Ideal Gas Law

$$PV = nRT$$

Use when you have only one of each variable.

P = pressure (variable units)

V = volume (MUST be in L)

T = temperature (MUST be in K, of course)

n = quantity (MUST be in mol)

R = universal gas constant → the value for R depends on the units for pressure! (on formula chart)

(R relates the energy scale in physics to the temperature scale: super important!)

The value for R is provided on the formula chart!

$$\text{Gas constant, } R = 8.314 \text{ J mol}^{-1}\text{K}^{-1}$$ energy R!

$$= 0.08206 \text{ L atm mol}^{-1}\text{ K}^{-1}$$

$$= 62.36 \text{ L torr mol}^{-1}\text{ K}^{-1}$$

$$1 \text{ atm} = 760 \text{ mm Hg} = 760 \text{ torr}$$

GAS CONSTANT **MUST** MATCH **ALL** THE UNITS!!!!!!!!!!

Guided Practice

P=? n V T

1. What is the pressure in atmospheres exerted by a 0.500 mol sample of nitrogen gas in a 10.0 L container at 298 K?

$$P = \frac{nRT}{V} = \frac{(0.500\text{ mol})(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(298\text{ K})}{10.0\text{ L}} = \boxed{1.22\text{ atm}}$$

V=? m→n T P

2. What is the volume, in liters, of 8.00 g of oxygen gas at 20.0°C and 740.24 mmHg pressure?

$$8.00\text{g } O_2 \times \frac{1\text{ mol}}{32.00\text{ g}} = 0.250 \text{ mol } O_2$$

$$V = \frac{nRT}{P} = \frac{(0.250\text{ mol})(62.36 \frac{\text{L}\cdot\text{mmHg}}{\text{mol}\cdot\text{K}})(293.0\text{ K})}{740.24\text{ mmHg}} = \boxed{6.17\text{ L } O_2}$$

3. What mass of chlorine gas, Cl_2, in grams, is contained in a 10.0 L tank at 27.0°C and 3.50 atm of pressure?

$$n = \frac{PV}{RT} = \frac{(0.350\text{ atm})(10.0\text{ L})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(300.0\text{ K})} = 1.42\text{ mol } Cl_2 \times \frac{70.9\text{ g}}{1\text{ mol}} = \boxed{101\text{ g } Cl_2}$$

Standard Molar Volume

Volume-Mass Relationships of Gases

The volume occupied by one mole of a gas at STP is known as the **standard** Molar **volume** of a gas. Let's solve the ideal gas equation for the volume of 1.00 mol of gas at **STP** ($2\cancel{73}$ K, 1.00 atm): 273.15 K

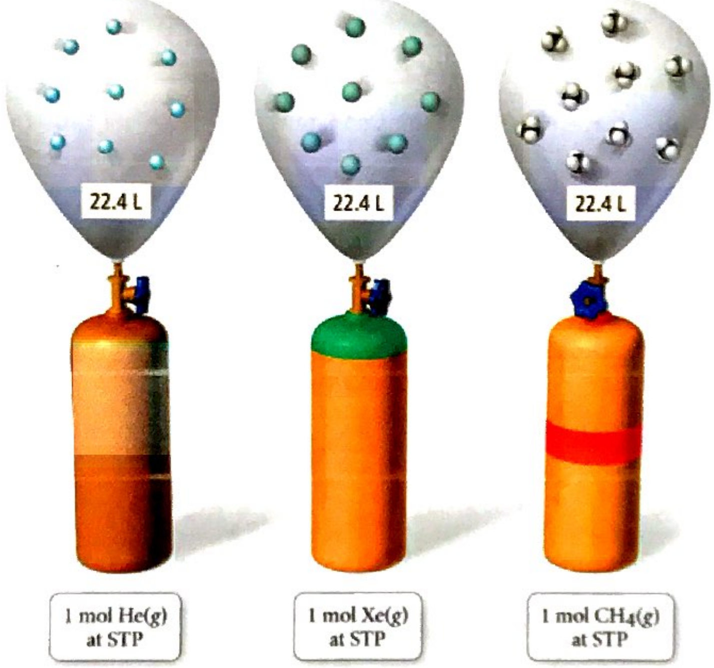
$$PV = nRT$$

$$V = \frac{nRT}{P} = \frac{(1.00\ mol)(0.08206\ \frac{L \cdot atm}{mol \cdot K})(273.15\ K)}{1.00\ atm} = \boxed{22.4\ L}$$

1. The following conversion factors can be written for the standard molar volume of a gas @ **STP**:

$$\frac{1\ mol\ GAS}{22.4\ L\ GAS} \quad OR \quad \frac{22.4\ L\ GAS}{1\ mol\ GAS}$$

2. At **STP**, 1 mole of ANY gas is equal to 22.4 L of gas but has different mass! since $d = \frac{m}{V}$, also different density!



4 g 131.29 g 16.042 g

Let's Practice!

