Announcements for Monday, 02DEC2024

- Wednesday's lecture will be a review
- Exam III is Wednesday, 04DEC2024, 7:45-9:05 **PM** (EST)
  - Coverage: Chapters 7.1-10.9; exam consists of 19 multiple-choice questions and open-ended questions; see "Other Resources" on Canvas for periodic table and formula sheet to be used on the exam
  - Exam 3 Locations are posted on Canvas
- Practice Exam 3 on Canvas
  - located under "General Course information," "Practice Exams"
- Exam III Calculator Policy
  - Scientific calculators and ***most*** graphing calculators are allowed
  - **TI-Nspire CX series & other calculators with *QWERTY* keyboards are NOT allowed**

ANY GENERAL QUESTIONS? Feel free to see me after class!

Try These On Your Own

- To what temperature (°C) would Xe atoms (131.3 g/mol) have to be brought to so that they have the same average velocity as He atoms (4.00 g/mol) at –10 °C? **8360 °C**
- Under a certain set of conditions it takes 25.0 s for an amount of CO_2(g) to escape from a container. How long would it take for the same amount of N_2O_4(g) to escape from the same container under the same conditions? **36.1 s**
- 2.0 g He atoms occupy a rigid container at a pressure of 2.00 atm. The root mean square velocity of the atoms is 1580 m/s. What is the volume of the container? **8.2 L**

Stoichiometry So Far

$$\mathbf{2}\,\mathrm{A} + \mathbf{3}\,\mathrm{B} \longrightarrow \mathbf{2}\,\mathrm{C} + \mathbf{4}\,\mathrm{D}$$

mass

molar mass, $\mathcal{M}$

gas

ideal gas law, $\frac{PV}{RT}$

moles

$$\frac{\mathbf{2}\ \mathrm{mol\ A}}{\mathbf{3}\ \mathrm{mol\ B}}, \frac{\mathbf{3}\ \mathrm{mol\ B}}{\mathbf{4}\ \mathrm{mol\ D}}, \mathrm{etc}$$

Avogadro's number, N_A

molarity, M

number of entities

volume of solution

Gas Stoichiometry

- same stoichiometry procedures as before
- remember that when a reaction is run under STP, 22.4 L/mol can be used as a conversion factor for the gases
- for gaseous reactions, establish which gas properties are constant and try to use relationships within PV = nRT to simplify calculations

nitrogen gas reacts with hydrogen gas to ammonia gas.

$$N_2(g) + 3\ H_2(g) \longrightarrow 2\ NH_3(g)$$

A 5.00-L vessel initially at 300 K contains nitrogen gas and hydrogen gas at partial pressures of 350 torr and 1025 torr, respectively. Determine the partial pressure of ammonia formed. Assume 100% yield. **683 torr $NH_3(g)$**

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Approach #1: the LONG approach (convert pressures into moles and then back into pressure)

$$\mathrm{N_2:}\ 350\ \mathrm{torr} \times \frac{1\ \mathrm{atm}}{760\ \mathrm{torr}} = 0.4605\ \mathrm{atm},\ \mathrm{n} = \frac{(0.4605\ \mathrm{atm})(5.00\ \mathrm{L})}{(0.08206)(300\ \mathrm{K})} = 0.0935\ \mathrm{mol\ N_2} \times \frac{2\ \mathrm{mol\ NH_3}}{1\ \mathrm{mol\ N_2}} = 0.187\ \mathrm{mol\ NH_3}$$

$$\mathrm{H_2:}\ 1025\ \mathrm{torr} \times \frac{1\ \mathrm{atm}}{760\ \mathrm{torr}} = 1.349\ \mathrm{atm},\ \mathrm{n} = \frac{(1.349\ \mathrm{atm})(5.00\ \mathrm{L})}{(0.08206)(300\ \mathrm{K})} = 0.274\ \mathrm{mol\ H_2} \times \frac{2\ \mathrm{mol\ NH_3}}{3\ \mathrm{mol\ H_2}} = \mathbf{0.183\ mol\ NH_3}$$

$$\mathrm{NH_3:}\ 0.183\ \mathrm{mol},\qquad \mathrm{P} = \frac{(0.183\ \mathrm{mol})(0.08206)(300\ \mathrm{K})}{(5.00\ \mathrm{L})} = 0.899\ \mathrm{atm\ NH_3} \times \frac{760\ \mathrm{torr}}{1\ \mathrm{atm}} = \mathbf{683\ torr\ NH_3}$$

