Chapter 12

Gases

12.1 Structure of matter

12.1.1 Observe and explain

PIVOTAL ***Lab or class:*** *Equipment per group:* 90% isopropyl alcohol, strips of paper, whiteboard, markers.

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. [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-12-1-1]

One of your friends described the observation 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?

12.1.2 Develop multiple explanations

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard, markers.

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. Work with your group to brainstorm possible reasons for how and why the alcohol disappeared from the paper. Come up with at least four different mechanisms and put them on your whiteboard. Share your ideas with another group.

12.1.3 Test multiple explanations

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard, markers.

Below are four testing experiments that Mindy, Marc, Alex, and Nina decided to perform. Working with your group, *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 in 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 in 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 in a beaker. Place a small drop of colored alcohol in 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, and consequently which mechanisms you can or cannot reject.

12.1.4 Explain

***PIVOTAL* Lab or class**

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?

12.1.5 Observe and explain

***PIVOTAL* Lab or class**

Have the members of your group stand at different distances from your desk, the farthest person being in a corner of the room. Open a bottle of strong perfume on your desk. Ask every group member to raise their hand when they smell the perfume. How long did it take the farthest person to detect the smell? Explain this phenomenon using the ideas from the previous activities or any other ideas.

12.1.6 Represent and reason

Lab or class: *Equipment per group:* whiteboard, markers.

Imagine that you have eyes that can see the particles of air in the room. Work with your group members to 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.

12.1.7 Reading exercise

Read Section 12.1 in the textbook and answer Review Question 12.1.

12.2 Pressure, density, and the mass of particles

12.2.1 Observe and explain

PIVOTAL ***Lab or class:*** *Equipment per group:* balloon, whiteboard, markers.

Blow up a balloon and carefully observe how its shape changes during the process. Working with your group, 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. Try to brainstorm multiple explanations with your group members. Describe an experiment you can perform to test your explanation(s).

12.2.2 Test multiple explanations

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard, markers. Equipment for whole class: bell-jar, vacuum pump, balloon, a firmly tied plastic bag.

In this experiment, a partially inflated (and tied) balloon will be placed in the bell-jar and the air will be removed by the vacuum pump. Working with your group, 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). Put your predicted outcome(s) on a whiteboard and compare with another group. Then perform the experiment. Repeat the same experiment using the tied plastic bag. Discuss with your group: Which of your predictions was consistent with the experimental outcome? What can you conclude about each of the ideas you were testing?

12.2.3 Explain

PIVOTAL Lab or class: *Equipment per group:* whiteboard, markers.

Working with your group, explain the following two observations using the model of particles moving randomly at different speeds.

Observation 1: You inflate a balloon indoors on a winter day and then take it outside; the balloon shrinks.

Observation 2: You inflate a balloon outdoors at sea level and take it to a mountaintop; the balloon expands.

For each observation, put the following on a whiteboard, working with your group members:

a. Write down your group's explanation.

b. List the assumptions that your group made while formulating your explanation.

c. Describe a possible testing experiment that would test your group's explanation.

12.2.4 Explain

Lab or class: *Equipment per group:* whiteboard, markers.

Work with your group to explain several observed phenomena listed below, using the physical quantity of pressure and 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. If you put a sealed, deflated balloon under a vacuum jar, it will expand when you pump the air out of the jar. [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-12-2-4]

c. When you pump air into a rubber raft, it becomes bigger.

12.2.5 Reading exercise

Read Section 12.2 in the textbook and answer Review Question 12.2.

12.3 Quantitative analysis of ideal gas

12.3.1 Represent and reason

Lab or class: *Equipment per group:* whiteboard, markers.

Work with your group members to answer the questions for the following exercise.

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 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.

