ADVANCED Physics WITH VERNIER – BEYOND MECHANICS

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Vernier
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[1] The Dynamics Track is included in the Vernier Dynamics System; it can also be purchased separately.
[2] If a Vernier Power Amplifier is not available, a conventional power supply can be used.
[3] A Voltage Probe or Instrumentation Amplifier is required.
[4] If a Vernier Power Amplifier is not available, a conventional power supply *and* Current Probe can be used.
[5] If a Vernier Power Amplifier is not available, two D-cell batteries can be used.

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Heat Engines

INTRODUCTION

If you examined the pressure-volume behavior of a gas (as in Experiment 1), you would have performed one of the thermodynamic processes involved in the cycle found in the operation of a heat engine. This process is known as an isothermal expansion – so named because the data were collected slowly enough that the temperature of the gas in the system remained constant.

In this experiment, you will examine some thermodynamic processes to understand how the internal energy of the system (E_{int} or U) is affected by exchanges of energy between the system and the surroundings.

OBJECTIVES

In this experiment, you will

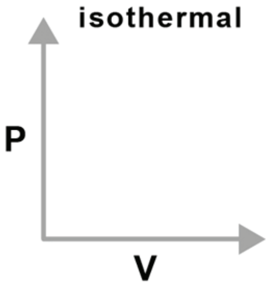
- Design and create a thermodynamic system consisting of a flask, tubing, syringe, and pressure sensor.
- Relate the terms isothermal, isochoric, isobaric and adiabatic to various thermodynamic processes, and how to move your thermodynamic system through these processes.
- Collect pressure, volume and temperature data for three of these processes.
- Analyze the various P-V processes to keep track of the work (W) done by or on the enclosed gas and the heat (Q) transferred between the gas and the surroundings.
- Use the first law of thermodynamics to account for the change in internal energy in each of these processes.
- Determine the total work done by enclosed gas in various thermodynamic cyclic processes.

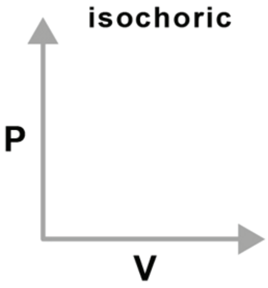
MATERIALS

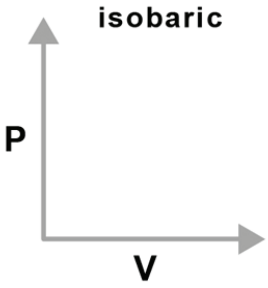
Vernier data-collection interface
Logger *Pro* or LabQuest App
Vernier Gas Pressure Sensor
Vernier Stainless Steel Temperature Probe
125 mL Erlenmeyer flask
400 mL beaker
supply of hot and cold water

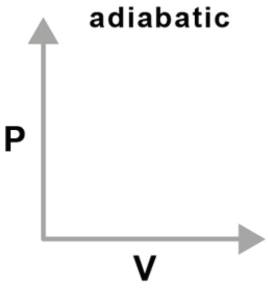
PRE-LAB INVESTIGATION

Find, in your physics text or an on-line source, definitions of the terms *isothermal, isochoric, isobaric* and *adiabatic* as they relate to ideal gases and heat engines. On the axes below, sketch the line or curve connecting the initial state (P_1, V_1) and the final state (P_2, V_2) for each of these processes. For three of these processes, make $V_2 > V_1$.









In which of these processes does the enclosed gas do no work on the surroundings? Explain.

PART 1 DETERMINE THE VOLUME OF THE SYSTEM

PROCEDURE

1. Connect the Gas Pressure Sensor to the interface and start the data-collection program. Rather than Time-based mode, you will collect data in Events with Entry mode in this experiment. Change the data-collection mode and enter **volume** as the Column Name and **mL** as the Units.
2. Insert the stopper that comes with the gas pressure sensor into the flask; use the tubing to connect it to the sensor. Set the syringe volume to zero and attach it to the other connector on the stopper (see Figure 1).
3. Start data collection. Click or tap Keep and enter **0** as the volume.
4. Repeat Step 3, increasing the volume 2–3 mL each time, until you are close to a volume of 20 mL. Stop data collection, and then store this run.

