Chemistry 3A

Introductory General Chemistry

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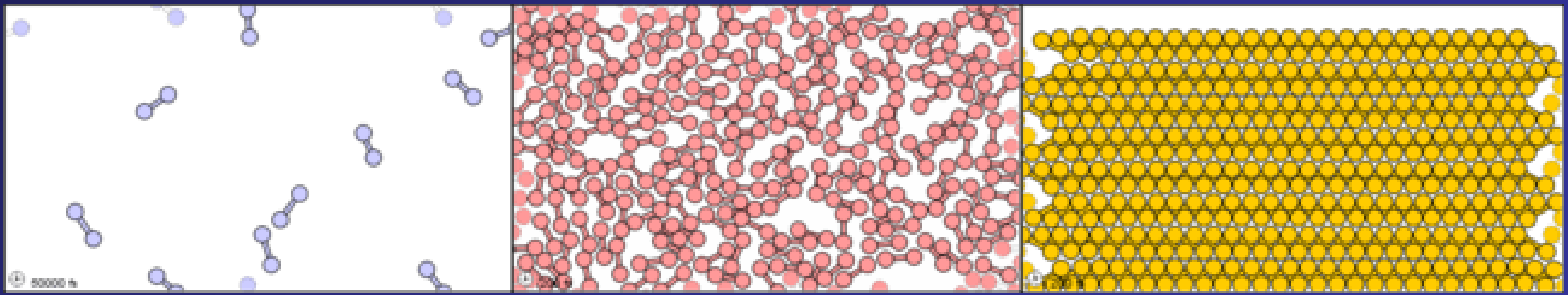
- Comparing Gases to Solids, Liquids
- Pressure
- Kinetic Molecular Theory as a Model for Gases
- The Gas Laws of Boyle, Charles, Gay-Lussac, Avogadro
- Ideal Gas Law and Applying It
- Understanding Gas Mixtures

Comparing Solids/Liquids/Gases

- H_2O has same chemical properties whether as steam (water vapor), water, or ice, but physical properties differ
- Covalent bonds affect molecular shape/geometry, bond energies, chemical properties
- Intermolecular forces set the physical properties of liquids and solids
- Kinetic molecular theory is used to explain properties of gases, but needs adjustments when gases become so dense they behave almost like liquids

Comparing Solids/Liquids/Gases

- A substance's state can be described as
  - Kinetic energy (moving around) of individual particles (molecules or atoms)
  - Temperature affects or indicates kinetic energy
  - The nature of intermolecular forces which are generally involved in attraction between molecules
- Both temperature and pressure affect gases
- Increasing pressure (which is a kind of density) also increases intermolecular forces



Properties of Gases, Liquids, Solids

Gases	• Molecules widely separated • Particle kinetic energy greater than intermolecular attractions • Molecules fill container easily • Non-ideal gas behavior occurs if attractive forces become significant
Liquids	• Intermolecular attractive forces become significant such that liquid states form from gas states • Liquids are not compressible and certainly denser than gases • Liquids show a definite volume which does not depend on container size or shape • Intermolecular attractive forces are not strong enough to fix position of molecules, so molecules and move around each other
Solids	• Intermolecular attractive forces are such that molecules can be locked or fixed in position • These solids like liquids are not compressible • If the molecules forming the solid adopt an ordered packing arrangement, they can become **crystalline**

Pressure

- Pressure is the physical property of a gas
- $Pressure = \frac{Force}{Area}$
- A TON of conversion factors for pressure

1 atmosphere (**atm**) [chemists] Expect to work with this in your calculations
= 760 millimeters of mercury (**mm Hg**) [meteorlogists]
= 760 **torr** (named after Italian scientist) [STEM people]
= 101,325 Pascal (**Pa**) [SI unit] = 101.325 kilopascals (**kPa**)
= 14.7 pounds per square inch (psi)
= 1.01325 bar

How many atmospheres in 595 torr?

$$595\text{ torr} \times \frac{1\text{ atm}}{760\text{ torr}} = 0.783\text{ atm}$$

Problem Practice

1 atmosphere (**atm**) [chemists] Expect to work with this in your calculations
= 760 millimeters of mercury (**mm Hg**) [meteorlogists]
= 760 **torr** (named after Italian scientist) [STEM people]
= 101,325 Pascal (**Pa**) [SI unit] = 101.325 kilopascals (**kPa**)
= 14.7 pounds per square inch (psi)
= 1.01325 bar

How many atmospheres in 1,022 torr?

$$1022 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 1.345 \text{ atm}$$

The atmosphere on Mars is largely CO_2 at a pressure of 6.01 mmHg. What is this pressure in atmospheres?

$$6.01 \text{ mm Hg} \times \frac{1 \text{ atm}}{760 \text{ mm Hg}} = 0.00791 \text{ atm} = 7.91 \times 10^{-3} \text{ atm}$$

Atmospheric pressure is low in the eye of a hurricane. In a 1979 hurricane in the Pacific Ocean, a pressure of 0.859 atm was reported inside the eye. What is this pressure in torr?