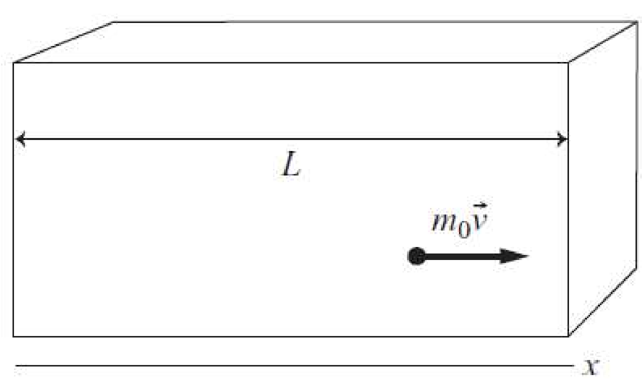
d. Draw the force exerted by the wall on the particle.

e. Draw the force exerted by the particle on the wall.

12.3.2 Derive

Lab or class: *Equipment per group:* whiteboard, markers.

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. Work with your group members to answer the questions below.



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 two surfaces 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 surface, has magnitude $2m_0v_x$.

b. Show that the time interval between hits 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 force that these collisions exert on the wall averaged over time of several passages of the ball (F_{avg}) is $m_0v_x^2/L$ and that the average pressure that N balls, or particles, will exert on a wall is $P = N(m_0v_x^2)/L^3$.

d. The v_x^2 in the equation 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 $P = \frac{1}{3}\frac{N}{V}\left(m_0\overline{v^2}\right)$.

12.3.3 Reason

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard, markers.

Collaborate with your group to answer the following questions to decide whether the expression for the pressure $P = \frac{1}{3}\frac{N}{V}\left(m_0\overline{v^2}\right)$ in 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.

12.3.4 Reading exercise

Read Section 12.3 in the textbook and answer Review Question 12.3.

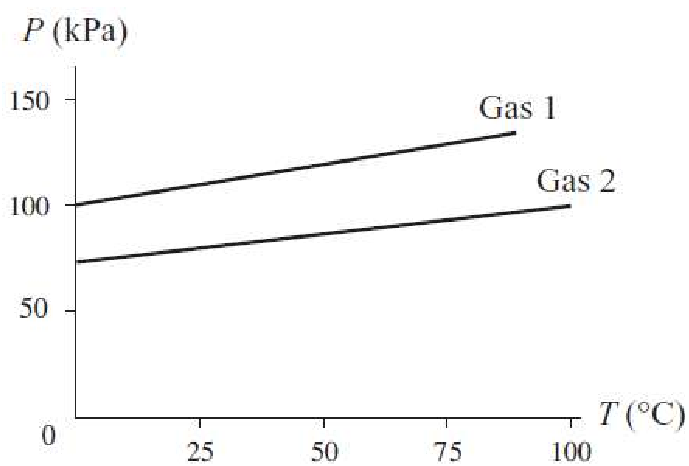
12.4 Temperature

12.4.1 Observe and explain

Lab or class: *Equipment per group:* whiteboard, markers.

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. Work with your group members to answer the following questions:

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. 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.

12.4.2 Reason

Lab or class: *Equipment per group:* whiteboard, markers.

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. Work with your group using proportional reasoning to determine the volume of 1 mol of any gas under the same conditions.

12.4.3 Explain

Lab or class: *Equipment per group:* whiteboard, markers.

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, but again it is the same for all three gases. Discuss with your group members: What is the meaning of the 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.

12.4.4 Reason

Lab or class: *Equipment per group:* whiteboard, markers.

The table below represents data collected when a constant-volume metal container with 1 mol of nitrogen ($N = N_A = 6.02\times10^{23}$ 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 quantities	$\frac{PV}{NT}=k$	**Known 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 the nitrogen at the two different temperatures.

d. Does the absolute temperature of the nitrogen depend on the total number of particles in the container? Explain.

e. Does the total thermal energy due to the motion of nitrogen particles depend on the number of particles in the container? Explain.

f. Compare and contrast two physical quantities: absolute temperature and thermal energy.

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

12.4.5 Reason

Lab or class: *Equipment per group:* whiteboard, markers.

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

12.4.6 Reading exercise

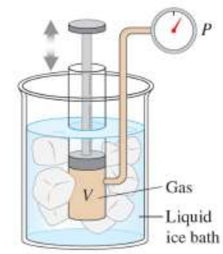
Read Section 12.4 in the textbook and answer Review Question 12.4.

