Chapter 12

Gases

12.1 Structure of matter

OALG 12.1.1 Observe and explain

Equipment: 90% isopropyl alcohol, strips of paper.

Dip a piece of paper in rubbing alcohol (or rub the paper with alcohol) and place it on a table. Observe what happens. Describe your observations in simple words. Note that you should observe the paper with rubbing alcohol for several minutes. Alternatively, you may view the experiment by watching the following video.
[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-12-1-1]
One of your friends described theirs in the following way: "The alcohol disappeared gradually". What do you need to assume about the internal composition of alcohol to explain that the alcohol disappeared gradually rather than all at once?

OALG 12.1.2 Develop multiple explanations

Mindy, Marc, Alex, and Nina are working on Activity 12.1.1. They agree that alcohol must be made of small parts to enable the paper to *gradually* dry. However, they disagree on the mechanism that allows these small parts to disappear. Brainstorm possible reasons for how and why the small parts of alcohol disappeared from the paper. Come up with at least four different mechanisms.

OALG 12.1.3 Test multiple explanations

Below are four testing experiments that Mindy, Marc, Alex, and Nina decided to perform. *Predict* the outcome of each experiment described below based on *each* of the four mechanisms you came up with in Activity 12.1.2. (For example, if the small parts soaked into the table through the paper and we hold the paper between our fingers when drying, then the paper should not dry—the table is not there to absorb the alcohol.) Remember that *each* testing experiment needs four predicted outcomes, one based on each mechanism.
Predict the outcome of each experiment below using all four explanations:
a. Hold the paper that has been dipped in alcohol between your fingers without putting it on the table while it is drying.

b. Weigh the paper before the experiment, when it is wet, and then again when it is dry.
[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-12-1-3a]
c. Take two identical pieces of paper and put the same amount of alcohol on each. Then, place one piece of paper under a vacuum jar and the other one just outside the jar.
[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-12-1-3b]
d. Pour some alcohol into a beaker. Place a small drop of colored alcohol (alcohol to which you added some dye and stirred to mix) into the beaker with clear alcohol, but do not stir it.
[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-12-1-3c]

After you have your predicted outcomes on a whiteboard, perform the experiments (or watch the videos of them) and decide which experimental outcomes are consistent with which predictions. Then, make judgements as to which mechanisms you have gained confidence in and which ones you can reject." Check your reasoning with the reasoning in Testing Experiment Table 12.1 on page 353 in the textbook.

OALG 12.1.4 Explain

The only explanation for drying alcohol that could not be rejected by testing experiments was the explanation that alcohol consists of tiny particles (called *molecules*) that move randomly. How do you need to modify this explanation to account for the fact that not all of the particles leave instantly?

OALG 12.1.5 Represent and reason

Imagine that you have eyes that can see the particles of air in the room. Draw a picture representing the behavior of several particles as they move through the room. Think of their possible collisions and how the collisions will affect the directions of their motion and the magnitudes of their speeds. Compare your picture with Figure 12.2 (a) on page 354 in the textbook.

OALG 12.1.6 Observe and analyze

In this experiment https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-12-1-6 we used a pipette to put 4 drops of oil mixed with benzene on the surface of water. As the drops spread, benzene evaporates and only oil remains in the droplets.
a. Use the data that you can collect from the video to estimate the size of one molecule of oil. Note that the numbers on the ruler show centimeters.
b. State what assumptions you made to make your estimate.
c. Compare your estimate with the known values for the size of oil molecules.

OALG 12.1.7 Read and interrogate
Read and interrogate Section 12.1 in the textbook and answer Review Question 12.1.

OALG 12.1.8 Practice
Answer Questions 1 and 2 on page 380 in the textbook.

12.2 Pressure, density, and the mass of particles

OALG 12.2.1 Observe and explain
Equipment: a balloon.
Blow up a balloon and carefully observe how its shape changes during the process. Use the idea of moving particles to explain why it expands when you blow air into it. Explain why the balloon does not expand any more when you stop blowing. Describe an experiment you can perform to test your explanation(s).

OALG 12.2.2 Test multiple explanations
In the experiment in the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-egv2e-testing-the-model-of-moving-gas-particles-pushing-on-the-surface], a partially inflated (and tied) balloon will be placed in the bell-jar and the air will be removed by the vacuum pump. Use each of the ideas you came up with in Activity 12.2.1 to make predictions about what the balloon will do when the air is pumped out of the bell-jar (state one prediction for each idea being tested). Write down your predicted outcome(s). Then watch the experiment. Which of your predictions was consistent with the experimental outcome? What is your judgment on each of the ideas you were testing?

OALG 12.2.3 Explain
Explain the observed phenomena listed below by using the physical quantity of pressure. In your explanations also use a simplified model that gases are made of small particles with empty space between them that move randomly and collide like hard billiard balls with the walls of the container.

a. A balloon keeps a rounded shape when filled with air.
b. When you take an inflated balloon into the mountains, it becomes bigger.
c. When you pump air into a rubber raft, it becomes bigger.

