

Skills Worksheet

Problem Solving**Gas Laws**

Chemists found that there were relationships among temperature, volume, pressure, and quantity of a gas that could be described mathematically. This chapter deals with Boyle's law, Charles's law, Gay-Lussac's law, the combined gas law, and Dalton's law of partial pressures. These laws have one condition in common.

They all assume that the molar amount of gas does not change. In other words, these laws work correctly only when no additional gas enters a system and when no gas leaks out of it. Remember also that a law describes a fact of nature. Gases do not "obey" laws. The law does not dictate the behavior of the gas. Rather, each gas law describes a certain behavior of gas that occurs if conditions are right.

BOYLE'S LAW

Robert Boyle, a British chemist who lived from 1627 to 1691 formulated the first gas law, now known as Boyle's law. This law describes the relationship between the pressure and volume of a sample of gas confined in a container. Boyle found that gases compress, much like a spring, when the pressure on the gas is increased. He also found that they "spring back" when the pressure is lowered. By "springing back" he meant that the volume increases when pressure is lowered. It's important to note that Boyle's law is true only if the temperature of the gas does not change and no additional gas is added to the container or leaks out of the container.

Boyle's law states that *the volume and pressure of a sample of gas are inversely proportional to each other at constant temperature*. This statement can be expressed as follows.

$$V \propto \frac{1}{P} \quad \text{and} \quad PV = k \quad \text{or} \quad V = k \frac{1}{P}$$

Proportionality symbol. It means "is proportional to." (points to \propto)
Proportionality constant (points to k)

According to Boyle's law, when the pressure on a gas is *increased*, the volume of the gas *decreases*. For example, if the pressure is doubled, the volume decreases by half. If the volume quadruples, the pressure decreases to one-fourth of its original value.

The expression $PV = k$ means that the product of the pressure and volume of any sample of gas is a constant, k . If this is true, then $P \times V$ under one set of conditions is equal to $P \times V$ for the same sample of gas under a second set of conditions, as long as the temperature remains constant.

Problem Solving *continued*

Boyle's law can be expressed by the following mathematical equation.

$$P_1V_1 = P_2V_2$$

Pressure under the *first* set of conditions \times Volume under the *first* set of conditions = Pressure under the *second* set of conditions \times Volume under the *second* set of conditions

General Plan for Solving Boyle's-Law Problems

1 Given three of the following four quantities:
 P_1, V_1, P_2, V_2

Rearrange the equation $P_1V_1 = P_2V_2$ algebraically to solve for the unknown quantity.

2 An equation that can be used to calculate the unknown quantity. It will be one of the following four:

$$V_2 = \frac{P_1V_1}{P_2}, P_2 = \frac{P_1V_1}{V_2}, V_1 = \frac{P_2V_2}{P_1}, P_1 = \frac{P_2V_2}{V_1}$$

Substitute each of the known quantities, and calculate.

3 Unknown
 P or V

Problem Solving *continued***Sample Problem 1**

A sample of nitrogen collected in the laboratory occupies a volume of 725 mL at a pressure of 0.971 atm. What volume will the gas occupy at a pressure of 1.40 atm, assuming the temperature remains constant?

Solution**ANALYZE**

What is given in the problem? **the original volume and pressure of the nitrogen sample, and the new pressure of the sample**

What are you asked to find? **the volume at the new pressure**

Items	Data
Original pressure, P_1	0.971 atm
Original volume, V_1	725 mL N ₂
New pressure, P_2	1.40 atm
New volume, V_2	? mL N ₂

PLAN

What steps are needed to calculate the new volume of the gas?

Rearrange the Boyle's law equation to solve for V_2 , substitute known quantities, and calculate.

$$P_1 V_1 = P_2 V_2 \xrightarrow[\text{insert data and solve for } V_2]{\substack{\text{to solve for } V_2, \\ \text{divide both sides of} \\ \text{the equation by } P_2 \text{ to} \\ \text{isolate } V_2}} V_2 = \frac{P_1 V_1}{P_2}$$

COMPUTE

Substitute data for the terms of the equation, and compute the result.

$$V_2 = \frac{P_1 V_1}{P_2} = \frac{0.971 \text{ atm} \times 725 \text{ mL N}_2}{1.40 \text{ atm}} = 503 \text{ mL N}_2$$

EVALUATE

Are the units correct?

Yes; units canceled to give mL N₂.

Is the number of significant figures correct?

Yes; the number of significant figures is correct because data were given to three significant figures.

Is the answer reasonable?

Yes; pressure increased by about 1/3, volume must decrease by about 1/3.

Problem Solving *continued*

Practice

In each of the following problems, assume that the temperature and molar quantity of gas do not change.