12.5 Testing the ideal gas law

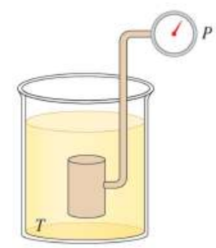
12.5.1 Test an idea

Lab or class: *Equipment per group:* whiteboard, markers.

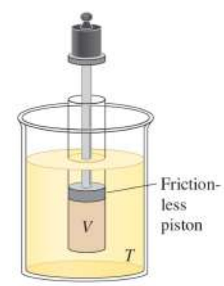
Discuss with your group members how you can use equation $PV = Nk_BT$ to make quantitative predictions about the following processes occurring to a fixed mass of an ideal gas. The initial conditions of the gas P_1, V_1, T_1 are known and you need to show how P_2, V_2, T_2 are related to them.



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 change as the temperature changes (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?

12.5.2 Design a testing experiment

Lab: *Equipment:* depends on local availability.

You goal is to use available equipment to test the mathematical descriptions of one or more processes that you discovered in Activity 12.5.1. Work with your group members to decide which process you will test – this depends on the available equipment.

12.5.3 Analyze

Lab or class: *Equipment per group:* whiteboard, markers.

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 $T_1 = 23°\text{C}$. Then you successively immerse the glass jar in water baths of temperatures $T_2 = 1°\text{C}$ and $T_3 = 98°\text{C}$ and record the gas pressure once it reaches a stable value:

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

Assume the air in the jar can be modeled as an ideal gas. Work with your group to answer the following questions:

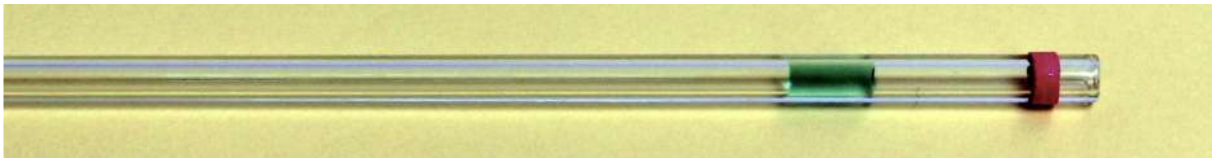
a. Estimate the number of moles of the air in the glass jar. (*Hint:* estimate the missing data from the photo).

b. Draw 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).

12.5.4 Analyze

Lab or class: *Equipment per group:* whiteboard, markers.

You have an air-filled glass tube with 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 $T_1 = 59\ °\text{C}$. 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 $T_2 = 6\ °\text{C}$ and $T_3 = 26\ °\text{C}$ and record the length of the air column (you should wait until the water drop stops moving). All three steps of the experiment are shown in the figure below.

You obtained the following data:

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

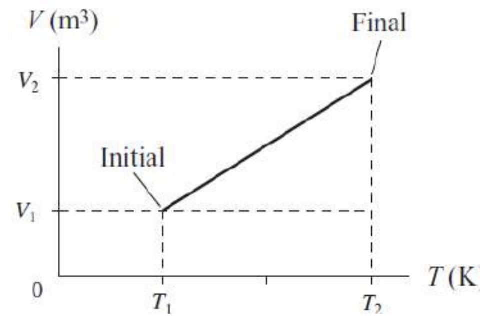
Work with your group to answer the following questions (assume the air in the glass tube can be modeled as an ideal gas).

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

b. Draw 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).

12.5.5 Represent and reason

Lab or class: *Equipment per group:* whiteboard, markers.



The graph on the right describes a process occurring in an ideal gas. Work with your group members to discuss and answer the questions that follow.

