



General Chemistry II

Chem 102



Lecture 2

Errors & Limiting Reactant

Gases

Ahmad Alakraa

Exercise

✚ The pressure of a gas is measured as 49 torr. Represent this pressure in both atmospheres and pascals?

Solution

$$P = 49 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 6.4 \times 10^{-2} \text{ atm}$$



$$\begin{aligned} P &= 6.4 \times 10^{-2} \text{ atm} \times \frac{101,325 \text{ Pa}}{1 \text{ atm}} \\ &= 6.5 \times 10^3 \text{ Pa} \end{aligned}$$

Errors

♣ Systematic or Determinate Errors

- ✚ exist in **every** reading of a series of repeated measurements. (like a speck of dust on a pan).
- ✚ occur always in the **same direction** with the **same magnitude** (high or low).
- ✚ in experimental observations, it usually comes from the measuring instruments.
- ✚ are difficult to detect even for experts

- Ex.**
- there is something wrong with the instrument or its data handling system.
 - instrument is wrongly used by the experimenter.

- <https://www.physics.umd.edu/courses/Phys276/Hill/Information/Notes/ErrorAnalysis.html>
- https://chemistnotes.com/analytical_chemistry/errors-in-chemical-analysis-determinate-and-indeterminate-errors/

Types of Systematic Errors

Offset or zero setting error

- ✚ instrument does not read zero when the quantity to be measured is zero

Multiplier or scale factor error

- ✚ instrument consistently reads changes in the quantity to be measured greater or less than the actual changes.

- Ex.**
- errors in measurements of temperature due to poor thermal contact between the thermometer and the substance whose temperature is to be found.
 - errors in measurements of solar radiation because trees or buildings shade the radiometer.

Accuracy of measurements is often reduced by SE

Errors

♣ Random, non-Systematic or Indeterminate Errors

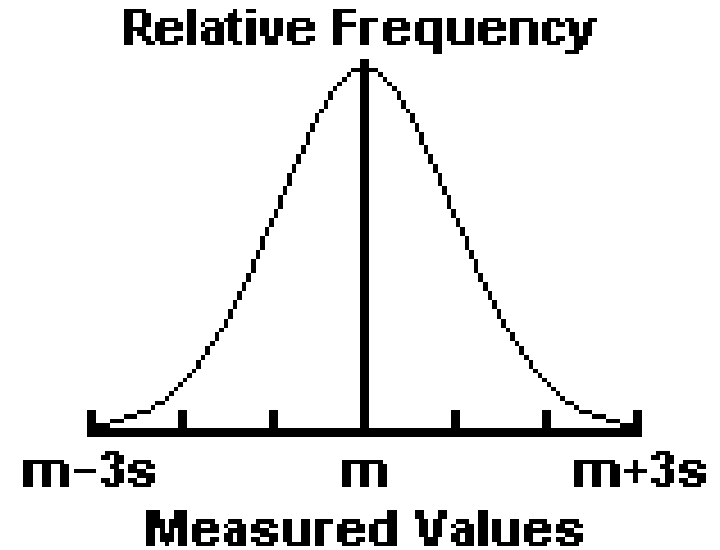
- ✚ caused by **unknown** and **unpredictable** changes in the measuring instruments or in the environmental conditions.
- ✚ vary **randomly** in a series of repeated measurements and can average to zero.
- ✚ have an equal probability of being **high** or **low**.
- ✚ occurs in estimating the value of the last digit of a measurement

Ex.

- electronic noise in the circuit of an electrical instrument,
- irregular changes in the heat loss rate from a solar collector due to changes in the wind.

Handling Random Errors

- RE often have a **Gaussian normal** distribution.
- Statistical methods may be used to analyze the data.



The **mean** m of a number n of measurements of the same quantity is the best estimate of that quantity, and the **standard deviation** s of the measurements shows the accuracy of the estimate. The **standard error** of the estimate m is s/\sqrt{n} .

Random Errors/Precision

- # The **precision** of a measurement is how close a number of measurements of the same quantity **agree** with each other.
- # The **precision** is limited by the **random errors**. It may usually be determined by repeating the measurements.

Accuracy & Precision

♣ Accuracy

✚ refers to the agreement of a particular value with the **true** value.

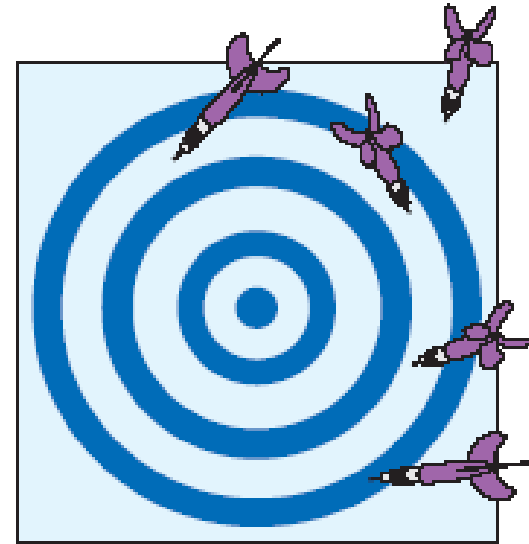
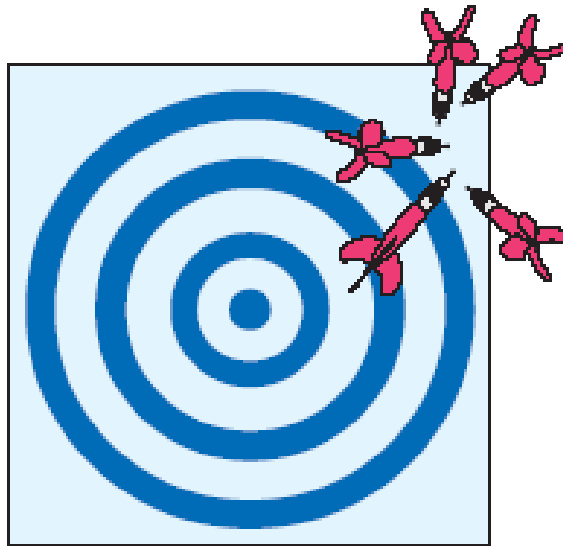
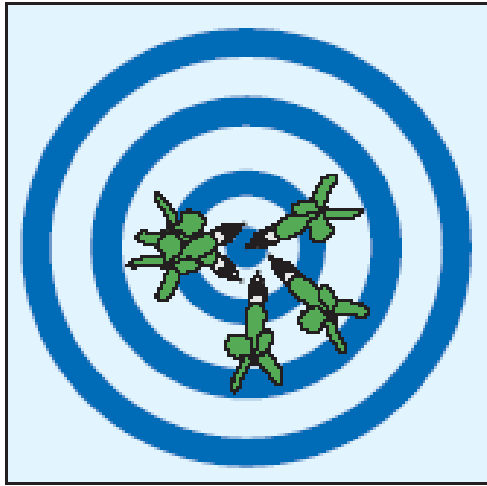
♣ Precision

✚ refers to the **degree of agreement** among several measurements of the same quantity.