1. Calculate the unknown quantity in each of the following measurements of gases.

	P_1	V_1	P_2	V_2	
a.	3.0 atm	25 mL	6.0 atm	? mL	ans: 13 mL
b.	99.97 kPa	550. mL	? kPa	275 mL	ans: 200. kPa
c.	0.89 atm	? L	3.56 atm	20.0 L	ans: 80. L
d.	? kPa	800. mL	500. kPa	160. mL	ans: 100. kPa
e.	0.040 atm	? L	250 atm	1.0×10^{-2} L	ans: 63 L

Problem Solving *continued*

2. A sample of neon gas occupies a volume of 2.8 L at 1.8 atm. What will its volume be at 1.2 atm? **ans: 4.2 L**
3. To what pressure would you have to compress 48.0 L of oxygen gas at 99.3 kPa in order to reduce its volume to 16.0 L? **ans: 298 kPa**
4. A chemist collects 59.0 mL of sulfur dioxide gas on a day when the atmospheric pressure is 0.989 atm. On the next day, the pressure has changed to 0.967 atm. What will the volume of the SO₂ gas be on the second day?
ans: 60.3 mL
5. 2.2 L of hydrogen at 6.5 atm pressure is used to fill a balloon at a final pressure of 1.15 atm. What is its final volume? **ans: 12 L**

CHARLES'S LAW

The French physicist Jacques Charles carried out experiments in 1786 and 1787 that showed a relationship between the temperature and volume of gases at constant pressure. You know that most matter expands as its temperature rises. Gases are no different. When Benjamin Thomson and Lord Kelvin proposed an absolute temperature scale in 1848, it was possible to set up the mathematical expression of Charles's law.

Problem Solving *continued*

Charles's law states that *the volume of a sample of gas is directly proportional to the absolute temperature when pressure remains constant*. Charles's law can be expressed as follows.

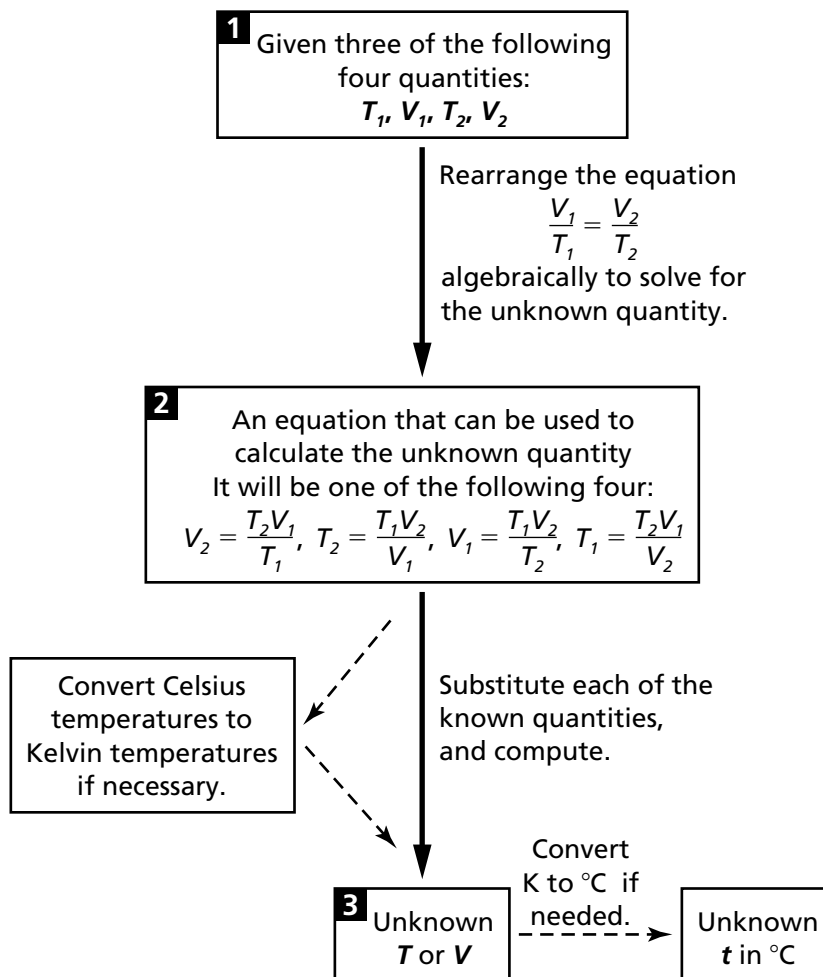
$$V \propto T \quad \text{and} \quad \frac{V}{T} = k, \quad \text{or} \quad V = kT$$

According to Charles's law, when the temperature of a sample of gas *increases*, the volume of the gas *increases* by the same factor. Therefore, doubling the Kelvin temperature of a gas will double its volume. Reducing the Kelvin temperature by 25% will reduce the volume by 25%.

The expression $V/T = k$ means that the result of volume divided by temperature is a constant, k , for any sample of gas. If this is true, then V/T under one set of conditions is equal to V/T for the same sample of gas under another set of conditions, as long as the pressure remains constant.

Charles's law can be expressed by the following mathematical equation.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

General Plan for Solving Charles's-Law Problems

Problem Solving *continued***Sample Problem 2**

A container of oxygen has a volume of 349 mL at a temperature of 22°C. What volume will the gas occupy at 50.°C?

