![PASCO ®]

Heat Conduction Apparatus
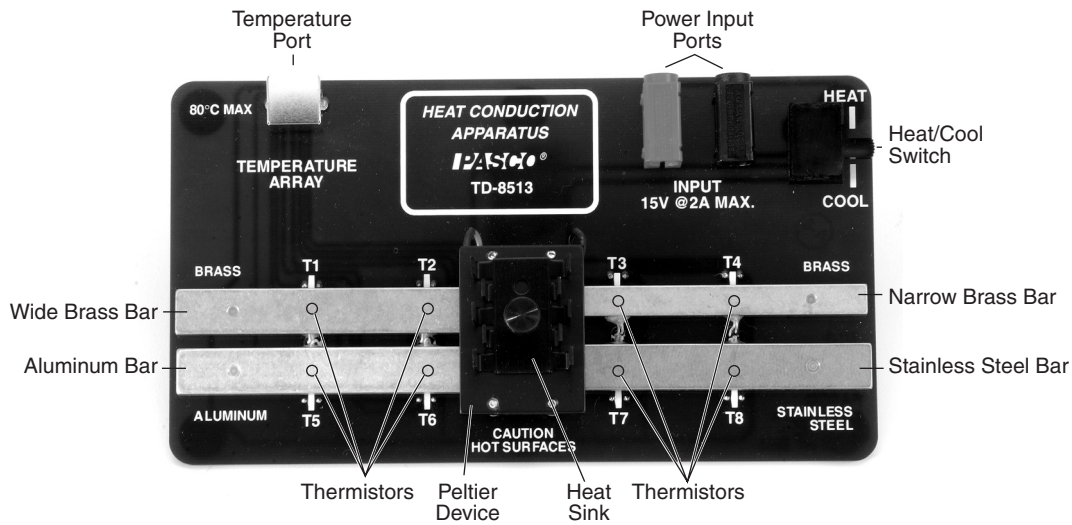
TD-8513

Contents

Heat Conduction Apparatus

TD-8513

Included Equipment	Part Number
Heat Conduction Board	TD-8513
Heat Sink	624-005
Thumbscrew	617-013
Foam Insulators (qty. 2)	648-09185
Temperature Array Cable	514-09162
Required Equipment	**Part Number**
PASPORT Temperature Array[1]	PS-2157
DC Power Supply	PI-9877[2]
4 mm Banana Patch Cords (qty. 2)	SE-9750, SE-9751, or similar

[1]Temperature Array requires a PASPORT interface; see PASCO catalog or www.pasco.com

[2]Or similar power supply capable of supplying at least 5 volts and 1 amp.

Introduction

The PASCO Heat Conduction Apparatus demonstrates the difference in the rate of heat conduction through bars of different materials and cross-sectional areas. The apparatus has four metal bars: one aluminum, one stainless steel, and two brass with different cross-sections. One end of each bar is heated or cooled by a Peltier device. Each bar has two 10 kΩ thermistors embedded about 3 cm from each other. A cable is supplied to connect the thermistors to a PASPORT Temperature Array (PS-2157) so data can be recorded from all eight sensors simultaneously. Foam insulators cover the bars to minimize heat exchange with the environment.

The embedded thermistors are labeled T1 through T8; these labels correspond to the Temperature Array channels (1 through 8) on which data is collected. The lines printed on the board indicate the lateral positions of the thermistors within the bars.

The Heat/Cool switch changes the polarity of the voltage applied to the Peltier device so that the lower surface of the device either heats or cools the bars. When the switch is set to Cool, the device pumps heat from the lower surface to the upper surface; the heat sink helps to dissipate this heat.

Connections

Use the included cable to connect the temperature port of the Heat Conduction Apparatus to the multiport of a PS-2157 Temperature Array. Connect the Temperature Array to a PASPORT interface. Connect the interface to a computer and start DataStudio.[1]

[1]If your PASPORT interface is an Xplorer GLX, you can use it without a computer or DataStudio.

Connect a PI-9877 DC Power Supply (or similar) to the power input ports of the apparatus with the positive terminal of the power supply connected to the red input port, and the negative terminal connected to the black input port. Set the voltage to zero.

Safety

⚠ The Peltier device and metal bars can be hot. Do not touch them while the apparatus is in use. When applying power to the device, always monitor the temperatures and do not allow them to exceed 80 °C. After use, do not leave the apparatus unattended until all parts have cooled.