✚ reflects the **reproducibility** of a given type of measurement.

رمي السهام

Throwing Darts



Both **precise** and **accurate** (small random errors, no systematic error)

Precise but **not accurate** (small random errors, large systematic error)

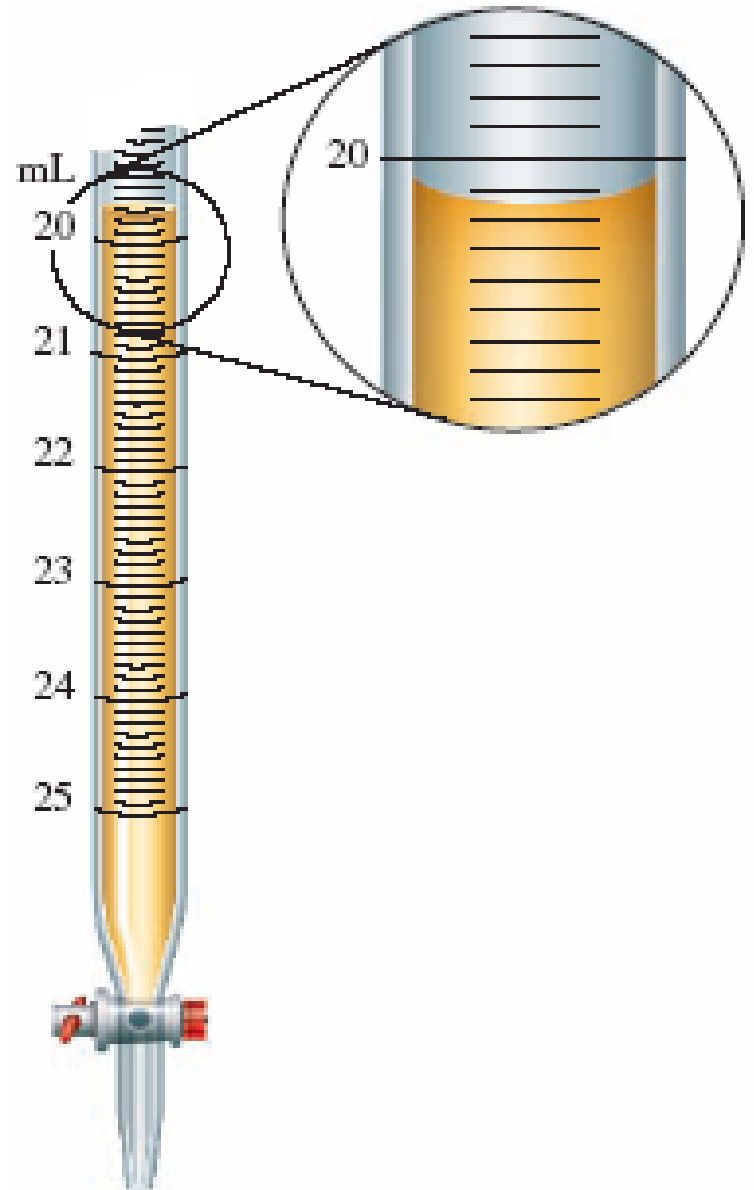
Neither accurate nor precise (large random errors).



Uncertainty in Measurement

✚ If five different people read same volume, the results **in mL** might be 20.16, 20.14, 20.16, 20.17, 20.15

✚ **20.1** are certain digits but the last digit is estimated (uncertain, doubtful) digit



Significant Figures, SF

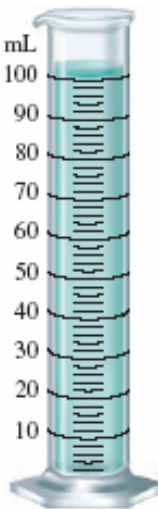
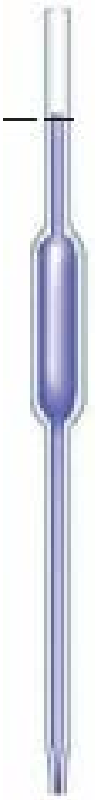
- ❑ Any measurement is reported by recording only **SF** (all certain digits + 1st uncertain digit).
- ❑ For a burette, it would not make any sense to record the volume of thousandths of a milliliter (0.004) (insignificant) because the value for hundredths of a milliliter must be estimated.

- ❑ In analyzing a sample of polluted water, a chemist measured out a 25.00 mL water sample with a pipette. Another chemist used a graduated cylinder to measure 25 mL of a solution. What is the difference between the measurements?

Solution

- ❑ The quantity 25 mL means that the volume is between 24 mL and 26 mL, whereas the quantity 25.00 mL means that the volume is between 24.99 mL and 25.01 mL.

A pipette measures volume with much greater precision



Counting SF: Rules

□ Nonzero → always SF

□ Zeros: three types

A- **Leading zeros** (zeros precede nonzero digits)

→ do not count as SF

0.0025 → has only **two** SF

B- **Captive zeros** (zeros between nonzero digits)

→ always count as SF

1.008 → has **four** SF

C- Trailing zeros (zeros at the right end of the number)

→ are SF only if the number contains a decimal point.

100 → has only **one** SF

1.00×10^2 → has **three** SF

Exact numbers: numbers obtained by **counting** or **definitions** & not measured by devices.

These have an **infinite number** of SF.

Examples

❑ 10 experiments, 3 apples, 8 molecules.

❑ 2 in $2\pi r$ (circumference of a circle) and $4/3$ in $4/3 r^3$ (volume of a sphere).

❑ **1 inch = 2.54 cm.**

⇒ Neither **2.54** nor **1** limits the number of SF when used in a calculation.

Exercise

Counting No. of SF

- ▶ A student's extraction on tea yields 0.0105 g of caffeine.