Approach #2: use pressures directly without converting into moles (MUST be at constant volume and temperature)

at constant T and V, $\mathbf{P \propto n}$ so use torr like moles:

$$\mathrm{N_2:}\ 350\ \mathrm{torr} \times \frac{2\ \mathrm{torr\ NH_3}}{1\ \mathrm{torr\ N_2}} = 700\ \mathrm{torr\ NH_3}\quad \mathrm{vs}\quad \mathrm{H_2:}\ 1025\ \mathrm{torr} \times \frac{2\ \mathrm{torr\ NH_3}}{3\ \mathrm{torr\ H_2}} = \mathbf{683\ torr\ NH_3}$$

from balanced reaction coefficients ***from balanced reaction coefficients***

Try This

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

2.0 L each of $N_2(g)$ and $H_2(g)$ are mixed at STP and allowed to react to form $NH_3(g)$. What volume of $NH_3(g)$ is produced in this reaction? Assume 100% yield and ideal behavior. **1.3 L**

at constant P and T, $\mathbf{V \propto n}$ so use Liters like moles:

$$2.0\ \mathrm{L\ N_2} \times \frac{2\ \mathrm{L\ NH_3}}{1\ \mathrm{L\ N_2}} = 4.0\ \mathrm{L\ NH_3}$$

$$2.0\ \mathrm{L\ H_2} \times \frac{2\ \mathrm{L\ NH_3}}{3\ \mathrm{L\ H_2}} = 1.3\ \mathrm{L\ NH_3}$$

