Gas Laws and Nature of Gases

Chapter 13 & 14

Gas Demos

- Soda Cans
  - Volume and temperature
  - What happened to the volume when the temperature decreased.
- Cartesian Diver
  - Pressure and volume
  - What happened to the volume when you applied pressure

Gas Basics

- Gas pressure results from the force exerted by a gas per unit surface area of an object.
- **Gas pressure is the result of simultaneous collisions of billions of rapidly moving particles in a gas with an object.**
- Vacuum is an empty space with no particles and no pressure

Gas Basics

- <u>Atmospheric pressure</u> results from the collisions of atoms and molecules in air with objects
  - Atmospheric pressure decreases as you climb a mountain because the density of Earth's atmosphere decreases as the elevation increases.
- <u>Barometer</u> is a device that is used to measure atmospheric pressure.

  - <u>Pascal (Pa)</u> is the SI unit of pressure, normal atmospheric pressure is about 101,300 Pa or 101.3 kilopascals (kPa)

Gas Basics

- *an increase in the average kinetic energy of the particles causes the temperature of a substance to rise*
- *as substance cools, the particles tend to move more slowly and their average kinetic energy declines.*
- The Kelvin temperature of a substance is directly proportional to the average kinetic energy of the particles of the substance.

The Nature of Gases

- Kinetic energy is the energy an object has because of its motion
- Kinetic theory all matter consists of tiny particles that are in constant motion
  - Three phases of matter
  - Solid: little motion, the atoms vibrate
  - Liquids: slightly more motion, the atoms vibrate and rotate
  - Gases: most motion, the atoms vibrate, rotate and translate

Kinetic Theory and Gases

- Kinetic theory as it applies to gases includes the following fundamentals assumptions about gases
  - **The particles in a gas are considered to be small, hard spheres with an insignificant volume**
    - No attractive or repulsive forces exist between the gas particles because of the distance between them.
    - The motion of one particle is independent of the motion of all the other particles.

Kinetic Theory and Gases

- **The motion of the particles in a gas is rapid, constant, and random**
  - Cases fill their containers regardless of the shape
  - Particles travel in straight-line paths until they collide with another particle, or object.
- **All collisions between particles in a gas are perfectly elastic**
  - Kinetic energy is transferred without loss from one particle to another.

Properties of gases

- Compressibility is a measure of how much the volume of matter decreases under pressure.
- **Gases are easily compressed because of the space between the particles in a gas**
- At room temperate the distance between particles in an enclosed gas is about 10 times the diameter of particles.
- **The amount of gas, volume and temperature are factors that affect gas pressure**
- By adding gas you increase the number of particles
- Increasing the number of particles increases the number of collisions, and gas pressure increases.
- In a closed rigid container doubling the number of gas atoms will double the pressure in the container.

Properties of gases

- Reducing the volume of a container will increase the pressure
- By reducing the volume of a container by ½ you will double the pressure of the gas.
- By doubling the volume of a container you will decrease the pressure of the gas by ½
- If the volume and the number of atoms in a container are constant and if the temperature (in Kelvin) of a container is doubled the pressure also doubles.
- Halving the Kelvin temperature of a gas in a rigid container decreases the pressure by half.

Standard Temperature and Pressure

- Gas Law conversions involve situations at standard temperature and pressure (stp)
- Standard temperature and pressure is a temperature of 273K (0℃), and pressure of 103 kPa (1 atm)
- Gas Law calculations may involve doing temperature and pressure conversions to get the correct units.
- Must know: **1 atm =760 mmHg = 101.3 kPa**
- Recall that: K = ˚C + 273
- ***Complete Temperature Conversion Practice***

Temperature Conversion Example

a. 25°C = ? K
   a. K = 25°C + 273 = 298K
b. 375 K = ? °C
   b. K-273 = °C   °C= 375 K-273 = 102°C
c. 0°C = ? K
   c. K = 0 °C +273= 273 K
d. 150 K
   d. °C = 150 K – 273 = -123

Temperature Conversion Practice Answers

a. 50°F
b. 86°F
c. 0°C
d. 7.2°C
e. 223K
f. 363K

g. 253 K
h. 443 K
i. -173°C
j. -73°C
k. 0°C
l. 77°C

Temperatures in Kelvin must be Zero or larger, they CANNOT be negative.