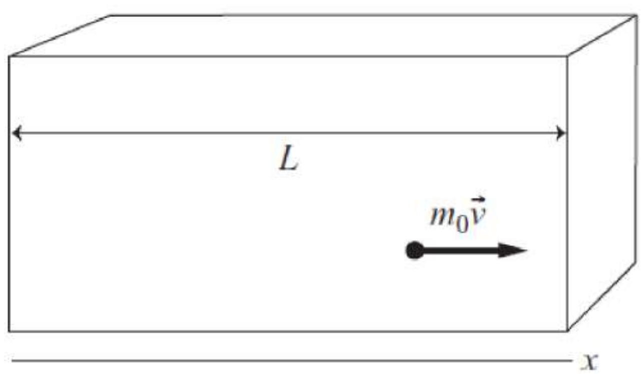
OALG 12.2.4 Read and interrogate
Read and interrogate Section 12.2 in the textbook and answer Review Question 12.2.

OALG 12.2.5 Practice
Solve Problems 2, 4, and 7 on page 381 in the textbook.

12.3 Quantitative analysis of ideal gas

OALG 12.3.1 Represent and reason
Imagine that a particle moves horizontally until it hits a vertical wall. Assume that it is an elastic collision (after the collision, the speed of the molecule is the same as before the collision, but in the opposite direction) and the motion of the particle obeys Newton's laws. Answer the following questions to analyze the motion of a single particle:
a. Draw an arrow representing the momentum of the particle before the collision.
b. Draw an arrow representing the momentum of the particle after the collision.
c. Draw a momentum change arrow.
d. Draw an arrow representing the force exerted by the wall on the particle.
e. Draw an arrow representing the force exerted by the particle on the wall.

OALG 12.3.2 Derive
Imagine that the gas inside a container has such low density that its particles almost never collide with each other; they collide only with the walls of the container. Assume a model of the gas as tiny moving billiard balls obeying Newton's laws. We wish to derive an expression for the pressure that the gas exerts on the walls of the container.



a. Start with one of the "balls" of mass m_0 traveling at speed v parallel to the x-axis at speed v_x. The ball bounces back and forth between the two walls of the container that are separated by distance L and that are perpendicular to the x-axis. Use your knowledge of the impulse–momentum principle to show that the impulse of the ball, as a result of one collision against one wall, has magnitude $2m_0v_x$.

b. Show that the time interval between impacts for the one ball against that same wall is $2L/v_x$.

c. Use the results from parts **a.** and **b.** to show that the average force that these collisions exert on the wall over the time of several passages of the ball (F_{avg}) is $m_0 v_x^2/L$ and that the average pressure that N balls, or particles, will exert on a wall is $P = N(m_0 v_x^2)/L^3$.

d. The v_x^2 in the expression for average pressure in part **c.** should more properly be designated as the average of the square of the x-components of the velocities $\overline{v_x^2}$. The N particles inside the container move at different speeds and in different directions. How is $\overline{v_x^2}$ related to the average of the square of the speeds $\overline{v^2}$? *Hint:* Assume that one-third of the particles move in each of the three directions (x, y, z).

e. Now consider the pressure that these particles exert on the walls of the container. Show that the pressure that they exert is equal to $P = \frac{1}{3}\frac{N}{V}\left(m_0 \overline{v^2}\right)$.

f. Read and interrogate Section 12.3 in the textbook and compare your derivation to the one in the book.

OALG 12.3.3 Reason

Answer the following questions to decide whether the expression for the pressure $P = \frac{1}{3}\frac{N}{V}\left(m_0 \overline{v^2}\right)$ of an ideal gas makes sense (where V = volume).

a. Why would you expect the pressure to depend on the total number of particles N in the container? Explain.

b. Why would you expect the pressure to depend on the average speed of the particles squared? Explain.

c. When we derived the expression $P = \frac{1}{3}\frac{N}{V}\left(m_0 \overline{v^2}\right)$, we neglected the size of the particles and the fact that they interact with each other. Discuss whether the pressure of a real gas for which these assumptions are not true should be larger or smaller than the pressure of the ideal gas calculated according to the derived expression. The gases are in containers of the same volume and have the same number of particles with the same average of the square of their speeds.

OALG 12.3.4 Practice

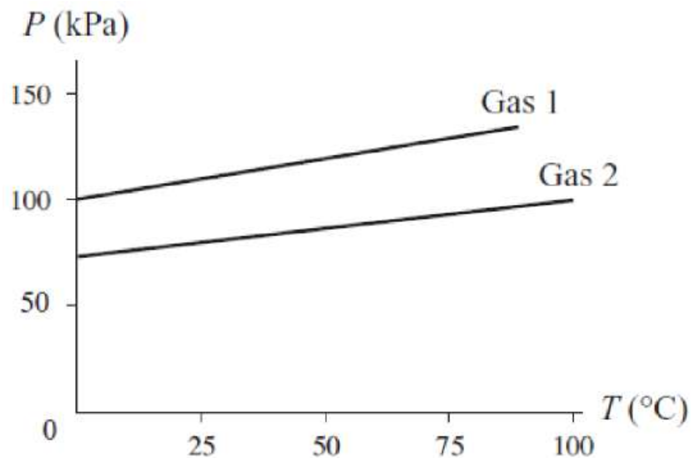
Answer Questions 5 and 7 on page 380 and solve Problems 10 and 16 on page 381 in the textbook.

