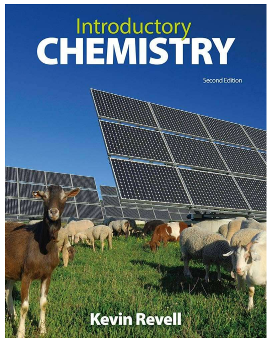
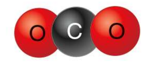
Introductory Chemistry
Chem 103

Chapter 9 – Covalent Bonding and Molecules

Lecture Slides



Covalent Molecules

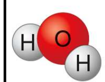


Covalent bonds:

Two atoms share electrons
Occur between nonmetal atoms

Octet rule:

Atoms are stabilized by having 8 electrons in the valence shell

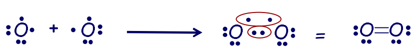


Lewis structures:

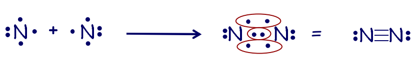
Show the arrangement of covalently bonded atoms
Use a dash to represent two shared electrons

Covalent Double and Triple Bonds

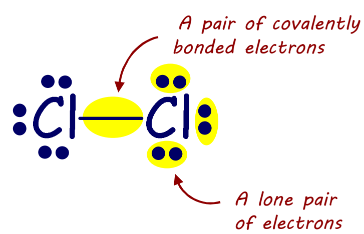
Covalent double bonds:



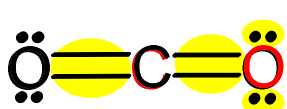
Covalent triple bonds:



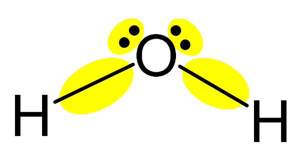
Pairs of Electrons in Compounds



In Most Molecules, Atoms Follow the Octet Rule

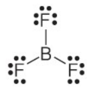


In Most Molecules, Atoms Follow the Octet Rule, Continued

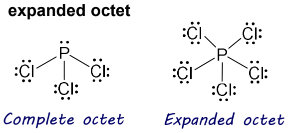


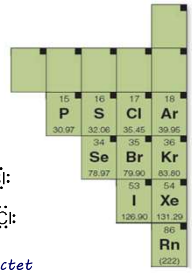
Exceptions to the Octet Rule

incomplete octet



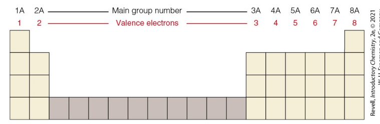
expanded octet





Drawing Lewis Structures

1. Add up all the valence electrons.
2. Frame the structure.
3. Fill octets on outer atoms first.
4. Fill the octet on the central atom.
   - any remaining electrons on central atom
   - use double/triple bonds if needed



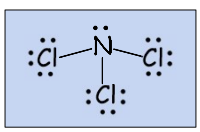
Drawing Lewis Structures Practice

Draw a Lewis structure for nitrogen trichloride, NCl_3.

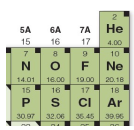
NCl_3

5 + 7(3)

= 26 valence electrons



1. Sum electrons.
2. Draw framework.
3. Fill octets on outer atoms.
4. Fill octet on central atom.



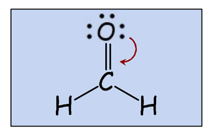
Drawing Lewis Structures, More Practice

Formaldehyde, CH_2O, is commonly used to manufacture plastics. Draw the Lewis structure for a formaldehyde molecule.

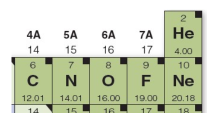
CH_2O

4 + 1(2) + 6

= 12 valence electrons



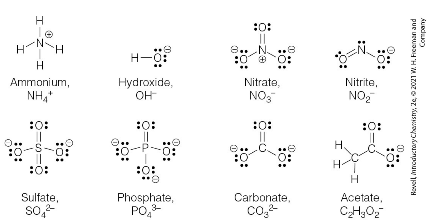
1. Sum electrons.
2. Draw framework.
3. Fill octets on outer atoms.
4. Fill octet on central atom.



Molecules and Charge

polyatomic ions groups of atoms with an overall charge

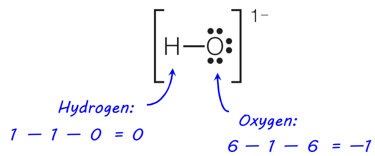
formal charges a method of identifying charged sites

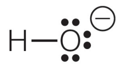


One Electron From Each Bond is Assigned to an Atom

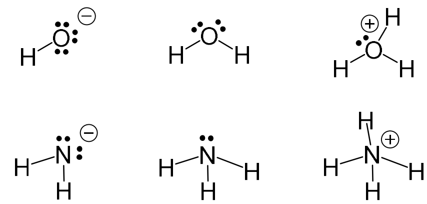
Calculating Formal Charge Practice

Formal charge = Valence electrons in the neutral atom – Number of covalent bonds – Number of unshared electrons



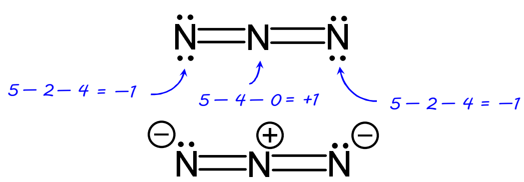


Oxygen and Nitrogen Atoms Often Have Formal Charges



Calculating Formal Charge, More Practice

Automotive air bags contain sodium azide, NaN_3. The Lewis structure for the azide ion (without charges) is shown. Calculate the formal charge on each atom in this structure. What is the overall charge of the azide ion?