°F and °C can be negative.

Pressure Conversion

1 atm = 760 Torr = 760 mmHg = 101.3 kPa =101300 Pa=14.7 psi

Can use any two to convert between different measurements of pressure

1) 3.2 atm = ? kPa

$$3.2\ atm \times \frac{101.3\ kPa}{1\ atm} = 324.16\ \text{kPa}$$

2) 980 mm Hg = ? Pa

$$980\ mm\ Hg \times \frac{101{,}300\ Pa}{760\ mm\ Hg} = 130623\ \text{Pa}$$

3) 98.7 mm Hg = ? psi

$$98.7\ mm\ Hg \times \frac{14.7\ psi}{760\ mm\ Hg} = 1.91\ \text{psi}$$

Complete Pressure Conversion w/s 13-1

Pressure conversion Work Sheet Answers

- Students are graded on work shown, they may have rounded answers different than shown. #1-8 can be done in one step.

1) 0.971 atm
2) 2.18 atm
3) 50650 Pa
4) 241.1 kPa
5) a. 748 torr, b. 0.984 atm
6) 620.2 kPa
7) 187561.70 mmHg
8) 62040.8 torr
9) 0.743 atm {2 step problem}
10) 250530.9 Pa { 3 step problem}

Combined gas law

- The combined gas law describes the relationship among the pressure, temperature, and volume of an enclosed gas.
- The combined gas law allows you to do calculations for situations in which only the amount of gas is constant.
- Temperature MUST be in KELVIN!!!

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

- 1 is initial values, 2 is final values

Combined gas law

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

You can't work with fractions so the first thing you need to do is cross multiply so that you have a liner equation.

$$P_1 \text{ x } V_1 \text{ x } T_2 = P_2 \text{ x } V_2 \text{ x } T_1$$

- Once you have plugged in all the number you will need to divide to get the NEEDED variable by it's self.
- Two of the units should cancel, use this to check if you have the equation set up properly.

Combined Gas Laws Problems

- A gas takes up a volume of 15 liters, has a pressure of 4.3 atm, and a temperature of 299 K. If I raise the temperature to 350 K and lower the pressure to 1.5 atm, what is the new volume of the gas?
- V1 = 15 L
- P1 = 4.3 atm
- T1 = 299 K
- T2 = 350 K
- P2 = 1.5 atm
- V2 = ?
- Make sure the units match so that they can cancel.

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

$$\frac{4.3\ atm \ \times 15\ L}{299\ K} = \frac{1.5\ atm \times V2}{350\ K}$$

4.3 atm x 15 L x 350 K = 1.5 atm x 299 K x V2

Solve for V2 (there is more than one way to do this)

$$\frac{4.3\ atm \ \times 15\ L \ \times 350\ K}{1.5\ atm \ \times 299K} = V2$$

$$50.3\ L = V2$$

All units cancel except liters

Combined Gas Laws Problems

- A sample of gas occupies 45.5 L at STP what temperate must it have to occupy 26.5 L at 2.00 atm

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

- V1 = 45.5 L
- T2 = ?
- P2 = 2.00 atm
- V2 = 26.5 L

$$\frac{1\,atm\ \times\ 45.5\,L}{273\,K} = \frac{2.00\ \times\ 26.5\,l}{T2}$$

- Remember that STP has set values and when ever you see it you MUST use those values.
- P1 = 1.0 atm
- T1 = 273 K
- Make sure the units match so that they can cancel.

1.00 atm x 45.5 L x T2 = 2.00 atm x 26.5 L x 273 K

Solve for T2 (there is more than one way to do this)

$$T2 = \frac{2.00\,atm\ \times 26.5\,L\ \times 273\,K}{1.00\,atm\ \times 45.5K}$$

$T2$ = 318 K

All units cancel except K

Combined Gas Laws Problems

- A 5.65 L sample of gas at 25 °C at 1.00 atm will occupy what volume at 1.50 atm and 50° C.

