

Lab Guide

Microscopic Heat

I. Objectives

After completing this simulation, the student will be able to:

1. Describe temperature in terms of kinetic energy of particles
2. Describe change in temperature as a result of transfer of kinetic energy
3. Describe thermal equilibrium
4. Describe the general shape of the Boltzmann distribution at low, medium and high temperatures

II. User Interface and Simulation Features

This simulation uses two groups of particles in an enclosed box. The particles are intended to represent free atoms or molecules. The initial velocities, and hence kinetic energies, for each of the two groups can be set from zero to an arbitrary value of 5. The default value for the left group of particles is a velocity of 2 and for the right group is a velocity of 4. The particles collide elastically with each other and with the walls of the box. The left wall of the box can remain an insulator, or can be changed to a hot wall or a cold wall by means of the selection box in the upper left corner of the screen. The energy of the system of particles inside the box remains constant unless you provide a means of adding or removing energy by selecting a hot wall or cold wall, respectively. The hot wall is constructed of molecules with a constant velocity of 7. The cold wall is constructed of particles with a constant velocity of 1.5. The particles change color as they gain or lose kinetic energy. A color key at the lower left indicates the relationship between color and temperature. A bar graph at the bottom of the screen indicates the total energy of the system of particles. A histogram at the left of the screen indicates the number of particles of each color, and hence temperature. Some of the following questions require the system to reach a dynamic equilibrium. This may take several minutes, depending on what you are trying to do. For some questions, the Date/Time window on your computer, or a timer or stopwatch will be helpful in order to make meaningful comparisons.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Set the initial velocities of both groups of particles to 3. Run the simulation, watching the shape of the histogram on the left. How does the shape of the histogram change over time? The shape of the histogram changes constantly, but is there a time after which there is no significant change in the shape of the histogram over 15 to 20 seconds? If so, about how long does it take to reach this point?
2. Repeat Item 1, but set the initial velocities of the particles to 5. Does the time to reach equilibrium depend on the initial velocity?

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3. Set the initial velocities of both groups of particles to 2. Observe the colors of the particles. Note the total energy of the system on the bar at the bottom. Run the simulation. Carefully watch the histogram at the left. After the system has reached equilibrium observe the color of the bars showing the greatest number of particles (near the center). Compare this color to their original color. What do you find? What is the energy of the system now? Did the energy change?

4. Repeat Item 1, but set the initial velocities of both groups of particles to 5 instead. Do your results depend on the initial velocity?

5. Set the initial velocity of one group of particles to 1 and the other to 5. Run the simulation. Let the simulation run until equilibrium is reached. Watch the histogram at the left. Compare and contrast what you observed with the results you obtained in Items 3 and 4.

b. Intermediate Level

6. Set the initial velocities of both groups of particles to zero. Run the simulation. What do you observe? What temperature does this simulate?

7. Set the initial velocities of both groups of particles to 1. Select the left wall to be hot. Run the simulation. Watch the value for the energy of the system on the graph. During the first two minutes, what do you observe? Let the simulation continue to run for several more minutes. Now what do you observe? Is there a limit to the amount of energy in the system?

8. Set the initial velocities of both groups of particles to 5. Select the left wall to be cold. Run the simulation. Watch the value for the energy of the system on the graph. During the first two minutes, what do you observe? Let the simulation continue to run for several more minutes. Now what do you observe? Why do the particles never completely stop?

9. Set the initial velocities of both groups of particles to 5. Select the left wall to be hot. Run the simulation. Watch the value for the energy of the system on the graph. Does the system reach equilibrium? If so, why? Compare the final energy of the system to that from Item 7

c. Advanced Level

10. Set the initial velocity of the left group of particles to zero and that of the right group of particles to 5. Set the left wall to cold. Run the simulation. Carefully watch the distribution histogram at the left. How does the shape of the distribution change with time?

11. Set the initial velocity of the left group of particles to zero and that of the right group of particles to 5. Set the left wall to cold. Run the simulation five times. In each instance, count the number of seconds that pass before every particle is in motion. Find the average time this takes. Is there a large range to these values compared to the average? Now reverse the velocities. Run the simulation five more times. Find the average time and range again. Is there a significant difference? Why or why not?