2 leading zeros (**not SF**), 1 captive zero (**SF**), 2 nonzeros (**SF**).



Overall: 3 SF

- ▶ 0.050080 g in a measurement.

2 leading zeros (**not SF**), 2 captive zero (**SF**), 1 trailing zero (**SF**), 2 nonzeros (**SF**).



Overall: 5 SF

- ▶ $8.050 \times 10^{-3} \text{ s}$



Overall: 4 SF

Rules in calculations

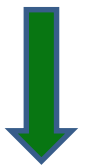
Multiplication and division

✚ Count No. of **SF** in each No. being multiplied or divided and limit the answer to the least of them

$$4.56 \times 1.4 = 6.38 \xrightarrow{\text{Corrected}} 6.4$$



Limiting: 2 SF



2 SF

Rules in calculations

Addition and subtraction

No. of **SF**, is
not
considered



The result should have the same number of **decimal places** as the **least precise** measurement in the calculation.

12.11 +

18.0 +

1.013

—————

31.123 $\xrightarrow{\text{Corrected}}$ **31.1**

Rounding

✚ Carry **extra digits** through to the final result, then **round**.

✚ If the digit to be removed

- < 5 , preceding digit stays the same.

1.33



1.3

- ≥ 5 , preceding digit is increased by 1.

1.36



1.4

✚ Use only the first number to the right of the last significant figure.

- Do not round **sequentially**. Rounding 6.834 to 3

SF

6.8347



6.83



6.84



Calculate and count SF

$$1.05 \times 10^{-3} \div 6.135 = 1.711491 \times 10^{-4}$$

Corrected to 3 SF $\rightarrow 1.71 \times 10^{-4}$

$$21 - 13.8 = 7 \quad \text{no DP 1 SF}$$

Determine the value of the gas constant (R) for a gas with a pressure (P = 2.560 atm), molar volume (V = 8.8 L/mol), and temperature (T = 275.15 K)?

$$R = \frac{PV}{T} = \frac{(2.560)(8.8)}{275.15} = \frac{22.528}{275.15} =$$

$$0.081875321 = 0.082 = 8.2 \times 10^{-2} \quad 2 \text{ SF}$$

Dimensional Analysis (unit factor)

It is a method used to convert a given result from one system of units to another.

Apples and oranges do not add

□ Calculate in inches the length of a 2.85 cm pen knowing that $2.54 \text{ cm} = 1 \text{ in}$?

$$1 = \frac{1 \text{ in}}{2.54 \text{ cm}}$$

is called a **unit factor** which does not affect SF

$$2.85 \text{ cm} \times \frac{1 \text{ in}}{2.54 \text{ cm}} = \frac{2.85}{2.54} \text{ in} = 1.12 \text{ in} \quad 3 \text{ SF}$$

Exercises

✚ How many mL are in 1.63 L?

$$1.63 \cancel{L} \times \frac{1000 \text{ mL}}{1 \cancel{L}} = 1630 \text{ mL} = 1.63 \times 10^3 \text{ mL}$$

✚ The speed of sound in air is about 343 m/s. What is this speed in miles per hour?

$$343 \frac{\cancel{m}}{\cancel{s}} \times \frac{3600 \cancel{s}}{1 \text{ h}} \times \frac{1 \text{ mi}}{1609 \cancel{m}} = 767 \frac{\text{mi}}{\text{h}}$$

Concept of Limiting Reactant

You have a **part-time job** in a **sandwich shop**.

One popular sandwich is always made:

2 slices bread

3 slices meat

1 slice cheese



Test your performance

- You have these ingredients. How many sandwiches can you make?
- What will be left over?

8 slices Bread

9 slices Meat

5 slices Cheese

Remember

Bread + **Meat** + **Cheese** → **Sandwich**
2 **3** **1** **1**

Approaches

1: How many sand. that each ingredient can make?

	Bread	+ Meat	+ Cheese	→	Sand.
Stoichiometry	2	3	1		1
Available	8	9	5		?
Sand.	4	3	5		3

Limiting reactant: is the reactant giving the lowest ratio of moles available/coefficient in the balanced equation (stoichiometry)

Approaches

2: Find the reactant having a deficiency :

	Bread	+ Meat	+ Cheese	→	Sand.
Stoichiometry	2	3	1		1
Available	8	9	5		?

Sand.

4

Can Meat make 4 Sand.? **No**

Can Cheese make 4 Sand.? **Yes**

Limiting reactant: is the reactant having deficiency relatively to other reactants in view of their stoichiometries

Approaches

3: Compare the moles ratios of required and available moles:

	Bread	+	Meat	+	Cheese	→	Sand.
Stoichiometry	2		3		1		1
coefficient							
Bread coefficient	1		1.5		0.5		
Available	8		9		5		
coefficient							
Bread coefficient	1		1.125		0.625		

Limiting reactant: is the reactant that can not provide the **quantity** required to consume the whole materials of other reactant (s)

How many sandwiches each component can make?

Bread

$$8 \text{ slices bread} \times \frac{1 \text{ sand}}{2 \text{ slices bread}} = 4 \text{ sand}$$

Meat

$$9 \text{ slices meat} \times \frac{1 \text{ sand}}{3 \text{ slices meat}} = 3 \text{ sand}$$

Cheese

$$5 \text{ slices cheese} \times \frac{1 \text{ sand}}{1 \text{ slices cheese}} = 5 \text{ sand}$$