Do not apply more than 15 V or 2 A to the apparatus.

Specifications

Aluminum, stainless steel, and wide brass bar dimensions	9 × 1.2 × 0.4 cm
Narrow brass bar dimensions	9 × 0.7 × 0.4 cm
Maximum input voltage	15 VDC
Thermistors	Eight embedded 10 kΩ thermistors

Material Properties

	Brass (360 Alloy)	Aluminum (6063-T5)	Stainless Steel (304)
Density ρ (kg/m^3)	8520	2800	8000
Specific Heat c (J/kg·K)	385	830	400
Conductivity k (W/m·K)	115	150	14

Experiment #1: Heat Conduction

Equipment Required	Model
Heat Conduction Apparatus	TD-8513
DC Power Supply	PI-9877
Temperature Array[1]	PS-2157
DC Power Supply	PI-9877
4 mm Banana Patch Cords (qty. 2)	SE-9750, SE-9751, or similar

   [1]*Temperature Array requires a PASPORT interface; see PASCO catalog or www.pasco.com*

Set-up

1. On the power supply, turn the Function switch to SET MAX and set the voltage limit to 8 V; this will prevent accidental overload during the experiment. Turn the Function switch to constant DC mode (⎓).

2. Use two banana patch cords to connect the power supply to the Heat Conduction Apparatus. Connect the positive (+) terminal of the power supply to the red input jack of the Heat Conduction Apparatus; connect the negative (−) terminal of the power supply to the black input jack of the Heat Conduction Apparatus.

3. Use the included cable to connect the temperature port of the apparatus to the multiport of the Temperature Array. Connect the Temperature Array to the PASPORT interface. Connect the interface to a computer and start DataStudio.

4. Measure the distance between the two thermistors embedded in each bar; their positions are marked by the white lines on the board.

5. Make a drawing showing the layout of the apparatus including the Peltier device, the four bars, and the thermistors. Label each thermistor with the following designations:

    T1 Wide Brass (far)
    T2 Wide Brass (close)
    T3 Narrow Brass (close)
    T4 Narrow Brass (far)
    T5 Aluminum (far)
    T6 Aluminum (close)
    T7 Stainless (close)
    T8 Stainless (far)

A. Heat Conduction Race

Set-up

1. Set the switch to HEAT and place the insulators over the bars.

2. In DataStudio, set the sampling rate of the Temperature Array to 5 Hz. Set up a graph display to show the temperatures measured by all four "far" thermistors (T1, T4, T5, and T8).

3. Collect a test run of data to make sure that all four bars are all at room temperature. Delete the data.

Procedure

1. Set the power supply to 5 V (constant DC) and simultaneously start recording in DataStudio. Watch the graph of "far" temperatures and allow them to increase for about 5 minutes. Stop recording.

2. Set the power supply voltage to zero. Remove the insulators to allow the bars to cool.[1]

Analysis

1. Look at the final temperature measured by the "far" thermistor of each bar. Which material is the best conductor? Which is the worst? Is there a difference between the two brass bars?

> [1]To cool the bars faster, you can set the switch to COOL and apply 5 volts for a few minutes; then wait a few more minutes with the apparatus un-powered for the bars to come to equilibrium.

2. Create a graph showing data from both thermistors in the wide brass bar (T1 and T2). Zoom in on the area of the graph where the temperatures start to increase. Notice that the temperature at the close thermistor (T2) starts to increase before the temperature at the far thermistor (T1). Measure this time difference.

3. Calculate the speed of the heat pulse down the brass bar. At this speed, how long would it take for the pulse to travel the length of the bar?

4. In DataStudio, create a calculation for the temperature difference (ΔT) between the close and far thermistors in the wide brass bar. Create similar calculations for the other three bars (be sure to subtract the "far" temperature from the "close" temperature). Display all four calculations in a graph.

   Which bar has the largest ΔT? Which bar has the smallest? What is the correlation between ΔT and how good a conductor each material is?
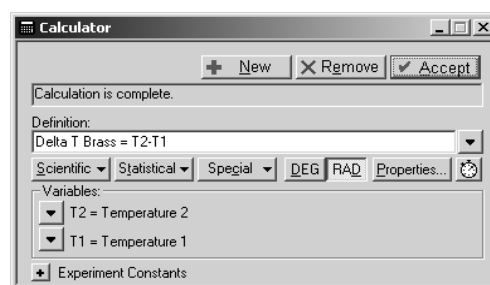
5. Why does ΔT peak and then decrease? Why does this peak occur at different times for the four bars?

