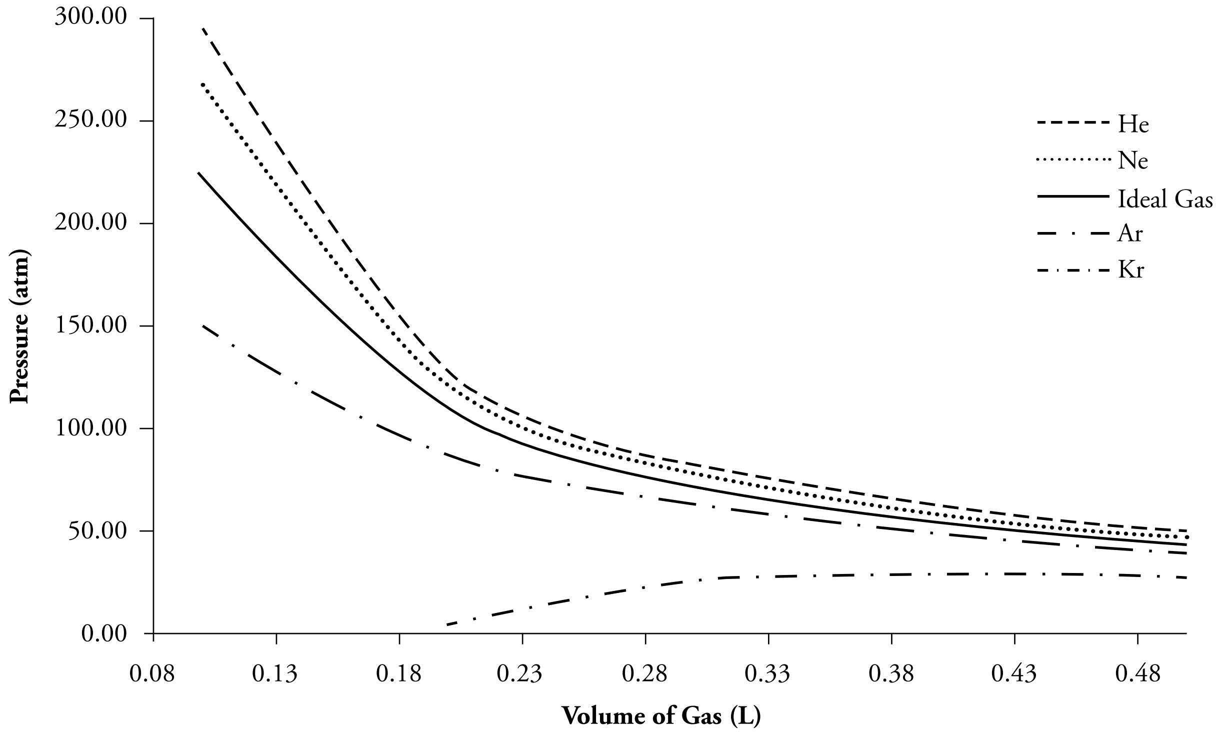
Deviations from the Ideal Gas Law

Does the Ideal Gas Law accurately calculate the pressure of a gas?

Why?

The equation $PV = nRT$, otherwise known as the Ideal Gas Law, is a powerful tool. A scientist can predict the pressure, volume, number of moles or temperature of a gas when the other variables are measurable. But how accurate is the calculated value? In real life we deal with real gases, not ideal gases. Can one simple equation predict all of these variables for all gases? Or does it only approximate the real values? What factors determine how well the Ideal Gas Law equation can predict values for real gases?

Model 1 – Deviations from Ideal



1. Consider the data in Model 1 for several gases measured at constant temperature.
   a. The relationship between what two gas variables is shown in the graph?

   b. Which line shows the predicted relationship between those two variables?

   c. The Ideal Gas Law, $PV = nRT$, shows the mathematical relationship between all gas variables.

2. The relationships between pressure and volume of four real gases are shown in Model 1. What four gases are illustrated?