Azide Ion: N_3^-

Drawing Lewis Structures for Polyatomic Ions

- Similar to neutral molecules
- Consider charge when finding the number of valence electrons

How many valence electrons are in a hydroxide ion?

OH^-

6 + 1 + 1 = 8 valence electrons

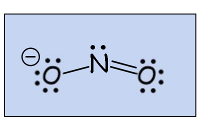
Lewis Structures for Polyatomic Ions Practice

Draw a Lewis structure for the nitrite ion, NO_2^-. Show all nonzero formal charges.

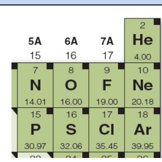
NO_2^-

5 + 6(2) + 1

= 18 valence electrons

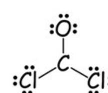


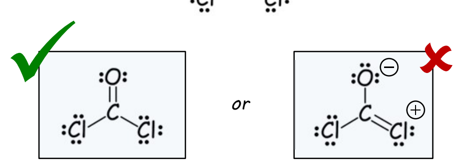
1. Sum electrons.
2. Draw framework.
3. Fill octets on outer atoms.
4. Fill octet on central atom.



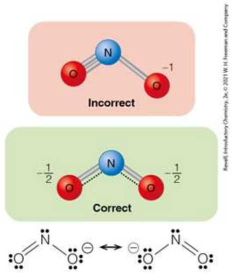
Identifying the Best Lewis Structure

What is the best structure for phosgene, $COCl_2$?



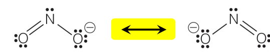


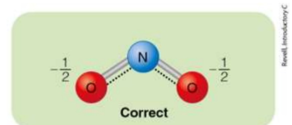
Resonance Structures



Resonance Structures, Continued

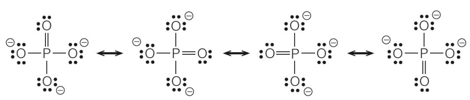
- a set of structures that show how electrons are distributed.
- used when a single Lewis structure is insufficient.





Ions With Resonance Structures Spread Charges Over Multiple Atoms

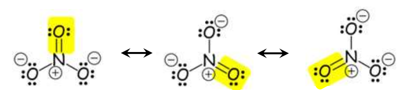
NO_3^-	SO_4^{2-}
NO_2^-	CO_3^{2-}
PO_4^{3-}	$C_2H_3O_2^-$



Only 2nd bonds and lone pairs change in resonance structures.

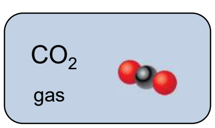
Using Resonance Structures to Calculate Formal Charge

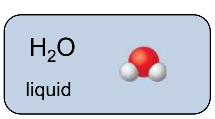
The nitrate ion (NO_3^-) has three major resonance structures. Draw each structure. Based on these structures, what is the average charge on each oxygen atom?

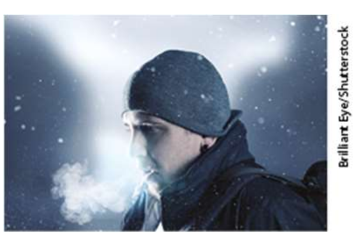


charge on each oxygen: $-\frac{2}{3}$

Shapes of Molecules



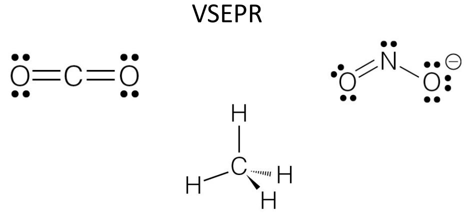




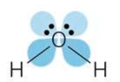
Predicting Molecular Shapes

Valence Shell Electron Pair Repulsion

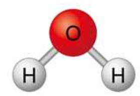
VSEPR



Predicting Molecular Shapes, Continued

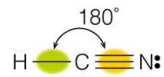


Electronic geometry
Arrangement of electrons around the central atom

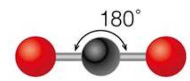


Molecular geometry
Shape caused by the arrangement of atoms

Two Electron Sets: Linear



Electronic geometry
Linear

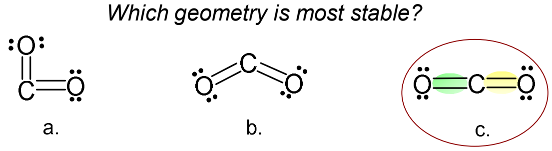


Molecular geometry
Linear

double and triple bonds count as 1 "set"

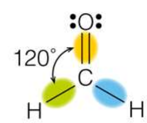
Geometric Stability

Which geometry is most stable?