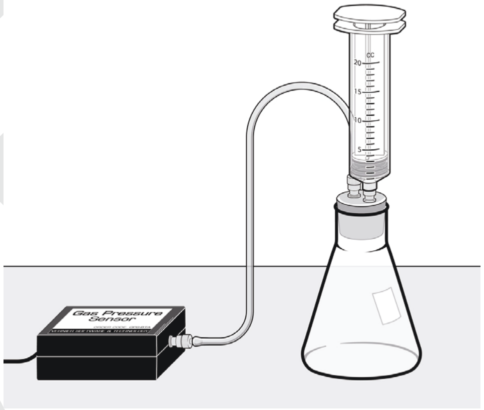


Figure 1

EVALUATION OF DATA

Clearly the volume of the gas in the system is much greater than the syringe readings you recorded. The following steps will enable you to determine the actual volume. Before you begin this analysis, estimate the volume of gas in the system when the syringe reading was zero.

1. From your knowledge of Boyle's Law, recognize that the product of pressure and the volume is a constant ($PV=A$). It follows that a plot of V vs. $1/P$ should be linear. Test this by making a new calculated column for the inverse of pressure.
2. Change what is plotted on the graph so that you have a graph of volume *vs.* 1/pressure. Apply a linear fit to these data.
3. The actual volume of the gas, V, is the sum of the syringe reading, v, and the gas in the flask and tubing, B. With this in mind, rearrange the equation for the linear fit to determine the value of B.

PART 2 INVESTIGATING THERMODYNAMIC CYCLES

In a thermodynamic cycle, the final values of pressure, volume and temperature are the same as those in the beginning ($P_f = P_i$, $V_f = V_i$, $T_f = T_i$). It is important, as you perform the processes in the cycles described below, that you identify each of the processes and reflect on how the internal energy (E_{int} or U) of the system changes due to heating or cooling (Q) or by the work done by or on the gas in the system (W).

PROCEDURE

A four–process cycle

1. Connect the Temperature Probe to the interface and choose New from the File menu. As before, change the data-collection mode to Events with Entry. Enter **Volume** as the Name and **mL** as the Units.
2. Set the syringe volume to zero and connect it to the stoppered flask. Place the flask in the 400 mL beaker as shown in Figure 2.
3. Begin data collection. Click or tap Keep and, in the volume field, enter the value you determined in Part 1 for the system volume.
4. Add hot water (60–75°C) to the beaker until the flask is immersed as much as possible. Friction between the seal on the plunger and the wall of the syringe will keep the gas from expanding. When the temperature and pressure readings are reasonably stable, click or tap Keep and enter the same volume as you did in Step 3.