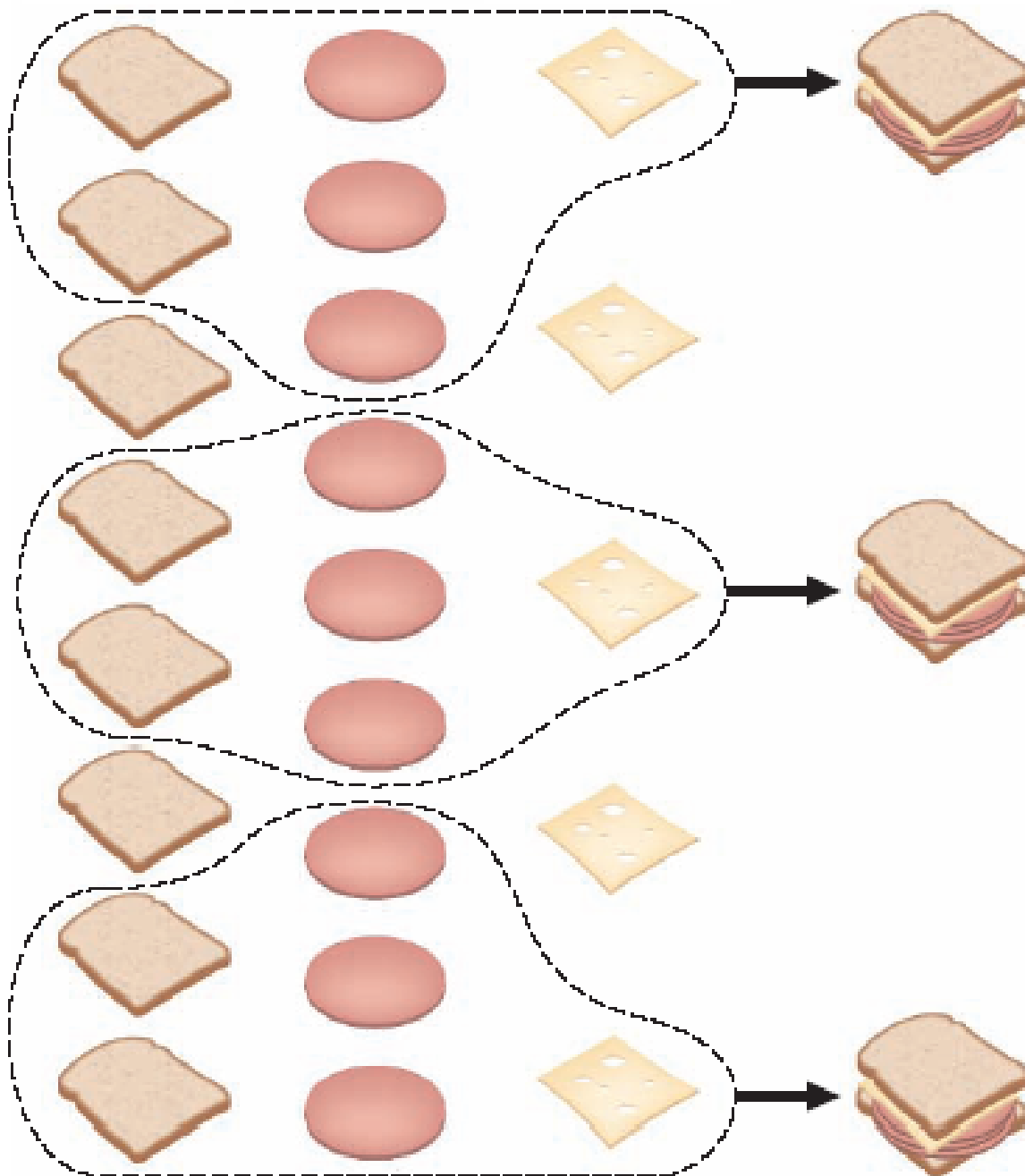
- ❑ Overall, how many sandwiches can you make? **3**
- ❑ When you run out of meat, you must stop making sandwiches. The meat is the limiting ingredient.
- ❑ What do you have left over? 2 slices of bread + 2 pieces of cheese

Bread

Meat

Cheese

Sand

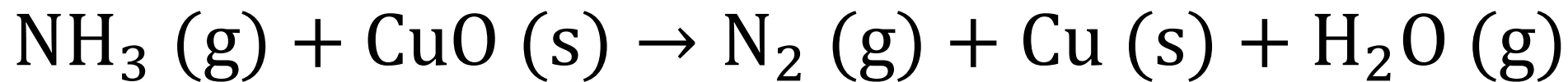


The Limiting reactant (meat) is the component that limits the number of products (sandwiches) you can make.

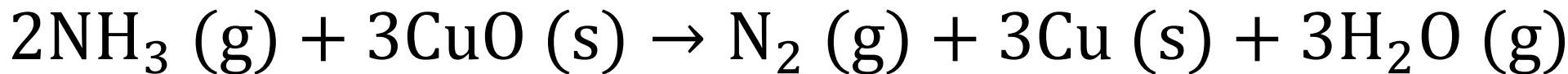
Exercise

Nitrogen gas can be prepared by passing gaseous ammonia over solid copper (II) oxide at high temperatures. The other products of the reaction are solid copper and water vapor. If a sample containing 18.1 g of NH_3 is reacted with 90.4 g of CuO , which is the limiting reactant? Find the mass of N_2 that will be formed?

Solution: Find limiting reactant



Balancing



Given moles of NH_3 and CuO ?

Molar masses $\text{NH}_3 = 17.03 \text{ g/mol}$ $\text{CuO} = 79.55 \text{ g/mol}$

$$\cancel{18.1 \text{ g NH}_3} \times \frac{1 \text{ mol NH}_3}{\cancel{17.03 \text{ g NH}_3}} = 1.06 \text{ mol NH}_3$$

$$\cancel{90.4 \text{ g CuO}} \times \frac{1 \text{ mol CuO}}{\cancel{79.55 \text{ g CuO}}} = 1.14 \text{ mol CuO}$$

Moles of CuO required to react with 1.06 mol NH₃

$$1.06 \cancel{\text{ mol NH}_3} \times \frac{3 \text{ mol CuO}}{2 \cancel{\text{ mol NH}_3}} = 1.59 \text{ mol CuO}$$

Only 1.14 mol CuO is available. CuO is limiting (CuO will run out before NH₃).

Verification: Compare the required and actual mole ratios of CuO and NH₃ in the balanced equation:

$$\text{Required} = \frac{\text{mol CuO}}{\text{mol NH}_3} = \frac{3}{2} = 1.5$$

$$\text{Actual} = \frac{\text{mol CuO}}{\text{mol NH}_3} = \frac{1.14}{1.06} = 1.08$$

Since the actual ratio is **smaller** than required (**1.5**), CuO is LR

A second verification: the limiting reactant should have the lowest ratio of moles available/coefficient in the balanced equation.

$$\text{For } \text{NH}_3 = \frac{\text{Moles available}}{\text{Stoichiometry}} = \frac{1.06}{2} = 0.535$$

$$\text{For } \text{CuO} = \frac{\text{Moles available}}{\text{Stoichiometry}} = \frac{1.14}{3} = 0.38$$

Since the ratio of CuO is smaller, CuO is the limiting reactant.