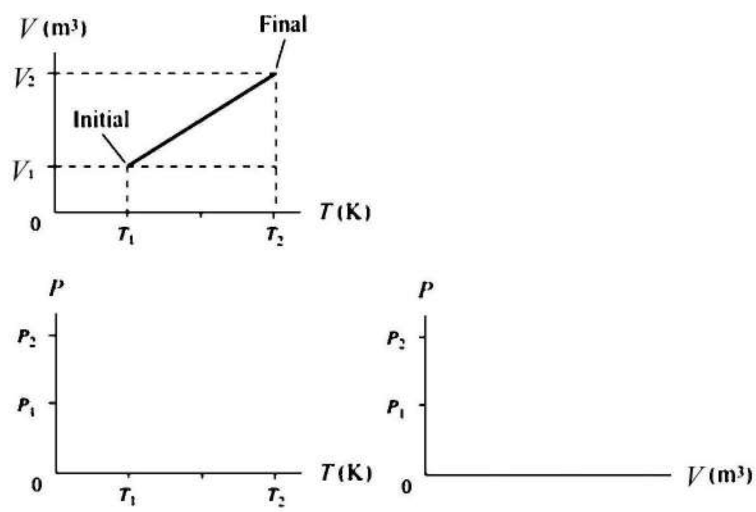
a. Describe the process macroscopically.

b. Describe how you can carry out the process.

c. Represent the process mathematically.

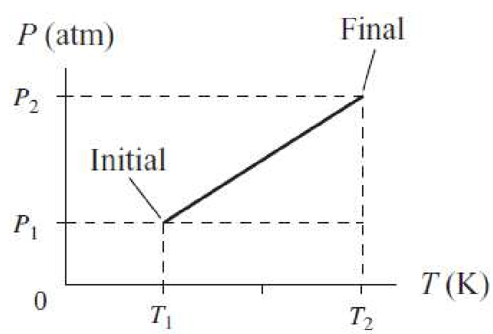
d. Explain the process microscopically.

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.



12.5.6 Represent and reason

Lab or class: *Equipment per group:* whiteboard, markers.



The P-versus-T graph to the right describes a real process. Work with your group members to discuss and answer the questions that follow.

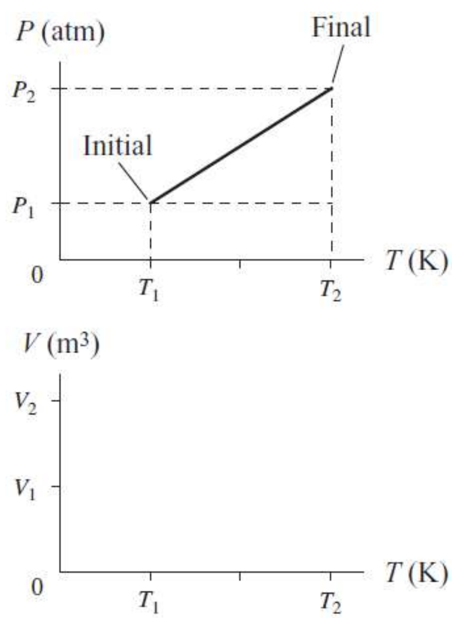
a. Describe the process macroscopically.

b. Describe how you can carry out the process.

c. Represent the process mathematically.

d. Explain the process microscopically.

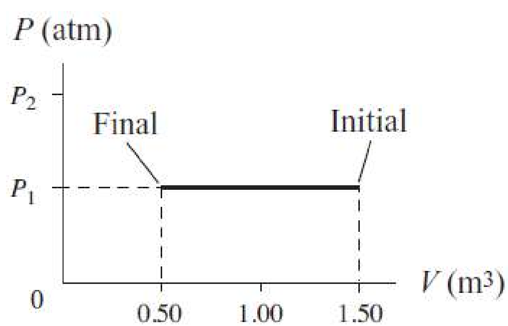
e. Now represent the same process in *P*-versus-*V* and *V*-versus-*T* graphs below. Notice how the graphs are positioned; this alignment allows you to keep the scale for the same variable on different graphs.



12.5.7 Represent and reason

Lab or class: *Equipment per group:* whiteboard, markers.

Work with your group members to find out everything you can about the process represented in the graph below. Make a list of physical quantities that you can determine.



12.5.8 Reading exercise

Read Section 12.5 in the textbook and explain how gas laws account for our breathing.

12.6 Speed distribution of particles

12.6.1 Reading exercise

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

12.6.2 Design an experiment

Lab or class: *Equipment per group:* whiteboard, markers.