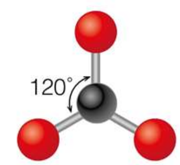


2 sets of electrons: Linear

Three Electron Sets: Trigonal Planar



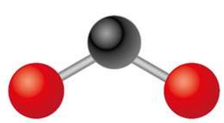
Electronic geometry
Trigonal planar



Molecular geometry
Trigonal planar

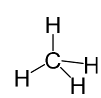
Three Electron Sets: Trigonal Planar, Continued

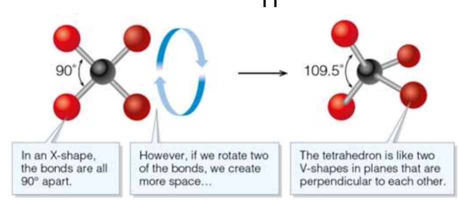
Electronic geometry
Trigonal planar



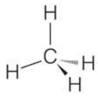
Molecular geometry
Bent

Four Electron Sets: Tetrahedral, Part 1

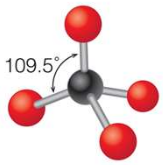




Four Electron Sets: Tetrahedral, Part 2

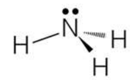


Electronic geometry
Tetrahedral

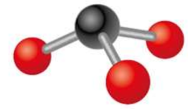


Molecular geometry
Tetrahedral

Four Electron Sets: Tetrahedral, Part 3



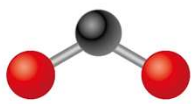
Electronic geometry
Tetrahedral



Molecular geometry
Trigonal pyramidal

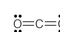
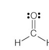
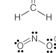
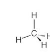
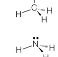
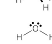
Four Electron Sets: Tetrahedral, Part 4

Electronic geometry
Tetrahedral

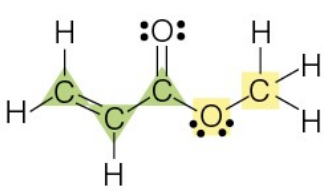


Molecular geometry
Bent

Electronic and Molecular Geometry

Electron sets	Electronic geometry	Model	Bonding sets	Lone pairs	Molecular geometry	Examples
2	Linear		2	0	Linear	
3	Trigonal Planar		3	0	Trigonal Planar	
			2	1	Bent	
4	Tetrahedral		4	0	Tetrahedral	
			3	1	Trigonal pyramidal	
			2	2	Bent	

Electronic and Molecular Geometry Practice

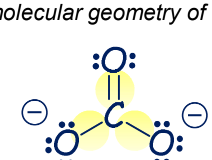


Trigonal planar

Tetrahedral

Electronic and Molecular Geometry, More Practice

Lithium carbonate is a simple ionic compound that is widely used to treat bipolar disorder. What is the molecular geometry of the carbonate ion?

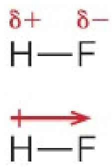


Electronic geometry:
Trigonal planar

Molecular geometry:
Trigonal planar

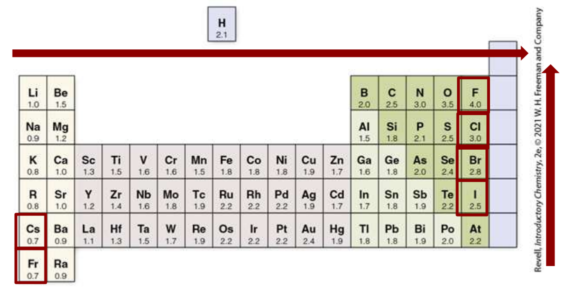
Polar Bonds and Molecules

Polar covalent bond atoms do not share the electrons evenly



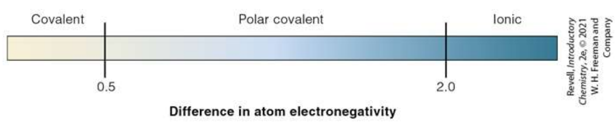
Electronegativity

how strongly atoms pull bonded electrons



Comparing Covalent, Polar Covalent and Ionic Bonds

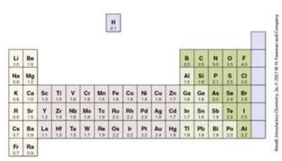
F—F H—F Na^{+} $:F^{-}$



Covalent: < 0.5

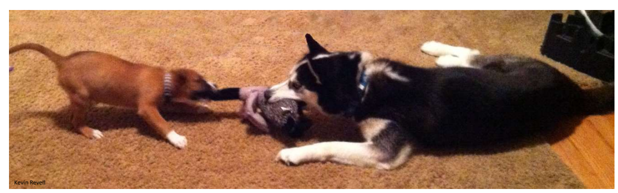
Polar Covalent: 0.5 – 2.0

Ionic: > 2.0



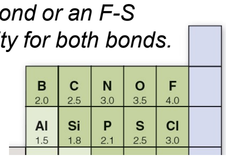
An Analogy for Polar Covalent Bonds

H—F



Classifying Bonds Practice

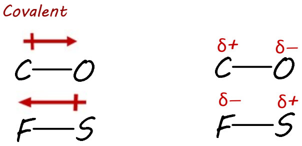
Which bond is more polar, a C-O bond or an F-S bond? Show the direction of polarity for both bonds.