Find the mass of N₂ produced:

We must use the amount of limiting reactant (CuO) to calculate the amount of N₂ formed.

First calculate the moles of N₂

$$\cancel{1.14 \text{ mol CuO}} \times \frac{1 \text{ mol N}_2}{\cancel{3 \text{ mol CuO}}} = 0.38 \text{ mol N}_2$$

Next calculate the mass of N₂

✓ Using the molar mass of N₂ (28.02 g/mol)

$$\cancel{0.38 \text{ mol N}_2} \times \frac{28.02 \text{ g N}_2}{\cancel{1 \text{ mol N}_2}} = 10.6 \text{ g N}_2$$

Percent yield

❑ **Theoretical yield:** the amount of a product that is expected by calculations to be obtained assuming the **limiting reactant is completely** consumed.

❑ Side reactions usually reduce the yield than calculations.

❑ **Actual yield:** the amount of a product that is obtained actually.

$$\text{Percent Yield, \%} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100$$

Exercise

- Methanol (CH_3OH) is the simplest alcohol. It is used as a fuel in race cars and is a potential replacement for gasoline. Methanol can be manufactured by combining gaseous carbon monoxide and hydrogen. Suppose 68.5 kg $\text{CO}(\text{g})$ is reacted with 8.60 kg $\text{H}_2(\text{g})$.
 - Calculate the theoretical yield of methanol?
 - If $3.57 \times 10^4 \text{ g}$ CH_3OH is actually produced, what is the percent yield of methanol?

Solution

Balanced equation



Convert mass to moles

$$68.5 \text{ kg CO} \times \frac{1000 \text{ g CO}}{1 \text{ kg CO}} \times \frac{1 \text{ mol CO}}{28.02 \text{ g CO}} \\ = 2.44 \times 10^3 \text{ mol CO}$$

$$8.60 \text{ kg H}_2 \times \frac{1000 \text{ g H}_2}{1 \text{ kg H}_2} \times \frac{1 \text{ mol H}_2}{2.016 \text{ g H}_2} \\ = 4.27 \times 10^3 \text{ mol H}_2$$

Which is limiting

$$\text{For H}_2 = \frac{\text{Moles available}}{\text{Stoichiometry}} = \frac{4.27 \times 10^3}{2} = 2.135 \times 10^3$$

$$\text{For CO} = \frac{\text{Moles available}}{\text{Stoichiometry}} = \frac{2.44 \times 10^3}{1} = 2.44 \times 10^3$$

H₂ is limiting

The theoretical Yield

H₂ : CH₃OH = 2:1

$$2.135 \times 10^3 \text{ mol } \cancel{\text{CH}_3\text{OH}} \times \frac{32.04 \text{ g CH}_3\text{OH}}{1 \cancel{\text{ mol CH}_3\text{OH}}} \\ = 6.86 \times 10^4 \text{ g CH}_3\text{OH}$$

$$\text{Percent Yield, \%} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100 \\ = \frac{3.57 \times 10^4 \text{ g}}{6.86 \times 10^4 \text{ g}} \times 100 = 52\%$$

Exercise

Consider the equation



If you mix 1.0 mole of A with 2.0 mole of B, the number of moles of A_2B produced if the reaction is 100 % complete is -----

A is the limiting reactant









0.5 mole A_2B produced

Exercise

Consider the following equation



Which of the following formula for molar masses **can** be correct?

- $C = A + B$   For Balanced eqn.
- $B = 2C$   Unbalanced eqn.
- $2A + B = AC$   For Balanced eqn.
- All of them

Exercise

A limiting reactant in a chemical reaction

has the lowest coefficient in a balanced equation. ✗

has the lowest ratio of moles available/coefficient in the balanced equation. ✓

has the lowest ratio of coefficient in the balanced equation/moles available. ✗

Ideal Gases

The state of a gas can be fully described in terms of **4 variables** (Mass, Volume, Pressure, Temperature). By knowing 3 of them, the fourth can be calculated

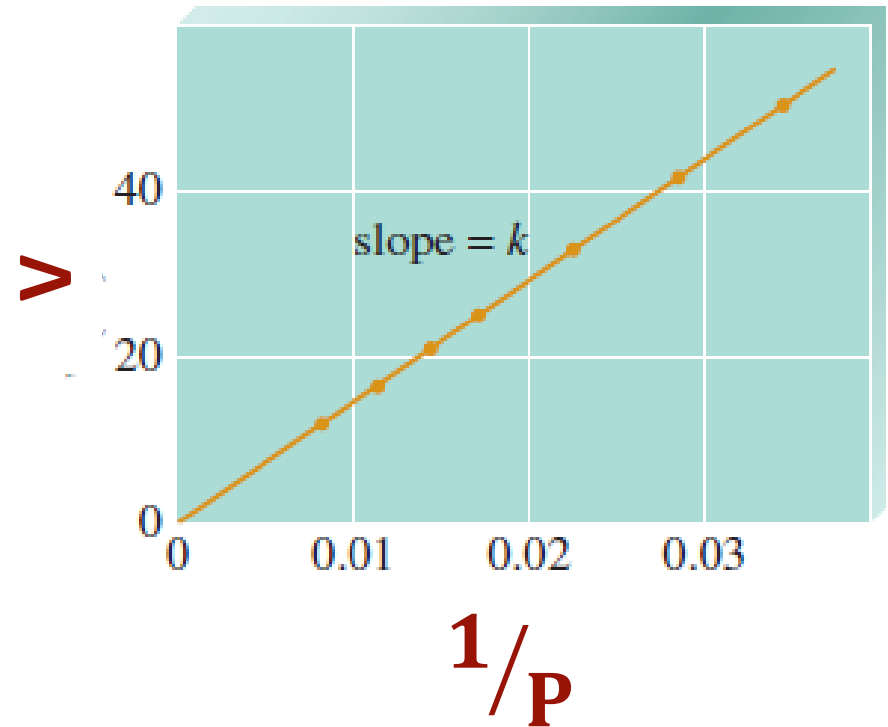
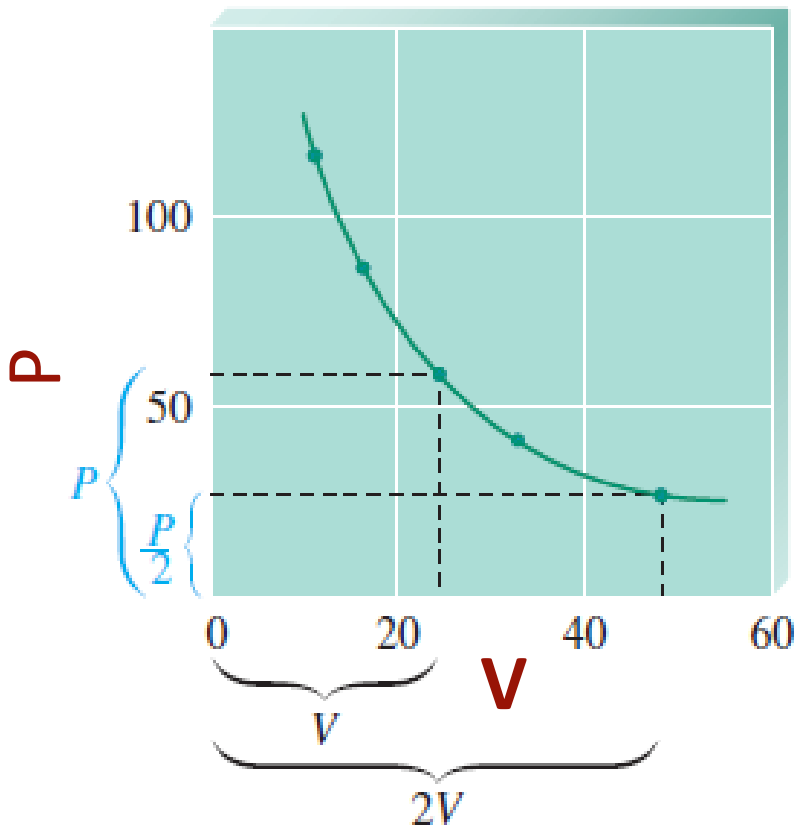
Boyle's Law