6. Notice that ΔT in each bar approaches a final equilibrium value. Estimate this final value for each bar.

7. The rate of heat flow ($\Delta Q/\Delta t$, in joules per second) is given by

$$\frac{\Delta Q}{\Delta t} = \frac{kA\Delta T}{x}$$

   where k is the thermal conductivity of the material, A is the cross-sectional area of the bar, and x is the distance between the thermistors.

   See page 4 for the conductivities of brass, aluminum, and stainless steel. Measure the dimensions of the bars. Calculate the final heat flow rate in each bar.

8. Which bar has the highest heat flow rate? Is there a correlation between ΔT and heat flow rate? Why is the heat flow lower in the narrow brass bar than in the wide one?

Further Study

Repeat the previous experiment with the switch set to COOL. Which direction does heat flow in this case?

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B. Heat Pulse

Set-up

1. Set the switch to HEAT and place the insulators over the bars.

2. In DataStudio, set the sampling rate of the Temperature Array to 2 Hz. Set up a graph display to show the temperatures measured by both thermistors in the wide brass bar (T1 and T2).

3. Collect a test run of data to make sure that all four bars are all at room temperature. Delete the data.

Procedure

1. Set the power supply to 5 volts (constant DC) and start recording in DataStudio. Wait until the "close" temperature (measured by T2) reaches about 40 °C. [2]

2. Change the switch to the COOL position and start timing with a clock or stopwatch. Change the switch every 30 seconds. In this way the end of the bar is alternately heated and cooled with a period of 60 s.

3. Continue for several minutes until the temperature wave at each thermistor has stabilized with a constant amplitude.

4. Stop data recording and set the power supply to 0 V. [3]

Analysis

1. Observe the shape of the two waves (it helps to zoom in on the last few cycles). What is the shape of the wave that you applied to the bar by switching between heating and cooling? What is the shape of this wave when it reaches the close thermistor (T2)? How has it changed when it reaches the far thermistor (T1)?

2. Notice that there is a time lag between the two waves. What causes this? Measure the time lag. How is the time lag related to the distance between the thermistors?

3. Why is there an amplitude change between the two waves? Are these really two different waves?

4. Create a new graph showing data collected by the thermistors in the aluminum bar (T5 and T6). Repeat analysis steps 1 through 3 for the aluminum bar.

5. Compare the shape of the waves in the aluminum and brass bars. Why are they different? Compare the amplitude of the waves. Which material is the better conductor?

6. Compare the time lags in the aluminum and brass bars? What does this tell you about the speed of the pulse in each bar?
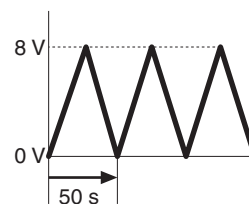
C. Heat Waves

Theory

In this part, the power supply will apply a triangle wave voltage to the Peltier device. This heating and cooling of one end of each bar causes a thermal wave to travel down the bar. The wave on each bar is measured by two thermistors. You will investigate the relationship between wave speed, period, and wavelength.

[2]You can decrease the wait time by applying a higher voltage (8 V), but reduce the voltage back to 5 V before the temperature reaches 40°C.

[3]If you are going to do part C of this lab, set the power supply now. This will allow the system to come to equilibrium while you perform the following analysis. See the Set-up section for part C below.

Set-up

1. Set the switch to COOL.

2. Place the insulators on the bars.

3. Set the power supply to output an 8 V positive triangle wave with a 50 s period, as shown in the diagram. See the PI-9877 DC Power Supply manual for detailed instructions.

4. In DataStudio, set the sampling rate to 2 Hz. Create a graph to show data collected by both thermistors in the wide brass bar (T1 and T2).

5. Start recording data. Wait for several minutes until the thermal wave at each thermistor has stabilized with a constant amplitude. Stop recording data and delete the data run.

