Announcements for Thursday, 05DEC2024

- none

ANY GENERAL QUESTIONS? Feel free to see me after class!

Try This On Your Own

A sealed, rigid container contains 6.60 mol Cl_2 and 9.90 mol F_2. The gases react to form ClF_3(g) according to the reaction $Cl_2(g) + 3\ F_2(g) \rightarrow 2\ ClF_3(g)$. If the total pressure within the container was 10. atm **before** the reaction took place, what was the total pressure *after* the reaction finished? Assume 100% yield and constant T. **6.0 atm**

Before reaction: $\mathrm{P_{total}} = 10.\,\mathrm{atm}$

1. Determine partial pressure of each reactant for stoichiometric calculations:

$$\chi_{\mathrm{Cl_2}} = \frac{6.60\ \mathrm{mol\ Cl_2}}{6.60\ \mathrm{mol\ Cl_2} + 9.90\ \mathrm{mol\ F_2}} = 0.400 \qquad \chi_{\mathrm{F_2}} = \frac{9.90\ \mathrm{mol\ F_2}}{6.60\ \mathrm{mol\ Cl_2} + 9.90\ \mathrm{mol\ F_2}} = 0.600$$

$$\mathrm{P_{Cl_2}} = \chi_{\mathrm{Cl_2}} \cdot \mathrm{P_{total}} = (0.400)(10.\,\mathrm{atm}) = 4.0\ \mathrm{atm\ Cl_2} \qquad \mathrm{P_{F_2}} = \chi_{\mathrm{F_2}} \cdot \mathrm{P_{total}} = (0.600)(10.\,\mathrm{atm}) = 6.0\ \mathrm{atm\ F_2}$$

After reaction: $\mathrm{P_{total}} = \mathrm{P_{ClF_3\ formed}} + \mathrm{P_{excess\ reactant}}$ **Constant T and V, so $n \propto P$**

2. Determine limiting reactant and pressure of theoretical yield:

$$4.0\ \mathrm{atm\ Cl_2} \times \frac{2\ \mathrm{atm\ ClF_3}}{1\ \mathrm{atm\ Cl_2}} = 8.0\ \mathrm{atm\ ClF_3} \qquad 6.0\ \mathrm{atm\ F_2} \times \frac{2\ \mathrm{atm\ ClF_3}}{3\ \mathrm{atm\ F_2}} = 4.0\ \mathrm{atm\ ClF_3}$$

limiting reactant theoretical yield

3. Determine pressure Cl_2(g) left over:

$$6.0\ \mathrm{atm\ F_2} \times \frac{1\ \mathrm{atm\ Cl_2}}{3\ \mathrm{atm\ F_2}} = 2.0\ \mathrm{atm\ Cl_2\ needed}\ \ \text{and excess}\ \mathrm{Cl_2} = 4.0\ \mathrm{atm} - 2.0\ \mathrm{atm} = 2.0\ \mathrm{atm\ Cl_2\ excess}$$

4. Determine total pressure after reaction:

$$\mathrm{P_{total}} = \mathrm{P_{ClF_3\ formed}} + \mathrm{P_{excess\ reactant}} = 4.0\ \mathrm{atm} + 2.0\ \mathrm{atm} = \mathbf{6.0\ atm\ total}$$

Try This On Your Own – a Second Approach

A sealed, rigid container contains 6.60 mol Cl_2 and 9.90 mol F_2. The gases react to form $ClF_3(g)$ according to the reaction $Cl_2(g) + 3\,F_2(g) \rightarrow 2\,ClF_3(g)$. If the total pressure within the container was 10. atm **before** the reaction took place, what was the total pressure *after* the reaction finished? Assume 100% yield and constant T. **6.0 atm**

Before reaction: $P_1 = 10.\text{ atm}, n_1 = 6.60\text{ mol Cl}_2 + 9.90\text{ mol F}_2 = 16.5\text{ mol}$

After reaction:

1. Determine limiting reactant and moles of theoretical yield:

$$6.60\text{ mol Cl}_2 \times \frac{2\text{ mol ClF}_3}{1\text{ mol Cl}_2} = 13.2\text{ mol ClF}_3 \qquad 9.90\text{ mol F}_2 \times \frac{2\text{ mol ClF}_3}{3\text{ mol F}_2} = 6.60\text{ mol ClF}_3$$

limiting reactant   theoretical yield

2. Determine moles of $Cl_2(g)$ left over:

$$9.90\text{ mol F}_2 \times \frac{1\text{ mol Cl}_2}{3\text{ mol F}_2} = 3.30\text{ mol Cl}_2\text{ needed and excess Cl}_2 = 6.60\text{ mol} - 3.30\text{ mol} = 3.30\text{ mol Cl}_2\text{ excess}$$

3. Determine total moles after reaction:

$$n_{\text{total}} = n_{\text{ClF}_3\text{ formed}} + n_{\text{excess reactant}} = 6.60\text{ mol} + 3.30\text{ mol} = 9.90\text{ mol} = n_2$$

4. Determine final pressure (P_2) using gas law:

$$\text{at constant V \& T: } \frac{P_1}{n_1} = \frac{P_2}{n_2} \rightarrow\rightarrow P_2 = \frac{P_1\,n_2}{n_1} = \frac{(10.\text{ atm})(9.90\text{ mol})}{16.5\text{ mol}} = \mathbf{6.0\text{ atm}}$$

Try These On Your Own

- What volume of $CO_2(g)$ is formed by the complete combustion of 2.25 mol $C_2H_6(g)$ in excess oxygen at 0 °C and 1 atm ? **101 L $CO_2(g)$**

- Consider the reaction $CO_3^{2-}(aq) + 2\ H^+(aq) \longrightarrow CO_2(g) + H_2O(\ell)$. What volume (mL) of 0.250 M $HClO_4(aq)$ needs to be added to excess $Na_2CO_3(s)$ to generate 844 mL $CO_2(g)$ at 35 °C and 776 torr? **273 mL $HClO_4(aq)$**

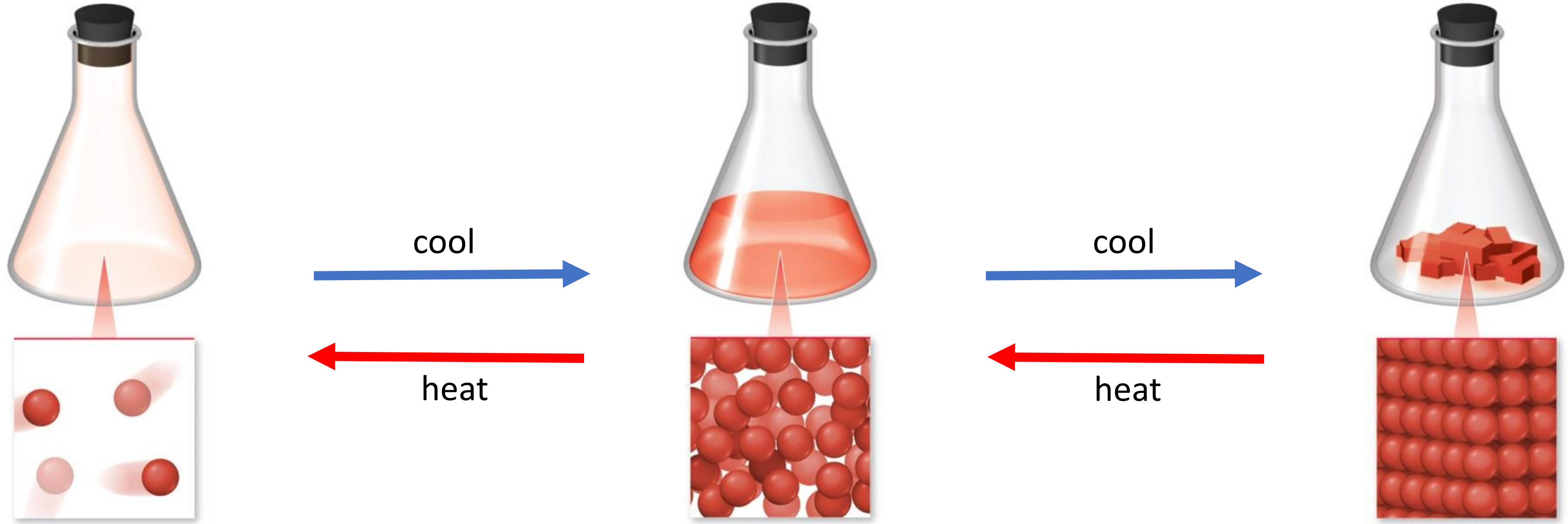
- 10.00 mL of water at 20 °C is poured into a 100. L container and sealed at 20 °C. What volume of $H_2O(\ell)$ will evaporate under these conditions? At 20 °C the vapor pressure of water is 17.55 mmHg and the density of liquid water is 0.9982 g/mL. **1.73 mL $H_2O(\ell)$**