12.4 Temperature

OALG 12.4.1 Observe and explain

A sealed metal container with a low-density gas is successively placed in baths of water at different temperatures. Then, a different gas is placed in the container and the procedure is repeated. Data related to the pressure and the temperature of the gases inside the containers are shown in the graph below.

a. Find the lowest possible temperature that the two gases can have. What assumptions did you make?



b. Use the lowest temperature value you determined in part **a**. to make a new temperature scale with the same temperature interval as in the Celsius scale, but with the new zero point that you determined. This new scale is called the *absolute temperature scale*.

c. Use the expression in Activity 12.3.3, part **c**., $P = \frac{1}{3}\frac{N}{V}\left(m_0\overline{v^2}\right)$, to discuss how the temperature on the absolute scale is related to the average kinetic energy of gas particles.

OALG 12.4.2 Reason

In the late 19th century, scientist John Loschmidt found that there were 2.69×10^{19} molecules of any type of gas in 1 cm^3 when at $0\ ^\circ C$ and at atmospheric pressure. Using proportional reasoning, determine the volume of 1 mol of any gas under the same conditions.

OALG 12.4.3 Explain

If we take different containers, each with 1 mol of different gases (for example, nitrogen, oxygen, and helium), and place each container in melting ice, we find that the ratio $\frac{PV}{N}$ is the same for all gases. If we place the same gases in a container with hot water, the ratio $\frac{PV}{N}$ is different from the value it was before, but again it is the same for all three gases. What is the meaning of this ratio? To answer this question, find the units of the ratio (the number does not have units) and think of when we encountered the same ratio before. After you decide on the units, think about why the ratio is the same when gas containers are placed in the same medium.

OALG 12.4.4 Reason

The table below represents data collected when a constant-volume metal container with 1 mol of helium ($N = N_A = 6.02\times10^{23}$ molecules) is placed in baths of very different temperatures. If we assume that the ratio $\frac{PV}{N}$ is proportional to the absolute temperature of the gas (i.e., $\frac{PV}{N} = kT$), we can find the coefficient of proportionality, *k*. Solve for the proportionality constant *k* for the two sets of data.

Known physical quantities	$\frac{PV}{NT} = k$	**Known physical quantities**	$\frac{PV}{NT} = k$
$P = 1.01\times 10^5\ \text{N/m}^2$	$k =$	$P = 1.38\times 10^5\ \text{N/m}^2$	$k =$
$T = 273$ K (melting ice)		$T = 373$ K (boiling water)	
$V = 22.4\times 10^{-3}\ \text{m}^3$		$V = 22.4\times 10^{-3}\ \text{m}^3$	

a. Is the value of *k* independent of gas temperature? Explain.
b. Find a relationship between the absolute temperature of the gas and the average kinetic energy of its particles. *Hint:* Use the results of Activities 12.3.2 and 12.3.3 to help.
c. Find the total kinetic energy of all the particles of helium at the two different temperatures.
d. Does the absolute temperature of the helium depend on the total number of particles in the container? Explain.
e. Does the total thermal energy due to the motion of helium particles depend on the number of particles in the container? Explain.
f. Read and interrogate Section 12.4 in the textbook.
g. Compare and contrast the following two physical quantities: absolute temperature and thermal energy.

Note that in the future we will use the subscript B with the coefficient *k:* k_B. The letter B denotes Ludwig Boltzmann, the physicists after whom the constant is named.

OALG 12.4.5 Reason

The following two mathematical representations are fairly similar: $PV = \frac{1}{3}Nm\overline{v^2}$ and $PV = Nk_BT$. How do these representations differ in terms of what they describe and the possibility of measuring the quantities that they relate?

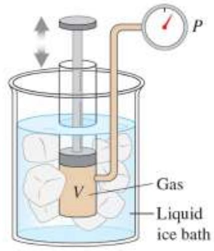
OALG 12.4.6 Practice

Solve Problems 23 and 24 on page 382 in the textbook.

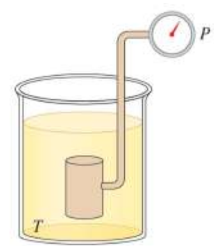
12.5 Testing the ideal gas law

OALG 12.5.1 Test an idea

How can you use the mathematical representation $PV = Nk_BT$ to make quantitative predictions about the following processes occurring to a fixed mass of an ideal gas? The initial conditions of the gas P_1, V_1, T_1 are known and you need to show how P_2, V_2, T_2 are related to their initial conditions



a. The gas is inside a container with a movable piston. The container is placed in a bath of constant temperature T_1. We push the piston slowly so that the temperature of the gas is always the same as the bath. Both the pressure and the volume change (see the figure on the right).



b. The gas is inside a container with a fixed volume V_1. The container is placed in different-temperature baths. Both the pressure and the temperature change (see the upper figure on the right).

c. The gas is inside a container with a movable frictionless piston. The frictionless piston in the gas container can move freely up and down, keeping the pressure P_1 constant. The pressure inside the container is the sum of the constant atmospheric pressure and the pressure exerted by the object on top of the piston. Both the gas volume and the temperature change (see the lower figure on the right).

d. Write down your predictions for the processes in parts **a.-c.** and compare them to the predictions and experimental outcomes described in Testing Experiment Table 12.5 in the textbook. What are the similarities in your predictions? What are the differences?

OALG 12.5.2 Analyze

You have an air-filled glass jar (height 11 cm), which is tightly closed and attached to a gas pressure sensor (see the photo on the right).