Procedure

Start recording data again. After two full cycles, stop recording.[4]

Analysis

1. Measure the time lag between the wave measured by the "close" and "far" thermistors.

2. Calculate the speed (v) of the wave using the distance between the thermistors and the time lag between the waves.

3. Calculate the frequency (f) of the wave in Hz.

4. The speed of any wave is related to its frequency and wavelength (λ) by

$$v = \lambda f$$

Calculate the wavelength of this wave. How does λ compare to the length of the entire bar?

5. Create another graph showing temperatures measured in the aluminum bar. Repeat analysis steps 1 through 4. Do the same for the narrow brass bar and the stainless steel bar.

Questions

1. Is the wave speed different in each material? Which has the highest speed? How is the wave speed related to the conductivity of the material?

2. Notice the decrease in amplitude (attenuation) of the wave measured at the far thermistor compared to the close thermistor. How is this related to the material and the conductivity? Which material has the most attenuation.

Further Study

Repeat the experiment for a wave with a period of 100 Hz. How are the wave speed, wavelength, and attenuation affected by the frequency of the wave?

Power Supply Settings:

Max. Voltage	8 V
Min. Voltage	0 V
Period	50 s
Auto-repeat	−0

[4]If you are going to do the Further Study part of this section, change the period of the triangle wave to 100 s now and allow the system stabilize while you do the following analysis.

Experiment #2: Angstrom's Method

Equipment Required	Model
Heat Conduction Apparatus	TD-8513
DC Power Supply	PI-9877
Temperature Array[1]	PS-2157
DC Power Supply	PI-9877
4 mm Banana Patch Cords (qty. 2)	SE-9750, SE-9751, or similar

[1]*Temperature Array requires a PASPORT interface; see PASCO catalog or www.pasco.com*

Set up

1. On the power supply, turn the Function switch to SET MAX and set the voltage limit to 8 V; this will prevent accidental overload during the experiment. Turn the Function switch to constant DC mode (‾‾‾‾).

2. Use two banana patch cords to connect the power supply to the Heat Conduction Apparatus. Connect the positive (+) terminal of the power supply to the red input jack of the Heat Conduction Apparatus; connect the negative (−) terminal of the power supply to the black input jack of the Heat Conduction Apparatus.

3. On the Heat Conduction Apparatus set the switch to COOL.

4. Use the included cable to connect the temperature port of the apparatus to the multiport of the Temperature Array. Connect the Temperature Array to the PASPORT interface. Connect the interface to a computer and start DataStudio.

5. Measure the distance between the two thermistors embedded in each bar; their positions are marked by the white lines on the board.

6. Make a drawing showing the layout of the apparatus including the Peltier device, the four bars, and the thermistors. Label each thermistor with the following designations:

   T1 Wide Brass (far)
   T2 Wide Brass (close)
   T3 Narrow Brass (close)
   T4 Narrow Brass (far)
   T5 Aluminum (far)
   T6 Aluminum (close)
   T7 Stainless (close)
   T8 Stainless (far)

Theory

In this experiment, you will measure the thermal conductivity of the metal bars using Angstrom's method. A periodic wave travels down the bar and the resulting temperature wave is measured at two points using thermistors. The thermal **diffusivity**, α, can determined by measuring the **amplitude** of the temperature wave at the close thermistor (A_c) and the amplitude at the far thermistor (A_f) as well as the relative **phase** (ϕ) between these two waves.

According to Angstrom's method

$$\alpha = \frac{n\omega(\Delta x)^2}{2\phi \ln\left(\frac{A_c}{A_f}\right)}$$

where n is the harmonic, ω is the driving frequency, and Δx is the distance between the thermistors.

In this experiment, the driving frequency is very small so it is easier to consider the **period** (T) of the wave, where

$$\omega = \frac{2\pi}{T}$$

The time delay (Δt) between the two waves is measured directly. The relative phase, (ϕ), is calculated using

$$\phi = 2\pi\frac{\Delta t}{T_n}$$

where T_n is the period of the *harmonic*. Thus

$$T_n = \frac{T}{n}$$

Combining these four equations yields

$$\alpha = \frac{\Delta x^2}{2\Delta t \ln\left(\frac{A_c}{A_f}\right)}$$

Note that α is independent of the harmonic (n) and of the driving frequency (ω).