1. A chemical reaction produces 0.0680 mol of oxygen gas. What volume (in L) is occupied by this gas at STP?

$$0.0680\ mol\ O_2 \times \frac{22.4\ L\ O_2}{1\ mol\ O_2} = \boxed{1.52\ L\ O_2}$$

2. A chemical reaction produced 98.0 mL of sulfur dioxide gas, SO_2, at STP. What mass in grams of the gas was produced?

$$98.0\ mL\ SO_2 \times \frac{1\ L}{1000\ mL} \times \frac{1\ mol}{22.4\ L} \times \frac{64.06\ g}{1\ mol} = \boxed{0.280\ g\ SO_2}$$

Equations You can Derive from the Ideal Gas Law: Yum!

Note: ONLY the ideal gas law is given on the AP Chem formula chart, so...

You must either be able to derive or memorize the following formulas!

1. **The Other Gas Laws:**

Rearranging the ideal gas law for R gives the following equation $R = \frac{PV}{nT}$

Because R is a constant, we can derive the combined gas, which can be used to compare changing conditions for a sample of gas:

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

Luckily, we are often only focused on one or two variables. All of the following gas laws can be derived from the combined gas law by holding two of the four variables constant:

Boyle's Law	Charles' Law	Avogadro's Law
$P_1V_1 = P_2V_2$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$\frac{V_1}{n_1} = \frac{V_2}{n_2}$
• Temperature, moles constant • If P ↑ then V ↓ = inverse relationship	• Pressure, moles constant • If T ↑ then V ↑ = direct relationship	• Temperature, pressure constant • If n ↑ then V ↑ = direct relationship

Key vocab words:

- rigid container: constant volume (for example, a sealed glass container)
- flexible container: volume can change (for example, a balloon)

2. **Density/ Molar Mass:**

Moles (the variable n), can be calculated by the mass of a sample divided by the molar mass of the substance.

$$Molar\ mass\ (MM) = \frac{mass\ (m)}{moles\ (n)} \quad \text{therefore } n = \frac{m}{MM}$$

Substituting this into the ideal gas law allows to solve for density! Remember, density (D) = $\frac{mass}{volume} = \frac{m}{V}$

$$PV = nRT \quad \text{therefore} \quad PV = \frac{m}{MM}RT \quad \text{therefore} \quad \frac{MM\ P}{RT} = \frac{m}{V} = D$$

or (if you know density): $\boxed{MM = \frac{DRT}{P}}$ $= \frac{mRT}{PV}$ } NOT on F.C. ⇒ memorize!

(kitty cat)

3. **Density related to Standard Molar Volume:** since density is the ratio of mass to volume,

$$\boxed{Density = \frac{molar\ mass}{molar\ volume} \text{ at STP}}$$

Examples: $density_{He} = \frac{4.00\ g/mol}{22.4\ L/mol} = 0.179\frac{g}{L}$, $density_{N_2} = \frac{28.02\ g/mol}{22.4\ L/mol} = 1.25\ g/L$

Let's Practice!

1. If we lower the temperature of a gaseous system by a factor of 4 and increase the volume by a factor of 2, what will happen to the pressure of the system (if all other variables remain constant)?

$$P = \frac{nRT}{V} = \frac{nR(\frac{1}{4}T)}{(2V)} = \frac{1/4}{2} \times \frac{nRT}{V} = \frac{1}{8} \times \boxed{\frac{nRT}{V}} \Rightarrow$$ decreased P by factor of 8!

↑ original pressure

2. Calculate the density of nitrogen gas at 125°C and a pressure of 755 mmHg.

$$D = \frac{(MM)(P)}{RT} = \frac{(28.02\ g/mol)(755\ mmHg)}{(62.36\ \frac{L\cdot mmHg}{mol\cdot K})(398\ K)} = \boxed{0.852\ g/L}$$

3. A helium-filled balloon has a volume of 50.0 L at STP. What volume will it have at 0.855 atm and 10.°C?

1.00 atm, 273.15 K

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \frac{(1.00\ atm)(50.0\ L)}{273.15\ K} = \frac{(0.855\ atm)V_2}{283\ K}$$

$$V_2 = \boxed{60.6\ L}$$

4. A sample of gas has a mass of 0.311 g. Its volume is 0.225 L at a temperature of 55°C and a pressure of 886 torr. Find its molar mass.

$$MM = \frac{DRT}{P} = \frac{mRT}{PV} = \frac{(0.311\ g)(62.36\ \frac{L\cdot torr}{mol\cdot K})(328\ K)}{(886\ torr)(0.225\ L)} = \boxed{31.9\ g/mol}$$

5. A sample of nitrogen gas is contained in a cylinder with a freely moving piston. At 0.00°C, the volume of the gas is 375 mL. To what temperature must the gas be heated to occupy a volume of 0.500 L?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \frac{375\ mL}{273\ K} = \frac{500.\ mL}{T_2}$$

$$T_2 = \boxed{364\ K}$$