The glass jar is initially immersed in a water bath of temperature $T_1 = 23°C.$ Then you successively immerse the glass jar in water baths of temperatures $T_2 = 1°C$ and $T_3 = 98°C$ and record the corresponding gas pressure once it reaches a stable value:

$$T_1 = 23°C \qquad P_1 = 98.8 \text{ kPa}$$
$$T_2 = 1°C \qquad P_2 = 90.6 \text{ kPa}$$
$$T_3 = 98°C \qquad P_3 = 122.6 \text{ kPa}$$

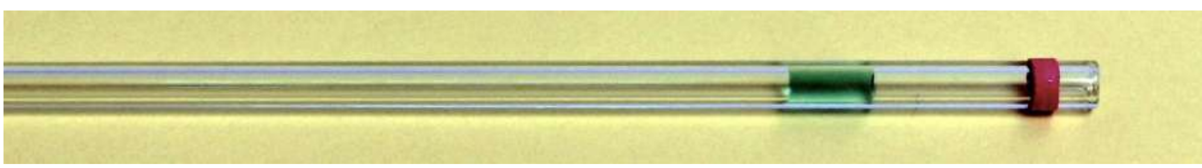
Assume the air in the jar can be modeled as an ideal gas.

a. Estimate the number of moles of air in the glass jar. (*Hint:* estimate the missing data from the photo).

b. Plot three points in a pressure-versus-temperature graph for the equilibrium states reached during the experiment. Based on this graph, estimate the temperature of absolute zero (in degrees Celsius).

12.5.3 Analyze

You have an air-filled glass tube with an inner diameter of 3.0 mm. One end is sealed and the other end is closed by a water drop that can move freely (see the photo below).



The tube is initially immersed in a water bath of temperature $T_1 = 59\ °C.$ The length of the air column in the tube (between the sealed end of the tube and the lower surface of the water drop) is 273 mm. You successively immerse the glass tube in water baths of temperatures $T_2 = 6\ °C$ and $T_3 = 26\ °C$ and record the length of the corresponding air column (you should wait until the water drop stops moving). All three steps of the experiment are shown in the figures below.

You obtained the following data:

$$T_1 = 59°\text{C} \qquad L_1 = 273 \text{ mm}$$
$$T_2 = 6°\text{C} \qquad L_2 = 227 \text{ mm}$$
$$T_3 = 26°\text{C} \qquad L_3 = 239 \text{ mm}$$

Answer the following questions (assume the air in the glass tube can be modeled as an ideal gas).

a. Estimate the number of moles of air in the glass tube. Indicate any additional assumptions that you made.

b. Plot three points in a volume-versus-temperature graph for the equilibrium states reached during the experiment. Based on this graph, estimate the temperature of absolute zero (in degrees Celsius).

OALG 12.5.4 Represent and reason

The graph on the right describes a process occurring in an ideal gas.

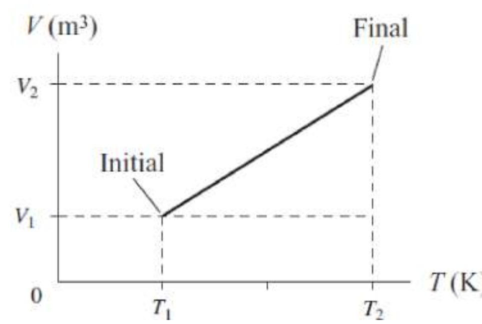
a. Describe the process macroscopically.

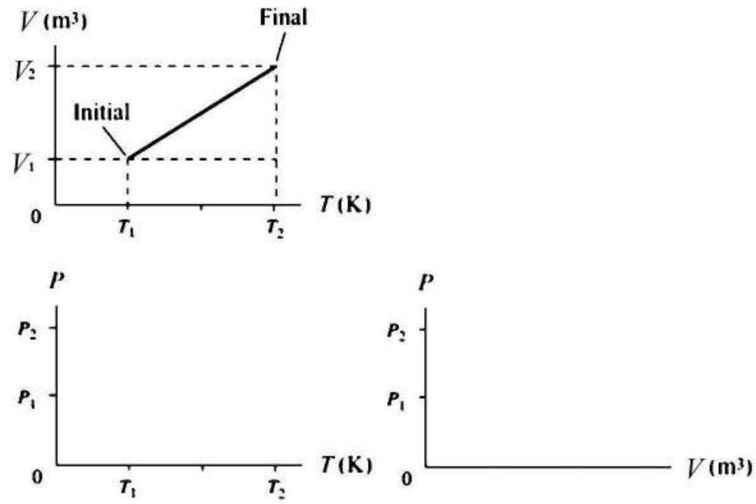
b. Describe how you can carry out the process experimentally.

c. Represent the process mathematically.

d. Explain the process microscopically.

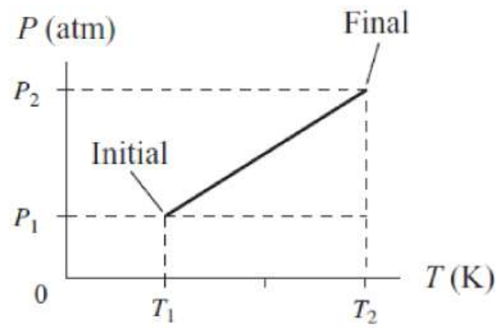
e. Represent the same process in the P-versus-T and P-versus-V graphs below. Notice how the graphs are positioned; this alignment allows you to keep the scale for the same variable on different graphs. Use Table 12.6 on page 370 in the textbook for help.