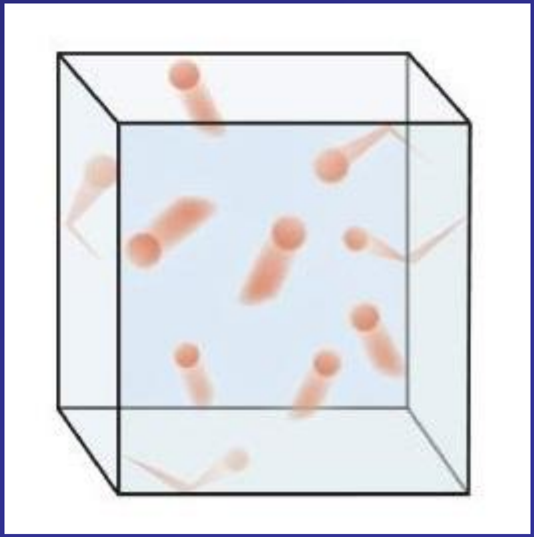
$$0.859 \text{ atm} \times \frac{760 \text{ torr}}{1 \text{ atm}} = 652 \text{ torr}$$

Kinetic Molecular Theory (KMT)

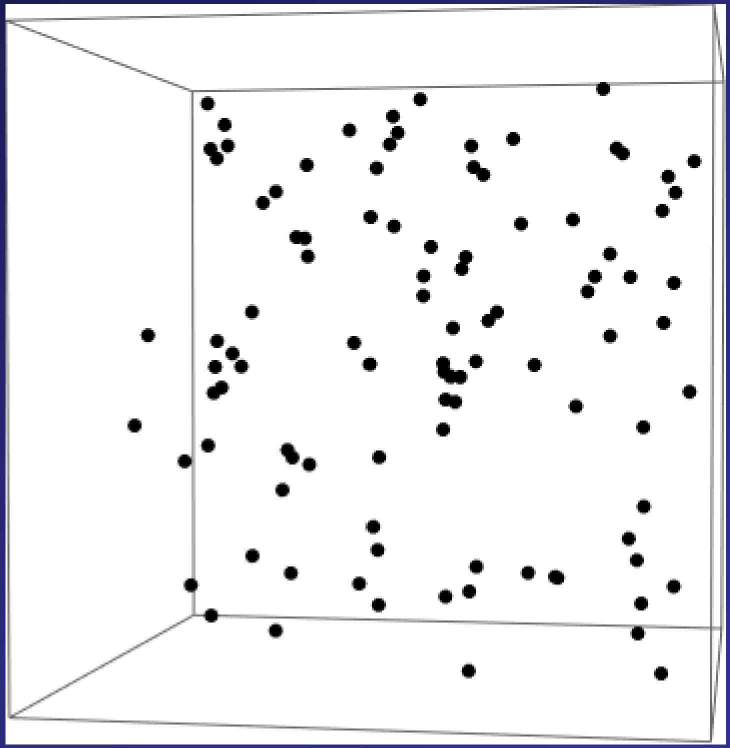
Also called "Kinetic [Molecular] Theory of Gases"

Principles/Assumptions

1. Gases are tiny particles in constant motion
2. Gases collide ***elastically*** with each other and walls of container. (In elastic collisions, no energy is lost)
3. Gas particles separated by large distances, relative to their own size
4. There can be no attractive or repulsive forces between the particles
5. Average speed dependent on temperature



Gas Laws



- In the 15th to 17th centuries scientists did experiments with gases in which they discovered properties they could reliably reproduce
- From the results, **gas laws** were described that developed the mathematics to explain behavior of the gases
- These laws are described next

Boyle's Law (*PV=k*)

- 1662: Boyle noted that if a gas is kept at *constant temperature*, that if the **volume** of the is ***increased***, the **pressure** of the gas **decreases**

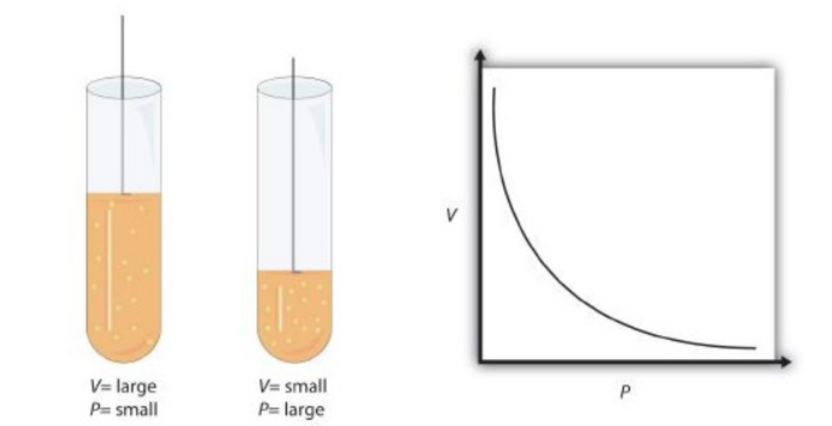


Figure 8.4.1.1: Boyle's Law. A piston having a certain pressure and volume (left piston) will have half the volume when its pressure is twice as much (right piston). One can also plot *P* versus *V* for a given amount of gas at a certain temperature; such a plot will look like the graph on the right.