Solution**ANALYZE**

What is given in the problem? **the original volume and temperature of the oxygen sample, and the new temperature of the sample**

What are you asked to find? **the volume at the new temperature**

Items	Data
Original volume, V_1	349 mL O ₂
Original temperature, t_1	22°C
Original Kelvin temperature, T_1	(22 + 273) K = 295 K
New volume, V_2	? mL O ₂
New temperature, t_2	50.°C
New Kelvin temperature, T_2	? (50. + 273) K = 323 K

PLAN

What steps are needed to calculate the new volume of the gas?

Rearrange the Charles's law equation to solve for V_2 , substitute known quantities, and calculate.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \xrightarrow[\text{insert data and solve for } V_2]{\substack{\text{to solve for } V_2, \\ \text{multiply both sides of} \\ \text{the equation by } T_2 \text{ to} \\ \text{isolate } V_2}} \frac{V_1 T_2}{T_1} = V_2$$

COMPUTE

Substitute data for the terms of the equation, and compute the result.

$$V_2 = \frac{V_1 T_2}{T_1} = \frac{349 \text{ mL O}_2 \times 323 \text{ K}}{295 \text{ K}} = 382 \text{ mL O}_2$$

EVALUATE

Are the units correct?

Yes; units canceled to give mL O₂.

Is the number of significant figures correct?

Yes; the number of significant figures is correct because data were given to three significant figures.

Is the answer reasonable?

Yes; the temperature increased, so the volume must also increase.

Problem Solving *continued*

Practice

In each of the following problems, assume that the pressure and molar quantity of gas do not change.

1. Calculate the unknown quantity in each of the following measurements of gases.

	V_1	T_1	V_2	T_2	
a.	40.0 mL	280. K	? mL	350. K	ans: 50.0 mL
b.	0.606 L	300. K	0.404 L	? K	ans: 200. K
c.	? mL	292 K	250. mL	365 K	ans: 200. mL
d.	100. mL	? K	125 mL	305 K	ans: 244 K
e.	0.0024 L	22°C	? L	-14°C	ans: 0.0021 L

Problem Solving *continued*

2. A balloon full of air has a volume of 2.75 L at a temperature of 18°C. What is the balloon's volume at 45°C? **ans: 3.01 L**
3. A sample of argon has a volume of 0.43 mL at 24°C. At what temperature in degrees Celsius will it have a volume of 0.57 mL? **ans: 121°C**

GAY-LUSSAC'S LAW

You may have noticed a warning on an aerosol spray can that says something similar to *Do not incinerate! Do not expose to temperatures greater than 140°F!* Warnings such as this appear because the pressure of a confined gas increases with increasing temperature. If the temperature of the can increases enough, the can will explode because of the pressure that builds up inside of it.

The relationship between the pressure and temperature of a gas is described by Gay-Lussac's law. Gay-Lussac's law states that *the pressure of a sample of gas is directly proportional to the absolute temperature when volume remains constant*. Gay-Lussac's law can be expressed as follows.

$$P \propto T \quad \text{and} \quad \frac{P}{T} = k, \quad \text{or} \quad P = kT$$

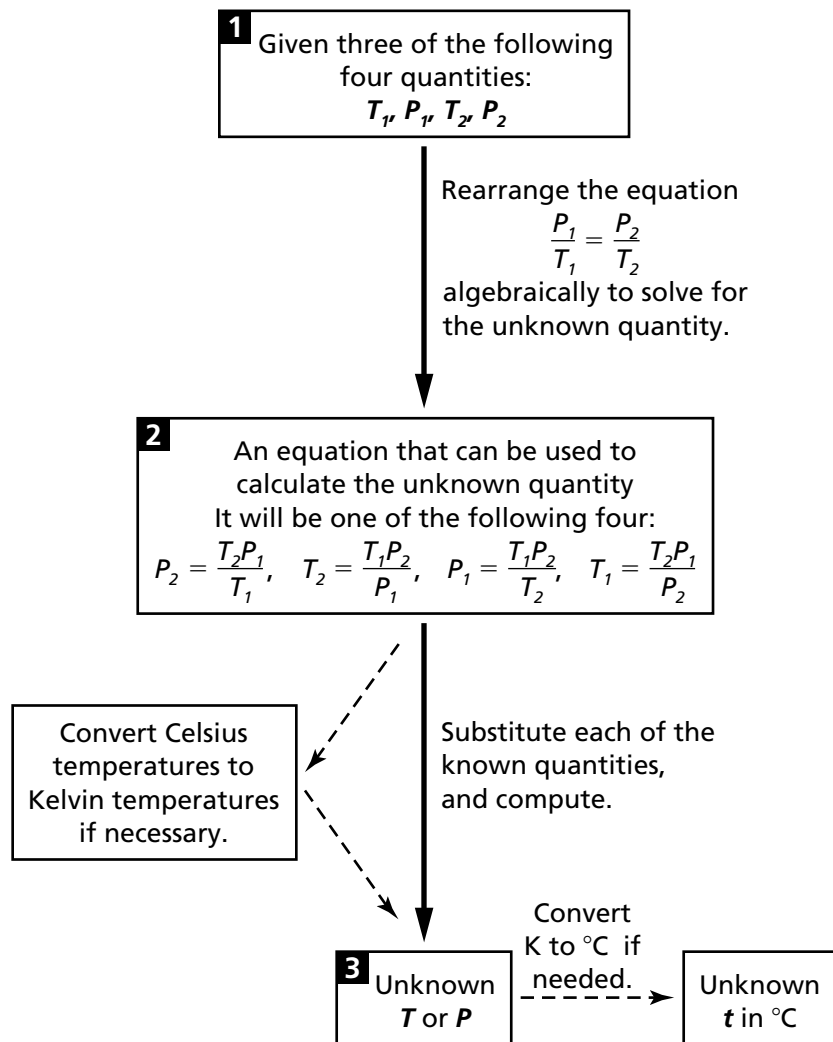
According to Gay-Lussac's law, when the temperature of a sample of gas *increases*, the pressure of the gas *increases* by the same factor. Therefore, doubling the temperature of a gas will double its pressure. Reducing the temperature of a gas to 75% of its original value will also reduce the pressure to 75% of its original value.