OALG 12.5.5 Represent and reason

The *P*-versus-*T* graph to the right describes a real process.



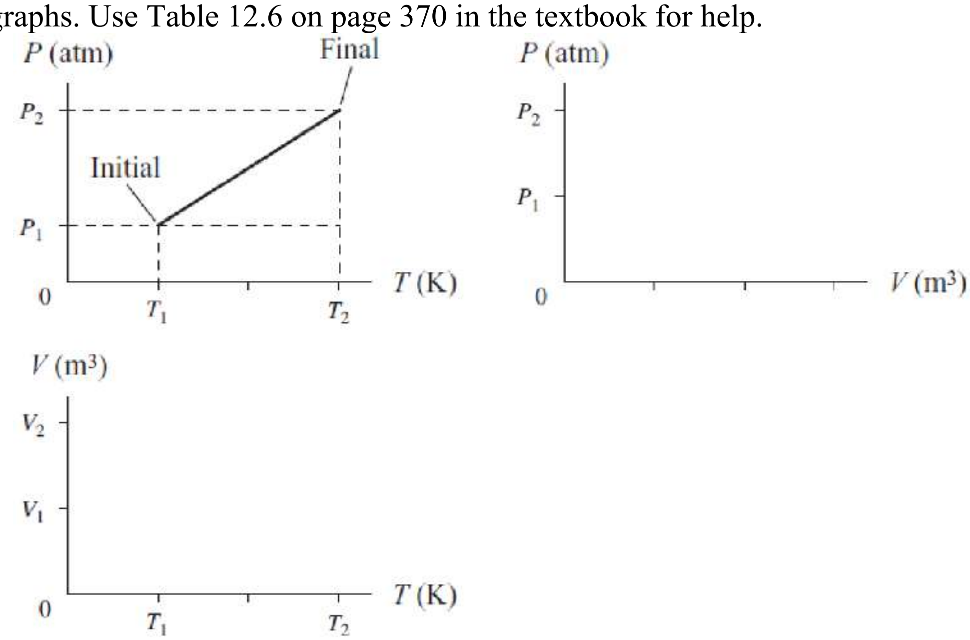
a. Describe the process macroscopically.

b. Describe how you can carry out the process experimentally.

c. Represent the process mathematically.

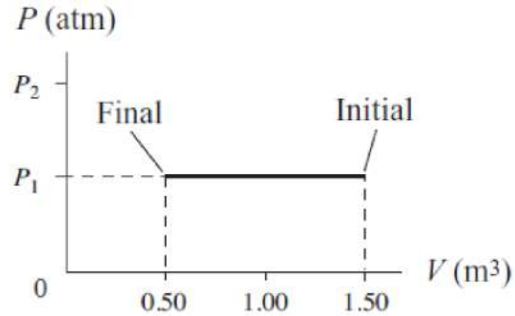
d. Explain the process microscopically.

e. Now represent the same process in the *P*-versus-*V* and *V*-versus-*T* graphs below. Notice how the graphs are positioned; this alignment allows you to keep the scale for the same variable on different graphs. Use Table 12.6 on page 370 in the textbook for help.



OALG 12.5.6 Represent and reason

Find out everything you can about the process represented in the graph below. Make a list of physical quantities that you can determine.



12.5.7 Read and interrogate

Read and interrogate Section 12.5 in the textbook and explain how gas laws account for the process of breathing.

OALG 12.5.8 Practice

Answer Questions 9-13 on page 380 and solve Problems 29, 30, 36, 37, 42, and 48 on pages 382 – 383 in the textbook.

12.6 Speed distribution of particles

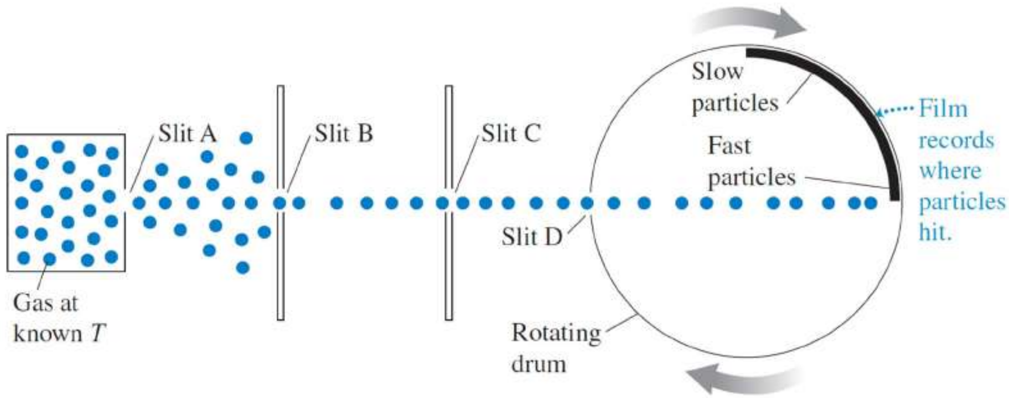
OALG 12.6.1 Read and interrogate

Read and interrogate Section 12.6 in the textbook and answer Review Question 12.6.