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

- V1 = 5.65 L
- T1 = 25°C + 273 = 298 K
- P1 = 1.00 atm
- P2 = 1.50 atm
- T2 = 50°C + 273 = 323 K
- V2 = ?
- Remember that temperature MUST be in Kelvin. Make sure the units match so that they can cancel.

$$\frac{1.00\ atm \times 5.65\ L}{298K} = \frac{1.5\ atm \times V2}{323\ K}$$

1.00atm x 5.65L x 323K = 1.50 atm x V2 x 298 K

Solve for V2 (there is more than one way to do this)

$$\frac{1.00\ atm \times 5.65\ L \times 323\ K}{298K\ X\ 1.50\ atm} = V2$$

4.08 L $= V2$

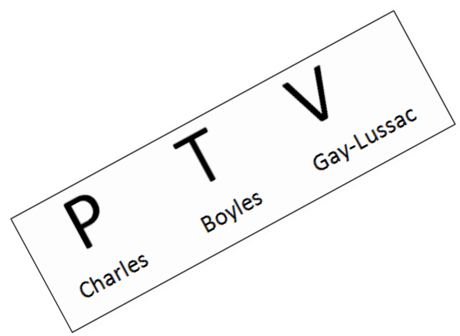
Gas Law Card

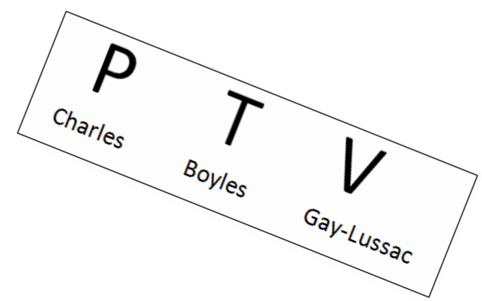
P	T	V
Charles	Boyles	Gay-Lussac

Can be used to check problems where one variable is being held constant

What happens when pressure is held constant and temperature is increased

Notice that Volume goes up





What happens when temperature is held constant and volume decreases.

Notice that Pressure goes up

Boyles Law

- Boyle's Law states that for a given mass of gas at constant temperature, the volume of the gas varies inversely with pressure.
  - **If the temperature is constant, as the pressure of a gas increases, the volume decreases.**
  - Also as the pressure of a gas decreases the volume increases.
- The mathematical express of Boyle's law is as follows: $P_1 \times V_1 = P_2 \times V_2$
  - Because temperature is constant the combined gas law equation is simplified (treat as if $T1 = T2 = 1$)

Boyle's Law Example

- 2.50 L of a gas at standard temperature and pressure is compressed to 473 mL. What is the new pressure of the gas if temperature is constant? $P_1 \times V_1 = P_2 \times V_2$
- V1 = 2.50 L
- V 2 = 473 mL [unites must be the same]
- V 2 = 473 mL x (1 L / 1000 mL) = 0.473 L
- P1 = 1 atm
- P2 = ?

