Section 4

Integrating Mathematics

Graphing Gas Behavior

Reading Preview

Key Concepts

- What type of relationship does the graph for Charles's law show?
- What type of relationship does the graph for Boyle's law show?

Key Terms

- graph
- origin
- directly proportional
- vary inversely

Target Reading Skill

Previewing Visuals Before you read, preview Figure 23. In a graphic organizer like the one below, write questions that you have about the diagram. As you read, answer your questions.

Graphing Charles's Law

Q. What is the relationship between gas volume and temperature?
A.
Q.

Lab zone Discover Activity

Can You Graph Gas Behavior?

Temperature (°C)	Pressure (kPa)
0	8
5	11
10	14
15	17
20	20
25	23

1. In an experiment, the temperature of a gas at a constant volume was varied. Gas pressure was measured after each 5°C change. Use the data in this table and follow Steps 2–4 to make a graph.
2. Show temperature on the horizontal axis with a scale from 0°C to 25°C. Show pressure on the vertical axis with a scale from 0 kPa to 25 kPa. (1 kPa = 1,000 Pa.)
3. For each pair of measurements, draw a point on the graph.
4. Draw a line to connect the points.

Think It Over

Drawing Conclusions What happens to the pressure of a gas when the temperature is increased at constant volume?

Graphs are a way to tell a story with data. A **graph** is a diagram that tells how two variables, or factors that change, are related. If you did the activity above, you made a graph that helped you understand how the pressure of a gas changes when its temperature is changed. In this section, you will learn how to make and interpret graphs that relate these and other properties of gases.

A graph consists of a grid set up by two lines, one horizontal and one vertical. Each line, or axis, is divided into equal units. The horizontal axis, or *x*-axis, shows the manipulated variable. The vertical axis, or *y*-axis, shows the responding variable. Each axis is labeled with the name of the variable, the unit of measurement, and a range of values.

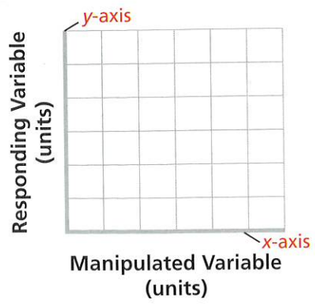
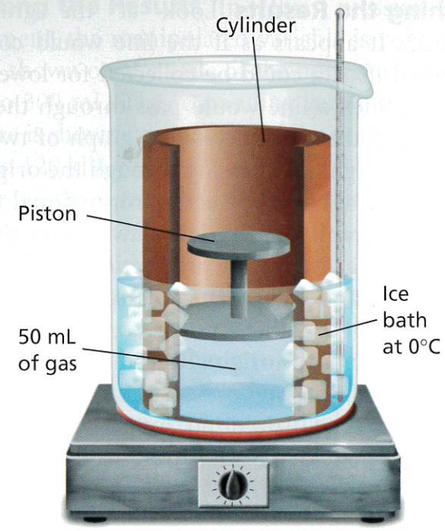
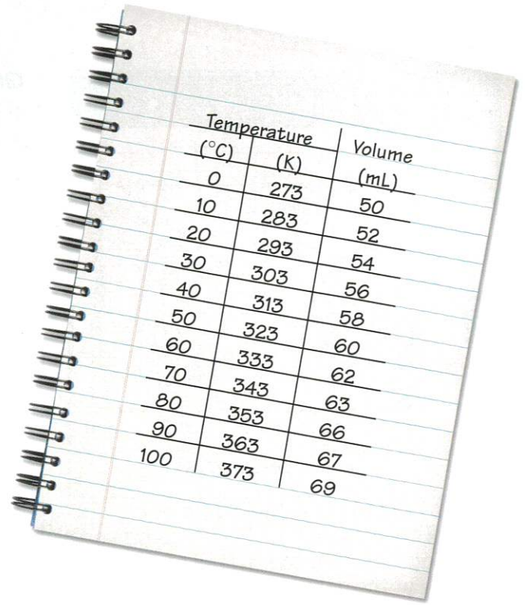


FIGURE 21
Making a Graph
The *x*-axis (horizontal) and the *y*-axis (vertical) form the "backbone" of a graph.