Lab Guide Calorimetry

I. Objectives

After completing this simulation, the student will be able to:

1. Compare the order of specific heat values of different substances
2. Calculate the specific heat of a substance from simulated data
3. Qualitatively describe the heat transfer between objects of different temperatures
4. Demonstrate thermal equilibrium
5. Qualitatively describe heat transfer during a change of state.

II. User Interface and Simulation Features

This simulation consists of a thermally insulated vessel (a calorimeter) containing water and a thermometer. You can vary the mass and initial temperature of the water. The simulation provides pellets of warm metal, consisting of aluminum, silver and gold. Each pellet has a mass of 200 g. You can vary the temperature of the pellets of each metal individually. There are also ice cubes, each with a mass of 50 g. You can vary the temperature of the ice cubes from the freezing point to $-100\text{ }^{\circ}\text{C}$. Temperatures are controlled by slider bars. You may place any combination of the metal pellets and ice cubes in the vessel at one time by dragging them into the vessel with your mouse. The simulation models the temperature changes of the metals and the water in the vessel. It also models the change in state of the ice cubes, should this occur during the simulation.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Accept the default values. Drag five of the gold pellets into the water. Run the simulation. Are both the water and the gold at the same final temperature? What is the final temperature?
2. Drag five of the aluminum pellets into the water. Set the temperature of the pellets to $90\text{ }^{\circ}\text{C}$. Run the simulation. What is the final temperature? Which of the metals had the greater amount of heat energy, the gold or the aluminum?
3. Drag five of the silver pellets into the water. Set the temperature of the pellets to $90\text{ }^{\circ}\text{C}$. Run the simulation. What is the final temperature? Which of the metals had the greater amount of heat energy, silver or aluminum? List the metals in order of increasing specific heat capacity.
4. You have used the same mass of metal pellets as water in the calorimeter. Look at the slopes of the temperature changes for these substances on the graphs. Which substance has a greater specific heat capacity, any of the metals, or the water? How can you tell this?

Exploration of Physics: Simulation Library Vol. I**b. Intermediate Level**

5. Consider Item 1. Water has a specific heat of $4.184 \frac{\text{kJ}}{\text{kg}\cdot^{\circ}\text{C}} = 4184 \frac{\text{J}}{\text{kg}\cdot^{\circ}\text{C}}$. What mass of water did you use? What was its temperature change? Using the theoretical formulas, how much energy did the water absorb when going from its initial temperature to its final temperature? Where did this energy come from? What was the temperature change for the gold pellets? What was their total mass? Calculate the specific heat capacity of gold.
6. Consider Item 2. Use the value of $4.184 \frac{\text{kJ}}{\text{kg}\cdot^{\circ}\text{C}}$ for the specific heat of water. What mass of water did you use? What was its temperature change? Using the theoretical formulas, how much energy did the water absorb when going from its initial temperature to its final temperature? Where did this energy come from? What was the temperature change for the aluminum pellets? What was their total mass? Calculate the specific heat capacity of aluminum.
7. Consider Item 2. Use the value of $4.184 \frac{\text{kJ}}{\text{kg}\cdot^{\circ}\text{C}}$ for the specific heat of water. What mass of water did you use? What was its temperature change? Using the theoretical formulas, how much energy did the water absorb when going from its initial temperature to its final temperature? Where did this energy come from? What was the temperature change for the silver pellets? What was their total mass? Calculate the specific heat capacity of silver.
8. Compare the values for the specific heat capacities of the three metals with an authoritative source such as the Handbook of Chemistry and Physics. Is there a difference between your values and the published values?

c. Advanced Level

9. Set the temperature of the aluminum pellets to 90°C . Drag five of the aluminum pellets into the water. Drag one ice cube at 0°C into the water. Run the simulation. What happens to the ice cube? What happens to the energy lost by the aluminum pellets?
10. Set the temperature of the ice cubes to -50°C . Drag one ice cube and all the gold pellets into the water. Run the simulation. What happens to the ice cubes? Observe the slopes of the temperature changes. Is the specific heat capacity for solid ice different than that of liquid water? How can you tell?
11. Can you make the water in the calorimeter freeze? How will you know that you have been successful in doing this? What input variables did you use to make this happen? If you were making heat energy measurements using a calorimeter, would you want the water to freeze? Explain your answer.