3. Of the four real gases included in Model 1, which has the largest deviations from the predicted pressure?

4. Discuss as a group how the actual pressures of the four gases deviate from that predicted by the Ideal Gas Law. Be sure to consider the following questions.

   a. Do all real gases have the same deviation from the predicted pressure?

   b. Are the deviations from predicted pressure always the same direction (higher than predicted or lower than predicted) for all gases?

   c. Are the deviations from the predicted pressure greater at lower volumes or higher volumes? Is this consistent with all gases?

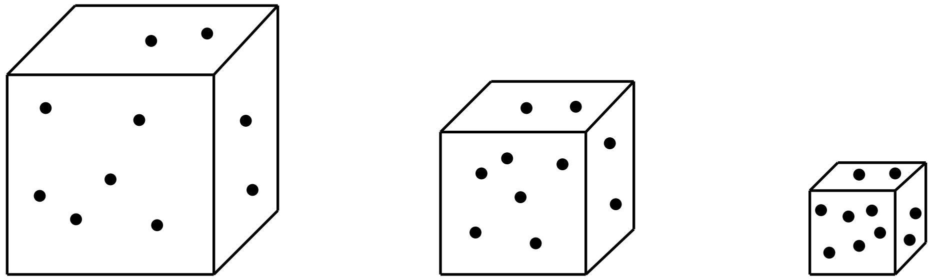
Read This!

The following assumptions about molecular behavior are made when working with an ideal gas:

- The gas sample consists of molecules. These molecules can be thought of as single, rigid points in space with mass. The volume of these points is infinitesimal in comparison with the volume of the gas sample or container.
- The gas molecules are in constant, random, straight line motion. Curved motion is not possible because there are no attractive or repulsive forces between molecules.
- The behavior of the gas molecules can be predicted by Newton's Laws. All collisions between molecules and between molecules and the walls of the container are completely elastic. No energy is lost to friction or heat.
- The gas molecules have a distribution of speeds and kinetic energies—some move faster than others. The temperature of the gas in Kelvins is proportional to the average kinetic energy of the molecules.

5. Consider the assumptions set forth in the *Read This!* box. box. Discuss with your group the major inconsistencies with real gases. In other words, what statements in the *Read This!* box are less applicable when working with real gases?

Model 2 – Volume of Gas Molecules



Moles of Gas	1.0000 mole	1.0000 mole	1.0000 mole
"Ideal" Volume of Container	1.00000 L	0.50000 L	0.25000 L
Volume of Gas Molecules			
Volume of "Real" Usable Space			
Percent of "Ideal" Volume that is "Real" Usable Space			

6. Imagine that each of the three containers in Model 2 contains krypton atoms. The atomic radius of a krypton atom is 88.00 pm. Assuming the atom is a solid sphere, calculate the volume of one krypton atom in liters.

   Hint: Volume of a sphere equation is $V = \frac{4}{3}\pi r^3$

7. Calculate the total volume occupied by the krypton atoms in each container in Model 2. Enter these data in the table.

Read This!

According to the assumptions of the Ideal Gas Law, atoms of gas have no volume. Therefore, if a krypton atom is in a 1.00000-L container it has, theoretically, 1.00000 L of space to roam—regardless of how many other krypton atoms are present in the container. Theoretically those other atoms do not take up space. In a real gas however, the other krypton atoms **do** take up space. Therefore, the krypton atom in question does not really have 1.00000-L of space in which to roam since it cannot be in the space occupied by another atom. So, the usable space, from that atom's perspective, is less than the volume of the container.

8. Calculate the “real” usable space in each of the containers in Model 2.

9. Calculate the percent of “ideal” space that is really available for atoms to move around in for each of the containers in Model 2.

STOP

10. According to Model 2, as the container containing the same amount of gas gets smaller, what happens to the percent available space for atom motion?

11. The ideal gas law equation can be used to predict the pressure of a gas in a 1.00000-L container. However, as you have just discovered, the atoms in that container do not really have 1.00000-L of space to occupy—they have less. How would this affect the observed pressure—would it be higher or lower than that predicted by the Ideal Gas Law? Explain your reasoning using the Ideal Gas Law equation.