limiting reactant **theoretical yield**

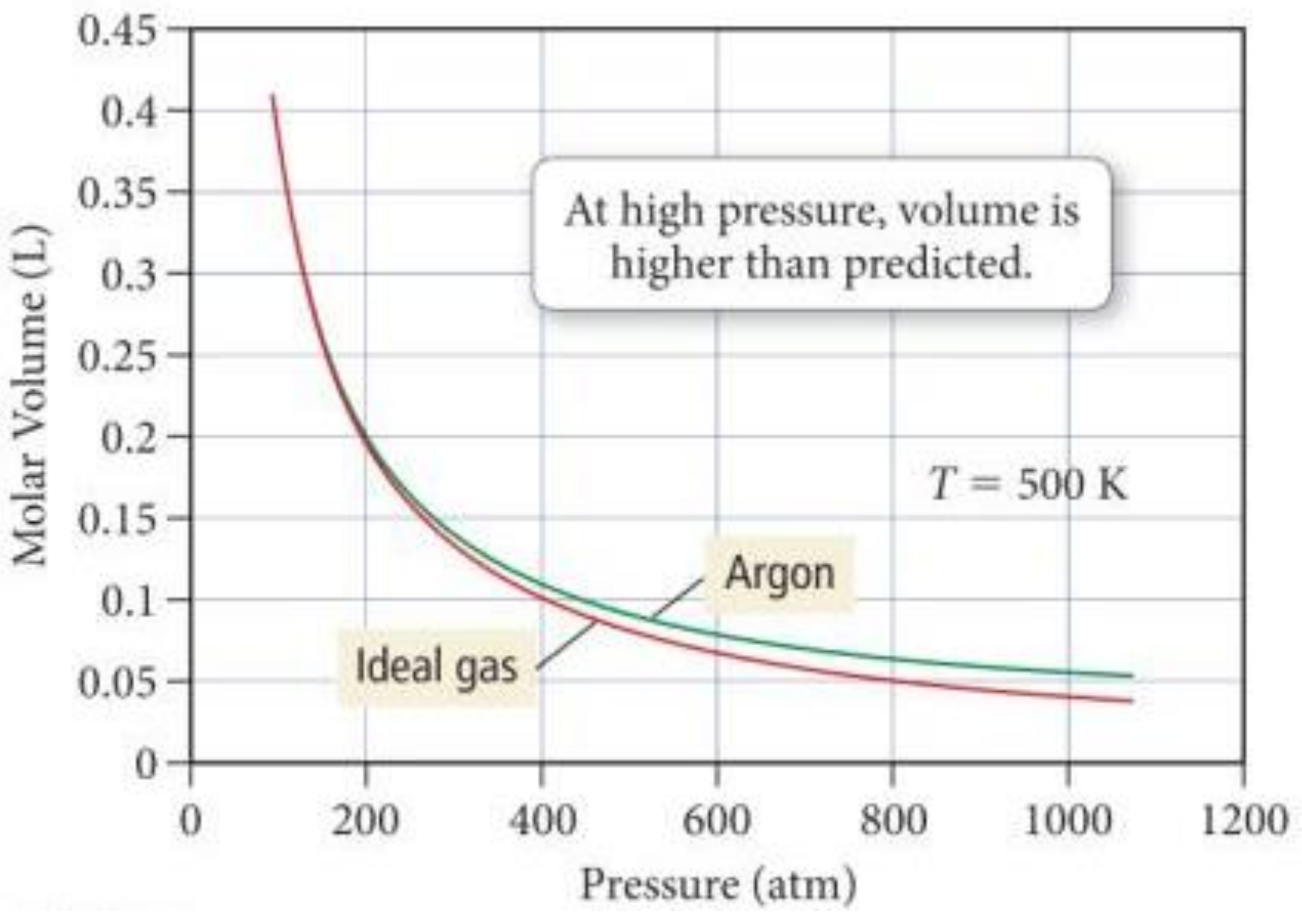
Real Gas Behavior

- 1 mole of an ideal gas at STP has a volume of 22.4 L
- 1 mole of an ideal gas at 273 K and 1.0 L exerts 22.4 atm of pressure
- gases in the real world do not always behave ideally
- certain assumptions of the ideal gas law break down under extreme conditions