Temperature (°C)	Temperature (K)	Volume (mL)
0	273	50
10	283	52
20	293	54
30	303	56
40	313	58
50	323	60
60	333	62
70	343	63
80	353	66
90	363	67
100	373	69

FIGURE 22
Temperature and Gas Volume
As the temperature of the water bath increases, the gas inside the cylinder is warmed by the water. The data from the experiment are recorded in the notebook table.
Calculating *How do you convert Celsius degrees to kelvins?*

Temperature and Volume

Recall that Charles's law relates the temperature and volume of a gas that is kept at a constant pressure. You can explore this relationship by doing an experiment in which you change the temperature of a gas and measure its volume. Then you can graph the data you have recorded and interpret the results.

Collecting Data As you can see from the cutaway view in Figure 22, the gas in the experiment is in a cylinder that has a movable piston. The piston moves up and down freely, which allows the gas to change volume and keep the same pressure. To control the temperature of the gas, the cylinder is placed in a water bath.

The experiment begins with an ice-water bath at 0°C and the gas volume at 50 mL. Then the water bath is slowly heated. Gradually, the temperature increases from 0°C to 100°C. Each time the temperature increases by 10°C, the volume of the gas in the cylinder is recorded.

You'll notice a second set of temperatures listed in the table in Figure 22. Scientists often work with gas temperatures in units called kelvins. To convert from Celsius degrees to kelvins (K), add 273. The kelvin temperatures will be used to graph the data.

Reading Checkpoint **What units do scientists use to measure gas temperatures?**

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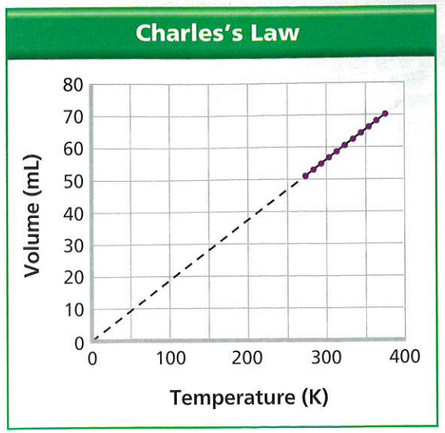

FIGURE 23
Graphing Charles's Law
A graph of the data from Figure 22 shows the relationship known as Charles's law. The dotted line predicts how the graph would look if the gas could be cooled further.

Graphing the Results Look at the graph in Figure 23. It appears as if the line would continue downward if data could be collected for lower temperatures. Such a line would pass through the point (0, 0), called the **origin.** When a graph of two variables is a straight line passing through the origin, the variables are said to be **directly proportional** to each other. **The graph of Charles's law shows that the volume of a gas is directly proportional to its kelvin temperature under constant pressure.**

In reality, the line on the graph cannot be extended as far as the origin. Remember that if a gas is cooled enough, it will condense into a liquid. After that, the volume would no longer change much. However, the line that results from the data represents a relationship that is directly proportional.

Pressure and Volume

A different experiment can show how gas pressure and volume are related when temperature is kept constant. Recall that this relationship is called Boyle's law.

Collecting Data The gas in this experiment is also contained in a cylinder with a movable piston. A gauge indicates the pressure of the gas inside the cylinder. The experiment begins with the volume of the gas at 300 mL. The pressure of the gas is 20 kPa. Next, the piston is pushed into the cylinder, making the gas volume smaller. The pressure of the gas is recorded after each 50-mL change in volume. Temperature remains constant.