C: 2.5
O: 3.5
Difference = 1.0
Polar Covalent

F: 4.0
S: 2.5
Difference = 1.5
Polar Covalent

F-S is more polar

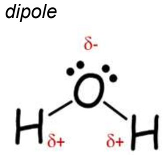


Molecules with dipoles

Molecular dipole an overall polarity in a molecule

net dipole

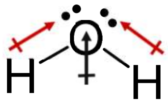
dipole



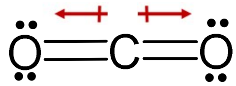
polar covalent bonds

shape

Identifying Molecules with a Net Dipole

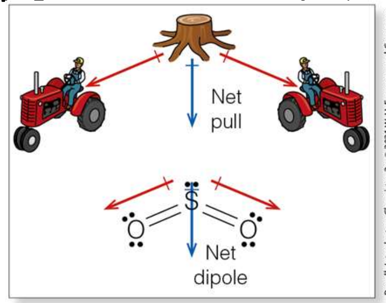


Net Dipole



No Net Dipole

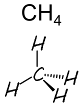
Identifying Molecules with a Net Dipole, Continued



Identifying Molecules with a Net Dipole Practice

Which of these have a net dipole?

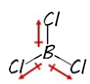
CH_4



Non-polar bonds

No dipole

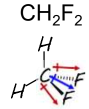
BCl_3



Polar bonds

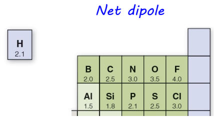
No net dipole

CH_2F_2



Polar bonds

Net dipole



How Dipoles Affect Properties – A Preview

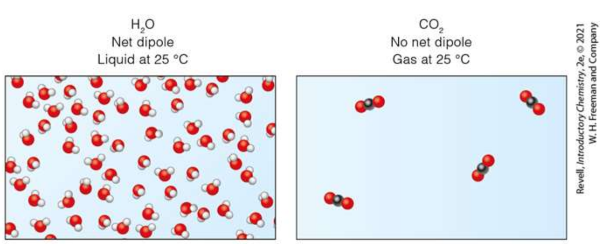
CO_2 Linear

No net dipole

H_2O Bent

Net dipole

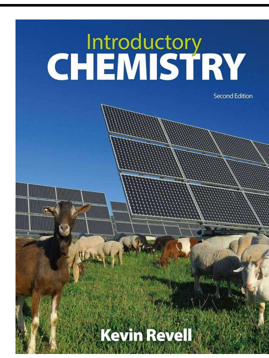
How Dipoles Affect Properties – A Preview, Continued



Introductory Chemistry
Chem 103

Chapter 10 – Solids, Liquids, Gases

Lecture Slides

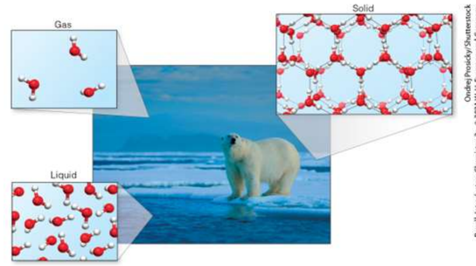


Interactions between Particles

	Atomic/Molecular Arrangement	Macroscopic Properties
Solid	Particles are close together and held in a fixed place.	Definite shape and volume
Liquid	Particles are close together but move freely past each other.	Definite volume; Adopts the shape of the container.
Gas	Particles are far apart and have very little interaction.	Adopts shape and volume of container

Phase change

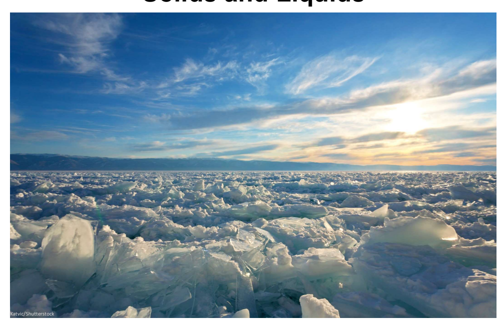
A transition from one state of matter to another.



The Forces Between Particles Influence Physical Properties

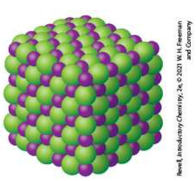
Stronger forces between particles - higher melting and boiling points.