$$V \propto \frac{1}{P}$$

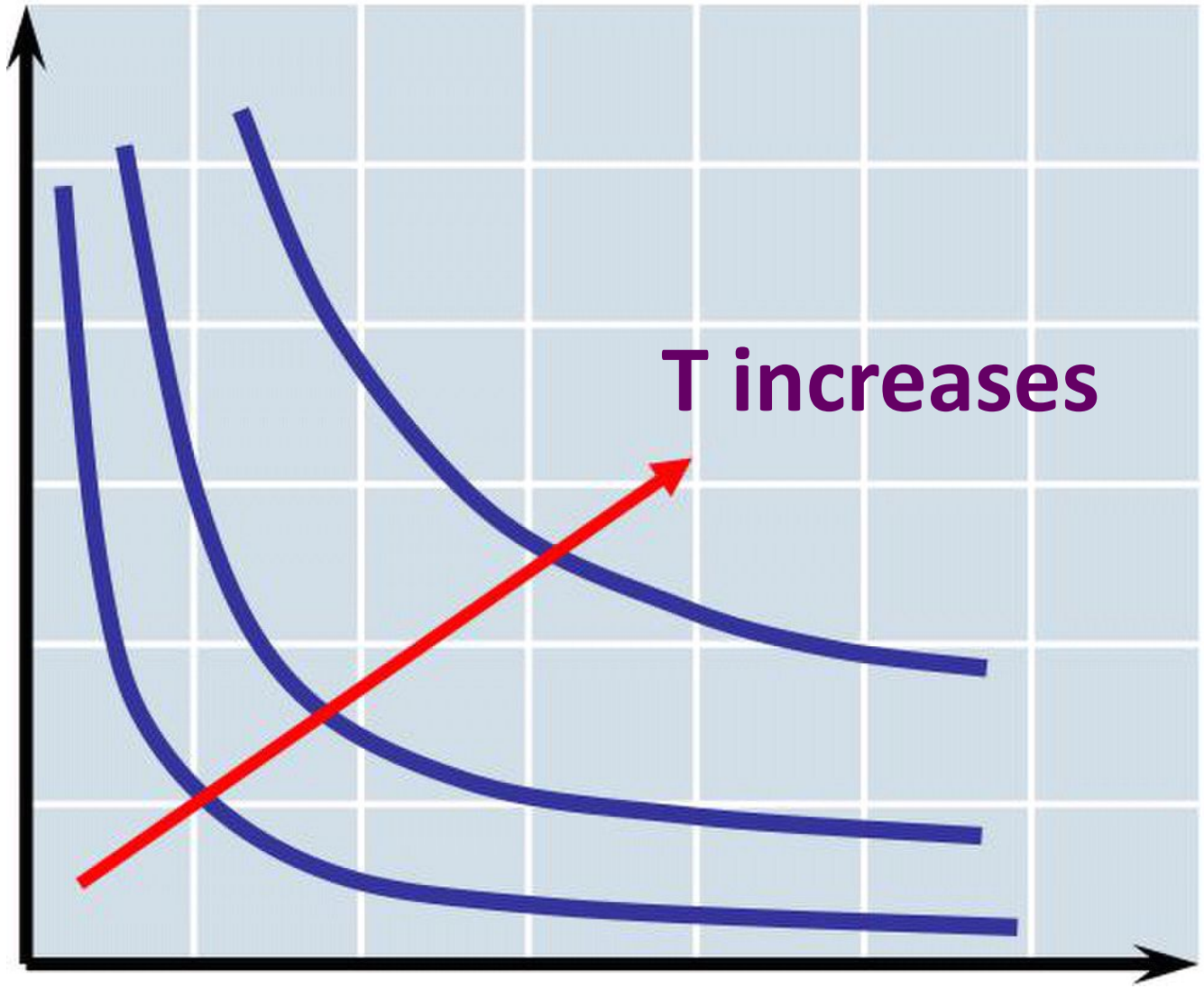
$$PV = \text{const. (k)}$$

$$P_1 V_1 = P_2 V_2$$

At a constant temperature, the volume of a fixed amount of gas is inversely proportional to its pressure.