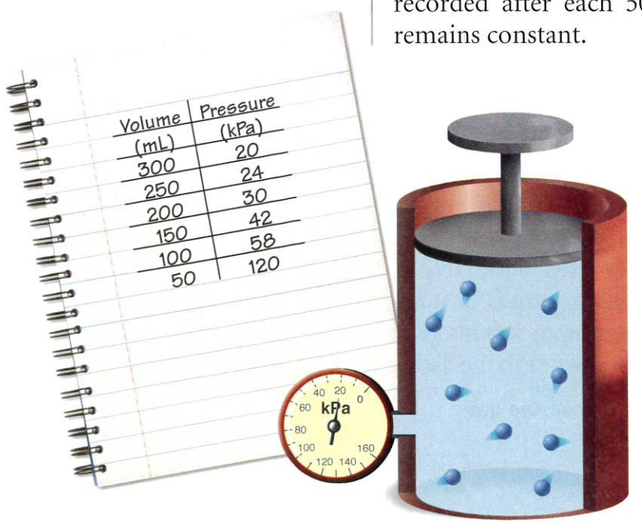

FIGURE 24
Pushing on the top of the piston decreases the volume of the gas. The pressure of the gas increases. The data from the experiment are recorded in the notebook table.
Predicting *What would happen if you pulled up on the piston?*

Graphing the Results In this pressure-volume experiment, the manipulated variable is volume. Volume is shown on the scale of the horizontal axis from 0 mL to 300 mL. The responding variable is pressure. Pressure is shown on the scale of the vertical axis from 0 kPa to 120 kPa.

As you can see in Figure 25, the plotted points lie on a curve. Notice that the curve slopes downward from left to right. Also notice that the curve is steep at lower volumes and becomes less steep as volume increases. When a graph of two variables forms this kind of curve, the variables are said to **vary inversely** with one another. Such a relationship means that when one variable goes up, the other variable goes down in a regular way. **The graph for Boyle's law shows that the pressure of a gas varies inversely with its volume at constant temperature.**

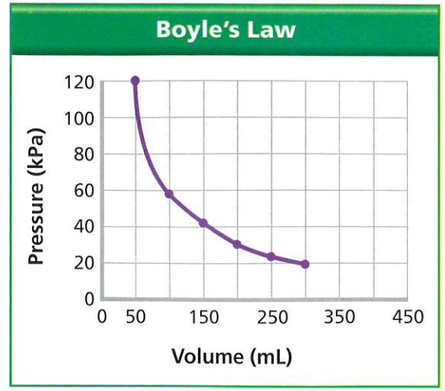

FIGURE 25
This graph of the data from Figure 24 shows the relationship between pressure and volume known as Boyle's law.

Reading Checkpoint **What is the manipulated variable in the pressure-volume experiment?**

Section 4 Assessment

Target Reading Skill **Previewing Visuals** Refer to your questions and answers about Figure 23 to help you answer Question 1 below.

Reviewing Key Concepts

1. a. **Classifying** What term describes the relationship illustrated by the graph in Figure 23?
   b. **Relating Cause and Effect** How does the volume of a gas change when its temperature is increased at constant pressure?
   c. **Predicting** Suppose the temperature of the gas is increased to 400 kelvins (127°C). Use Figure 23 to predict the volume of the gas at this temperature.
2. a. **Classifying** What is the relationship between the pressure and the volume of a gas?
   b. **Estimating** Use the graph in Figure 25 to estimate the gas pressure when the gas volume is 125 mL.
   c. **Comparing and Contrasting** Compare and contrast the Charles's law and Boyle's law graphs. How can you tell the difference between a graph in which one variable is directly proportional to another and a graph in which two variables vary inversely?

Lab zone **At-Home Activity**

Finding Graphs Look for graphs in your newspaper or in magazines. Point out to members of your family which variable is the manipulated variable and which is the responding variable for each graph. Then compare any line graphs you have found to the graphs in this section. Which of your graphs show two variables that are directly proportional to each other? Do any show variables that vary inversely?