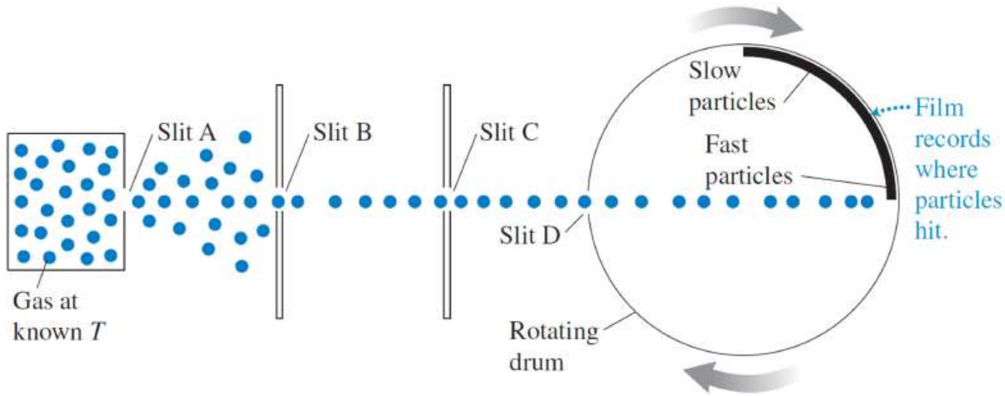
Brainstorm with your group members about what experiments you could perform if you wanted to test Maxwell's distribution of molecular speeds. Imagine you have any equipment you might think of. Suggest as many ways to test the distribution as you can.

12.6.3 Reading exercise

Lab or class: *Equipment per group:* whiteboard, markers.

Below we provide information about a historical experiment that tested Maxwell's distribution. However, the text has a few mistakes. Your group's goal is to read carefully and correct the mistakes. Discuss with you group after you have read the passage.

"To test Maxwell's predictions one needs to actually measure the speeds of atoms and molecules at a particular temperature and then compare the 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 Eq. (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 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 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 each time with the gas at different temperature. The determined average speed squared and gas temperature is consistent with Eq. (12.10). The measured speed distribution patterns matched perfectly the Maxwell predicted distributions. These results were a resounding support for the kinetic theory of gases.

Therefore we can say that 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 the testing experiments is called 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

12.7.1 Represent and reason

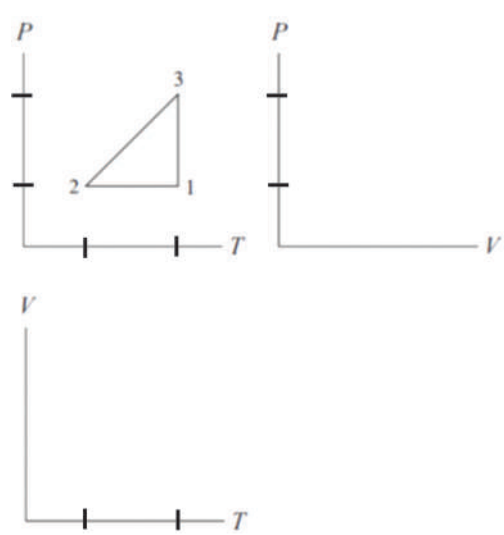
Lab or class: *Equipment per group:* whiteboard, markers.

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

a. Collaborating with your group, describe the processes represented on the P-versus-T graph in part **b**. by completing the table that follows.

Process	**Write what happens to the pressure of the gas.**	**Write what happens to the temperature of the gas.**	**Write 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)
$3 \rightarrow 1$			

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. Put your graphs on a whiteboard and compare your ideas with those from another group.



12.7.2 Represent and reason

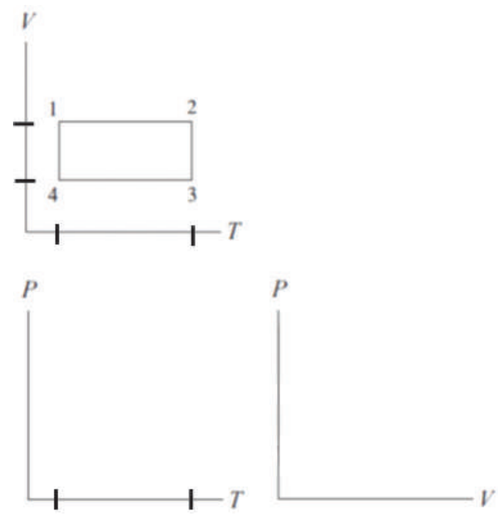
Lab or class: *Equipment per group:* whiteboard, markers.