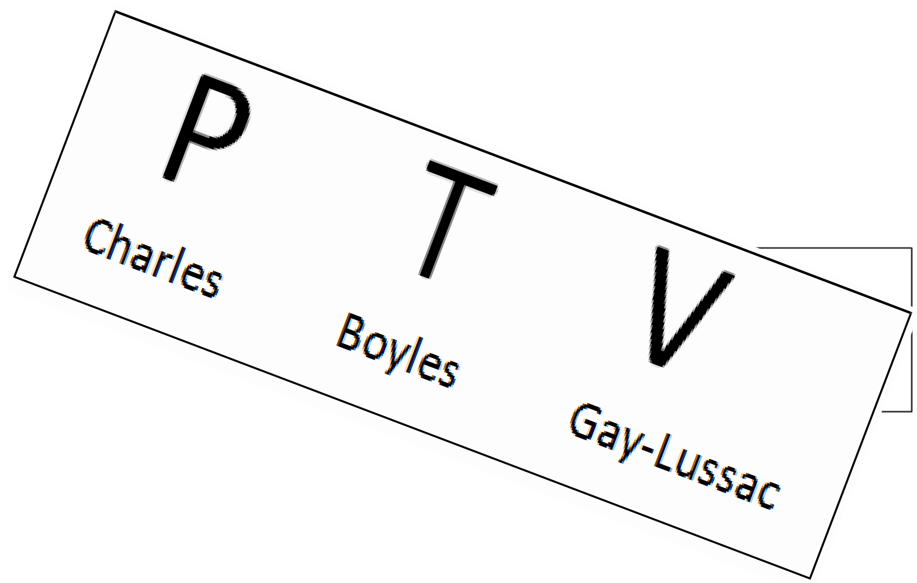
1 atm x 2.50 L = P2 x 0.473 L

Solve for P2

$$\frac{1\ atm\ \times 2.50\ L}{0.473\ L} = P2$$

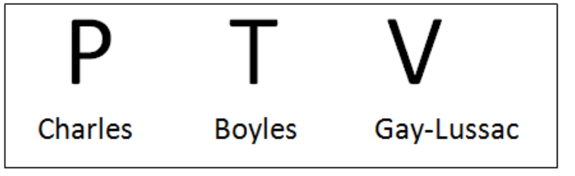
5.29 atm = P2

Check with your PTV card



Boyle's Law Example

- While using explosives to knock down a building, the shock wave can be so strong that 12 liters of gas will reach a pressure of 3.8×10^4 mm Hg. When the shock wave passes and the gas returns to a pressure of 760 mm Hg, what will the volume of that gas be?
- V1 = 12 L
- P1 = 3.8×10^4 mm Hg
- V 2 = ?
- P2 = 760 mm Hg



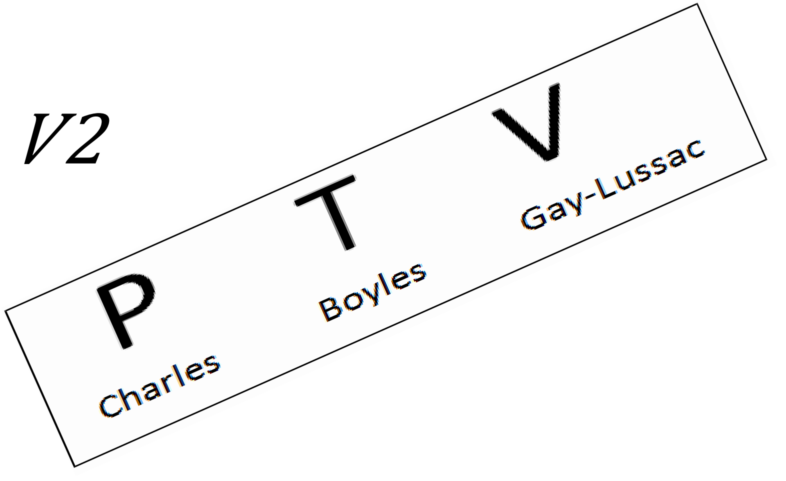
12 L x (3.8×10^4 mm Hg) = V2 x 760 mm Hg

Solve for V2

$$\frac{[12\,L\,x\,(3.8\,x\,104\,mm\,Hg)]}{760\,mm\,Hg} = V2$$

600 L = V2

Check with your PTV card



Boyles Law Practice Answers

1) 2.11 atm
2) 200,000L
3) 0.0000333L
4) 72.7 L
5) 2026.7L
6) 600L
7) 72L
8) 0.25 L

Charles's Law

- <u>Charles's Law</u> states that the volume of a fixed mass of gas is directly proportional to its **Kelvin** temperature if the pressure is kept constant.
  - As the temperature of an enclosed gas increase, the volume increases, if the pressure is constant.
  - The mathematical expression of Charles' Law is:
  - Temperature MUST be in Kelvin