The expression $P/T = k$ means that the result of pressure divided by temperature is a constant, k , for any sample of gas. If this is true, then P/T under one set of conditions is equal to P/T for the same sample of gas under another set of conditions, as long as the volume remains constant.

Problem Solving *continued*

Gay-Lussac's law can be expressed by the following mathematical equation.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

General Plan for Solving Gay-Lussac's-Law Problems

Problem Solving *continued***Sample Problem 3**

A cylinder of gas has a pressure of 4.40 atm at 25°C. At what temperature in °C will it reach a pressure of 6.50 atm?

Solution**ANALYZE**

What is given in the problem? **the original pressure and temperature of the gas in the cylinder, and the new pressure of the sample**

What are you asked to find? **the temperature at which the gas reaches the specified pressure**

Items	Data
Original pressure, P_1	4.40 atm
Original temperature, t_1	25°C
Original Kelvin temperature, T_1	$(25 + 273)$ K = 298 K
New pressure, P_2	6.50 atm
New temperature, t_2	?°C
New Kelvin temperature, T_2	? K

PLAN

What steps are needed to calculate the new temperature of the gas?

Rearrange the Gay-Lussac's law equation to solve for T_2 , substitute known quantities, and calculate.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \xrightarrow[\text{insert data and solve for } T_2]{\substack{\text{to solve for } T_2, \text{ divide} \\ \text{both sides of the equation} \\ \text{by } P_2, \text{ and invert the} \\ \text{equality to isolate } T_2}} \frac{T_1 P_2}{P_1} = T_2$$

COMPUTE

Substitute data for the terms of the equation, and compute the result.

$$T_2 = \frac{T_1 P_2}{P_1} = \frac{298 \text{ K} \times 6.50 \text{ atm}}{4.40 \text{ atm}} = 440. \text{ K}$$

Convert back to °C.

$$440. \text{ K} = (440. - 273)^\circ\text{C} = 167^\circ\text{C}$$

EVALUATE

Are the units correct?

Yes; units canceled to give Kelvin temperature, which was converted to °C.

Problem Solving *continued*

Is the number of significant figures correct?

Yes; the number of significant figures is correct because the data were given to three significant figures.

Is the answer reasonable?

Yes; the pressure increases, so the temperature must also increase.

Practice

In each of the following problems, assume that the volume and molar quantity of gas do not change.

1. Calculate the unknown quantity in each of the following measurements of gases:

	P_1	T_1	P_2	T_2	
a.	1.50 atm	273 K	? atm	410 K	ans: 2.25 atm
b.	0.208 atm	300. K	0.156 atm	? K	ans: 225 K
c.	? kPa	52°C	99.7 kPa	77°C	ans: 92.6 kPa
d.	5.20 atm	?°C	4.16 atm	-13°C	ans: 52°C
e.	8.33×10^{-4} atm	-84°C	3.92×10^{-3} atm	?°C	ans: 616°C

Problem Solving *continued*

2. A cylinder of compressed gas has a pressure of 4.882 atm on one day. The next day, the same cylinder of gas has a pressure of 4.690 atm, and its temperature is 8°C. What was the temperature on the previous day in °C? **ans: 20.°C**
3. A mylar balloon is filled with helium gas to a pressure of 107 kPa when the temperature is 22°C. If the temperature changes to 45°C, what will be the pressure of the helium in the balloon? **ans: 115 kPa**

THE COMBINED GAS LAW

Look at the relationships among temperature, volume, and pressure of a gas that you have studied so far.