Solids and Liquids



Ionic Substances

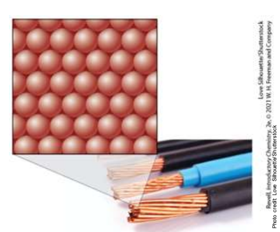
Lattices: rigid frameworks of atoms, molecules or ions.



Compound	Melting Point (°C)
NaCl	801
KCl	770
$MgCl_2$	714
CaO	2,572
Al_2O_3	2,072

Metallic Substances

- Form lattices of tightly packed atoms.
- Electrons move easily between atoms.
- Shapes of metals are easily altered.
  - Malleable
  - Ductile



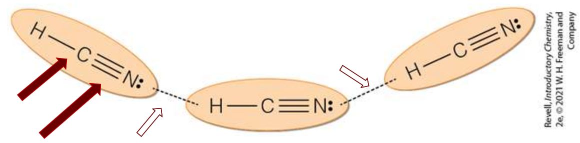
Metallic Substances, Continued

Element	Melting Point (°C)
Lead	327
Aluminum	660
Gold	1,064
Copper	1,085
Iron	1,538

Molecular Substances

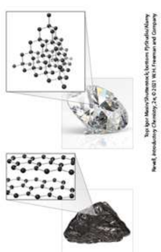
Forces <u>within</u> molecules: covalent bonds

Forces <u>between</u> molecules: intermolecular forces



Covalent Networks and Polymers

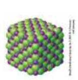
covalent networks: lattices of covalent bonds that form giant molecules



Covalent Networks and Polymers, Continued

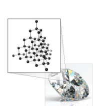
polymers: contain long chains of covalently-bonded atoms

Solids and Liquids Summary



- Ionic Substances
- Metallic Substances

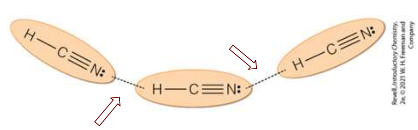
- Molecular Substances
- Covalent Networks and Polymers



Forces Within and Between Molecules

Forces <u>within</u> molecules: covalent bonds

Forces <u>between</u> molecules: intermolecular forces



Forces Between Molecules

intermolecular forces

1. Dipole-dipole Interactions
2. Hydrogen bonds
3. Dispersion forces

Dipole-Dipole Interactions, Part 1

Attractions between polar covalent molecules:

δ+ δ−
H—Cl

H—Cl

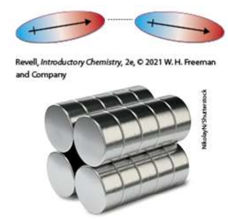


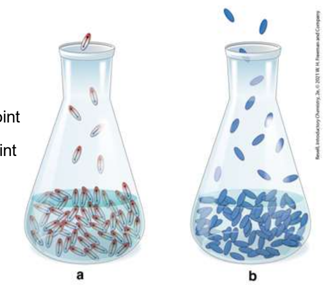
Photo credit: NikolayN/Shutterstock

Dipole-Dipole Interactions, Part 2

Dipole

Higher Melting Point

Higher Boiling Point



No dipole

Dipole-Dipole Interactions, Part 3

	Carbon dioxide	Sulfur dioxide	Acetonitrile
Geometry	Linear	Bent	Linear
Dipole	Zero	Small	Large
Boiling Point			

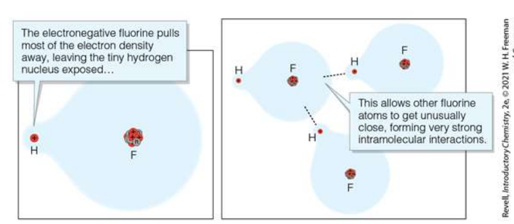
Hydrogen Bonding, Part 1

	Methane	Hydrogen cyanide	Water
Formula mass	16.0 u	27.0 u	18.0 u
Dipole strength*	0	2.98	1.85
Boiling point			

*These numbers convey the relative size of each dipole.

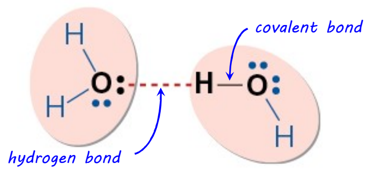
Hydrogen Bonding, Part 2

A strong intermolecular force between molecules containing H-F, H-O, or H-N bonds.

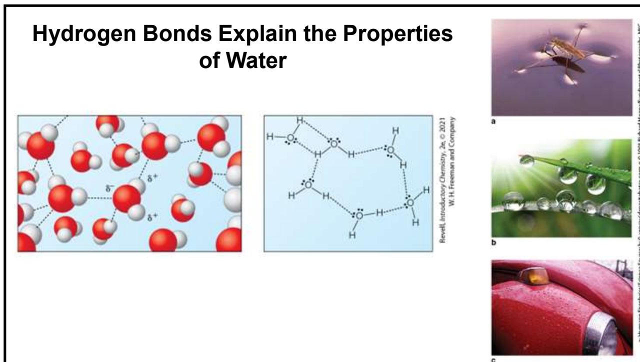


Hydrogen Bonding, Part 3

A strong intermolecular force between molecules containing H-F, H-O, or H-N bonds.