- He also noted if the **volume** of the gas is ***decreased*** again at constant temperature, the **pressure** is increased
- The mathematical description of this observation is the **hyperbola** plot shown in the figure. This shows that volume (V) times pressure (P) is a constant (k)

Boyle's Law ($PV=k$)

- Because the ***V vs P*** plot is on an *X*-*Y* coordinate system is a hyperbola, this means that ***PV = k***
- This also means that for any point on that curve, say Point 1 and Point 2, that $P_1 \times V_1 = P_2 \times V_2$

For example, if a gas has a pressure of 1 atm in a 10 L volume container, and the gas is put into container with volume of 1 L, then the pressure should be increased:

$$P_2 = \frac{P_1 \times V_1}{V_2} = \frac{1\ \text{atm} \times 10\ \text{L}}{1\ \text{L}} = 10\ \text{atm}$$

- ALWAYS MAKE SURE UNITS CANCEL (CROSS OUT)—if they don't, set up the proper conversion!

Problem Practice

A sample of gas has an *initial* **pressure** of **2.44 atm** and an *initial* **volume** of **4.01 L**. Its **pressure** changes to **1.93 atm**. What is the new **volume** if temperature?

- Find applicable mathematical relationship: $P_1V_1 = P_2V_2$
- Do any necessary algebra: $V_2 = \frac{P_1V_1}{P_2}$
- Substitute values and solve: $V_2 = \frac{2.44 \text{ atm} \times 4.01 \text{ L}}{1.93 \text{ atm}} = 5.07 \text{ L}$

Solve: P_1 = **334 torr**, V_1 = **37.8 mL** and P_2 = **102 torr**. What is V_2?

- Find applicable mathematical relationship: $P_1V_1 = P_2V_2$
- Do any necessary algebra: $V_2 = \frac{P_1V_1}{P_2}$
- Substitute values and solve: $V_2 = \frac{334 \text{ torr} \times 37.8 \text{ mL}}{102 \text{ torr}} = 124 \text{ mL}$

Problem Practice

A sample of gas has an *initial* **pressure** of **722 torr** and an *initial* **volume** of **88.8 mL**. Its **volume** changes to **0.663 L**. What is the new **pressure**?

- Find applicable mathematical relationship: $\boldsymbol{P_1V_1 = P_2V_2}$
- Do any necessary algebra: $\boldsymbol{P_2 = \frac{P_1V_1}{V_2}}$
- Substitute values: $\boldsymbol{P_2} = \frac{722\ \mathrm{atm} \times 88.8\ \mathrm{mL}}{0.663\ \mathrm{L}}$
- If units don't cancel (cross out), do conversions!:
- $\boldsymbol{P_2} = \frac{722\ \mathrm{torr} \times \left(88.8\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}\right)}{0.663\ \mathrm{L}}$ **OR** $\boldsymbol{P_2} = \frac{722\ \mathrm{torr} \times 88.8\ \mathrm{mL}}{0.663\ \mathrm{L} \times \frac{1000\ mL}{1\ \mathrm{L}}}$
- Result time: $\boldsymbol{P_2 = 96.7\ \mathrm{torr}}$

Solve: **P_1 = 308 torr**, **V_1 = 456 mL** and **P_2 = 1.55 atm**. What is **V_2**?

- Find applicable mathematical relationship: $\boldsymbol{P_1V_1 = P_2V_2}$
- Do any necessary algebra: $\boldsymbol{V_2 = \frac{P_1V_1}{P_2}}$
- Substitute values: $\boldsymbol{V_2} = \frac{308\ \mathrm{torr} \times 456\ \mathrm{mL}}{1.55\ \mathrm{atm}}$
- If units don't cancel (cross out), do conversions!:
- $\boldsymbol{V_2} = \frac{\left(308\ \mathrm{torr} \times \frac{1\ \mathrm{atm}}{760\ \mathrm{torr}}\right) \times 456\ \mathrm{mL}}{1.55\ \mathrm{atm}}$ **OR** $\boldsymbol{V_2} = \frac{308\ \mathrm{torr} \times 456\ \mathrm{mL}}{1.55\ \mathrm{atm} \times \frac{760\ \mathrm{torr}}{1\ \mathrm{atm}}}$
- Result time: $\boldsymbol{V_2 = 119\ \ \mathrm{mL}}$

Charle's Law (*V=kT*)

- As a gas is heated (**temperature (T)** is monitored) with important part of keeping the **pressure** constant
- In the process, the gas **increases** in **volume (V)** in a **linearly constant** way (*k*)
- Temperate ***must*** be measured on the **Kelvin** scale for mathematical relation to work