Lab Guide Gas Flow

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the random motion of gas molecules
2. Describe diffusion of molecules
3. Describe the effect of tube width on time to equilibrium
4. Describe the effect of initial velocity on time to equilibrium
5. Describe the release of gas molecules in terms of entropy

II. User Interface and Simulation Features

This simulation demonstrates the diffusion of gas molecules from one end of a large tube to the other. Between the two ends is a constriction. You can vary the width of the constriction and the initial velocity of the molecules. The molecules all have the same initial velocity but random initial directions. They collide with the walls of the tube, but do not interact with each other.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Run the simulation. Pick one molecule to watch. Does it change direction when it appears to strike other molecules? Does it change direction when it strikes the walls of the tube? Describe how it bounces off the wall.
2. What two factors govern the rate at which particles travel from one side to the other, that is, particles per unit time?
3. Run the simulation. Allow it to run for 150 s. How long did it take to reach the point where there were about 20 particles on each side? After it reached that point, was there variation in the numbers of particle on each side? What was the highest number? What was the lowest number?
4. Set the initial velocity to 4.0 m/s. Run the simulation for about 150 s. How long did it take to reach the point where there were about 20 particles on each side? After it reached that point, was there variation in the numbers of particle on each side? What was the highest number? What was the lowest number?
5. Set the initial velocity to 1.0 m/s. Run the simulation for about 150 s. How long did it take to reach the point where there were about 20 particles on each side? After it reached that point,

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was there variation in the numbers of particle on each side? What was the highest number? What was the lowest number?

b. Intermediate Level

6. Set the tube width to 10.0. Run the simulation for about 150 s . How long did it take to reach the point where there were about 20 particles on each side? After it reached that point, was there variation in the numbers of particle on each side? What was the highest number? What was the lowest number? Did the variation seem to be periodic?

7. Set the tube width to 3.0. Run the simulation for about 150 s . How long did it take to reach the point where there were about 20 particles on each side? After it reached that point, was there variation in the numbers of particle on each side? What was the highest number? What was the lowest number? Did the variation seem to be periodic?

8. Set the tube width to 1.0. Run the simulation for about 150 s . How long did it take to reach the point where there were about 20 particles on each side? After it reached that point, was there variation in the numbers of particle on each side? What was the highest number? What was the lowest number? Did the variation seem to be periodic?

c. Advanced Level

9. Did initial velocity or tube width have the greatest effect on equalizing the number of particles on each side, or did they have about the same effect?

10. Did reducing initial velocity or tube width have a greater effect on smoothing the graph (reducing periodicity) of the number of particles on each side?

11. Physical systems tend to change spontaneously toward greater disorder. The quantity known as entropy is a direct measure of the disorder of the system. Before you start the simulation, is it in a state of higher or lower entropy? After the system comes to equilibrium, has the entropy increased or decreased? Would entropy have to increase or decrease for all the particles to be on the left side of the tube once they had come to equilibrium? Is there a high or low probability of this happening spontaneously?

Lab Guide

Thermal Conduction

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the effect of temperature difference on heat flow
2. Describe the effect of area on heat flow
3. Describe the effect of changing the coefficient of thermal conductivity on heat flow
4. Apply heat flow concepts to practical situations

II. User Interface and Simulation Features

This simulation gives you a heat reservoir (a continuous supply of heat energy) and a cold reservoir. A cylinder of a heat conductor connects the two reservoirs. The moving red arrows represent heat energy flowing from hot to cold. You can change the temperatures of the two reservoirs. You can change the area of the heat conductor. You can change the coefficient of thermal conductivity, the k -value. A histogram at the right side of the screen shows these four variables plus heat flow in watts. There is also a digital display of heat flow at the lower right of the screen.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Observe the simulation. Notice the heat flowing from the heat reservoir to the cold reservoir. Set both the temperatures of the two reservoirs to $50\text{ }^{\circ}\text{C}$. What is the difference in temperature? Does any heat flow?
2. What is the temperature of the heat reservoir? What is the temperature of the cold reservoir? What is the temperature difference between them? What is the rate of heat flow? Now set the heat reservoir temperature to $50\text{ }^{\circ}\text{C}$. What is the rate of heat flow now? How does heat flow vary with temperature difference?
3. What is the rate of heat flow? What is the temperature difference between the heat and cold reservoirs? Now decrease the cold reservoir to $-50\text{ }^{\circ}\text{C}$ and the hot reservoir to $+50\text{ }^{\circ}\text{C}$. What is the temperature difference now? What is the rate of heat flow? Does the heat flow depend on the temperature difference or the absolute temperature?
4. What is the area of the cylindrical connector? What is the rate of heat flow? Set the area to 1 cm^2 . What is the ratio of the new area to the old area? What is the rate of heat flow with the smaller area? What is the ratio of the new heat flow to the old heat flow? How does heat flow vary with conductor area?