A more commonly used quantity that is related to the thermal diffusivity, but includes the **specific heat** (c) and **density** (ρ) of the material, is the **thermal conductivity** (k).

$$k = c\rho\alpha$$

This gives the final expression:

$$k = \frac{c\rho\alpha(\Delta x)^2}{2\Delta t \ln\left(\frac{A_c}{A_f}\right)}$$

A. Aluminum

Set-up

1. In DataStudio set the sampling rate of the Temperature Array to 2 Hz. Create a graph to display temperatures measured by both thermistors in the aluminum bar (T5 and T6).

2. Set the power supply to output an 8 V positive triangle wave with a 30 s period, as shown in the diagram. See the PI-9877 DC Power Supply manual for detailed instructions.
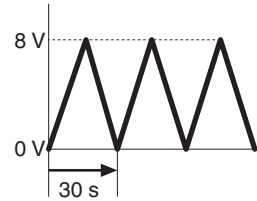
Procedure

1. Start recording data. While driving the apparatus with the triangle wave, monitor the temperature waves until each has stabilized with constant amplitude. Stop recording and delete the data run. (Let the power supply continue to run.)

2. Start recording data. After two complete cycles of the driving wave, stop recording.

3. On the graph, measure the amplitudes of both waves (A_c and A_f) and the time difference between corresponding peaks of the two waves (Δt). Make a copy of the table below and record these measurements in it.

Power Supply Settings:

Max. Voltage	8 V
Min. Voltage	0 V
Period	30 s
Auto-repeat	−0

Period (s)	A_c	A_f	Δt	k (W/m·K)	Average k (W/m·K)
30					
40					
50					
			Average		

4. Repeat steps 2 and 3 for a total of three data runs and record all values in your table.

5. On the power supply, set the period of the triangle wave to 40 s and repeat steps 1 through 4.

You can start the following analysis while you wait for the system to stabilize.

6. Set the period of the wave to 50 s and repeat steps 1 through 4 again.

Analysis

1. For each of the data runs recorded with a 30-second triangle wave, calculate the thermal conductivity (k). What is the average value of k? What is the uncertainty of the average?

2. Repeat the calculations for the data runs taken with 40-second and 50-second tri-
    angle waves.

Save the three data runs recorded with 50-second triangle wave for the next part.

3. Does k appear to depend on the period of the wave?

4. Calculate the average k (including uncertainty) for all data runs and compare
    your answer to the accepted value of k for aluminum.

B. Brass

Record two more data runs with a 50-second triangle wave so that you have a total of
five. Repeat the analysis from part A for the wide brass bar and narrow brass bar sep-
erately. Does the bar's cross-sectional area appear to affect the value of k?

C. Stainless Steel

Record five data runs with a 100-second triangle wave. Repeat the analysis for the
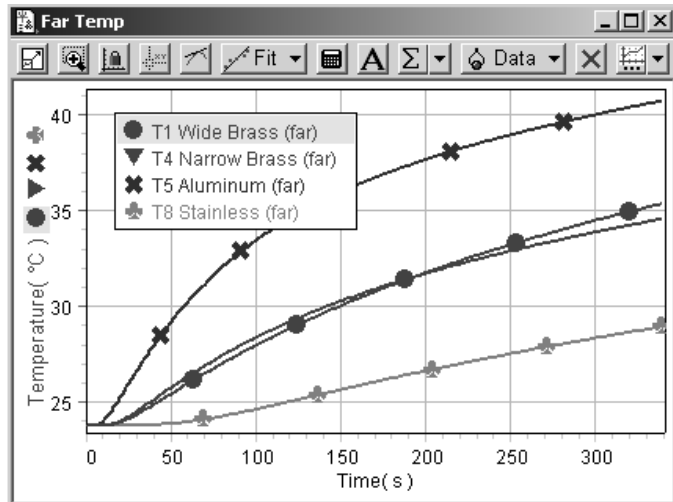stainless steel bar.

Compare the thermal conductivities of the three materials that you tested.

Sample Data

Experiment #1: Heat Conduction

A. Heat Conduction Race

Temperatures measured by the "far" thermistors show the aluminum bar to be the best conductor and stainless steel the worst. Notice the cross-over point for the two brass bars (two central traces).