Chapter 11: Liquids, Solids, and Intermolecular Forces

Some questions we'll try to answer

- What is responsible for the physical state of a substance under a set of conditions?
- What are intermolecular forces and how are they classified?
- How do the various types of intermolecular forces differ in terms of nature and strength?
- How can the predominant intermolecular forces be determined from a molecule's structure?
- How do intermolecular forces impact the physical properties of a substance?
- What energy changes are associated with phase changes of matter?
- How can the phase of a substance be determined using a phase diagram?

Gas vs. Liquids vs. Solids – a Review



gases

- low density
- highly compressible
- ***completely*** takes shape of container
- **very** mobile particles

liquids

- high density
- not compressible
- *partially* takes shape of container
- mobile particles

solids

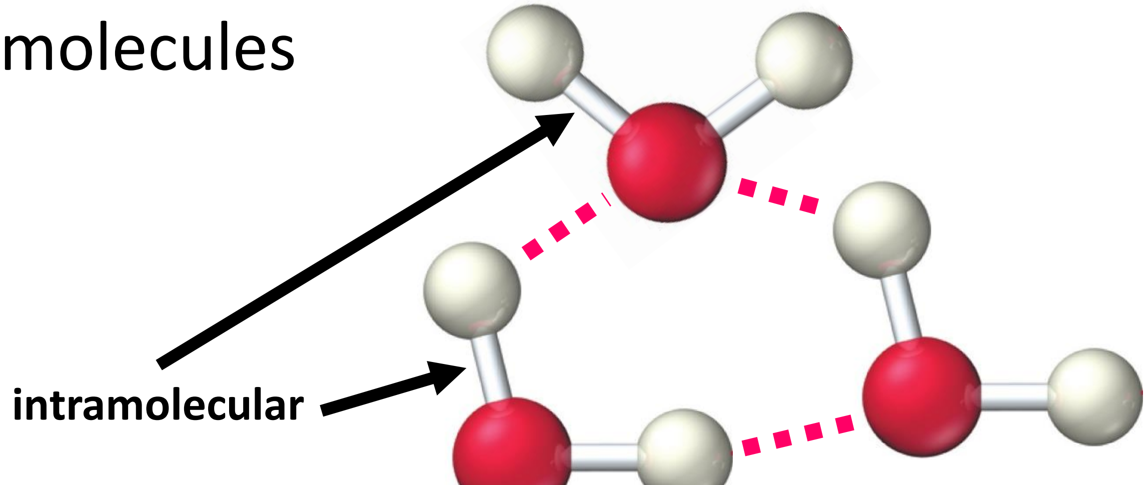
- high density
- not compressible
- shape independent of container
- relatively fixed particles

weak interactions among particles relative to thermal energy

strong interactions among particles relative to thermal energy

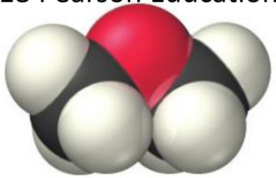
Intermolecular Forces (IMFs)