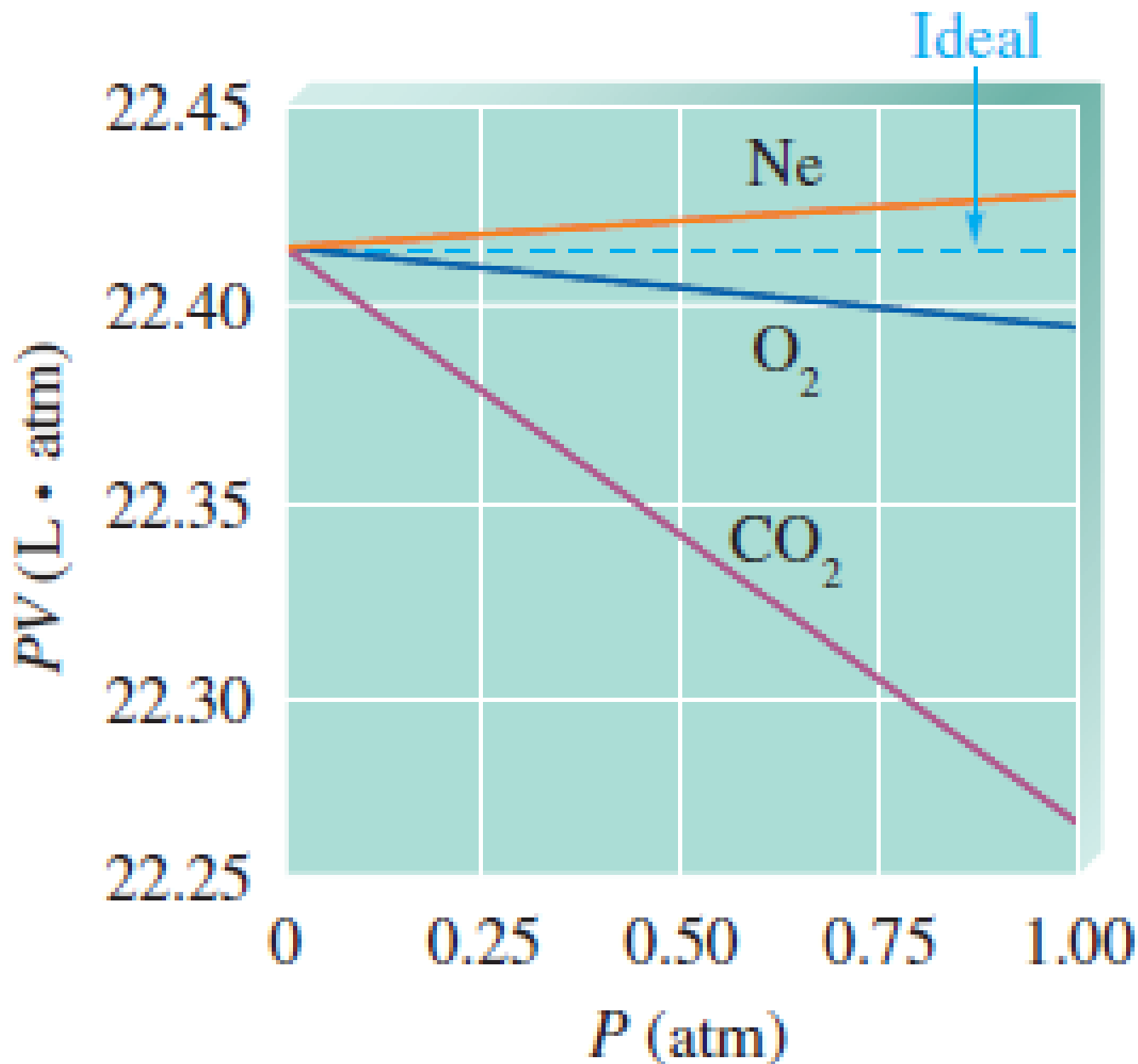
Pressure



T increases

Volume

Boyle's Law holds precisely only at very low **P**



Exercise

Sulfur dioxide (SO_2), a gas that plays a central role in the formation of acid rain, is found in the exhaust of automobiles and power plants. Consider a 1.53 L sample of gaseous SO_2 at a pressure of $5.6 \times 10^3 \text{ Pa}$. If the pressure is changed to $1.5 \times 10^4 \text{ Pa}$ at a constant temperature, what will be the new volume of the gas?

$$P_1 = 5.6 \times 10^3 \text{ Pa}$$

$$P_2 = 1.5 \times 10^4 \text{ Pa}$$



$$V_1 = 1.53 \text{ L}$$



$$V_2 = ? \text{ L}$$

$$P_1 V_1 = P_2 V_2$$

$$V_2 = \frac{P_1 V_1}{P_2} = \frac{5.6 \times 10^3 \cancel{\text{ Pa}} \times 1.53 \text{ L}}{1.5 \times 10^4 \cancel{\text{ Pa}}} = 0.57 \text{ L}$$

V decreases \checkmark

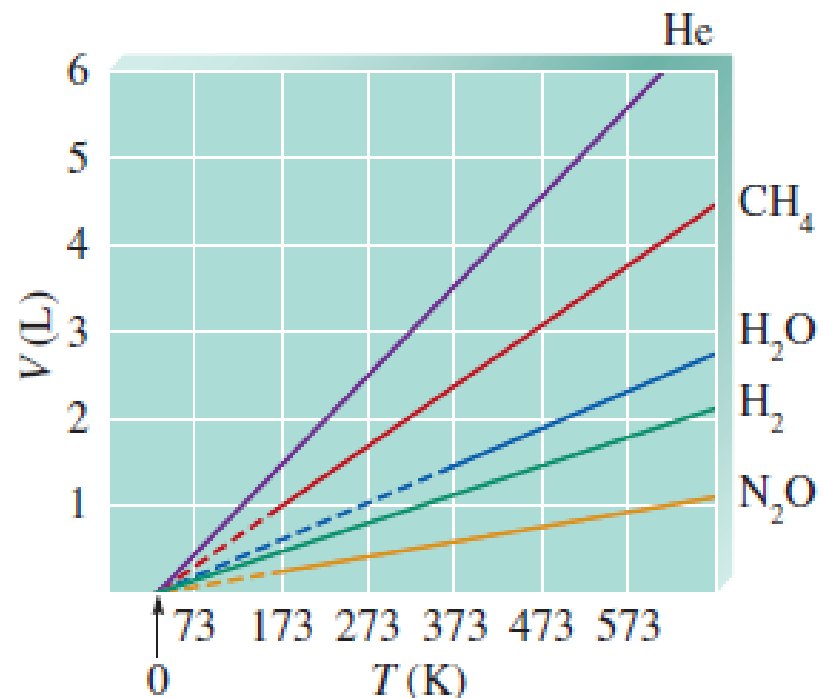
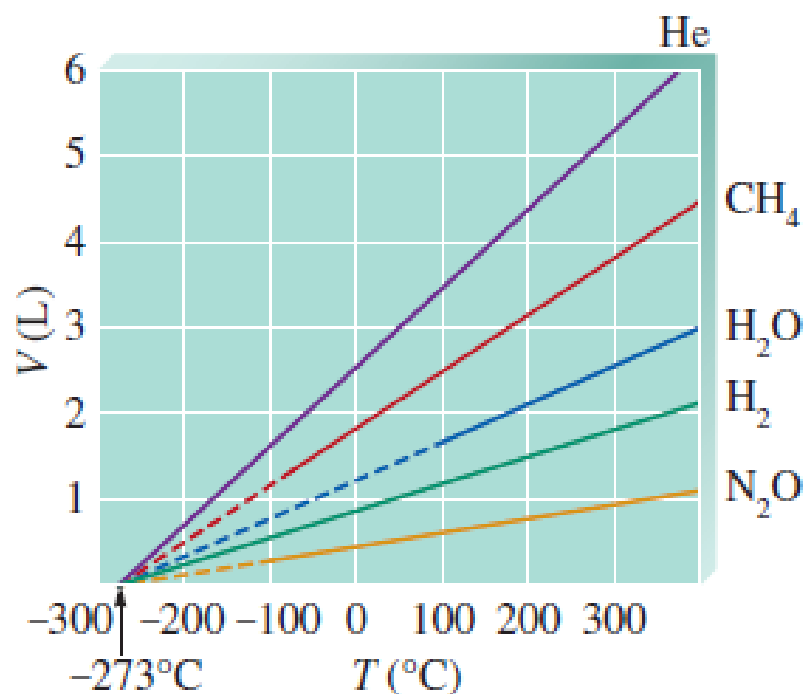
Charles's Law