Boyle's law At constant temperature: $PV = k$	Charles's law At constant pressure: $\frac{V}{T} = k$	Gay-Lussac's law At constant volume: $\frac{P}{T} = k$
--	--	---

Notice in these proportions that while P and V are inversely proportional to each other, they are each directly proportional to temperature. These three gas laws can be combined in one *combined gas law*. This law can be expressed as follows.

$$\frac{PV}{T} = k$$

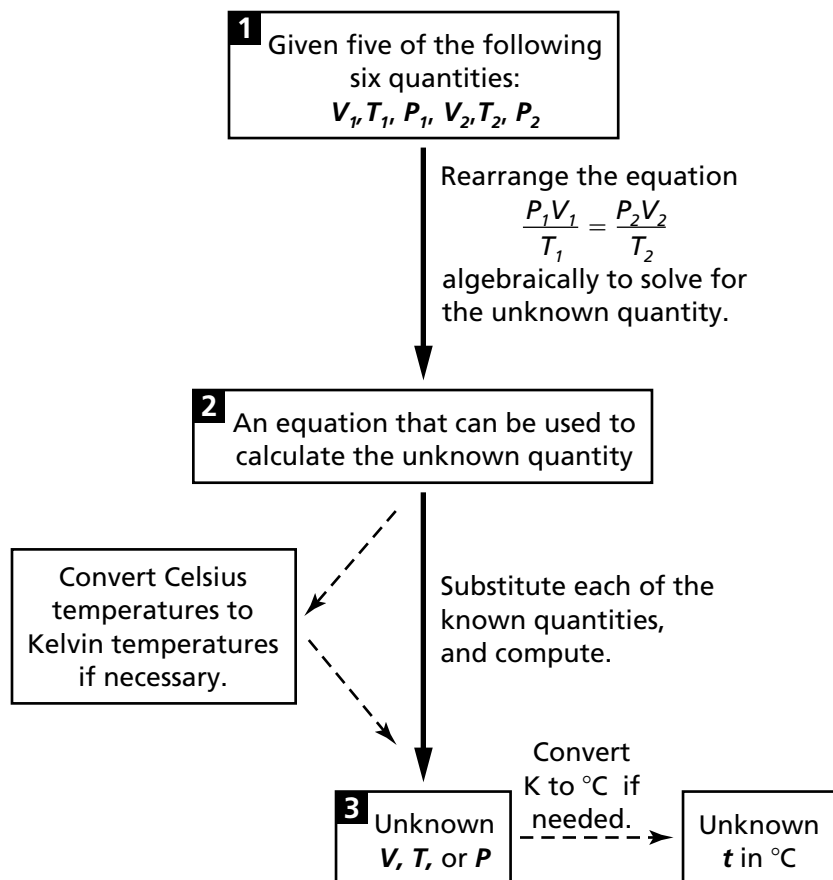
If PV/T equals a constant, k , then PV/T for a sample of gas under one set of conditions equals PV/T under another set of conditions, assuming the amount of gas remains the same.

Therefore, the combined gas law can be expressed by the following mathematical equation. This equation can be used to solve problems in which pressure,

Problem Solving *continued*

volume, and temperature of a gas vary. Only the molar quantity of the gas must be constant.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

General Plan for Solving Combined-Gas-Law Problems

Problem Solving *continued***Sample Problem 4**

A sample of hydrogen gas has a volume of 65.0 mL at a pressure of 0.992 atm and a temperature of 16°C. What volume will the hydrogen occupy at 0.984 atm and 25°C?

Solution**ANALYZE**

What is given in the problem? **the original volume, pressure, and temperature of the hydrogen, and the new pressure and temperature of the hydrogen**

What are you asked to find? **the volume at the new temperature and pressure**

Items	Data
Original volume, V_1	65.0 mL
Original pressure, P_1	0.992 atm
Original temperature, t_1	16°C
Original Kelvin temperature, T_1	$(16 + 273) \text{ K} = 289 \text{ K}$
New volume, V_2	? mL
New pressure, P_2	0.984 atm
New temperature, t_2	25°C
New Kelvin temperature, T_2	$(25 + 273) \text{ K} = 298 \text{ K}$

PLAN

What steps are needed to calculate the new volume of the gas?

Rearrange the combined gas law equation to solve for V_2 , substitute known quantities, and calculate.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \xrightarrow[\text{insert data and solve for } V_2]{\substack{\text{to solve for } V_2, \\ \text{multiply both sides of} \\ \text{the equation by } T_2/P_2 \text{ to} \\ \text{isolate } V_2}} \frac{T_2 P_1 V_1}{P_2 T_1} = V_2$$

COMPUTE

Substitute data for the terms of the equation, and compute the result.

$$V_2 = \frac{T_2 P_1 V_1}{P_2 T_1} = \frac{298 \text{ K} \times 0.992 \text{ atm} \times 65.0 \text{ mL H}_2}{0.984 \text{ atm} \times 289 \text{ K}} = 67.6 \text{ mL H}_2$$

EVALUATE

Are the units correct?

Yes; units canceled to give mL of H₂.

Problem Solving *continued*

Is the number of significant figures correct?