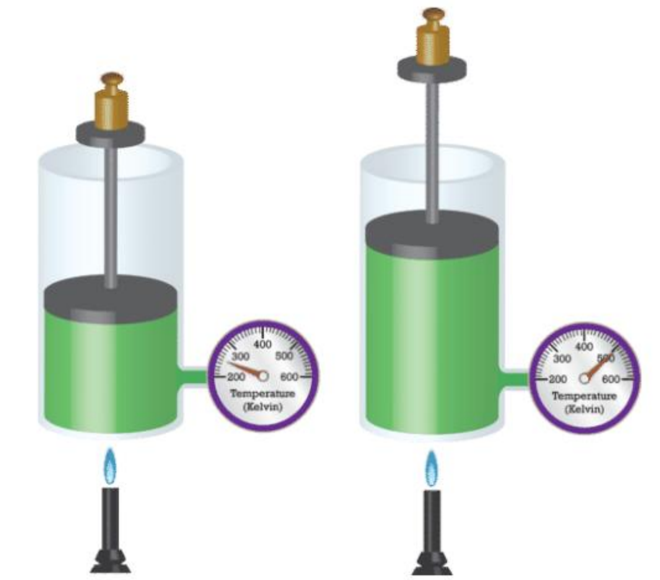


Figure 8.4.2.1: As a container of confined gas is heated, its molecules increase in kinetic energy and push the movable piston outward, resulting in an increase in volume.

$$V = kT \quad \rightarrow \quad \frac{V}{T} = k$$

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

Table 8.4.2.1: Temperature-Volume Data

Temperature (K)	**Volume** (mL)	$\frac{V}{T} = k\left(\frac{\text{mL}}{\text{K}}\right)$
50	20	0.40
100	40	0.40
150	60	0.40
200	80	0.40
300	120	0.40
500	200	0.40
1000	400	0.40

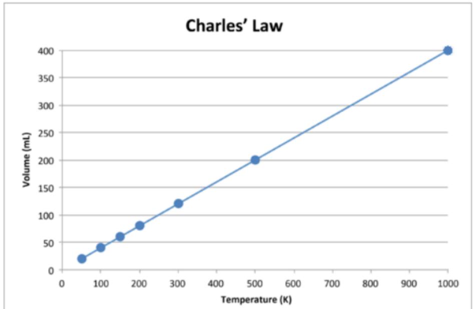


Figure 8.4.2.2:The volume of a gas increases as the Kelvin temperature increases.

Problem Practice

A balloon is filled to a volume of **2.20 L** at a temperature of **22°C**. The balloon is then heated to a temperature of **71°C**. Find the new volume of the balloon?

- Temperatures must be converted to K ➔ K = °C + 273
- Find applicable mathematical relationship: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- Do any necessary algebra: $V_2 = T_2 \times \frac{V_1}{T_1}$
- Substitute values and solve: $V_2 = (71 + 273)\mathrm{K} \times \frac{2.20\ \mathrm{L}}{(22+273)\mathrm{K}} = 2.57\ \mathrm{L}$

Solve: V_1 = **3.77 L**, T_1 = **255 K** and T_2 = **123 K**. What is V_2?

- Temperatures must be converted to K? No need
- Find applicable mathematical relationship: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- Do any necessary algebra: $V_2 = T_2 \times \frac{V_1}{T_1}$
- Substitute values and solve: $V_2 = 123\ \mathrm{K} \times \frac{3.77\ \mathrm{L}}{255\ \mathrm{K}} = 1.82\ \mathrm{L}$

Problem Practice

A sample of a gas has an *initial* **volume** of **34.8 L** and an *initial* **temperature** of **−67°C**. What must be the **temperature** of the gas for its **volume** to be **25.0 L**? (Make sure result is in °C)

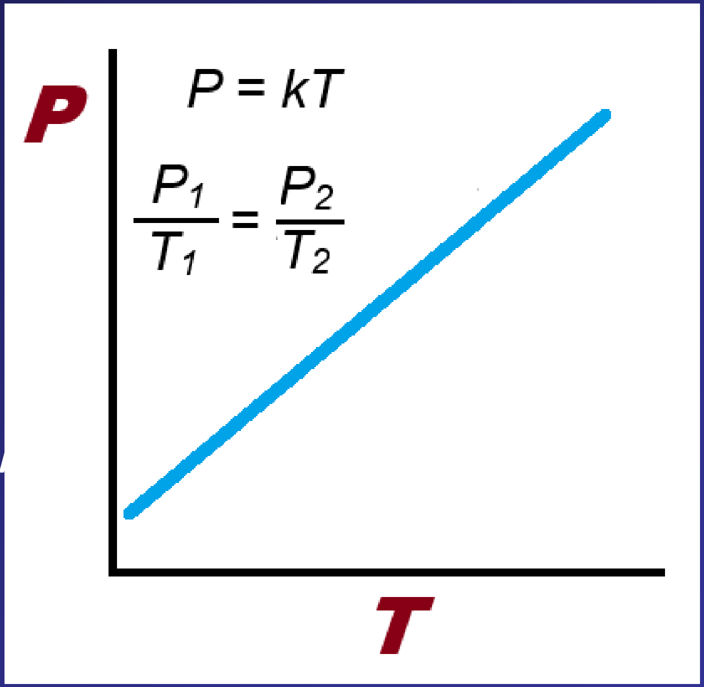
- Temperatures must be converted to K ➔ K = °C + 273 also °C = K − 273
- Find applicable mathematical relationship: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- Do any necessary algebra: $T_2 = V_2 \times \frac{T_1}{V_1}$
- Substitute values and solve: $T_2 = 25.0\ \text{L} \times \frac{(-67+273)\text{K}}{34.8\ \text{L}} = 148\ \text{K}$
- Convert to units that were initial units: $T_2 = (148 - 273)\text{K} = -125°\text{C}$

Solve: V_1 = **623 mL**, T_1 = **255°C** and V_2 = **277 mL**. What is T_2?