A close-up of the wave measured at two points in the wide brass bar shows the pulse arriving at the "close" thermistor 5.2 s before the "far" thermistor. The distance between the thermistors is 30 mm. The pulse speed is
30 mm / 5.2 s = 5.8 mm/s
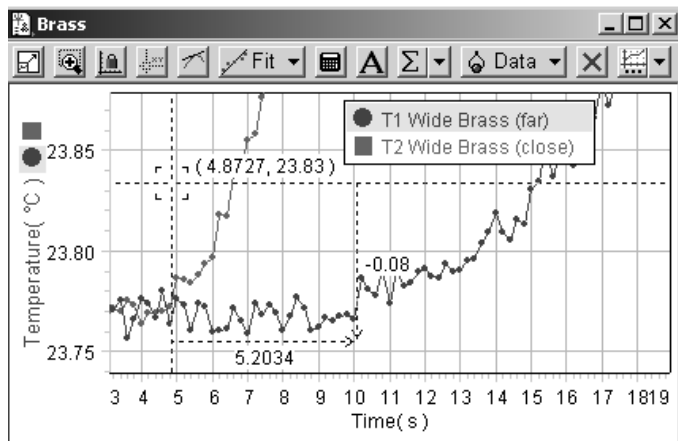
The temperature differences between the thermistors in each bar show that aluminum (with the smallest ΔT) is the best conductor and stainless steel (with the largest ΔT) is the worst.

The peak occurs because the leading edge of the heat pulse arrives at the "close" thermistor before the "far" thermistor. These peaks occur at different times because the pulses in different bars travel at different speeds.
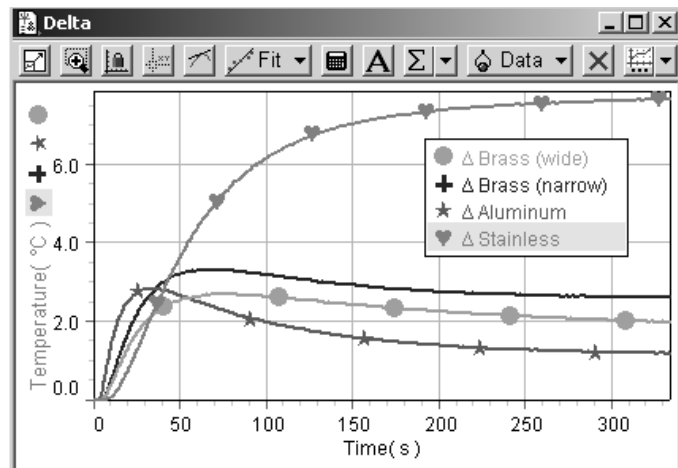
For these sample data, the heat flow rates are:

|	
Wide Brass	0.36 J/s
Narrow Brass	0.28 J/s
Aluminum	0.28 J/s
Stainless Steel	0.17 J/s

The wide brass bar has a higher heat flow rate than the narrow brass bar. The data also show that ΔT in different materials is not directly related to heat flow rate.

B. Heat Pulse

This graph shows the temperatures increasing (with the switch set to HEAT) before the switch starts alternating. The apparatus is driven with a square wave. At the first close thermistor (upper trace on the graph) the wave resembles a triangle wave; at the far thermistor is looks more like a sine wave.
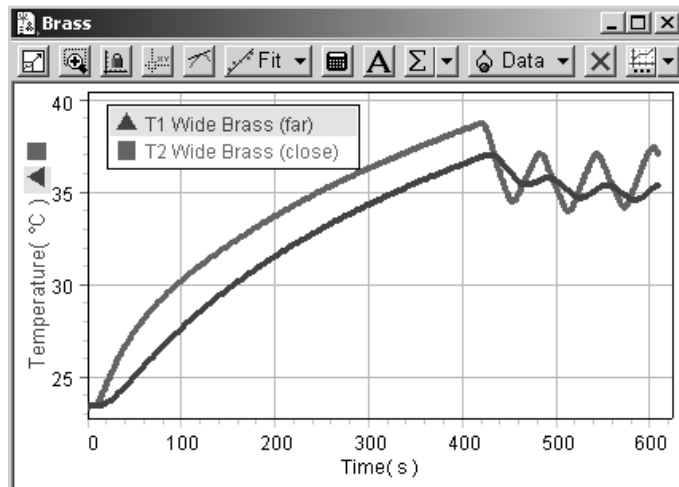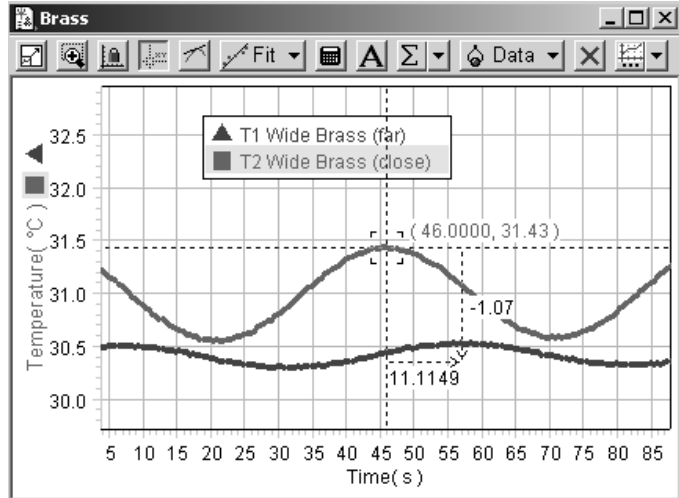