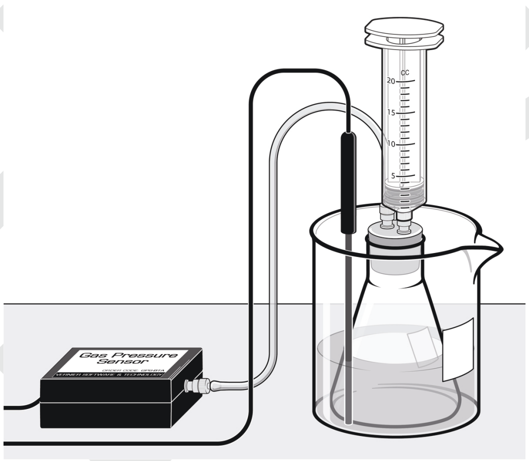


Figure 2

5. As quickly as you can, perform the isothermal expansion you did in Part 1, keeping the volume readings. If the temperature drops more than a couple of degrees before your final volume reading, you should stop the run, cool the flask back to room temperature, and repeat Steps 2–5.
6. Cool the flask to your starting temperature without changing the volume. When the temperature and pressure readings are stable, select Keep, and enter the system volume.
7. Now, perform an isothermal compression of the gas in a series of 2–3 mL steps, this time decreasing the syringe volume and keeping the readings as you enter the volumes. What should be the reading on the pressure sensor when the syringe volume returns to zero? Stop data collection.
8. If you are using Logger *Pro*, choose Text Annotation from the Insert menu to label each of the four processes in your thermodynamic cycle. If you are using LabQuest App, either print your graph and label the processes by hand, or import your data into Logger *Pro* to label them. Save your file.

A three–process cycle

Consider how you might get back to the original values of *P* and *V* after performing the first two processes of the previous cycle.

1. Choose New from the File menu. Repeat Steps 2–5 from the previous process.
2. Make the necessary adjustments to the experimental conditions to reach the initial values of pressure and volume. When these values have been reached, stop collecting data. Consider the energy transfers between system and surroundings via *Q* and *W* during this last process in the cycle.
3. If you are using Logger *Pro*, choose Text Annotation from the Insert menu to label each of the three processes in your thermodynamic cycle. If you are using LabQuest App, either print your graph and label the processes by hand, or import your data into Logger *Pro* to label them. Save your experiment file.

EVALUATION OF DATA

A four–process cycle

1. Open your data file for the 4–process cycle. Label each of the processes in the cycle and determine the signs of Q, W and ΔE_{int}. For this experiment use the convention that a positive value of *Q* or *W increases* the internal energy of the system. Record your answers in a table like the one below.

Step	Process	Q	W	ΔE_{int}
1				
2				
3				
4				

2. What does the area under the *PV* curve in the isothermal processes represent? Explain why the sign of this quantity is different in these two processes.
3. Explain how the internal energy of the system remains constant during the isothermal processes.
4. Choose Integral from the Analyze menu to determine the net work done by the system during the cycle. Convert the volume from mL to m^3 in order to obtain the value in joules.

A three–process cycle

1. Open your data file for the 3-process cycle. Label each of the processes in the cycle and determine the signs of Q, W and ΔE_{int}. For this experiment use the convention that a positive value of *Q* or *W increases* the internal energy of the system. Record your answers in a table like the one below.

Step	Process	Q	W	ΔE_{int}
1				
2				
3				

2. Explain how you were able to keep the pressure constant in the final process.

3. Choose Integral from the Analyze menu to determine the net work done by the system during the cycle. As before, convert your value to joules.

EXTENSIONS

1. Suppose that you performed the following cycle: 1–isothermal expansion at room temperature, 2–isochoric heating, 3–isothermal compression at higher temperature, 4–isochoric return to room temperature. How would the net work done by the gas in the system compare to that in the first cycle?

2. Using your text or a web-based resource, describe how a Carnot cycle differs from the 4-step cycle you performed. Use a table like the ones above to keep track of the signs of Q, W, and ΔE_{int} in each of the steps.

3. If you have the opportunity to experiment with a syringe that has been modified as shown in Figure 3, observe the effect that a rapid expansion or compression has on the temperature of the gas in the syringe. Note that a surface temperature sensor has been inserted through a small hole drilled in the body of the syringe. The hole was later sealed with epoxy.

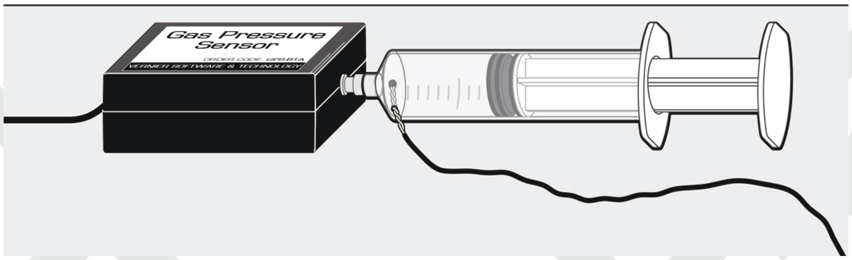


Figure 3

Explain the shape of the temperature *vs.* time graphs you obtain during expansion and compression.