$$V \propto T$$

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

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

The **volume** of a **fixed** amount of a gas at a constant **pressure** increases linearly with the gas **temperature**



- **Different Slopes:** because of different numbers of moles of gas.
- Volumes of gases extrapolate to **ZERO** at **-273°C = 0 K** (absolute Zero)

Exercise

A sample of gas at 15°C and 1 atm has a volume of 2.58 L. What volume will this gas occupy at 38°C and 1 atm?

Solution

P and $n = \text{constant}$

$$V_1 = 2.58\text{L} \longrightarrow T_1 = 15^\circ\text{C} + 273 = 288\text{K}$$

$$V_2 = ?\text{L} \longrightarrow T_2 = 38^\circ\text{C} + 273 = 311\text{K}$$

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

$$V_2 = \frac{V_1 T_2}{T_1} = \frac{2.58\text{L} \times 311\text{K}}{288\text{K}} = 2.79\text{L}$$

V increases ✓

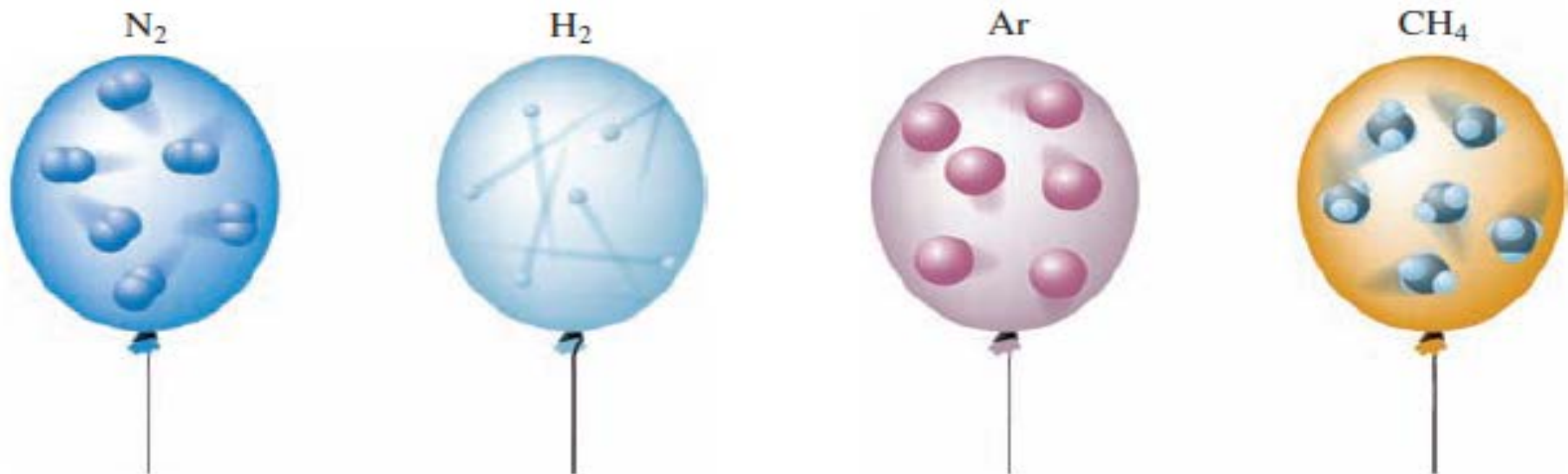
Avogadro's Law

$$V \propto n$$

$$\frac{V}{n} = k$$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

- Equal **volumes** of gases at the same temperature and pressure contain the same **number of "particles"**.
- For a gas at constant **T** and **P**, the **volume** is directly proportional to its **number of moles**.



Exercise

P and $T = \text{constant}$

Suppose we have a **12.2 L** sample containing **0.50 mole** of oxygen gas (O_2) at a pressure of **1 atm** and a temperature of **25°C**. If all this O_2 were converted to **0.33 mole** of ozone (O_3) at the same temperature and pressure, what would be the volume of the ozone?

Solution

$$V_1 = 12.2 \text{ L}$$



$$n_1 = 0.5 \text{ mol O}_2$$

$$V_2 = ? \text{ L}$$



$$n_2 = 0.33 \text{ mol O}_3$$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

$$V_2 = \frac{V_1 n_2}{n_1} = \frac{12.2 \text{ L} \times 0.33 \text{ mol}}{0.5 \text{ mol}} = 8.1 \text{ L}$$

V decreases ✓

Exercise

Ammonia burns in oxygen to form nitric oxide (NO) and water vapor. How many volumes of NO are obtained from one volume of ammonia at the same temperature and pressure?

Solution



P and $T = \text{constant}$