- ***inter***molecular = ***between*** different molecules
  - think ***inter***national
- ***intra***molecular = ***within*** a molecule
  - covalent bonds

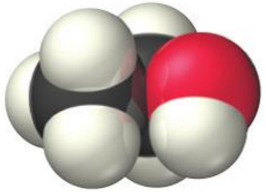


- IMFs are weak compared to bonding forces (covalent or ionic)
  - 44 kJ to vaporize 1 mole of water vs. 928 kJ to break all O–H bonds
  - due to lower magnitude charges and larger distances
- at room temperature, moderate to strong IMFs tend to result in liquids and solids; weak IMFs tend to result in gases
  - IMFs are directly responsible for the existence of **condensed states of matter** in compounds
- different types of IMFs may occur within a given substance but strongest force usually predominates

Impact of Intermolecular Forces on Physical State



- dimethyl ether vs. ethanol (25 °C and 1 atm)
  - both have chemical formula C_2H_6O
  - ether: gas (boiling point = –22 °C); structure: $CH_3–O–CH_3$
  - ethanol: liquid (boiling point = 78.3 °C); structure: $CH_3– CH_2–OH$

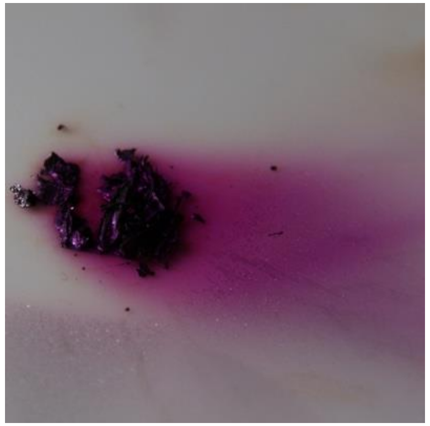


- group 7A elements (25 °C and 1 atm)

F_2(**g**)
bp = –188 °C

Cl_2(**g**)
bp = –34 °C

Br_2(**ℓ**)
bp = 58 °C



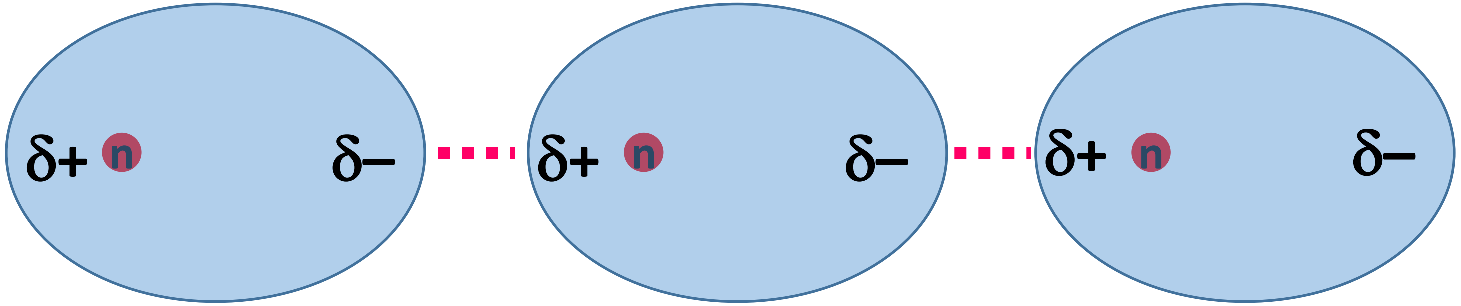
I_2(**s**)
bp = 184 °C

- more condensed states of matter = stronger intermolecular forces
- different types of IMFs can be exhibited

(London) Dispersion Forces

- in general, the weakest type of intermolecular force
- ALL atoms and molecules exhibit dispersion forces
- the **ONLY** type of IMF exhibited by **nonpolar** molecules
- the result of fluctuations in electron distribution & **instantaneous/temporary dipoles**