- Temperatures must be converted to K ➔ K = °C + 273 also °C = K − 273
- Find applicable mathematical relationship: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- Do any necessary algebra: $T_2 = V_2 \times \frac{T_1}{V_1}$
- Substitute values and solve: $T_2 = 277\ \text{mL} \times \frac{(255+273)\text{K}}{623\ \text{mL}} = 235\ \text{K}$
- Convert to units that were initial units: $T_2 = (235 - 273)\text{K} = -38°\text{C}$

Gay-Lussac's Law ($P_1/T_1=P_2/T_2$)

- This particular gas law brings in temperature as a factor in how gases behave
- The law states very simply that as the **temperature** of a gas in a container is **increased**, the pressure of the gas is **increased** in a **linearly constant** way as well
- The **P vs T** plot should be a straight line with positive slope (***k* > 0**)



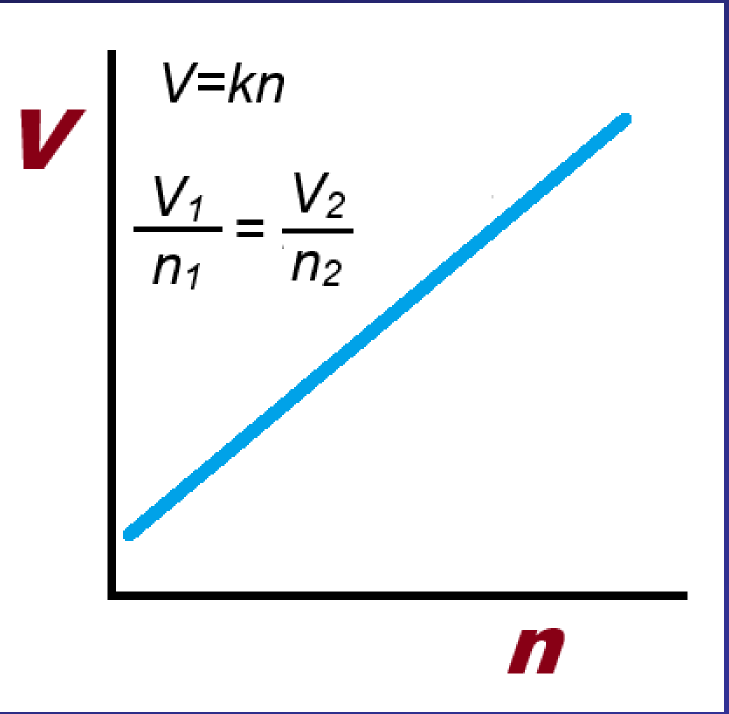
Problem Practice

The gas in an aerosol can is under a **pressure** of **3.00 atm** at a **temperature** of **25°C**. It is dangerous to dispose of an aerosol can by incineration. What would the **pressure** in the aerosol can be at a **temperature** of **845°C**?

- Temperatures must be converted to K ➔ K = °C + 273 also °C = K – 273
- Find applicable mathematical relationship: $\frac{\boldsymbol{P_1}}{\boldsymbol{T_1}} = \frac{\boldsymbol{P_2}}{\boldsymbol{T_2}}$
- Do any necessary algebra: $\boldsymbol{P_2} = \boldsymbol{T_2} \times \frac{\boldsymbol{P_1}}{\boldsymbol{T_1}}$
- Substitute values and solve: $\boldsymbol{P_2} = (\mathbf{845 + 273})\mathrm{K} \times \frac{3.00\ \mathrm{atm}}{(25+273)\mathrm{K}} = 11.3\ \mathrm{atm}$
- Convert to units that were initial units: no need. Temperature was not calculated

Avogadro's Law ($V=k \times n$)

- Avogadro studied amounts of atoms and molecules. The number of atoms and molecules totaling **6.022×10^{23}** amounting to 1 mole is attributed to Avogadro
- Avogadro stated:
  "***Equal*** volumes of all gases, at the ***same*** temperature and pressure, contain the same number of molecules"



- Just like the ***P=kT*** gas law, the ***V=kn*** gas law is a straight line with positive slope (***k > 0***)

Problem Practice

A balloon has been filled to a **volume** of **1.90 L** with **0.0920 mol** of helium gas. If **0.0210 mol** of ***additional*** helium is added to the balloon while the **temperature** and **pressure** are held constant, what is the new **volume** of the balloon?

- Temperatures must be converted to K ➔ no need: temperature not involved
- Find applicable mathematical relationship: $\frac{V_1}{n_1} = \frac{V_2}{n_2}$
- Do any necessary algebra: $V_2 = n_2 \times \frac{V_1}{n_1}$
- Substitute values and solve: $V_2 = (0.0210 + 0.0920)\text{mol} \times \frac{1.90\text{ L}}{0.0920\text{ mol}} = 2.33\text{ L}$

A **12.8 L volume** of gas contains **0.000498 moles** of oxygen gas. At constant temperature and pressure, what **volume** does **0.0000136 moles** of the gas fill?