5. What is the rate of heat flow? What is the value of the k -value? Increase it to $100 \text{ W/m}\cdot\text{K}$. What is the new heat flow? How does heat flow vary with k -value?

b. Intermediate Level

6. Suppose you owned a fertilizer manufacturing plant. If you wanted to minimize heat flow from the air to a large tank of liquid ammonia fertilizer, would you choose a tank covering with a large k -value or a small k -value?

7. Using the theoretical equation $I = kA \Delta T / \Delta x$ where I is heat flow and Δx is the length of the heat conductor, calculate the length of the conductor under default settings..

c. Advanced Level

8. In commercial and industrial systems, pipes carrying hot fluids such as steam are covered with cylindrical insulation, coaxial with the pipe. There is a radius of insulation that minimizes heat flow from the heat reservoir (the pipe) to the cold reservoir (the air). If a greater radius of insulation is applied to the pipe, heat flow actually increases. Why is this so?

Lab Guide

First Law of Thermodynamics

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the relationship between mechanical energy and heat energy
2. Describe the variables that control gravitational potential energy
3. Describe the effect of the absorption of kinetic energy on temperature.
4. Calculate the specific heat capacity of water from simulated laboratory data

II. User Interface and Simulation Features

This simulation shows an apparatus that converts gravitational potential energy to rotational kinetic energy and thence to heat energy. It consists of a mass attached to a string. The string runs over a pulley to change its direction, and is wrapped around a wheel. The wheel is fixed to a paddle which turns within a thermally insulated container. The container holds water. The mass, the length of the string and acceleration due to gravity can be varied. The mass of water and the initial temperature of the water can be varied. In this simulation, the paddle stirs the water. The paddle is always submerged in the water, no matter how little water is selected. The paddle turns at a constant rate because of its friction with the water molecules. The ranges of values for the variables are limited so that the water is always in the liquid state. A line graph at the upper left of the screen shows the height of the mass and the temperature of the water as the simulation progresses. A digital display at the upper right of the screen shows the instantaneous values for height and temperature.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Accept the default values for the variables and run the simulation. Record the initial and final values for the temperature of the water. What is the change in temperature, ΔT ?
2. Increase the mass to 10 kg. Run the simulation again. Compare ΔT of the water to the ΔT that you observed in Item 1.
3. Set the mass to 10 kg and the height to 400 m. Run the simulation and compare ΔT to the ΔT that you observed in Item 2.
4. Set the mass of the water to 2.0 kg. Run the simulation. Compare the ΔT to the ΔT you observed in Item 1. Is it larger or smaller? Why?

b. Intermediate Level

5. Suppose you are conducting this experiment on a dense planet where $g = 20 \text{ m/s}^2$. Set g to this value and run the simulation. What do you observe about ΔT compared to Item 1? Where did the extra energy originally come from?
6. What is the maximum increase in temperature you can produce with this apparatus? What values will you set for each variable?
7. Set the hanging mass to 10 kg, height to 1000 m and the mass of water to 5 kg. Set the initial water temperature to 0°C . Run the simulation. Record or print the final temperature of the water. Now repeat the simulation with the initial water temperature set to 40°C . Does the initial temperature affect ΔT ?

c. Advanced Level

8. Set the mass of water to 1.0 kg, the height to 1000 m, and the hanging mass to 10 kg. Run the simulation. Solve the theoretical equation for c , substitute in the values that you set and observed, and calculate the value for c . Repeat the simulation using different combinations of settings. Calculate a value for c each time. What is the range of values that you obtain? What is the average value that you obtain?
9. Suppose you were creating a written procedure for this simulation for technicians to follow in which the value for specific heat for a substance (not necessarily water) would be the same as the final temperature. Discuss whether this is possible. If it is possible, what values would you use for the initial settings?