OALG 12.6.2 Reading exercise

Below we provide information about a historical experiment that tested Maxwell's distribution. However, the text has a few mistakes. Carefully read and correct any mistakes.

To test Maxwell's predictions, one needs to actually measure the speeds of atoms and molecules at a particular temperature and then compare their distribution of speeds to the calculated distribution curve shown in Figure 12.17 in the textbook. The task seems almost impossible—measuring the speeds of objects that are 10^{-10} m in diameter. However, the problem was tackled and successfully solved by German physicist Otto Stern in 1920, many years after the development of Equation 12.10. This led to a whole field of study called molecular beam spectroscopy. An apparatus such as that shown in the figure below is used in molecular beam spectroscopy.



A gas is heated to some pre-determined temperature. A small fraction of the rapidly moving gas particles leaves the container through slit A. Some of these particles pass through slits B and C, forming a narrow beam of particles that hit a rapidly rotating drum with a slit D. The particles can only enter the drum as slit D passes along the line from slits A-C. The particles that enter the drum travel across it to the other side where they are detected by a sensitive film that produces a mark (a dot) when hit by a particle. Slow-moving particles hit the film almost directly across from the slit, whereas fast-moving particles hit the film somewhat later as the drum has rotated farther. After the drum completes one rotation, a new group of particles enter the drum. Thus, even if the beam has only a few particles hitting slit D per rotation, after many rotations a denser pattern develops on the film.

The density of the number of particles hitting a particular part of the film indicates the relative speed of those particles (the more particles that hit the same spot, the lower the density). Thus, you can make a graph of the darkening of the film (the relative number of particles hitting a part of the film) versus the position on the film (the speed of the particles hitting that part of the film). The pattern can be used to calculate the average particle speed squared. The experiment can be repeated multiple times with the gas at a different temperature for each trial. The determined average speed squared and gas temperature is consistent with Equation 12.10. The measured speed distribution patterns matched perfectly Maxwell's predicted distributions. These results were resounding support for the kinetic theory of gases.

Therefore, we can say that the ideal gas model is a productive model for describing gases. A combination of the model, the ideal gas law, and all of the testable predictions and testing experiments is called the kinetic molecular theory – a theory that describes and explains the behavior of gases based on their particle structure.

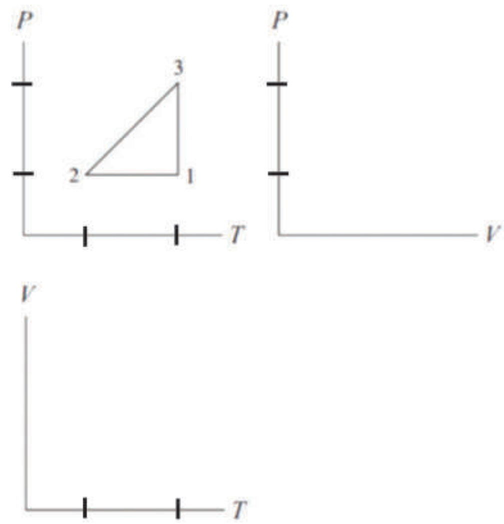
12.7 Skills for analyzing processes using the ideal gas law

OALG 12.7.1 Represent and reason

The P-versus-T graph in part **b**. describes a cyclic process comprised of three hypothetical processes. The mass of the gas is constant.

a. Describe the processes represented on the P-versus-T graph in part **b**. by completing the table that follows.

b. Use the information in the table to represent the processes in *P*-versus-*V* and *V*-versus-*T* graphs. Notice that we placed the *P*-versus-*V* graph to the right of the *P*-versus-*T* graph to keep the same scale for pressure, and the *V*-versus-*T* graph under the *P*-versus-*T* graph to keep the same scale for temperature.



Process	Describe what happens to the pressure of the gas.	Describe what happens to the temperature of the gas.	Describe what happens to the volume of the gas.
$1 \rightarrow 2$	Remains constant		
$2 \rightarrow 3$		Increases	Remains constant (the line passes through the origin)
$3 \rightarrow 1$			

For help, use Table 12.6 in the textbook on page 370.

OALG 12.7.2 Represent and reason

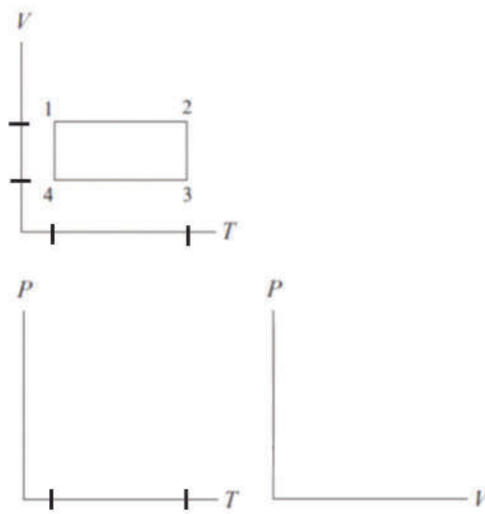
The *V*-versus-*T* graph in part **b**. represents a cyclic process comprised of four hypothetical processes. The mass of the gas remains constant.

a. Describe the processes represented on the graph in part **b** by completing the table.