Experiment
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Curved Mirrors and Images

INTRODUCTION

While we all feel familiar with the images we see in plane mirrors, our experiences with their curved counterparts might be limited to cosmetic mirrors or the side view mirrors on automobiles. In this experiment, you will explore the characteristics of the real and virtual images formed by curved mirrors. Then you will develop a mathematical relationship describing the relationship between the positions of the object and the real image formed by concave mirrors.

OBJECTIVES

In this experiment, you will

- Use curved mirrors to produce real and virtual images.
- Explore how the position of the object affects the appearance, orientation, and size of real images produced by concave mirrors.
- Explore how mirror characteristics and the position of the object affect the appearance, orientation, and size of virtual images produced by concave and convex mirrors.
- Determine the relationship between object distance, image distance, focal length, and magnification in real images produced by concave mirrors.

MATERIALS

Logger *Pro* or LabQuest App
Vernier Dynamics System track
Vernier Optics Expansion Kit
Vernier Mirror Set
small plane mirror

PRE-LAB INVESTIGATION

1. Place the convex mirror at one end of the track. Position your eye at the other end of the track and examine the image of yourself. In what way does the image of yourself differ from that which you would see if you were looking into a plane mirror? How does the image change when you move the mirror closer to you?
2. Replace the convex mirror with the concave one and move it to the end of the track. As you did before, position your eye at the other end of the track and examine the image of yourself. In what ways does the image of yourself differ from that which you observed with the convex mirror? What happens to the image when you move your head slightly from side to side?
3. Gradually move the concave mirror closer to you. How does this affect the image you observe? What happens to the image when the mirror is approximately 20 cm from your eye?

In your class discussion, you will learn how the use of ray diagrams can help you to determine how and where light from a particular point on an object converges to form an image. You can get a conceptual understanding of the process of image-formation by a curved mirror using the simulation available at the Davidson University web site.[1]

PROCEDURE

Part 1 Concave mirror and real images

1. Set up the light source and concave mirror to project a clear image on the half screen.
   a. Attach the light source assembly from the Optics Expansion Kit to the Vernier track. Position it so that the pointer in the base is at the 10 cm mark and the light source faces the other end of the track.
   b. Place the concave mirror near the other end of the track so that it faces the light source. Attach the half screen to the track between the light source and the mirror.
   c. Turn the light source wheel until the number "4" is visible in the opening. This will be your "object" for this investigation.
   d. Adjust the position of the screen until the image of the "4" on the screen is in focus (see Figure 1). You may need to adjust the angle of the mirror in its holder so that the image projected by the mirror shows on the screen. One approach to obtain the sharpest image, once you think you have it, is to move the screen in either direction until the image begins to blur, then move it back until it again appears sharp.