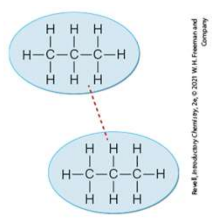


Hydrogen Bonds Explain the Properties of Water



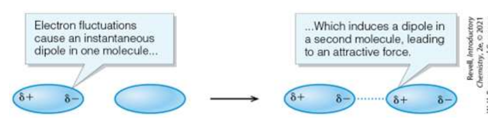
London Dispersion Forces, Part 1

Weak intermolecular forces that result from instantaneous dipoles

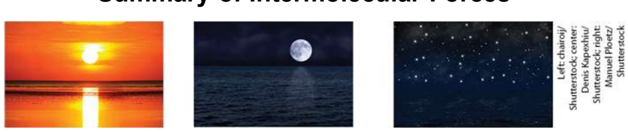


London Dispersion Forces, Part 2

Weak intermolecular forces that result from instantaneous dipoles



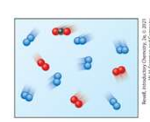
Summary of Intermolecular Forces



Type	Description	Strength
Hydrogen bonding	molecules with H-F, H-O, or H-N bonds	strongest
Dipole-dipole forces	molecules with net dipole	
London dispersion forces	all covalent molecules	weakest

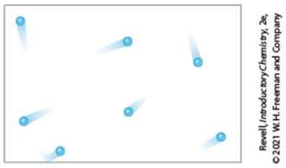
Describing Gases

particles are spaced far apart
very little interaction between particles



Ideal Gas

1. Volume of particles is much less than container.
2. Particles have no attraction for each other.

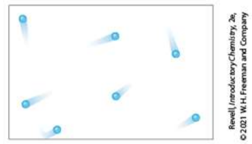


Temperature
Volume
Pressure

Pressure

The force that gases exert on their surroundings.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$



Measuring Pressure

Measuring Pressure – Barometers

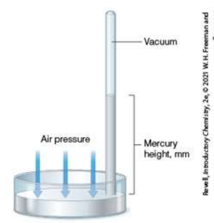
Barometer: a device used to measure atmospheric pressure

Millimeters of mercury (mm Hg)

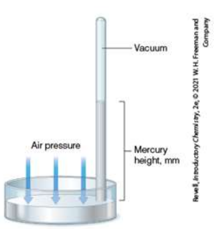
1 mm Hg = 1 torr

Average air pressure at sea level:

760 mm Hg
760 torr
] **Standard pressure**



Measuring Pressure – Barometers Continued



Measuring Pressure – Gauge Pressure

Gauge Pressure: The difference between the compressed gas pressure and the atmospheric pressure.

Measuring Pressure – Conversion Factors

1 **atmosphere** (atm) = 760 mm Hg (torr)

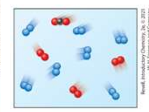
1 atm = 14.70 pounds per square inch (psi)

1 atm = 101.3 kilopascals (kPa)

1 atm = 1.013 bar

The Gas Laws, Part 1

- Boyle's Law
- Charles's Law
- Combined Gas Law



Boyle's Law

The pressure and volume of a gas are inversely related.

P↑ V↓

PV = constant

$P_1V_1 = P_2V_2$

Boyle's Law Practice

A commercial compressor stores 2.8 liters of air at a pressure of 150 psi. If this air is allowed to expand until the pressure is equal to 15 psi (just over atmospheric pressure), what volume will the air occupy?

$P_1V_1 = P_2V_2$

P_1 = 150 psi

V_1 = 2.8 L

P_2 = 15 psi

V_2 = ?

$$V_2 = \frac{P_1V_1}{P_2} = \frac{(150\ \text{psi})(2.8\ \text{L})}{(15\ \text{psi})} = 28\ \text{L}$$

Charles's Law

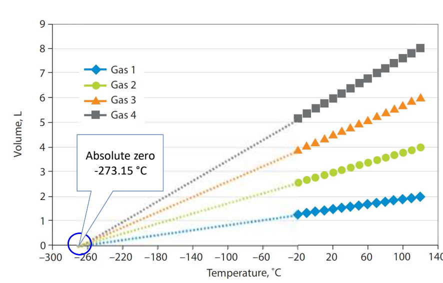
At constant pressure, the volume of a gas is directly proportional to its temperature.

T↑ V↑

$V \propto T$

$$\frac{V}{T} = \text{constant}$$

Using Charles's Law to Find Absolute Zero



The Kelvin Scale

Absolute zero

−273.15 °C

0 K

kelvin = °C + 273.15

Working to the nearest degree:

kelvin = °C + 273

Solving Problems with Charles's Law

$$\frac{V}{T} = \text{constant}$$

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

Charles's Law Practice

A balloon has a volume of 3.2 liters at room temperature (25 °C). The gas inside the balloon is then heated to 100 °C. What is the new volume of the balloon?