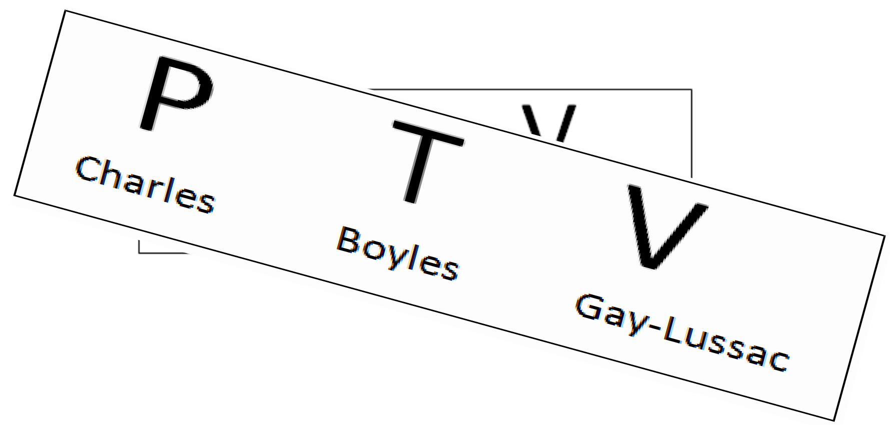
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

or $V1 \times T2 = V2 \times T1$

Charles’s Law Example

- The temperature inside my refrigerator is about 4 ^{0}C. If I place a balloon in my fridge that initially has a temperature of 22^0 C and a volume of 0.5 liters, what will be the volume of the balloon when it is fully cooled by my refrigerator?
- V1 = 0.5 L
- T1 = 22 ^{0}C + 273 = 295 K
- V 2 = ?
- T2 = 4 ^{0} C + 273 = 277 K

Temperature MUST be in Kelvin



Check with your PTV card

Charles's Law Example 2

If the balloon initially has a volume of 0.25 liters at standard temperature what must the temperature be for it to increase to a volume of 0.75 liters?

- $V1 = 0.25$ L
- $V2 = 0.75$ L
- $T2 = ?$
- Remember standard temperature has a set value
- $T1 = 273$ K

Gay-Lussac's Law

- Gay-Lussac's Law states that the pressure of a gas is directly proportional to the Kelvin temperature if the volume remains constant.
  - As the temperature of an enclosed as increases, the pressure increases, if the volume is constant
  - As the temperate (in Kelvin) of a gas increase the pressure increases.
  - The mathematical expression of Gay-Lussac's Law is:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$ or $P_1 \times T_2 = P_2 \times T_1$

Gas Laws Summary

Name	Equation	Things that change	Things held constant
Combined	$P_1 \times V_1 \times T_2 = P_2 \times V_2 \times T_1$	Pressure, volume and temperature	Amount of gas
Boyles	$P_1 \times V_1 = P_2 \times V_2$	Pressure and Volume	Temperature Amount of gas
Charles	$V_1 \times T_2 = V_2 \times T_1$	Volume and Temperature	Pressure Amount of gas
Gay-Lussac	$P_1 \times T_2 = P_2 \times T_1$	Pressure Temperature	Volume Amount of gas

- Remember
  - Temperature MUST be in KELVIN
    - K = °C+ 273
  - any other units MUST CANCLE
    - Can’t have mL and L in same problem, can’t have atm and mm Hg in same problem you MUST convert
    - 1 L = 1000 mL
    - 1atm = 760 mm Hg = 760 torr = 101.3 kPa = 101,300 Pa

Charles's Law worksheet answers

1) V2= 0.47L
2) V2= 0.7L
3) V2= 219.2L
4) V2 = 1.8L
5) V2 = 2.4 L
6) T2 = 51, 826.1 K
7) T2 = 279.75K

Mixed Gas Law Problem Answers

Your answers may be rounded differently than me. Temperature MUST be converted to Kelvin to solve the problem.