Lab Guide

Ideal Gas

I. Objectives

After completing this simulation, the student will be able to:

1. Describe how pressure of an ideal gas varies with volume at constant temperature
2. Describe the effect on pressure of adding more ideal gas to a system
3. Describe the effect on pressure of changing the temperature
4. Describe practical uses of ideal gas properties

II. User Interface and Simulation Features

This simulation gives you an amount of ideal gas in an insulated cylinder with a movable piston. This means that no heat enters or leaves the cylinder or the gas. You can vary the amount of gas in moles, the temperature and the volume by means of slider bars. Changing the volume causes the graphic display of the piston to move. A scatter graph at the lower right shows the amount of energy in the system as the product of P and V . You can clear the display on the graph by clicking the "Clear" button. A digital display shows the value of pressure at any time.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. What is the pressure of the gas inside the cylinder? What is the temperature? What is the initial volume? Change the volume to 6.8 m^3 , half of the initial value. What change do you observe in the pressure? As you made this change, what did you observe on the graph?
2. What is the magnitude of the pressure at a volume of 20 m^3 ? What is the magnitude of the pressure at a volume of 2 m^3 ?
3. Decrease the temperature to $0 \text{ }^\circ\text{C}$. What happens to the volume? What happens to the pressure? Now increase the temperature to $150 \text{ }^\circ\text{C}$. What happens to the volume? How does the pressure change?
4. The units on the product of P and V are joules, representing energy or work. If you keep the volume constant and increase the temperature, how does the pressure change? How does the amount of energy in the gas change?

b. Intermediate Level

5. Move the volume slider slowly back and forth through its full range two or three times. Observe the curve that is formed. If PV has the units of work or energy expressed in units of joules, what would an area of the graph represent?
6. Set the volume to 20 m^3 . Clear the graph. Change the volume slowly back to its original volume of 13.6 m^3 . Observe the curve that you generated. How would you represent the work required to compress the gas from the larger volume to the smaller?
7. Move the volume slider slowly back and forth through its full range two or three times. Now decrease the temperature to $0 \text{ }^\circ\text{C}$. Move the volume slider back and forth again. Compare the two curves. Would you have to do more or less work to compress the gas from 20.0 m^3 to 13.6 m^3 at a temperature of $0 \text{ }^\circ\text{C}$ compared to the amount of work at $53 \text{ }^\circ\text{C}$? Why do you know this?
8. Move the volume slider slowly back and forth through its full range two or three times. Increase the number of moles of gas to 1.5 mol . Move the slider again. Does the greater amount of gas have more or less energy than the lesser amount of gas?

c. Advanced Level

9. If the piston does 50 J of work was done on the gas in the cylinder, and then the gas does 75 J of work on the piston, what is the net energy change of the piston?
10. When gasoline burns in the closed cylinder of an automobile engine, 27 mol of gasoline and oxygen produce about 34 mol of carbon dioxide and water. If the gases in the cylinder combust and release energy in this closed cylinder, will the pressure of the gases produced be greater or less than it would just because of the increase in the number of moles? Is the energy of the combusted gases greater or less than the uncombusted gases?

Lab Guide

Adiabatic/Isothermal Compression

I. Objectives

After completing this simulation, the student will be able to:

1. Distinguish between an adiabatic and an isothermal process
2. Explain the work done on an ideal gas in terms of pressure and volume
3. Describe the effect of initial temperature on compression
4. Describe the difference between monatomic and diatomic gases in the work required for compression

II. User Interface and Simulation Features

This simulation shows a large piston and cylinder enclosing a fixed number of moles of an ideal gas. You can choose whether to observe an adiabatic or an isothermal compression by clicking on the switch. You can choose whether the gas is monatomic or diatomic in the same way. You can select the initial kelvin temperature. Three line graphs on the left side of the screen individually plot pressure, temperature and work against volume on the horizontal axis. A digital display gives instantaneous values for temperature, pressure, volume, work done on the gas and change in heat energy