- Find applicable mathematical relationship: $\frac{V_1}{n_1} = \frac{V_2}{n_2}$
- Do any necessary algebra: $V_2 = n_2 \times \frac{V_1}{n_1}$
- Substitute values and solve: $V_2 = 0.0000136\text{ mol} \times \frac{12.8\text{ L}}{0.000498\text{ mol}} = 0.350\text{ L}$

Ideal Gas Law (*PV* = *nRT*)

- Up to this point, we have four gas laws that connect the properties of pressure (*P*), volume (*V*), temperature (*T*), and substance amount (*n*) to each other
- These connections bring us to the realization of this mathematical equation that

$$\frac{PV}{nT} = constant$$

This will be independent of the composition of the gas. A constant R is defined to represent the constant, and the equation expressed in a known way

$$\frac{PV}{nT} = R \quad \rightarrow \boldsymbol{PV = nRT}$$

- This is called the **ideal gas law**

R, Ideal Gas Law Constant

- The constant R in the $PV=nRT$ gas law equation is experimentally determined and is true for all gases
- Its value can be different depending on the units being utilized

Table $8.5.1$: Values of the Ideal Gas Law Constant lists the numerical values of R.

Numerical Value	Units
0.08205	$\frac{L.atm}{mol.K}$
62.36	$\frac{L.torr}{mol.K} = \frac{L.mmHg}{mol.K}$
8.314	$\frac{J}{mol.K}$

Ideal Gas Law Problem Practice

What is the **volume** of a **4.22 mol** argon (Ar) gas sample at pressure of **1.21 atm** with temperature of **34°C**?

- Temperatures must be converted to K ➔ 34°C + 273°C = 307 K
- Find applicable mathematical relationship: $PV = nRT$
- Do any necessary algebra: $V = nRT/P$
- Substitute values and solve:

$$V = (4.22\ \mathrm{mol})\left(0.08205\ \frac{\mathrm{L\ atm}}{\mathrm{mol\ K}}\right)(307\mathrm{K})/(1.21\ \mathrm{atm}) = 87.9\ \mathrm{L}$$

What is the **volume** of a **0.0997 mol** diatomic oxygen (O_2) gas sample at pressure of **0.692 atm** with temperature of **333 K**?

- Temperatures must be converted to K ➔ not necessary, already in Kelvin
- Find applicable mathematical relationship: $PV = nRT$
- Do any necessary algebra: $V = nRT/P$
- Substitute values and solve:

$$V = (0.0997\ \mathrm{mol})\left(0.08205\ \frac{\mathrm{L\ atm}}{\mathrm{mol\ K}}\right)(333\ \mathrm{K})/(0.692\ \mathrm{atm}) = 3.94\ \mathrm{L}$$

Ideal Gas Law Problem Practice

What is the **temperature** of **0.00332 g** of mercury (Hg) in gas phase with pressure of **0.00120 mm Hg** in a volume of **435 L**?

- Temperatures must be converted to K ➔ trying to solve for this, answer in K
- Find applicable mathematical relationship: $\boldsymbol{PV = nRT}$
- Do any necessary algebra: $\boldsymbol{T = PV/nR}$
- Substitute values and solve: $\boldsymbol{T = \dfrac{0.00120\ \text{mm Hg} \times 435\ \text{L}}{(0.00332\ \text{g Hg})\left(\frac{1\ \text{mol Hg}}{200.59\ \text{g Hg}}\right) \times 62.36\ \frac{\text{L mm Hg}}{(\text{mol Hg})\ \text{K}}} =}$

506 K (book gave wrong answer because of entering wrong input for pressure)

Find **volume** of a **0.00554 mol** diatomic hydrogen (H_2) gas sample at pressure of **23.44 torr** with temperature of **557 K**?

- Temperatures must be converted to K ➔ not necessary, already in Kelvin
- Find applicable mathematical relationship: $\boldsymbol{PV = nRT}$
- Do any necessary algebra: $\boldsymbol{V = nRT/P}$
- Substitute values and solve:

$$\boldsymbol{V = (0.00554\ \text{mol})\left(62.36\ \frac{\text{L torr}}{\text{mol K}}\right)(557\ \text{K})/(23.44\ \text{torr}) = 8.21\ \text{L}}$$

Ideal Gas Law Problem Practice

What is **volume** of hydrogen gas (H_2) produced at temperature of **299 K** with pressure of **1.07 atm** when **55.8 g** zinc (Zn) metal is reacted with hydrochloric acid (HCl)? The reaction is

Zn (*s*) + 2 **HCl** (*aq*) → $\mathbf{ZnCl_2}$ (*aq*) + $\mathbf{H_2}$ (*g*)

- Understand elements of problem:
  - A mass (not moles) of REACTANT Zn is given, and Zn is NOT a gas
  - We have to get the moles of PRODUCT gas H_2
  - The reaction states 1 mole of Zn will make 1 mole of H_2
  - We have to convert the mass of Zn to moles Zn

$$55.8\ \mathrm{g\ Zn} \times \frac{1\ \mathrm{mol\ Zn}}{65.41\ \mathrm{g\ Zn}} \times \frac{1\ \mathrm{mol\ H_2\ produced}}{1\ \mathrm{mol\ Zn\ reacted}} = 0.853\ \mathrm{mol\ H_2}$$