The wave at the far thermistor lags the near thermistor by 10.5 s. The wave speed is 30 mm/10.5 s = 2.9 mm/s.
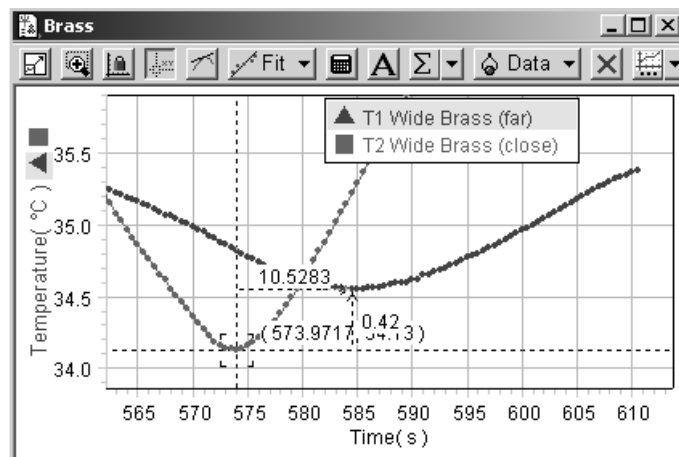
C. Heat Waves

In this graph the far thermistor lags the near thermistor by 11.1 s. The wave speed is 30 mm/11.1 s = 2.7 mm/s.

The wavelength is 140 mm, about twice the length of the bar.

Experiment #2: Angstrom's Method

A. Aluminum

Period (s)	A_c	A_f	Δt	k (W/m·K)	Average k (W/m·K)
	0.671	0.206	5.38	165	
30	0.673	0.214	5.22	174	172
	0.673	0.219	5.28	176	
	0.912	0.341	6.21	171	
40	0.909	0.339	6.28	169	166
	0.903	0.330	6.51	159	
	1.09	0.449	7.5	157	
50	1.09	0.441	7.6	152	160
	1.12	0.471	7.05	171	
				Average	165

B. Brass

Wide brass bar:

Period (s)	A_c	A_f	Δt	k (W/m·K)	Average k (W/m·K)
	0.430	0.110	10.2	106	
	0.452	0.121	9.7	115	
50	0.426	0.108	11.1	97	107
	0.429	0.118	11.1	103	
	0.440	0.123	10.3	112	

Narrow brass bar:

Period (s)	A_c	A_f	Δt	k (W/m·K)	Average k (W/m·K)
50	0.578	0.142	10.2	103	102
	0.599	0.150	9.9	108	
	0.571	0.142	10.8	98	
	0.577	0.147	10.8	100	
	0.589	0.151	10.5	103	

C. Stainless Steel

Period (s)	A_c	A_f	Δt	k (W/m·K)	Average k (W/m·K)
100	0.800	0.051	37.5	14	13
	0.792	0.060	37.1	15	
	0.796	0.042	45.0	11	
	0.778	0.048	41.1	13	
	0.815	0.044	44.3	11	

Technical Support

For assistance with any PASCO product, contact PASCO at:

Address: PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100

Phone: 916-786-3800 (worldwide)
800-772-8700 (U.S.)

Fax: (916) 786-3292

Web: www.pasco.com

Email: support@pasco.com

Limited Warranty
For a description of the product warranty, see the PASCO catalog.

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