Section 8: Gases

The following maps the videos in this section to the Texas Essential Knowledge and Skills for Science TAC §112.35(c).

8.01 Simple Gas Laws

- Chemistry (9)(A)

8.02 Ideal Gas Law

- Chemistry (9)(A)

8.03 Partial Pressure

- Chemistry (9)(A)

8.04 Application of the Ideal Gas Law

- Chemistry (9)(B)

8.05 Graham's Law of Effusion

- N/A

8.06 Kinetic Molecular Theory

- Chemistry (9)(C)

Note: Unless stated otherwise, any sample data is fictitious and used solely for the purpose of instruction.

Safety Note: Any chemicals mentioned in these videos are potentially harmful and should be handled with the appropriate safety precautions.

8.01

Simple Gas Laws

The ***pressure*** of a gas is defined as the force that the gas's particles exert on the walls of a container per unit area. Recall that a gas is readily compressible because of the large amount of empty space between particles.

A ***barometer*** is a device commonly used to measure atmospheric pressure. When a long tube is filled with mercury and turned upside down on a dish also filled with mercury, the height of the mercury in the tube shows the atmospheric pressure outside.

The SI unit for pressure is the ***pascal (Pa)***, a derived unit that is defined as one newton per square meter. There are many other common units of pressure, shown in the table below.

SI Unit of Pressure	Common Equivalent Units				
101.325 kilopascals	1 atmosphere	1.01325 bar	760 mmHg	760 torr	14.7 psi

1. In 1980, Hurricane Allen made landfall over Brownsville, Texas. With sustained winds over 190 mph, it still stands as one of the strongest hurricanes ever recorded. At the peak of Hurricane Allen's strength, the pressure near the eye was measured as 899 millibars (Roth, n.d.). Convert this pressure into kilopascals and atmospheres.

The pressure of a gas can be affected by three factors:

- The ***amount (n)*** of a gas present in a container, usually expressed in units of moles
- The absolute ***temperature (T)*** of the gas, in units of kelvin
- The ***volume (V)*** that the gas occupies, expressed in many different units, most commonly liters

STUDY EDGE TIP

To convert from degrees Celsius to kelvin, use the formula

$$K = \,^{\circ}C + 273.15$$

The laws that describe the relationships among these variables holds true when we assume the gas is behaving ideally, which is a valid assumption at conditions of relatively low external pressure and relatively high temperatures. We must also assume that the properties discussed do not depend on the identity of the gas.

- ***Boyle's law*** states that for a given amount of gas at a constant temperature, the pressure and volume of the gas are inversely proportional to each other.

$$P_1V_1 = P_2V_2$$

- ***Charles's law*** states that for a given amount of gas at a constant pressure, the volume of the gas is directly proportional to the temperature of that gas.

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

- ***Gay-Lussac's law*** states that for a given amount of gas at a constant volume, the pressure of the gas is directly proportional to the temperature of that gas.

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

- The ***combined gas law*** or ***general gas law*** states that for a given amount of gas at a constant volume, the relationship among pressure, volume, and temperature can be expressed as shown below.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

2. In a laboratory experiment, a rigid 5.0-liter cylinder is filled with a mass of helium gas. At a temperature of 27 °C, the gas exerts a pressure of 450 torr on the walls of the cylinder. The safety information for the procedure states that the cylinder will rupture if the internal pressure exceeds 1,000 torr. What is the maximum temperature to which the cylinder can be heated before it ruptures?

A. 667 °C
B. 394 °C
C. 122 °C
D. 54 °C

8.02

Ideal Gas Law

The ***ideal gas law*** expresses the relationship of the pressure (P), volume (V), temperature (T), and amount (n) of a gas, and the ***ideal gas constant (R).***

$$PV = nRT$$

The ideal gas constant has a value of 0.0821 (atm · L)/(mol · K). To maintain unit consistency with the value of R, the pressure of the gas must be expressed in atmospheres, the volume expressed in liters, the amount expressed in moles, and the temperature expressed in kelvin.

1. What mass of neon gas is contained in a 2.50-liter balloon at 50 °C and 400.0 mmHg?

2. An alternative form of the gas constant, R, has the value 8.314 (kPa · L)/(mol · K). Use this constant to find the temperature to which a 25-gram sample of oxygen gas must be heated in order for it to reach a pressure of 150.0 mmHg if the gas occupies a constant volume of 375 milliliters.

8.03

Partial Pressure

In a mixture of gases, the individual pressure contribution of each gas is referred to as the ***partial pressure*** of that gas. The partial pressure of a gas is directly proportional to the ***mole fraction*** of the specified gas in the mixture.

$$P_A = \chi_A \cdot P_{Total}$$

The mole fraction of a gas in a mixture can be calculated as the ratio of the moles of the specified gas to the total moles of gas present in the mixture.

$$\chi_A = \frac{\text{moles of A}}{\text{total moles}}$$

For example, consider a mixture of one mole of neon gas and four moles of xenon gas, exerting a total pressure of 25.0 kPa.