- Temperatures must be converted to K ➔ already in K
- Find applicable mathematical relationship: $\boldsymbol{PV = nRT}$
- Do any necessary algebra: $\boldsymbol{V = nRT/P}$
- Substitute values and solve: $\boldsymbol{V = \frac{0.853\ mol \times 0.08205\ \frac{L\ atm}{mol\ K} \times 299\ K}{1.07\ atm} = 19.6\ L}$

Ideal Gas Law Problem Practice

What is **pressure** of hydrochloric acid (HCl) generated as a gas if hydrogen (H_2) and chlorine (Cl_2) gases are reacted in a chamber of **4.55 L** volume at temperature of **455 K**? The amount of Cl_2 is **3.44 g**
The reaction is

$$\mathbf{H_2}\ (g) + \mathbf{Cl_2}\ (g) \rightarrow \mathbf{2\ HCl}\ (g)$$

- Understand elements of problem:
  - Only one of REACTANTS (Cl_2) is given: we assume the other reactant H_2 is in excess
  - We have to get the moles of PRODUCT gas HCl
  - The reaction states 1 mole of Cl_2 will make 2 moles of HCl!
  - We have to convert the mass of Cl_2 to moles Cl_2

$$3.44\ \text{g Cl}_2 \times \frac{1\ \text{molCl}_2}{70.90\ \text{g Cl}_2} \times \frac{2\ \text{mol HCl produced}}{1\ \text{mol reacted}} = 0.0970\ \text{mol HCl}$$

- Temperatures must be converted to K ➔ already in K
- Find applicable mathematical relationship: $\boldsymbol{PV = nRT}$
- Do any necessary algebra: $\boldsymbol{P = nRT/V}$
- Substitute values and solve: $\boldsymbol{P = \dfrac{0.0970\ \text{mol} \times 0.08205\ \frac{\text{L atm}}{\text{mol K}} \times 455\ \text{K}}{4.55\ \text{L}} = 0.796\ \text{atm}}$

STP and Molar Volume

- Gas at a at temperature = **273 K**, which is **0°C**, and at a pressure = **100 kilopascals** (**kPa**), which is about **0.986** atm, is called **standard temperature and pressure** (**STP**)
- STP is basically assumed to be **1 atm**
- This allows a reference to gases under other conditions
- If there is ***n*** = **1 mol** of gas, the **molar volume** calculates to be

$$V = \frac{1\ \text{mol} \times \dfrac{0.08205\ \text{L atm}}{\text{mol K}} \times 273\ \text{K}}{1\ \text{atm}} = 22.4\ \text{L}$$

The composition/identity of the gas is not relevant. This is true for all ideal gases

STP Problem Practice

How many moles of argon (Ar) gas are present in **38.7 L** at **STP**?

- Understand elements of problem:
  - STP applies ONLY to the specification of the temperature and pressure
  - A molar volume (where there is 1 mol gas) would immediately indicate the volume of 22.4 L. But the volume is not a molar volumes, so the moles are not 1 mol!
  - We can use the relationship $\frac{1\ \text{mol gas}}{22.4\ \text{L gas}} = \frac{x\ \text{mol gas}}{y\ \text{L gas}}$
  - If we know *x*, we can solve for *y*. If we know *y*, we can solve for *x*
- Find applicable mathematical relationship: $\frac{1\ \text{mol gas}}{22.4\ \text{L gas}} = \frac{x\ \text{mol gas}}{y\ \text{L gas}}$
- Do any necessary algebra: $x\ \text{mol gas} = y\ \text{L gas} \times \frac{1\ \text{mol gas}}{22.4\ \text{L gas}}$
- Substitute values and solve: $\boldsymbol{x = 38.7\ \text{L} \times \frac{1\ \text{mol}}{22.4\ \text{L}} = 1.73\ \text{mol}}$

What is volume of krypton (Kr) gas at **STP** where ***n*** = **4.87 mol**?

$$\boldsymbol{y = 4.87\ \text{mol} \times \frac{22.4\ \text{L}}{1\ \text{mol}} = 109\ \text{L}}$$

Gas Density

- Recalling that *density* = *mass* / *volume*, and that we have a mole value for a gas and we can get its mass in grams if we know what the compound is, we can compute the density of a gas

What is *density* of $\mathbf{N_2}$ at T = **25°C** and P = **0.955 atm**?