Yes; the number of significant figures is correct because data were given to three significant figures.

Is the answer reasonable?

Yes; the temperature increases, and the pressure decreases, both of which have the effect of making the volume larger.

Practice

In each of the following problems, it is assumed that the molar quantity of gas does not change.

1. Calculate the unknown quantity in each of the following measurements of gases.

	P_1	V_1	T_1	P_2	V_2	T_2	
a.	99.3 kPa	225 mL	15°C	102.8 kPa	? mL	24°C	ans: 224 mL
b.	0.959 atm	3.50 L	45°C	? atm	3.70 L	37°C	ans: 0.884 atm
c.	0.0036 atm	62 mL	373 K	0.0029 atm	64 mL	? K	ans: 310 K
d.	100. kPa	43.2 mL	19°C	101.3 kPa	? mL	0°C	ans: 39.9 mL

2. A student collects 450. mL of $\text{HCl}(g)$ hydrogen chloride gas at a pressure of 100. kPa and a temperature of 17°C. What is the volume of the HCl at 0°C and 101.3 kPa? **ans: 418 mL**

Problem Solving *continued***DALTON'S LAW OF PARTIAL PRESSURES**

Air is a mixture of approximately 78% N₂, 20% O₂, 1% Ar, and 1% other gases by volume, so at any barometric pressure 78% of that pressure is exerted by nitrogen, 20% by oxygen, and so on. This phenomenon is described by Dalton's law of partial pressures, which says that *the total pressure of a mixture of gases is equal to the sum of the partial pressures of the component gases*. It can be stated mathematically as follows.

$$P_{Total} = P_{Gas\ 1} + P_{Gas\ 2} + P_{Gas\ 3} + P_{Gas\ 4} + \dots$$

A common method of collecting gas samples in the laboratory is to bubble the gas into a bottle filled with water and allow it to displace the water. When this technique is used, however, the gas collected in the bottle contains a small but significant amount of water vapor. As a result, the pressure of the gas that has displaced the liquid water is the sum of the pressure of the gas plus the vapor pressure of water at that temperature. The vapor pressures of water at various temperatures are given in **Table 1** below.

TABLE 1 VAPOR PRESSURE OF WATER

Temp in °C	Vapor pressure in kPa	Temp in °C	Vapor pressure in kPa	Temp in °C	Vapor pressure in kPa
10	1.23	17	1.94	24	2.98
11	1.31	18	2.06	25	3.17
12	1.40	19	2.19	26	3.36
13	1.50	20	2.34	27	3.57
14	1.60	21	2.49	28	3.78
15	1.71	22	2.64	29	4.01
16	1.82	23	2.81	30	4.25

$$P_{Total} = P_{Gas} + P_{H_2O\ vapor}$$

To find the true pressure of the gas alone, the pressure of the water vapor must be subtracted from the total pressure.

$$P_{Gas} = P_{Total} - P_{H_2O\ vapor}$$

You can use this corrected pressure in gas-law calculations to determine what the volume of the gas alone would be.

Problem Solving *continued***Sample Problem 5**

A student collects oxygen gas by water displacement at a temperature of 16°C. The total volume is 188 mL at a pressure of 92.3 kPa. What is the pressure of oxygen collected?

Solution**ANALYZE**

What is given in the problem? **the total pressure, the fact that the gas was collected by water displacement, and the temperature**

What are you asked to find? **the pressure of oxygen collected**

Items	Data
Total pressure, P_{total}	92.3 kPa
Temperature	16°C
Vapor pressure of water at 16°C, $P_{H_2O}^*$	1.82 kPa
Pressure of collected O_2 , P_{O_2}	? kPa

* determined from Table 1

PLAN

What step is needed to calculate the pressure of the oxygen collected?

Use Dalton's law of partial pressures to determine the pressure of the oxygen alone in the container.

Use the following equation to determine the pressure of oxygen alone.

$$P_{O_2} = \overset{\text{given}}{P_{total}} - \overset{\text{from Table 1}}{P_{H_2O \text{ vapor}}}$$

COMPUTE

$$P_{O_2} = P_{total} - P_{H_2O \text{ vapor}} = 92.3 \text{ kPa} - 1.82 \text{ kPa} = 90.5 \text{ kPa}$$

EVALUATE

Are the units correct?

Yes; the units should be kPa.

Is the number of significant figures correct?

Yes; the number of significant figures is correct because the total pressure was given to one decimal place.

Is the answer reasonable?

Yes; the pressure of the collected oxygen and the water vapor add up to the total pressure of the system.

Problem Solving *continued*

Practice

1. A chemist collects a sample of $\text{H}_2\text{S}(g)$ over water at a temperature of 27°C . The total pressure of the gas that has displaced a volume of 15 mL of water is 207.33 kPa. What is the pressure of the H_2S gas collected? **ans: 203.76 kPa**

Problem Solving *continued***Sample Problem 6**

Chlorine gas is collected by water displacement at a temperature of 19°C. The total volume is 1.45 L at a pressure of 156.5 kPa. Assume that no chlorine gas dissolves in the water. What is the volume of chlorine corrected to STP?