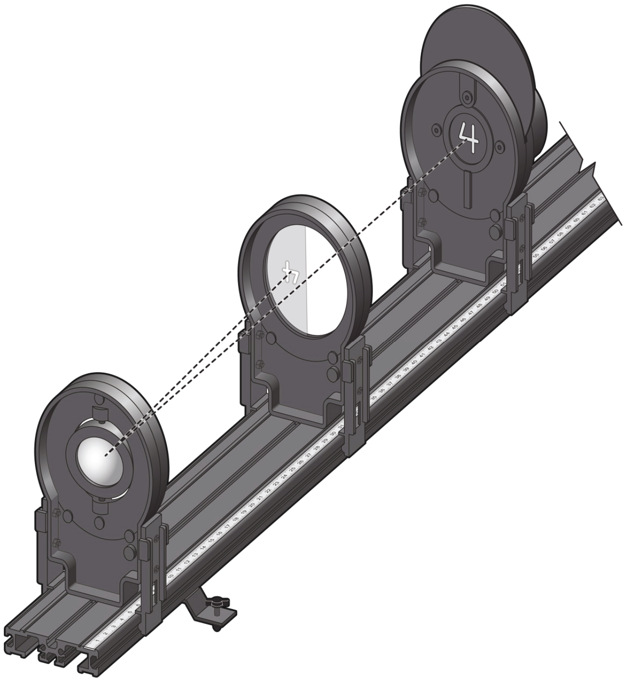

Figure 1

2. Describe the size, shape, and orientation of the image.

3. Now, move the mirror to the 100 cm mark, then move the screen toward the mirror until you can see a sharp image of the "4" on the half screen. Record the distance between the light source and the mirror as "object distance" and the distance between the mirror and the screen as "image distance" in your lab notebook.

4. Obtain object distance and image distance data for four more points, moving the mirror 10 cm closer each time. Note what happens to the size of the image as the object distance decreases.

5. Move the mirror to the 50 cm mark, leaving the light source at 10 cm. Note that you cannot obtain a sharp image on the screen. If you remove the screen and rotate the mirror slightly, you can observe a sharp image of the "4" on the light source assembly itself. Compare the size of the image to that of the object.

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[1] webphysics.davidson.edu/course_material/py230L/optics/lenses.htm

6. It is possible to obtain another data point for which the mirror is even closer to the light source. To do so, move the light source to the middle of the track and the mirror 30 cm away. Hold the screen off to the side *behind* the light source and rotate the mirror until you can observe the projected image on the screen. Make your best estimate of the image distance.

Part 2 Convex mirror and virtual images

Locating a virtual image is more difficult because it cannot be projected onto a screen, like a real image. The technique described below involves the use of parallax to determine the position of the virtual image.

1. Draw a vertical line on a 3″ × 5″ index card; place this card in the slot on the full viewing screen. This screen is your image position marker. Place the half screen (which serves as the object), convex mirror, and full screen on the track as shown in Figure 2.

2. Move the convex mirror to a position 40 to 50 cm from the half screen. Record this as the object distance. Stand at the end of the track near the half screen so that you can view both the virtual image of the half screen and the index card attached to the full screen.

3. Place the index card and screen serving as the position marker just behind the convex mirror. Position your head directly behind and above the half screen. As you look over the top of the half screen toward the mirror, you can view the half screen in the mirror. Move your head so that the line on marker and the edge of the half screen are aligned.

4. Move your head to the right of the half screen. Note that the edge of the screen in the image appears to the right of the line on the marker. When you move your head to the left of the half screen you should note that the edge in the image shifts to the left of the marker line. (See Figure 3.) This difference in relative positions is called parallax.

5. Move the marker 5 cm farther from the mirror. When you repeat Step 4, the parallax is reduced. Gradually move the marker farther from the mirror and check the alignment of the edge of the half screen and the line on the marker until there is no parallax. Record this distance as the distance of the virtual image. If you go beyond the no-parallax point, the image and the object will move in opposite directions.