Process	Describe what happens to the pressure of the gas.	Describe what happens to the temperature of the gas.	Describe what happens to the volume of the gas.
$1 \rightarrow 2$			
$2 \rightarrow 3$			

$3 \rightarrow 4$			
$4 \rightarrow 1$			

b. Use the information in the table to represent the processes in *P*-versus-*T* and *P*-versus-*V* graphs. What strategies did you develop to solve this problem?



For help, use Table 12.6 in the textbook on page 370.

OALG 12.7.3 Regular problem

The variation of the volume and pressure of a constant-mass ideal gas is provided in the table below. The process starts at 0°C. Answer the following questions.

$V(\mathbf{m}^3)$	$P\ (\mathbf{N/m}^2)$
6.00×10^{-4}	1.00×10^{5}
5.45×10^{-4}	1.10×10^{5}
6.67×10^{-4}	0.90×10^{5}

a. How big is the container with the gas? Use objects in the room to compare.
b. Determine the number of gas particles.
c. Does the temperature change during the process? How do you know?
d. Explain the process microscopically.
e. If you carried out this process, what equipment would you need? What would you do?

OALG 12.7.4 Regular problem

The constant volume (isochoric) variation of the temperature of 1 mol of an ideal gas is provided in the table below. Complete the table. (*Note:* Find the unknown pressures in the second column. For help, use Conceptual exercise 12.6 on page 371 in the textbook.)

$T(K)$	$P(\text{N/m}^2)$	**Describe the process. Explain the process microscopically and sketch a *P*-versus-*T* graph.**
273	1.00×10^5	
336		
410		

OALG 12.7.5 Equation Jeopardy

The mathematical representations below describe a thermodynamic process (each representation can describe more than one process). Create a word description of a process that is consistent with the representation.

a. $$(0.012\ \text{m}^3 - 0.010\ \text{m}^3) = \frac{(0.25\ \text{mol})(8.3\ \text{J/K})}{(1.0\times10^5\ \text{N/m}^2)(T - 300\ \text{K})}$$

b. $$\frac{(1.0\times10^5\ \text{N/m}^2)(0.018\ \text{m}^3)}{(300\ \text{K})} = \frac{P(0.020\ \text{m}^3)}{(280\ \text{K})}$$

OALG 12.7.6 Evaluate a solution

The problem: A deflated balloon starts with 0.017 mols of air inside of it, an internal volume of $3.0\ \text{cm}^3$, and an internal pressure of 1.0 atm. You add air so that, when filled, the balloon contains 0.33 mols of air and has a volume of $30\ \text{cm}^3$. The process occurs at constant temperature. Determine the final pressure in the balloon.

Proposed solution: For a constant-temperature process, $P_0V_0 = PV$. Thus:

$$P = P_0V_0/V = (1.0\ \text{atm})(3.0\ \text{cm}^3)/(30\ \text{cm}^3) = 0.10\ \text{atm}$$

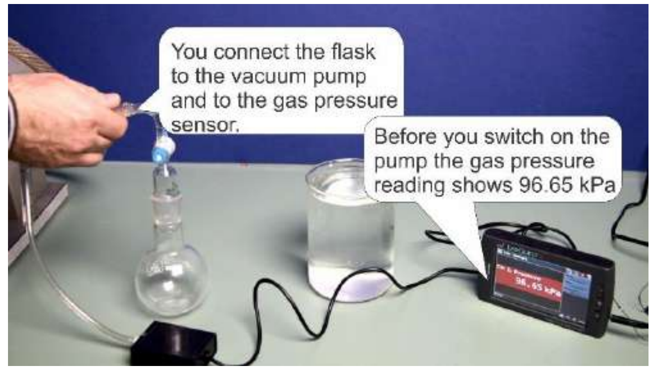
a. Identify any missing elements or errors in the solution.
b. Provide a corrected solution if you find any errors.

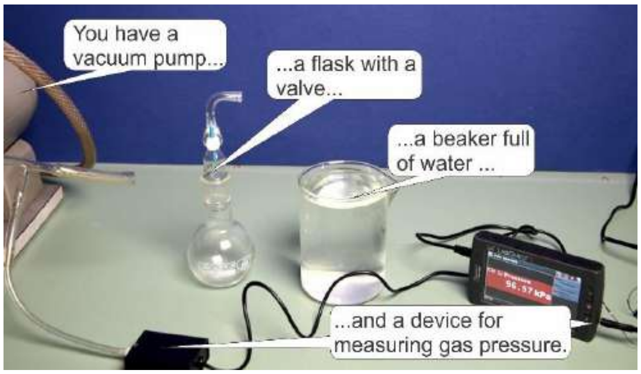
OALG 12.7.7 Apply

Part 1: Application experiment

1.

2.


You connect the flask to the vacuum pump and to the gas pressure sensor.
Before you switch on the pump the gas pressure reading shows 96.65 kPa


You have a vacuum pump...
...a flask with a valve...
...a beaker full of water ...
...and a device for measuring gas pressure.

3.

4.

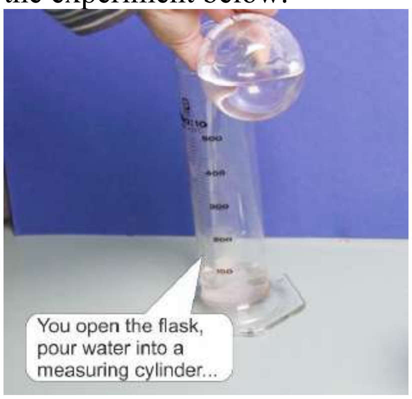

You disconnect the flask from the pump, dip the nozzle into water and slowly open the valve...