12. As the container holding the same amount of gas gets smaller, would the deviation between the observed pressure and predicted pressure increase or decrease? Justify your answer with information from Model 2.

13. Not all gas molecules are the same size. Predict how the deviation from ideal behavior might change as the gas molecules become larger.

14. Revisit the graph in Model 1 and consider your answers to Questions 11–13. Are your answers supported by the data in Model 1? Provide specific evidence from the graph to justify your answers.

    a. In Question 11, we said the space occupied by atoms should cause the pressure to be __________ than predicted. Is this observed in Model 1?

b. In Question 12, we said the deviation from ideal pressure should __________ as the container gets smaller. Is this observed in Model 1?

c. In Question 13, we said the deviation from ideal pressure should __________ as the gas molecules get larger. Is this observed in Model 1?

15. Based on the information in Models 1 and 2, does the volume of gas molecules fully explain deviations from ideal gas behavior?

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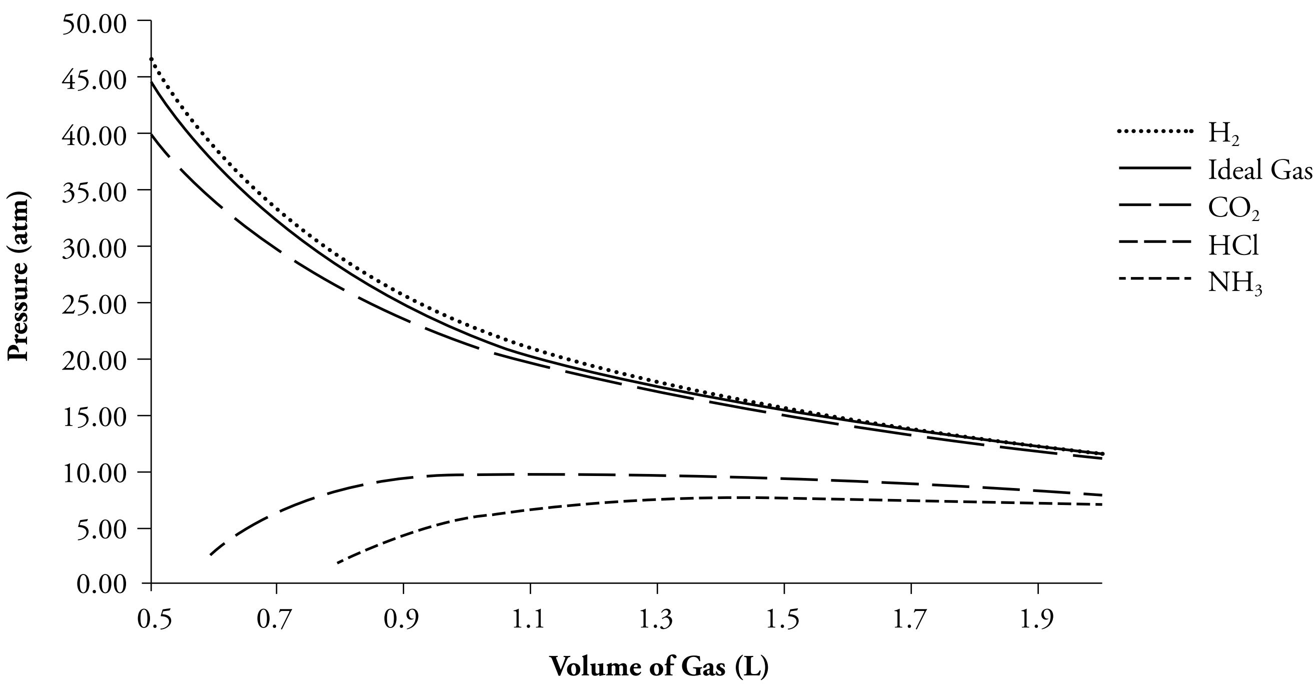
Model 3 – Polarity of Gas Molecules



16. Which four gases are compared to ideal gas behavior in Model 3?

17. Of the four gases in Model 3, which are polar and which are nonpolar? Draw dot diagrams to support your answer.

18. Based on the data in Model 3, does polarity seem to affect the deviation from ideal behavior for a gas? Explain your reasoning.