Solution**ANALYZE**

What is given in the problem? **the total initial volume, pressure, and temperature; the fact that the gas was collected by water displacement; and the final temperature and pressure of the chlorine**

What are you asked to find? **the volume of chlorine at STP**

Items	Data
Total original volume, V_1	1.45 L
Total original pressure, P_{total}	156.5 kPa
Original temperature, t_1	19°C
Original Kelvin temperature, T_1	(19 + 273) K = 292 K
Vapor pressure of water at 19°C, P_{H_2O}	2.19 kPa
Pressure of collected Cl_2 , P_1	? kPa
New volume, V_2	? mL
New pressure, P_2	101.3 kPa
New temperature, t_2	0°C
New Kelvin temperature, T_2	273 K

PLAN

What steps are needed to calculate the volume of the chlorine at STP?

Use Dalton's law of partial pressures to determine the pressure of the chlorine alone in the container. Use the combined gas law to solve for the new volume.

$$P_1 = \overset{\text{given}}{P_{total}} - \overset{\text{from table}}{P_{H_2O \text{ vapor}}}$$

Calculate the volume of chlorine at STP using the following equation.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Solve for V_2 .

$$\frac{\overset{\text{calculated}}{\underset{\text{above}}{P_1}} \overset{\text{given}}{T_2 V_1}}{\underset{\text{given}}{P_2 T_1}} = V_2$$

Problem Solving *continued***COMPUTE**

Determine the pressure of chlorine alone.

$$P_1 = P_{total} - P_{H_2O \text{ vapor}} = 156.5 \text{ kPa} - 2.19 \text{ kPa} = 154.3 \text{ kPa}$$

Calculate the volume of Cl_2 at STP.

$$V_2 = \frac{154.3 \text{ kPa} \times 273 \text{ K} \times 1.45 \text{ L}}{101.3 \text{ kPa} \times 292 \text{ K}} = 2.06 \text{ L}$$

EVALUATE

Are the units correct?

Yes; the units canceled leaving the correct units, L.

Is the number of significant figures correct?

Yes; the number of significant figures is correct because the data were given to a minimum of three significant figures.

Is the answer reasonable?

Yes; the pressure decreased, so the volume had to increase.

Practice

In each of the following problems, assume that the molar quantity of gas does not change.

1. Some hydrogen is collected over water at 10°C and 105.5 kPa pressure. The total volume of the sample was 1.93 L . Calculate the volume of the hydrogen corrected to STP. **ans: 1.92 L**

2. One student carries out a reaction that gives off methane gas and obtains a total volume by water displacement of 338 mL at a temperature of 19°C and a pressure of 0.9566 atm . Another student does the identical experiment on another day at a temperature of 26°C and a pressure of 0.989 atm . Which student collected more CH_4 ? **ans: The second student collected more CH_4 .**

Problem Solving *continued***Additional Problems**

In each of the following problems, assume that the molar quantity of gas does not change.

1. Calculate the unknown quantity in each of the following measurements of gases.

	P_1	V_1	P_2	V_2
a.	127.3 kPa	796 cm ³	? kPa	965 cm ³
b.	7.1×10^2 atm	? mL	9.6×10^{-1} atm	3.7×10^3 mL
c.	? kPa	1.77 L	30.79 kPa	2.44 L
d.	114 kPa	2.93 dm ³	4.93×10^4 kPa	? dm ³
e.	1.00 atm	120. mL	? atm	97.0 mL
f.	0.77 atm	3.6 m ³	1.90 atm	? m ³

2. A gas cylinder contains 0.722 m³ of hydrogen gas at a pressure of 10.6 atm. If the gas is used to fill a balloon at a pressure of 0.96 atm, what is the volume in m³ of the filled balloon?
3. A weather balloon has a maximum volume of 7.50×10^3 L. The balloon contains 195 L of helium gas at a pressure of 0.993 atm. What will be the pressure when the balloon is at maximum volume?
4. A rubber ball contains 5.70×10^{-1} dm³ of gas at a pressure of 1.05 atm. What volume will the gas occupy at 7.47 atm?
5. Calculate the unknown quantity in each of the following measurements of gases.

	V_1	T_1	V_2	T_2
a.	26.5 mL	? K	32.9 mL	290. K
b.	? dm ³	100.°C	0.83 dm ³	-9°C
c.	7.44×10^4 mm ³	870.°C	2.59×10^2 mm ³	?°C
d.	5.63×10^{-2} L	132 K	? L	190. K
e.	? cm ³	243 K	819 cm ³	409 K
f.	679 m ³	-3°C	? m ³	-246°C

6. A bubble of carbon dioxide gas in some unbaked bread dough has a volume of 1.15 cm³ at a temperature of 22°C. What volume will the bubble have when the bread is baked and the bubble reaches a temperature of 99°C?
7. A perfectly elastic balloon contains 6.75 dm³ of air at a temperature of 40.°C. What is the temperature if the balloon has a volume of 5.03 dm³?