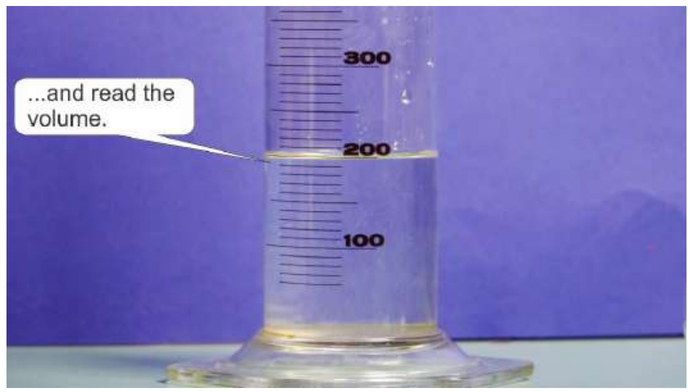

After pumping some air from the flask you close the valve.
At this point the gas pressure reading shows 36.63 kPa

a. You determined that the total volume of the flask with the part before the valve is 320 ± 3 ml. In the manual of the gas pressure sensor, you found that the instrumental uncertainty of the gas reading is ± 3 kPa.

b. Determine how much water will flow into the flask. Your result should include the experimental uncertainty. Indicate any assumptions that you made. Show all steps of your work.

c. Compare your prediction about how much water will flow into the flask with the outcome of the experiment below.





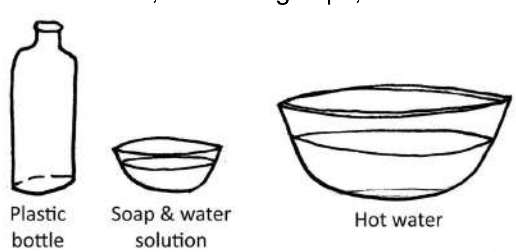
Note: each division on the cylinder represents 10 ml.

d. Is the result that you obtained in the first part of the activity consistent with the outcome of the experiment? If yes, explain how you know.

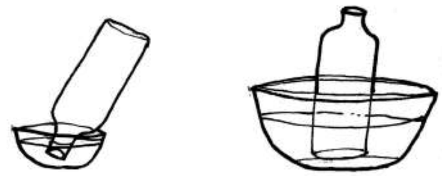
e. If it is not consistent, resolve any discrepancies and present the revised solution.

OALG 12.7.8 Observe, explain, and test

Equipment: Plastic water bottle (~0.5 liter and with the cap removed), a small container with clear dish-soap & water solution suitable for making bubbles (make sure the bubble solution doesn't foam), a larger container with hot water (around 50°C, the hottest water that you can tolerate if you put your hand in), a length measuring instrument such as a ruler, measuring cups, a thermometer if you have one.



a. Take the plastic bottle and dip the open mouth of the bottle into the container with soapy water (see figure below, step 1). Check if the thin film appears across the opening and that it remains intact. Do not squeeze the bottle! Then, lower the bottom of the bottle in the container with hot water so that water covers about one third of the bottle (see figure below, step 2). Again, make sure you do not squeeze the bottle. Watch the behavior of the soap film. Once it stops changing shape, use the length measuring instrument to measure the size of the new shape of the soap film (keep the bottle in the hot water container at all times). Take a picture if you can or make a video of the process! In addition, determine the total volume of the plastic bottle by using a measuring cup. Measure or estimate the air temperature in the room where you are performing the experiment. Estimate the uncertainty in all of your measurements.



b. Describe what you observe. Draw force diagrams for a small part of the film

- before the bottle is put into hot water
- as the bubble starts to expand
- when the bubble stops expanding.

c. Use the representations to explain why the film starts bulging out and why it stops bulging. Then, think of possible experiments to test your explanations. Describe the experiments and, if you have necessary equipment, carry them out. If you do not have the equipment, skip the testing experiment.

d. Estimate the temperature of hot water in which you placed the plastic bottle by using your previous measurements (the size of the bubble and the total volume of the plastic bottle). If you do not have the measurements, here are our measurements: total volume of the plastic bottle $V = 525\ \text{ml} \pm 5\ \text{ml}$, final diameter of the bubble $d_{\text{bubble}} = 35\ \text{mm} \pm 2\ \text{mm}$ and the ambient temperature was 25°C.

Indicate any assumptions that you made. Evaluate your result. In case you measured the temperature of hot water directly by using a thermometer, compare both results. Are the results consistent? Explain.

OALG 12.7.9 Read and interrogate

Read and interrogate Section 12.7 and answer Review Question 12.7.

OALG 12.7.10 Practice

Solve Problems 49, 50, 57-59, 65, 69, and 72 on pages 383-384.

12.8 Thermal energy, the Sun, and diffusion

OALG 12.8.1 Regular problem

Estimate the energy that the Sun possesses due to the kinetic energy of its particles. Assume that the Sun is made entirely of atomic hydrogen. The mass of the Sun is 2×10^{30} kg, and its average temperature is about 100,000 K. For help, use Section 12.8 in the textbook.

OALG 12.8.2 Read and interrogate

Read and interrogate Section 12.8 in the textbook and explain how diffusion works.