Read This!

According to the assumptions of Ideal Gas Theory, gas molecules have no attraction towards one another. Therefore, the motion of molecules is only in straight lines and there is no preference for moving towards one another, away from one another or into a wall of the container—theoretically. In a real gas, however, the molecules **do** have attraction for one another through intermolecular forces. Therefore, the molecules may have a slight preference for moving towards one another instead of moving towards the wall of the container.

19. If pressure is determined by the number of times and the force with which a gas molecule collides with the walls of the container, how will the attractions between gas molecules affect the pressure—will the observed pressure be higher or lower than that predicted by the Ideal Gas Law? Explain your reasoning.

20. As the intermolecular forces between gas molecules become stronger, will the deviation between the observed pressure and predicted pressure increase or decrease? Explain your reasoning.

21. As the volume of the container gets larger and the gas molecules move farther apart on average, will the effect of intermolecular forces cause a greater or lesser deviation on the pressure of the gas? Explain your reasoning.

22. Consider the graph in Model 3. Are your answers to Questions 19–21 supported by the data in Model 3? Provide specific evidence from the graph to justify your answer.

    a. In Question 19, we said intermolecular forces should cause the pressure to be __________ than predicted. Is this observed in Model 3?

    b. In Question 20, we said the deviation from ideal pressure should _________ as the intermolecular forces get stronger. Is this observed in Model 3?

c. In Question 21, we said the deviation from ideal pressure should __________ as the volume of the container gets larger. Is this observed in Model 3?

23. Consider the graph in Model 1. Is your answer to Question 20 supported by the data in Model 1? Provide specific evidence from the graph to justify your answer.

24. All of the gases below have observed pressures that are lower than that predicted by the Ideal Gas Law at all volumes. Rank the gases in order of smallest deviations from ideal behavior to greatest deviations from ideal behavior. Justify your reasoning.

Cl_2 F_2 N_2 O_2

25. Considering both the effect of volume and the effect of intermolecular forces, how would the deviation from ideal behavior for a gas change when more moles of gas are introduced into a rigid container? Justify your reasoning.

26. Considering both the effect of volume and the effect of intermolecular forces, how would the deviation from ideal behavior for a gas change when the gas is at a higher temperature? (Assume a rigid container.) Justify your reasoning.

Extension Questions

Model 4 – Van der Waals Equation

	a **($L^2 \cdot$ atm/mole^2)**	***b*** **(L/mole)**
He	0.0341	0.0237
N_2	1.39	0.0391
CO_2	3.5900	0.0427
NH_3	4.1700	0.0370

$$P = \frac{nRT}{V - nb} - \frac{n^2a}{V^2}$$

27. The Van der Waals equation is basically the Ideal Gas Law equation with some correction factors. The constants *a* and *b* are proportional to the effects of volume and intermolecular forces that cause the deviations from ideal behavior. These constants are derived by fitting a mathematical model to real data.

    a. Look at the Van der Waals equation in Model 4. The Ideal Gas Law is in there. Circle the terms that make up the Ideal Gas Law.

    b. Draw squares around the two correction factors in the Van der Waals equation.

28. One of the Van der Waals constants is related to the reduction of usable volume because the molecules of gas take up space. Which correction factor and which constant adjusts for this loss of usable space?

29. The other Van der Waals constant is related to the reduction of pressure due to attractive forces between gas molecules. Which correction factor and which constant adjusts for the loss in pressure?

30. Consider the constants *a* and *b* for carbon dioxide (CO_2) and ammonia (NH_3). Ammonia has a larger *a* constant than CO_2, but a smaller *b* constant. Explain why this is so.

31. A 10.000-L tank of nitrogen contains 4.000 moles of gas at 22.00 °C.

a. Calculate the pressure that would be expected if neon was an ideal gas.

b. Calculate the actual pressure using the Van der Waals equation.

c. How precise would the anemometer on the tank need to be to detect a deviation from the pressure calculated with the Ideal Gas Law?