$V_1 = 3.2$ L

$V_2 = ?$

$T_1 = 25\,°C + 273 = 298$ K

$T_2 = 100\,°C + 273 = 373$ K

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

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

$$= \frac{(3.2\text{ L})(373\text{ K})}{(298\text{ K})} = 4.0\text{ L}$$

The Combined Gas Law

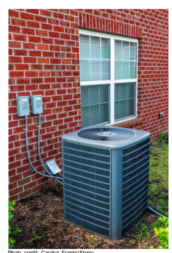


Photo credit: Carolyn Franks/Alamy

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

The Combined Gas Law Practice

A gas with a temperature of 280 K, a pressure of 200 kPa, and a volume of 25.8 L is compressed to 15.8 L, causing the pressure to increase to 350 kPa. What is the temperature of the gas under the new conditions?

$P_1 = 200$ kPa

$V_1 = 25.8$ L

$T_1 = 280$ K

$P_2 = 350$ kPa

$V_2 = 15.8$ L

$T_2 = ?$

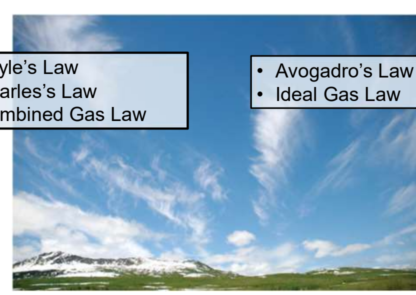
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$T_2 = \frac{P_2V_2T_1}{P_1V_1}$$

$$= \frac{(350\text{ kPa})(15.8\text{ L})(280\text{ K})}{(200\text{ kPa})(25.8\text{ L})}$$

$$= 300\text{ K}$$

The Gas Laws, Part 2



- Boyle's Law
- Charles's Law
- Combined Gas Law

- Avogadro's Law
- Ideal Gas Law

Avogadro's Law

If temperature and pressure are constant, the volume of a gas is proportional to the number of moles of gas present.

$$V \propto n$$

at Standard Temperature and Pressure (STP)…

T = 0 °C (273 K)
P = 1.0 atm

…1 mole of gas occupies 22.4 Liters

The Ideal Gas Law

$$PV = nRT$$

- R = 0.0821 L·atm/mol·K
- *T* must be in kelvins
- *P*, *V* units must match gas constant

The Ideal Gas Law Practice

What volume does 1.00 mole of gas occupy at a temperature of 0.00 °C and a pressure of 1.00 atmospheres?

$PV = nRT$ $\quad T = 0.00\ °C = 273.15\ K$

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

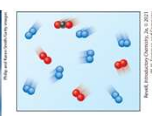
$$= \frac{(1.00\ \text{mol})(0.0821\ \text{L·atm/mol·K})(273.15}{1.00\ \text{atm}}$$

$= 22.4\ L$

Mixtures of Gases: Partial Pressure

partial pressure: The pressure caused by one gas in a mixture.

Adding up all partial pressures gives the total pressure.



Air:
78% nitrogen
21% oxygen

Partial Pressure Practice

If a 40.0-L cylinder is filled with 5.00 moles of nitrogen, 2.00 moles of oxygen, and 3.00 moles of carbon dioxide at a temperature of 400 K, what is the pressure inside the cylinder?

$$P_{N2} = \frac{nRT}{V} = \frac{(5.00\ \text{mol})(0.0821\ \text{L·atm/mol·K})(400\ \text{K})}{40.0\ \text{L}} = 4.11\ \text{atm}$$

$$P_{O2} = \frac{nRT}{V} = \frac{(2.00\ \text{mol})(0.0821\ \text{L·atm/mol·K})(400\ \text{K})}{40.0\ \text{L}} = 1.64\ \text{atm}$$

$$P_{CO2} = \frac{nRT}{V} = \frac{(3.00\ \text{mol})(0.0821\ \text{L·atm/mol·K})(400\ \text{K})}{40.0\ \text{L}} = 2.46\ \text{atm}$$

$$P_{Total} = P_{N2} + P_{O2} + P_{CO2}$$

$$= 4.11\ \text{atm} + 1.64\ \text{atm} + 2.46\ \text{atm} = 8.21\ \text{atm}$$

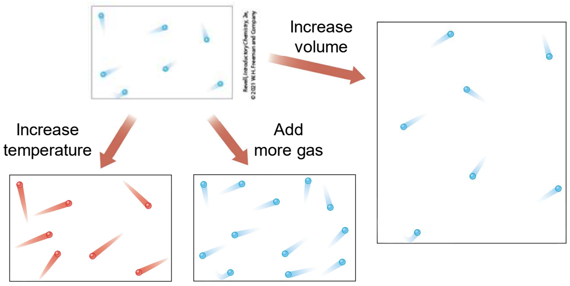
Partial Pressure, More Practice

If a 40.0-L cylinder is filled with 5.00 moles of nitrogen, 2.00 moles of oxygen, and 3.00 moles of carbon dioxide at a temperature of 400 K, what is the pressure inside the cylinder?