Dalton's law of partial pressures states that the total pressure of a mixture of gases is the sum of the individual partial pressures of the gases in the system.

$$P_{Total} = P_A + P_B + P_C \ldots$$

1. A gas mixture consists of equal masses of carbon dioxide and neon. If the partial pressure of the neon is 300 mmHg, what is the partial pressure of the carbon dioxide?

   A. 438 mmHg
   B. 405 mmHg
   C. 138 mmHg
   D. 216 mmHg

8.04

Applications of the Ideal Gas Law

The ideal gas law allows us to relate the amount of a gas present to the pressure, temperature, and volume of the gas. Thus, we can use the ideal gas law to perform stoichiometric calculations.

1. Solid magnesium reacts with oxygen gas according to the reaction below.

$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

   What volume of oxygen gas, at 300 kelvin and 855 millibars, will fully react with 25 grams of magnesium? 1 atm = 1013.25 millibars

2. In a process called electrolysis, an electric current passed through water causes hydrogen gas and oxygen gas to be evolved. The unbalanced reaction below shows this process.

$$H_2O(l) \rightarrow H_2(g) + O_2(g)$$

If a 12.5 mL sample of water is electrolyzed until all the liquid water is gone, what volume of oxygen gas is produced at 100 °C and 1 atm?

8.05

Graham's Law of Effusion

Effusion is the process by which a gas escapes from a small hole in a container. ***Graham's law of effusion*** states that the rate of effusion of a gas is inversely proportional to the square root of its molar mass.

$$\frac{\text{Rate of Effusion of Gas A}}{\text{Rate of Effusion of Gas B}} = \frac{\sqrt{\text{molar mass of Gas B}}}{\sqrt{\text{molar mass of Gas A}}}$$

STUDY EDGE TIP

The greater the molar mass of a gas, the ____________ its effusion rate, and the ____________ time it takes for the gas to effuse.

1. A balloon is filled with equimolar amounts of xenon gas, oxygen gas, and helium gas. After 24 hours, the balloon is noticeably smaller in size. Based on relative rates of effusion, rank the gases from largest to smallest in terms of partial pressure after 24 hours.

2. If an unknown gas effuses through a hole in a container 1.87 times faster than chlorine gas, which of the following is closest to the molar mass of the unknown gas?

   A. 17.64 g/mol
   B. 32.07 g/mol
   C. 20.28 g/mol
   D. 247.9 g/mol

8.06

Kinetic Molecular Theory

The ***kinetic molecular theory of gases*** describes the behavior of ideal gases at the atomic level. The theory has three important postulates:

- Gases consist of particles whose separation is much greater than the size of the particles themselves.
- The particles of a gas are in constant motion. The movement of the gases causes ***elastic*** collisions with other gas particles and the walls of the container, but the particles do not lose energy.
- The ***average kinetic energy*** of a gas depends only on the temperature of the gas.

$$KE_{avg} = \frac{1}{2}mv^2 = \frac{3}{2}RT$$

In normal conditions (relatively high temperatures and low external pressure), most gases exhibit nearly ideal behavior. However, the postulates of the kinetic molecular theory fail to explain the behavior of real gases at low temperatures or high external pressures.

For a real gas, the PV/RT ratio can be plotted against external pressure (P_{ext}) to show how increasing the external pressure causes non-ideal behavior.

At moderately high pressure, the value of PV/RT is less than 1, due predominantly to ***forces of attraction*** among the gas particles. At very high pressure, the value of PV/RT is greater than 1, due predominantly to the ***molecular volume*** of the gas particles.

1. Consider two separate, evacuated one-liter containers at 35 °C. One gram of O_2 gas is placed into one of the containers and one gram of Cl_2 gas is placed in the other container. Which of the following statements will be true?

   A. The Cl_2 gas will exhibit a higher pressure.
   B. The O_2 gas will have a higher density.
   C. The Cl_2 gas will have fewer molecules.
   D. At very high pressures, the ratio of PV to RT will be greater than 1 for the O_2 gas because of forces of attraction.

References

Roth, David. (n.d.). “Hurricane Allen - August 1-14, 1980.” Retrieved from http://www.wpc.ncep.noaa.gov/tropical/rain/allen1980.html

PERIODIC TABLE OF THE ELEMENTS

	1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	<--- 8	8B 9	---> 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (99)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226.0	89 **Ac** 227.0	104 **Rf** (261)	105 **Ha** (262)	106 (263)	107 (262)	108	109									

Lanthanides	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.2	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
Actinides	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.0	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)