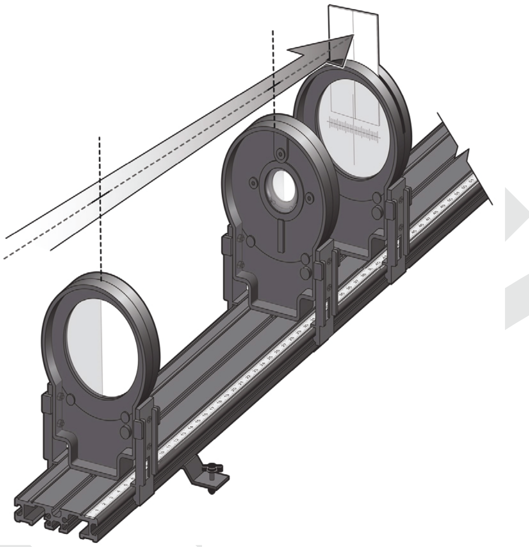

Figure 2

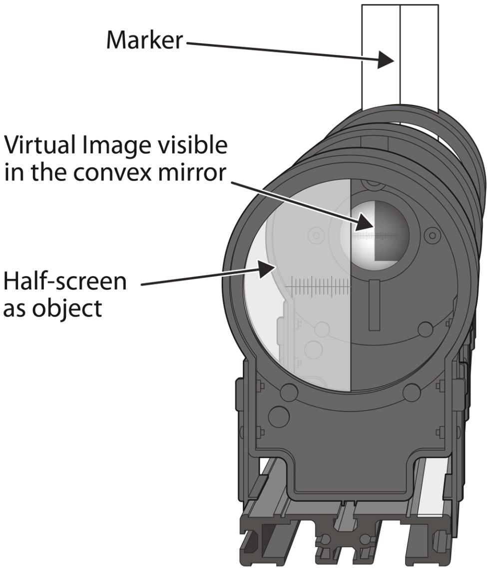

Figure 3

EVALUATION OF DATA

1. Choose New from the File menu in the data-collection program. In the table, manually enter your data for your measurement with the concave mirror. Enter **d-o** (for object distance) and **d-i** (for image distance) as the Names of the columns.

2. Examine your graph of image distance *vs.* object distance. What relationship appears to exist between these variables? Rather than performing a curve fit to the data, take steps to modify one of the variables so as to produce a linear graph.

   Using Logger *Pro*

   Choose New Calculated Column from the Data menu. After entering a name and units for the column, click the equation field, enter the expression to modify the variable you choose from the drop-down menu, then click Done. Change the variable on the axis you have chosen to modify to see the resulting graph.

   Using LabQuest App

   Choose New Calculated Column from the Table menu. After choosing a name and units for the column, select *A/X* as the Equation Type. Enter the column you wish to modify, then select OK. Tap the Graph tab and change the variable on the axis you have chosen to modify to see the resulting graph.

   You may find it necessary to modify the variables on *both* axes to linearize the graph. When you have done so, write the equation of the best-fit line.

3. Examine the value and the units of the slope. Discuss with your instructor what the ideal value of the slope might be.

4. Examine the value and units of the vertical intercept. In view of the modifications you made to the object distance and image distance in order to produce a linear graph, draw a conclusion about the physical significance of the intercept.

5. Write a general equation of your best-fit line in terms of d_i, d_o and f; rearrange the equation so that d_i and d_o are on the same side. Compare your results to the spherical mirror equation in your text or a web-based resource.

6. The magnification, m, of an image is the ratio of the image height, i, to the object height, o. Using similar triangles, one can show that it is also equal to the ratio of the image distance to the object distance.

   $$m = \frac{i}{o} = -\frac{d_i}{d_o}$$

   Note: the negative sign is included as part of the convention to indicate that the real image is inverted.

   Find a configuration of the mirror and the screen that produces an image of the “4” used as the object that measures 10 mm across. Measure d_i and d_o and compare the agreement between the two ratios. Repeat this process for an image that is half as large. The “4” on the light source is 20 mm across.

7. In the sign convention used for spherical mirrors, both the focal length of a convex mirror and the image distance for a virtual image have negative values. The focal length of the convex mirror in the mirror set is –20 cm. Use the spherical mirror equation to calculate the expected distance for the virtual image. How does this compare to the value you obtained from your observations?

EXTENSIONS

1. Suppose you had used a 15 cm concave mirror in your experiment. Predict the slope and intercept of the graph of $1/d_i$ *vs*. $1/d_o$.

2. In what ways are the virtual images one can see with both convex and concave mirrors the same? How are they different?

3. Determine the virtual image distance for at least five more positions of the half screen serving as the object as you did in Part 2. Create a new Data Set in your Logger *Pro* or LabQuest App file and enter the values for the object and image distances. Insert a new graph and choose $1/d_i$ as the vertical axis label and $1/d_o$ as the horizontal axis label. Apply a linear fit as before and determine the agreement between your data and the spherical mirror equation.