored jacks on the apparatus. (The cube may be heating up, but if your Thermistor Sensor is not properly connected, the software display may not show the actual temperature.)

Problem: *The cube is taking too long to heat up.*

Solution(s): Increase the voltage on the power supply (or the power amplifier in DataStudio's Signal Generator box) up to 10 volts. Do not exceed 10 volts. If you are using a CI-6552A Power Amplifier, you may want to repeat the experiment with a separate power supply (SF-9584A.) Using the SF-9584A Power Supply, you can heat the cube to equilibrium temperature in approximately 20 minutes at a power of 9 volts. We recommend that you pre-heat the aluminum cube *before* performing the experiment.

Problem: *The infrared measurements are negative or do not appear to be accurate.*

Solution(s): a) Ensure that you tare the Infrared Sensor before the start of and between each run. b) In DataStudio, check that you are reading voltage measurements from the Infrared Sensor instead of the Thermistor Sensor. c) Ensure the Infrared Sensor is directly facing and aligned to the same height as the cube. d) Check that the DIN connector of the Infrared Sensor is correctly plugged to the *ScienceWorkshop®* interface. e) Reduce the light on your computer screen and take another measurement. Even when performing the experiment in the dark, it's possible to get some variability due to the lighting coming off of your computer screen. If you are performing a standalone measurement with the Infrared Sensor and shutter, make sure that the experimental lighting/darkness conditions are the same between surfaces. Take each measurement from the same distance and position and use the knob to rotate between surfaces, rather than moving the sensor around the cube to take surface measurements.

Problem: *Voltage and/or resistance measurements do not appear to be accurate.*

Solution(s): Check the following: a) Ensure you have properly connected the cables of the Thermal Radiation Sensor into your multimeter. Ensure that the red lead is in the "V" (voltage) slot and the black lead is inserted into the "COM" slot. b) Check your settings on the multimeter or ohmmeter. For voltage, turn the dial to the 200m mark in the "V" section. For resistance, turn the dial to the 20K mark in the resistance section. For measurement consistency, ensure that you turn the dial to same mark between surfaces. Be sure to note the reading after each measurement.

Problem: *The DataStudio® power setting appears to fluctuate (reduce over time).*

Solution(s): Check the cable connections to the Power Amplifier (as described on page 3). The cables must be connected to the power amplifier and the DIN connector to the *ScienceWorkshop* interface. Check to ensure that the voltage setting is for DC (direct current) and not AC (alternating current). If necessary, calibrate the power amplifier (See the instructions under "calibration" in the DataStudio online help.)

Additional or Replacement Parts

You can order any of the following parts from PASCO scientific. See the Technical Support section of this manual (page 24) for telephone and address information.

Description	Part/Model No.
Accessory Photogate Base	ME-9204B
Aperture Bracket	OS-8534
Banana plugs	517-010
Base for the Thermal Cavity	648-01081
DataStudio, ver. 1.5.2 or later	CI-6870B
Linear Translator	OS-8535
Light Sensor	CI-6504A
Infrared Sensor	CI-6628
Multimeter	SE-9631B
Optics Bench	OS-8541
Power Amplifier	CI-6552A
Power Supply	SF-9584A
Rotary Motion Sensor	CI-6538
Shutter for the Infrared Sensor	648-06954
Temperature vs. Resistance Chart	646-07115
Thermal Cavity	TD-8580
Thermal Radiation Sensor	TD-8553
Thermistor Sensor	CI-6527
Thumbscrew, 1/4-20 x 1/2	617-015

Notes

Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Fax: (916) 786-3292

E-mail: techsupp@pasco.com

Web: www.pasco.com

The exclamation point within an equilateral triangle is intended to alert the user of important operating and safety instructions that will help prevent damage to the equipment or injury to the user.

Note: This manual was written with the assumption that the user has a basic familiarity with DataStudio. For more information about DataStudio, see the DataStudio online help.

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

➤ If your problem is with the PASCO apparatus, note:

- Title and model number (usually listed on the label);
- Approximate age of apparatus;
- A detailed description of the problem/sequence of events (in case you can't call PASCO right away, you won't lose valuable data);
- If possible, have the apparatus within reach when calling to facilitate description of individual parts.

➤ If your problem relates to the instruction manual, note:

- Part number and revision (listed by month and year on the front cover);
- Have the manual at hand to discuss your questions.