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

a. Working with your group, describe the processes represented on the graph in part b by completing the table.

Process	**Write what happens to the pressure of the gas.**	**Write what happens to the temperature of the gas.**	**Write what happens to the volume of the gas.**
$1 \to 2$			
$2 \to 3$			
$3 \to 4$			
$4 \to 1$			

b. Use the information in the table to represent the processes in P-versus-T and P-versus-V graphs. Discuss with your group members what strategies you developed to solve this problem. Put your graphs on a whiteboard and compare your ideas with those from another group.



12.7.3 Regular problem

Lab or class: *Equipment per group:* whiteboard, markers.

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. Work with your group to answer the following questions. Put your work on a whiteboard.

$V\,(\mathbf{m^3})$	$P\ (\mathbf{N/m^2})$
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?

12.7.4 Regular problem

Lab or class: *Equipment per group:* whiteboard, markers.

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.)

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

12.7.5 Equation Jeopardy

Lab or class: *Equipment per group:* whiteboard, markers.

The equations below describe a thermodynamic process (each equation can describe more than one process). Work with your group to create a word description of a process that is consistent with the equation. Put your word descriptions on a whiteboard and compare with those from another group.

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

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

12.7.6 Evaluate a solution

Lab or class: *Equipment per group:* whiteboard, markers.

The problem: A deflated balloon starts with 0.017 mol of air inside of it, an internal volume of 3.0 cm^3, and an internal pressure of 1.0 atm. You add air so that, when filled, the balloon contains 0.33 mol of air and has a volume of 30 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:

$$P = P_0 V_0 / V = (1.0\text{ atm})(3.0\text{ cm}^3)/(30\text{ cm}^3) = 0.10\text{ atm}$$

a. Work with your group members to identify any missing elements or errors in the solution.

b. Provide a corrected solution or missing elements if you find errors.

12.7.7 Regular problem

Lab or class: *Equipment per group:* whiteboard, markers.

Examine the air in the room in which you are solving this problem with your group. Assume that the pressure is normal.

a. How many molecules of air are in 1 m^3 at normal conditions?

b. What is the average distance between air molecules compared to the dimensions of the molecules? Consider the diameter of molecules to be about 10^{-10} m.

c. Can you consider air to be an ideal gas?

12.7.7 Reading exercise

Read Section 12.7 and answer Review Question 12.7.

12.8 Thermal energy, the Sun, and diffusion

12.8.1 Regular problem

Lab or class: *Equipment per group:* whiteboard, markers.

Working with your group, estimate the energy that the Sun possesses due to the kinetic energy of its particles. Assume that the Sun is made of atomic hydrogen. The mass of the Sun is 2×10^{30} kg, and its average temperature is about 100,000 K.

12.8.2 Design an experiment

Lab or class: *Equipment per group:* whiteboard, markers.

Observe the motion of your rib cage as you breathe. How does your body manage to inhale and exhale air from your lungs? After describing in words how this process works, work with your group using the suggested materials to construct an apparatus that can be used as a breathing model: an open plastic bottle with the bottom cut off, a surgical glove, 15-inch balloons, and rubber bands.

12.8.3 Estimate

Lab or class: *Equipment per group:* whiteboard, markers.

a. Estimate the mass of the air in a typical home. Indicate any assumptions that you make about the size of the room, the air pressure, and the temperature.

b. Estimate the average speed of air particles in the room. Indicate any assumptions you make.

c. How many molecules are in 1 g of air at normal conditions? If these molecules lie uniformly on Earth's surface, *estimate* the number that would be under your feet right now. The radius of Earth is about 6400 km. Indicate any assumptions you made.

12.8.4 Reading exercise

Read Section 12.8 in the textbook and answer Review Question 12.8.