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Run the simulation. Is this an adiabatic or isothermal compression? What are the initial and final volumes? How much work did it take to compress the gas?
2. Switch to an isothermal compression. Run the simulation. What are the initial and final volumes? How much work did the compression require?
3. Switch to a diatomic gas and compress it adiabatically. What are the initial and final volumes? How much work is required?
4. Switch to a diatomic gas and compress it isothermally. What are the initial and final volumes? How much work is required?

b. Intermediate Level

5. If the compression is isothermal, does the amount of work to compress the gas depend on whether it is monatomic or diatomic? What if the compression is adiabatic?

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6. Which settings require the least work to compress the gas? Which settings require the most work?

7. Set the initial temperature to 120 K . Run the simulation. Does it take more or less work to compress a hot gas? Now set the temperature to 40 K . Run the simulation. Observe the amount of work required. For an adiabatic compression, how does the amount of work required compare to the initial temperature? Remember, for all these comparisons, the gas is compressed to a certain volume ratio, nearly 6:1 .

c. Advanced Level

8. Theory tells us that monatomic and diatomic molecules require different amounts of energy to raise their temperature in adiabatic processes. What is it about the motion of these molecules that causes this effect?

Lab Guide Carnot Cycle

I. Objectives

After completing this simulation, the student will be able to:

1. Define adiabatic and isothermal processes
2. Describe a Carnot cycle heat engine
3. Describe work being done during the stages of a Carnot cycle
4. Calculate the efficiency of a Carnot engine
5. Describe the effect on efficiency of the temperatures of the cold and hot reservoirs

II. User Interface and Simulation Features

This simulation shows a piston containing an ideal gas going through a Carnot engine cycle. The ideal gas inside the piston absorbs heat from a heat reservoir and expands. Then it gives off heat to a cold reservoir and compresses. Sadi Carnot was a French engineer in the early 1800s who developed this idealized heat engine. The Carnot cycle consists of two isothermal processes and two adiabatic processes. Given the temperatures of the two reservoirs, the cycle produces maximum efficiency allowed by the 2nd law of thermodynamics. The pressure-volume graph shows isotherms in red and the steeper adiabats in green. Each of the four steps in the Carnot cycle must lie along an isotherm or an adiabat. To change the parameters of the cycle, drag and drop the red balls at the upper left and lower right of the cycle on the graph. To see the pressure, volume and temperature at the beginning of compression or expansion, click and hold on the associated ball.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Run the simulation. Observe the blue line on the graph run down the red isotherm, then onto the green adiabat at their intersection. In steps 1 and 2, is the gas doing work or is work being done on the gas? How is the temperature of the gas changing?
2. Will the maximum temperature, T_H , be found at the end of compression or at the end of expansion? Where will the minimum temperature, T_C , be found? What are these values in the default settings? One method of calculating efficiency is $\varepsilon = \frac{T_H - T_C}{T_H}$. What is the value of efficiency for the default settings? Does your calculation agree with the display?

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3. What is the highest temperature you can achieve with this experiment? What is the lowest temperature? Can you obtain both of these temperatures with the red balls in the same place?
4. Describe what happens when you move one corner of the Carnot cycle to try to achieve a very high or very low temperature.

b. Intermediate Level

5. Move the upper left corner of the cycle to (2 L, 10 atm). Move the beginning of the compression cycles to (7.76 L, 1.0 atm). Run the simulation. What is the efficiency of this run? How much work did the gas do?
6. Move the upper left corner of the cycle to (2 L, 10 atm). Move the beginning of the compression cycles to (1 L, 10 atm). Run the simulation. What is the efficiency of this run? How much work did the gas do? Which engine would you rather have doing work for you, this one or the one in Item 5?

c. Advanced Level

7. What can you do to make the Carnot efficiency as large as possible? What is the largest efficiency you can obtain? What can you do to obtain a very low efficiency? What is the lowest efficiency you can obtain?
8. Select one corner of the Carnot cycle. Examine the constraints on the location of the other corner. Place the corner you are investigation near the center of the graph. Then drag the first corner back and forth parallel to the volume axis. What two lines bound the other corner?