3 Xe atoms



electron cloud polarizes
unsymmetrical e⁻ distribution
instantaneous dipole forms

temporary dipoles induced on other atoms
dispersion forces occur

- the more polarizable the electron cloud around an atom/molecule, the stronger the dispersion forces that will result
  - polarizability is related to an atom’s size
  - larger size = more polarizable cloud = stronger dispersion forces

Effect of Atomic Size on Dispersion Force Magnitude

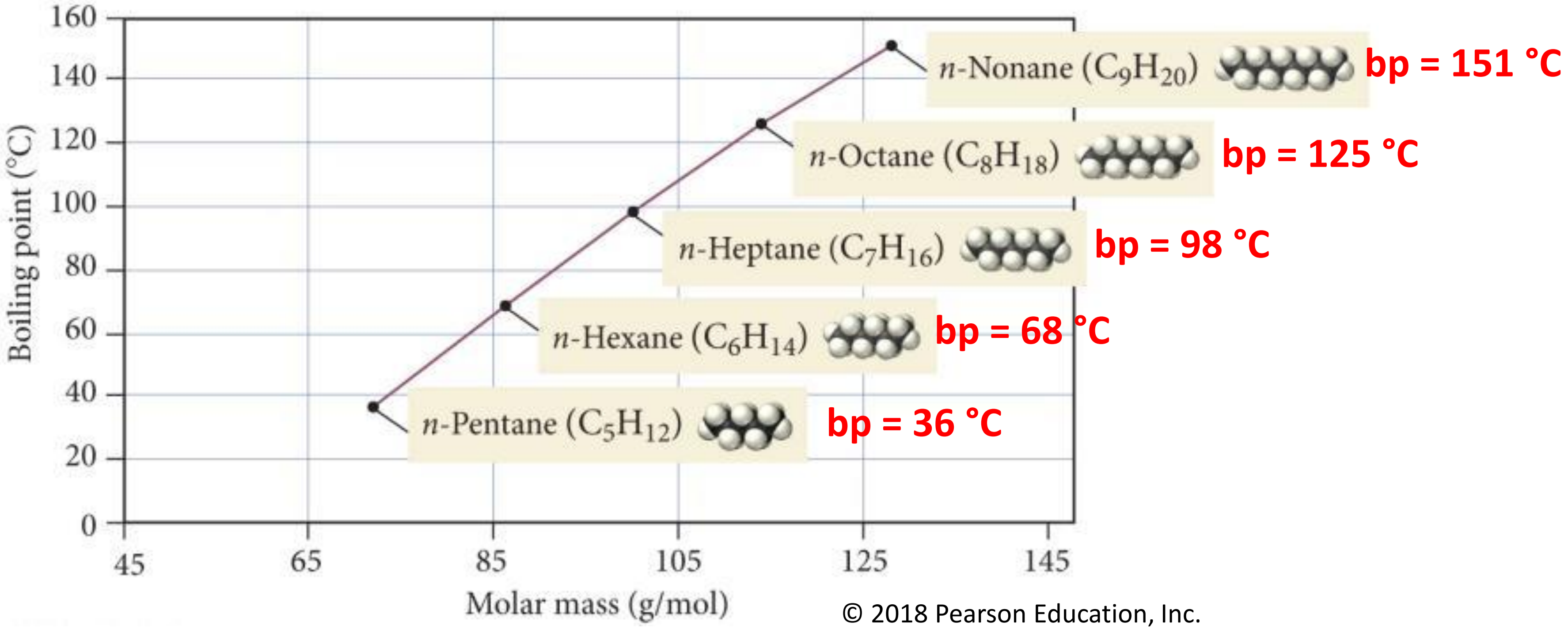
- boiling points of the noble gases
  - nonpolar atomic elements
- the larger elements have higher boiling points
- higher boiling pt = stronger IMFs
- ***stronger*** dispersion forces result