Problem Solving *continued*

8. Calculate the unknown quantity in each of the following measurements of gases.

	P_1	T_1	P_2	T_2
a.	0.777 atm	?°C	5.6 atm	192°C
b.	152 kPa	302 K	? kPa	11 K
c.	? atm	-76°C	3.97 atm	27°C
d.	395 atm	46°C	706 atm	?°C
e.	? atm	-37°C	350. atm	2050°C
f.	0.39 atm	263 K	0.058 atm	? K

9. A 2 L bottle containing only air is sealed at a temperature of 22°C and a pressure of 0.982 atm. The bottle is placed in a freezer and allowed to cool to -3°C. What is the pressure in the bottle?
10. The pressure in a car tire is 2.50 atm at a temperature of 33°C. What would the pressure be if the tire were allowed to cool to 0°C? Assume that the tire does not change volume.
11. A container filled with helium gas has a pressure of 127.5 kPa at a temperature of 290. K. What is the temperature when the pressure is 3.51 kPa?
12. Calculate the unknown quantity in each of the following measurements of gases.

	P_1	V_1	T_1	P_2	V_2	T_2
a.	1.03 atm	1.65 L	19°C	0.920 atm	? L	46°C
b.	107.0 kPa	3.79 dm ³	73°C	? kPa	7.58 dm ³	217°C
c.	0.029 atm	249 mL	? K	0.098 atm	197 mL	293 K
d.	113 kPa	? mm ³	12°C	149 kPa	3.18 × 10 ³ mm ³	-18°C
e.	1.15 atm	0.93 m ³	-22°C	1.01 atm	0.85 m ³	?°C
f.	? atm	156 cm ³	195 K	2.25 atm	468 cm ³	584 K

13. A scientist has a sample of gas that was collected several days earlier. The sample has a volume of 392 cm³ at a pressure of 0.987 atm and a temperature of 21°C. On the day the gas was collected, the temperature was 13°C and the pressure was 0.992 atm. What volume did the gas have on the day it was collected?
14. Hydrogen gas is collected by water displacement. Total volume collected is 0.461 L at a temperature of 17°C and a pressure of 0.989 atm. What is the pressure of dry hydrogen gas collected?

Problem Solving *continued*

- 15.** One container with a volume of 1.00 L contains argon at a pressure of 1.77 atm, and a second container of 1.50 L volume contains argon at a pressure of 0.487 atm. They are then connected to each other so that the pressure can become equal in both containers. What is the equalized pressure? Hint: Each sample of gas now occupies the total space. Dalton's law of partial pressures applies here.
- 16.** Oxygen gas is collected over water at a temperature of 10.°C and a pressure of 1.02 atm. The volume of gas plus water vapor collected is 293 mL. What volume of oxygen at STP was collected?
- 17.** A 500 mL bottle is partially filled with water so that the total volume of gases (water vapor and air) remaining in the bottle is 325 cm³, measured at 20.°C and 101.3 kPa. The bottle is sealed and taken to a mountaintop where the pressure is 76.24 kPa and the temperature is 10°C. If the bottle is upside down and the seal leaks, how much water will leak out? The key to this problem is to determine the pressure in the 325 cm³ space when the bottle is at the top of the mountain.
- 18.** An air thermometer can be constructed by using a glass bubble attached to a piece of small-diameter glass tubing. The tubing contains a small amount of colored water that rises when the temperature increases and the trapped air expands. You want a 0.20 cm³ change in volume to equal a 1°C change in temperature. What total volume of air at 20.°C should be trapped in the apparatus below the liquid?
- 19.** A sample of nitrogen gas is collected over water, yielding a total volume of 62.25 mL at a temperature of 22°C and a total pressure of 97.7 kPa. At what pressure will the nitrogen alone occupy a volume of 50.00 mL at the same temperature?
- 20.** The theoretical yield of a reaction that gives off nitrogen trifluoride gas is 844 mL at STP. What total volume of NF₃ plus water vapor will be collected over water at 25°C and a total pressure of 1.017 atm?
- 21.** A weather balloon is inflated with 2.94 kL of helium at a location where the pressure is 1.06 atm and the temperature is 32°C. What will be the volume of the balloon at an altitude where the pressure is 0.092 atm and the temperature is -35°C?
- 22.** The safety limit for a certain can of aerosol spray is 95°C. If the pressure of the gas in the can is 2.96 atm when it is 17°C, what will the pressure be at the safety limit?
- 23.** A chemistry student collects a sample of ammonia gas at a temperature of 39°C. Later, the student measures the volume of the ammonia as 108 mL, but its temperature is now 21°C. What was the volume of the ammonia when it was collected?
- 24.** A quantity of CO₂ gas occupies a volume of 624 L at a pressure of 1.40 atm. If this CO₂ is pumped into a gas cylinder that has a volume of 80.0 L, what pressure will the CO₂ exert on the cylinder?