    - high pressure/low volume
    - low temperature
- the liquefaction of gases at high pressures and low temperatures demonstrates non-ideal gas behavior at these extreme conditions

liquid nitrogen

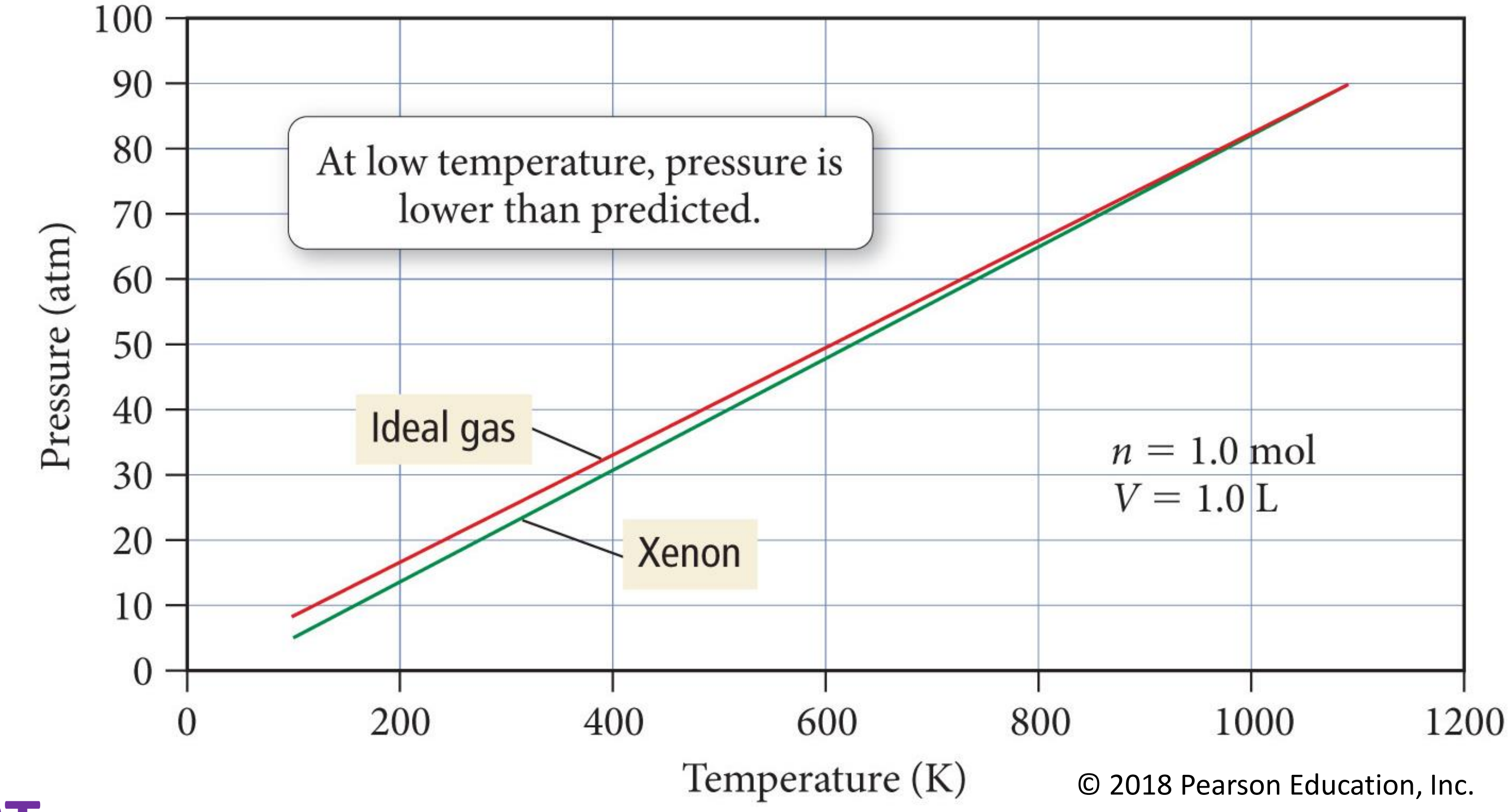
Deviations from Ideality
the effect of particle volume