TABLE 11.3 Boiling Points of the Noble Gases

Noble Gas		Molar Mass (g/mol)	Boiling Point (K)
He		4.00	4.2
Ne		20.18	27
Ar		39.95	87
Kr		83.80	120
Xe		131.30	165

Effect of Molecular Size on Dispersion Forces

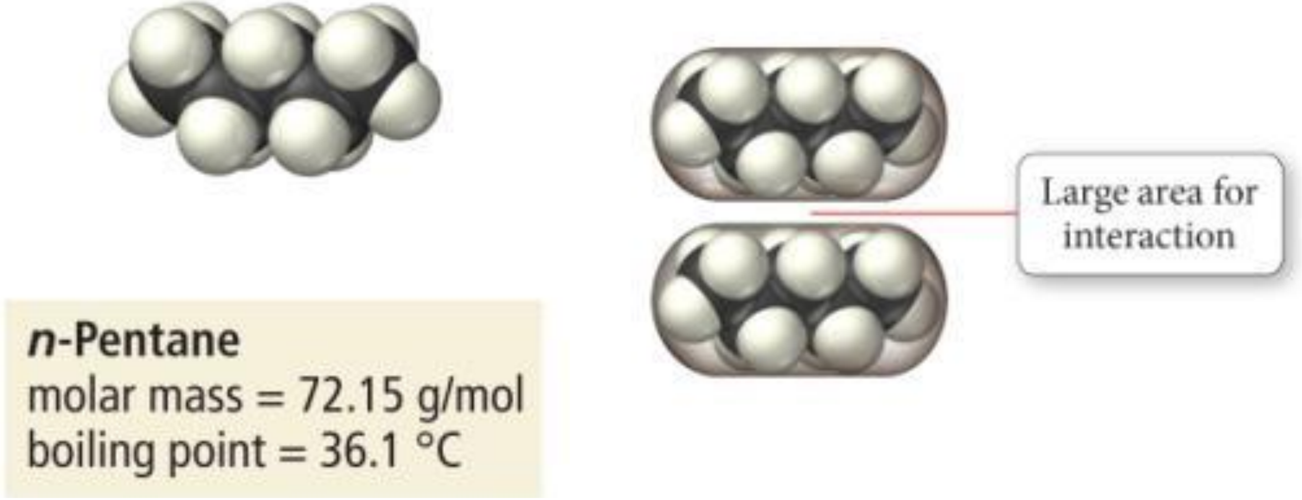
- boiling points of straight-chain alkanes
  - nonpolar molecules