$$n_{total} = 5.00\ \text{moles} + 2.00\ \text{moles} + 3.00\ \text{moles} = 10.00\ \text{moles total}$$

$$P_{total} = \frac{nRT}{V} = \frac{(10.00\ \text{mol})(0.0821\ \text{L·atm/mol·K})(400\ \text{K})}{40.0\ \text{L}} = 8.21\ \text{atm}$$

A Molecular View of the Gas Laws



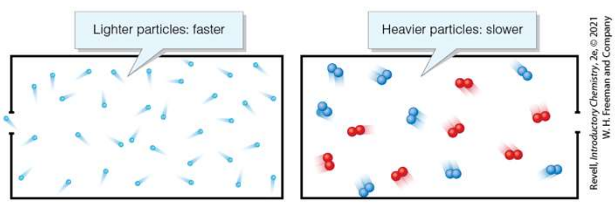
Diffusion

The spread of particles through random motion.

Lighter particles diffuse more quickly.

Effusion

The process of a gas escaping from a container.

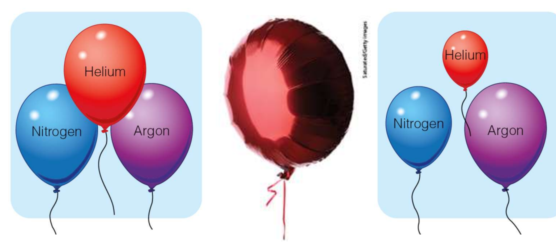


Helium

Air

Particles leak out more quickly

Effusion, Continued



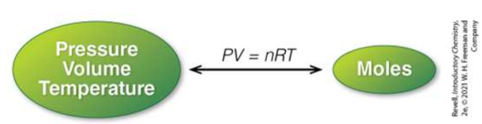
Gas Stoichiometry, Part 1

$C_6H_{12}O_6\,(s) \rightarrow 2\,C_2H_6O\,(l) + 2\,CO_2\,(g)$

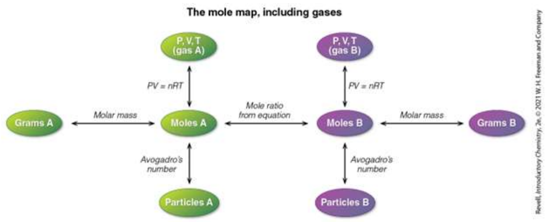
Stoichiometry

Gas Laws

Gas Stoichiometry, Part 2



Gas Stoichiometry, Part 3



Gas Stoichiometry Practice

In the fermentation of glucose, how many moles of carbon dioxide are produced for each kilogram of glucose that reacts? If the reaction takes place in a sealed container and the gas occupies a volume of 8.10 liters at a temperature of 21 °C, find the pressure of the carbon dioxide gas inside the container.

$$C_6H_{12}O_6\ (s) \rightarrow 2\ C_2H_6O\ (l) + 2\ CO_2\ (g)$$

g $C_6H_{12}O_6$ ⇨ Moles $C_6H_{12}O_6$ ⇨ Moles CO_2

$$1{,}000\ \text{g}\ C_6H_{12}O_6 \times \frac{1\ \text{mol}\ C_6H_{12}O_6}{180.18\ \text{g}\ C_6H_{12}O_6} \times \frac{2\ \text{mol}\ CO_2}{1\ \text{mol}\ C_6H_{12}O_6} = 11.10\ \text{mol}\ CO_2$$

Moles CO_2 ⇨ Pressure CO_2

$$P = \frac{nRT}{V} = \frac{(11.10\ \text{mol}\ CO_2)(0.0821\ \text{L·atm/mol·K})(294\ \text{K})}{8.10\ \text{L}} = 33.1\ \text{atm}\ CO_2$$

$T = 21°C + 273 = 294\ K$

Gas Stoichiometry, More Practice

Natural gas burns cleanly in air, according to this equation:

$$CH_4\ (g) + 2\ O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ (g)$$

If 13.1 liters of CH_4 burn at a pressure of 1.00 atmosphere and a temperature of 290 K, what mass of carbon dioxide gas is produced?

Pressure, Volume CH_4 ⇨ Moles CH_4

$$n = \frac{PV}{RT} = \frac{(1.00\ \text{atm})(13.1\ \text{L})}{(0.0821\ \text{L·atm/mol·K})(290\ \text{K})} = 0.550\ \text{moles}\ CH_4$$

Moles CH_4 ⇨ Moles CO_2 ⇨ Grams CO_2

$$0.550\ \text{mol}\ CH_4 \times \frac{1\ \text{mol}\ CO_2}{1\ \text{mol}\ CH_4} \times \frac{44.01\ \text{g}\ CO_2}{1\ \text{mol}\ CO_2} = 24.2\ \text{g}\ CO_2$$

Gas Stoichiometry Summary