- ideal gases: the size of gas particles are negligibly small
- real gases: not true at very high pressures/low volumes
- at **extremely high pressures (i.e., extremely low volumes)**, gases exhibit **LARGER volumes** than predicted by PV = nRT
  - example: 1 mol Ar(g) at 500 K
- at **high pressure**, **PV > nRT** and gases show a **positive deviation** from ideality



Deviations from Ideality
the effect of intermolecular forces

- ideal gases: gas particles do not interact with each other
- real gases: not true at very low temperatures
- at **very low temperatures**, gases exhibit **LOWER pressures** than predicted by PV = nRT
  - example: 1 mol Xe(g) at 1.0 L
- at **low temperature**, **PV < nRT** and gases show a **negative deviation** from ideality

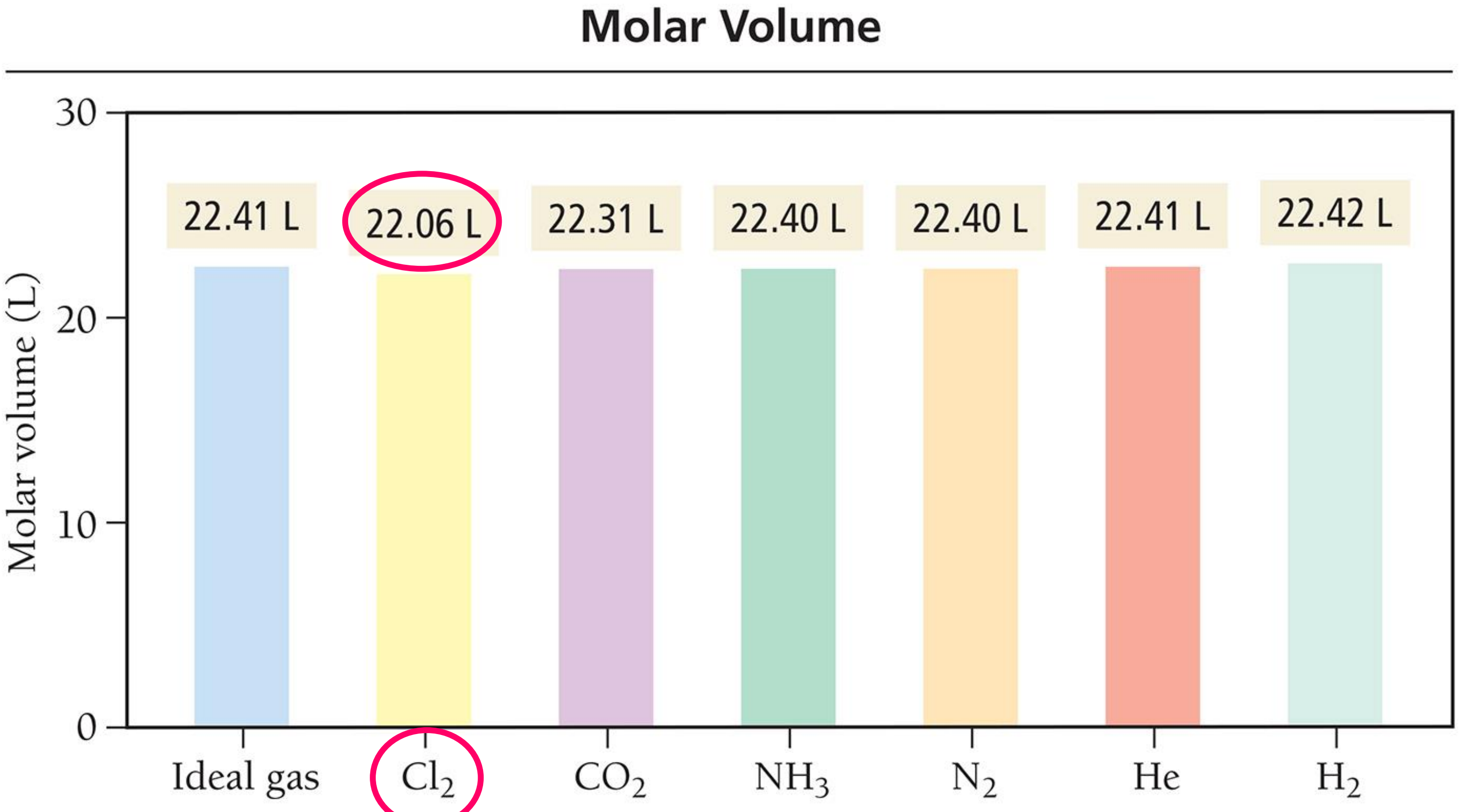


- at lower temperature, particles move slow enough for weak intermolecular forces to become significant
- collisions with container are less frequent and less forceful

Deviations from Ideality
the effect of intermolecular forces (continued)

- at **moderate temperatures and pressures**, some gases exhibit **LOWER molar volumes** than predicted by PV = nRT

- **PV < nRT** and gases show a **negative deviation** from ideality



- intermolecular forces between gas particles cause attractions between them
- particles are prevented from spreading out as much and occupying larger volumes

the van der Waals equation

- corrects the ideal gas law for the finite volume and intermolecular forces of gas particles

$$PV = nRT$$

for real gas, this term may be too low

for real gas, this term may be too high

van der Waals equation

$$[P + a(\frac{n}{V})^2] \times [V - nb] = nRT$$

Correction for intermolecular forces

Correction for particle volume

- a and b are correction factors that depend on the specific gas

TABLE 10.4 Van der Waals Constants for Common Gases

Gas	a ($L^2 \cdot atm/mol^2$)	b (L/mol)
He	0.0342	0.02370
Ne	0.211	0.0171
Ar	1.35	0.0322
Kr	2.32	0.0398
Xe	4.19	0.0511
H_2	0.244	0.0266
N_2	1.39	0.0391
O_2	1.36	0.0318
Cl_2	6.49	0.0562
H_2O	5.46	0.0305
CH_4	2.25	0.0428
CO_2	3.59	0.0427
CCl_4	20.4	0.1383

Try This On Your Own

A sealed, rigid container contains 6.60 mol Cl_2 and 9.90 mol F_2. The gases react to form $ClF_3(g)$ according to the reaction $Cl_2(g) + 3\ F_2(g) \longrightarrow 2\ ClF_3(g)$. If the total pressure within the container was 10. atm **before** the reaction took place, what was the total pressure *after* the reaction finished? Assume 100% yield and constant T.

Try These On Your Own

- What volume of $CO_2(g)$ is formed by the complete combustion of 2.25 mol $C_2H_6(g)$ in excess oxygen at 0 °C and 1 atm ?

- Consider the reaction $CO_3^{2-}(aq) + 2\ H^+(aq) \rightarrow CO_2(g) + H_2O(\ell)$. What volume (mL) of 0.250 M $HClO_4(aq)$ needs to be added to excess $Na_2CO_3(s)$ to generate 844 mL $CO_2(g)$ at 35 °C and 776 torr?

- 10.00 mL of water at 20 °C is poured into a 100. L container and sealed at 20 °C. What volume of $H_2O(\ell)$ will evaporate under these conditions? At 20 °C the vapor pressure of water is 17.55 mmHg and the density of liquid water is 0.9982 g/mL.