1) 250.3 mL
2) 453.8 K
3) 651.4 K
4) 140.2 K
5) 260 mL
6) 606.3 torr
7) 1.22 atm
8) 666.67 mmHg
9) 1.93 L
10) 4.38 atm
11) 2.78 L
12) 310.3 K
13) 2.96 L
14) 15.98 atm
15) 1609.8 mmHg

Ideal Gas Law

- **To calculate the number of moles of a contained gas requires an expression that contains the variable *n*.**
- The number of moles of gas is directly proportional to the number of particles
- *n* indicates the number of moles of gas in an enclosed container.
- Recall 1 mole of every gas occupies 22.4 L at STP (101.3 kPa and 273 K).

Ideal Gas Law

- Ideal gas law includes all for variables and is written as follows: PV=*n*RT
- Ideal gas constant (R) has a set value

$$R = 8.31\frac{L \cdot kPa}{K \cdot mol} \quad \text{or} \quad R = 0.0821\frac{L \cdot atm}{K \cdot mol}$$

- An ideal gas is one that follows the gas laws at ALL conditions of pressure and temperature
- Ideal gases don't exist but real gases behave very much like an ideal gas
- **Real gases differ most from an ideal gas at LOW temperate and HIGH pressures**

Ideal Gas Law

- Depending on the problem pick the R value that allows the units to cancel

PV=nRt

Pressure is in atm or kPa

Volume is in LITERS

n is the number of MOLES of gas

$R = 8.31\frac{L \cdot kPa}{K \cdot mol}$ or $R = 0.0821\frac{L \cdot atm}{K \cdot mol}$

Temperature MUST be in Kelvin

Ideal Gas Law example 1

- At what temperature in ℃ does 48.5 g of CO_2 occupy 4.56 L and have a pressure of 2.5 atm.

PV=nRT

$$n = 48.5\ g\ CO_2 \frac{1\ mol CO_2}{44.01 g CO_2} = 1.10\ mol$$

V = 4.56 L

P = 2.5 atm

T = ?

$$R = 0.0821 \frac{L \cdot atm}{K \cdot mol}$$

$$\frac{PV}{nR} = T \qquad T = \frac{2.5\ atm \times 4.56\ L}{1.10\ mol \times 0.0821 \frac{L \cdot atm}{K \cdot mol}}$$

T = 126 K

Ideal Gas Law and Density

What is the density of CO_2 at 955 torr and 22.5 °C?

Remember: $D = \frac{m}{v}$ and 1 mol = molar mass g

$$P = 955\ torr \frac{1\ atm}{760\ torr} = 1.26\ atm$$

T = 22.5 °C + 273 = 295.5 K

n= 1 mole (assume 1 mole so you know the molar mass)

$v = \frac{nRT}{P}$ V=

$$\frac{1\ mol \times 0.0821 \frac{L \cdot atm}{mol \cdot K} \times 295.5K}{1.26\ atm}$$

V = 19. 25 L

$$D = \frac{44.01\ g}{19.5\ L}$$

D = 2.26 g/L

Partial Pressure

- Partial pressure is the contribution each gas in a mixture makes to the total pressure
- Dalton's law of partial pressures states that, at constant volume and temperature, the total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of the component gases.
- **In a mixture of gases, the total pressure is the sum of the partial pressures of the gases.**
- $P_{total} = P_1 + P_2 + P_3 + \dots$

Partial Pressure Example

- A gas mixture containing oxygen, nitrogen and carbon dioxide has a total pressure of 52.9 kPa if the pressure of oxygen is 6.6kPa and the pressure of nitrogen is 0.250 atm what is the pressure of carbon dioxide.
- $P_{total} = P_1 + P_2 + P_3 + \ldots$
- P_{total} = 52.9 kPa
- P_{oxygen} = 6.6 kPa
- $P_{nitrogen}$ = 0.250 atm

$$\frac{101.3\ kPa}{1\ atm} = 25.3\ kPa$$

- P CO_2 = ?
- 52.9 kPa = 6.6 kPa + 25.3 kPa + P CO_2
- 52.9 kPa - 31.9 kPa = P CO_2
- 21.0 kPa = P CO_2
-