- Temperatures must be converted to K ➔ T = 25+273 = 298 K
- Find applicable mathematical relationship: $\boldsymbol{PV = nRT}$ (solve for volume first)
- Do any necessary algebra: $V = \boldsymbol{nRT/P}$
- Substitute values and solve: $\boldsymbol{V = \dfrac{1\ \mathrm{mol} \times 0.08205\ \frac{\mathrm{L\ atm}}{\mathrm{mol\ K}} \times 298\ \mathrm{K}}{0.955\ \mathrm{atm}} = 25.6\ \mathrm{L}}$
- Get the density of 1 mol N_2: $\boldsymbol{d = \dfrac{1\ \mathrm{mol\ N_2} \times \frac{28.0\ \mathrm{g\ N_2}}{1\ \mathrm{mol\ N_2}}}{25.6\ \mathrm{L}} = 1.09\ \mathrm{g/L}}$
- What is *density* of $\mathbf{CO_2}$ at T = **227 K** and P = **0.0079 atm**?

$$\boldsymbol{V = \frac{1\ \mathrm{mol} \times 0.08205\ \frac{\mathrm{L\ atm}}{\mathrm{mol\ K}} \times 227\ \mathrm{K}}{0.0079\ \mathrm{atm}} = 2357\ \mathrm{L} \rightarrow d = \frac{1\ \mathrm{mol\ N_2} \times \frac{44.01\ \mathrm{g\ N_2}}{1\ \mathrm{mol\ N_2}}}{2357\ \mathrm{L}} = 0.019\ \mathrm{g/L}}$$

Gas Mixtures

- Gas pressure is created by particles colliding with each other and container walls
- As particles (moles) are added, to the pressure increases ($PV = nRT$)
- This is true no matter the composition of the gas → gas mixtures
- Dalton showed that if the air is **78%** N_2 and **21%** O_2, then N_2 was responsible for **0.78** of pressure *P* and O_2 was responsible for **0.21** of pressure *P*
- So if air is at **1 atm**, *P* for N_2 = **0.78 atm** and *P* for O_2 = **0.21 atm**

Dalton's Law of Partial Pressures

- Suppose a container of gas at P_1 and another container of gas at P_2
- If the two gases are combined in a container at same volume and temperature, the pressure of the combination is the sum of the individual pressures

$$P_{total} = P_1 + P_2$$

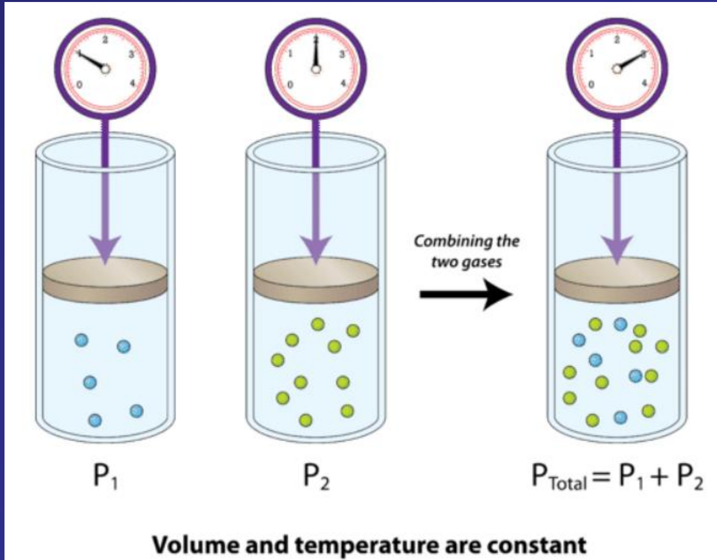


Figure 8.6.1: Dalton's Law states that the pressure of a gas mixture is equal to the partial pressures of the combining gases.

Gas Displacement of Water

- In the laboratory, you have a container filled with water whose opening is inverted in an outer container
- You do an experiment where you produce gas up into the inverted container and the gas displaces the water
- The pressure of the contained gas is equal to the pressure outside of the container (namely the atmosphere, where P = 1 atm). So this helps in calculating the amount of gas produced.
- Water vapor contributes as well, so we have to compensate for its effect on pressure

Figure 8.6.2: A gas produced in a chemical reaction can be collected by water displacement.

Table 8.6.1: Vapor Pressure of Water (mm Hg) at Selected Temperatures (°C)

0	**5**	**10**	**15**	**20**	**25**	**30**
4.58	6.54	9.21	12.79	17.54	23.76	31.82
35	**40**	**45**	**50**	**55**	**60**	
42.18	55.32	71.88	92.51	118.04	149.38	

Gas Displacement Problem Practice

A certain experiment generates a volume = **2.58 L** of H_2 gas collected over water. The temperature is **20°C**, atmospheric pressure is **98.60 kPa**. What is volume of dry H_2 at **STP**?

- Understand elements of problem:
  - The P, V, T values are given for one condition. The problem to solve for V where P and T are at another condition.
  - If amount (*n*) does not change (is constant), then $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
- For standard pressure, use 739.7 mm Hg. Compensate for water vapor at 20°C (17.54 mm Hg).
- Find applicable mathematical relationship: stated above
- Do any necessary algebra: $V_2 = \frac{P_1V_1T_2}{T_1P_2}$
- Substitute values and solve:

$$V_2 = \frac{\left(\mathbf{98.60\ kPa} \times \frac{\mathbf{760\ mm\ Hg}}{\mathbf{101.325\ kPa}} - \mathbf{17.54\ mm\ Hg}\right) \times \mathbf{2.58\ L} \times \mathbf{273\ K}}{\mathbf{293\ K} \times \mathbf{760\ mm\ Hg}} = \mathbf{2.28\ L}$$