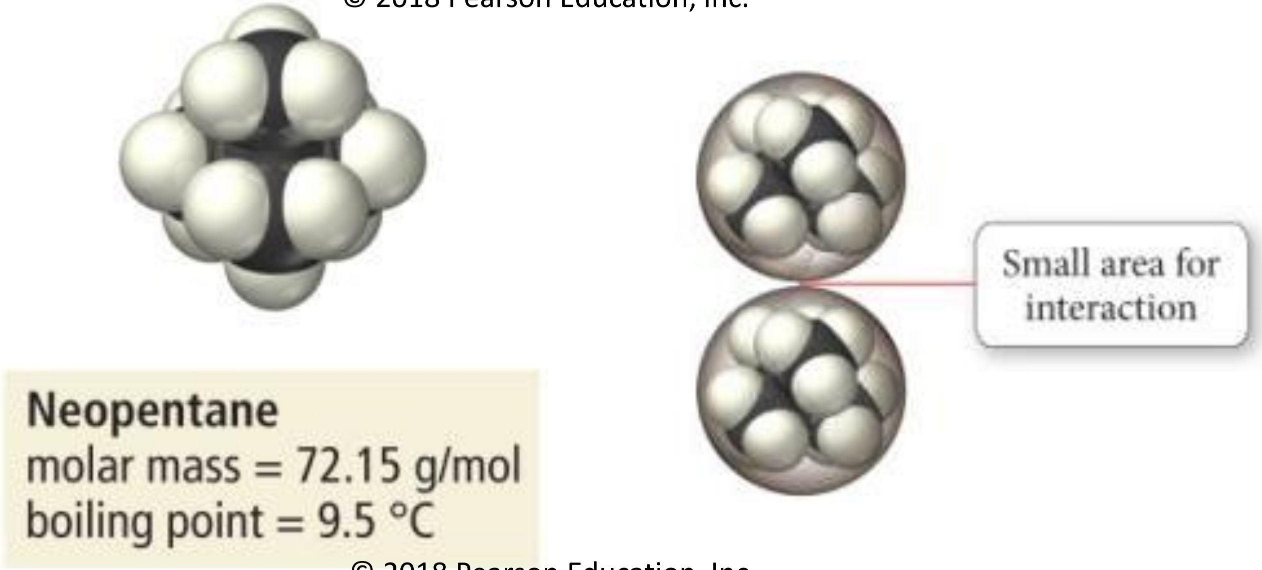


- larger alkanes have higher boiling points
- larger molecules = more sites/atoms for dispersion forces to occur
- ***stronger*** dispersion forces overall

Effect of Surface Area on Dispersion Forces

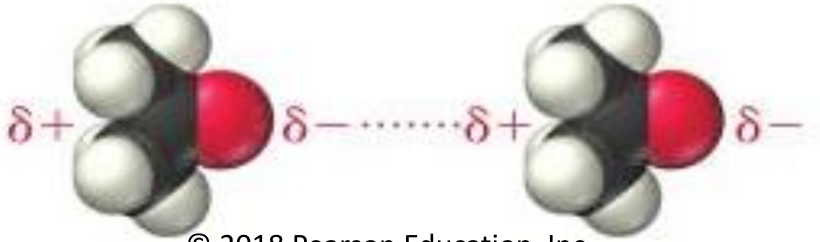
- straight-chain alkanes vs. branched alkanes
  - *n*-pentane vs. neopentane
- straight-chain alkanes overlap with each other more effectively than branched alkanes
  - more surface-to-surface contact
- better overlap between molecules = stronger dispersion forces





Dipole-Dipole Interactions

- resulting from **permanent dipoles** exhibited by **polar** molecules
  - the dipole moments do NOT fluctuate over time
- example: acetone



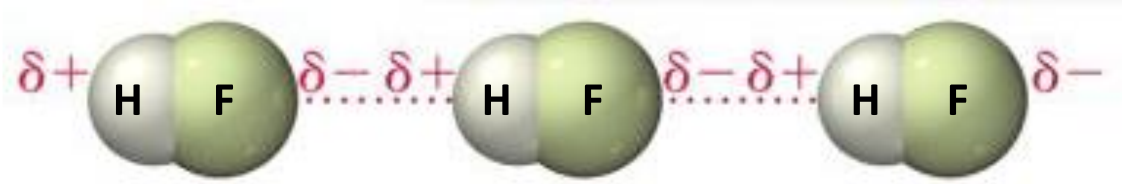
dipole-dipole interactions in acetone

- in general, dipole-dipoles are stronger than dispersion forces (when comparing similarly sized molecules)
  - acetone (MM = 58 g/mol): **liquid** at room temp; BP = 56.05 °C
  - 2-methylpropane (MM = 58 g/mol): **gas** at room temp; BP = –11.7 °C
- although polar molecules also exhibit dispersion forces, dipole-dipole interactions are usually more significant contributors to the IMFs
- the polarity of a molecule determines miscibility (more in Chapter 13)

Hydrogen Bonding (H-Bonding)

an especially strong type of dipole-dipole interaction

- a hydrogen atom is attached to an extremely electronegative atom (**F, O, N**)
  - the hydrogen atom becomes deshielded and a strong dipole results
- the H then interacts with highly electronegative atoms (**F, O, N**) on other molecules



- in general, the strongest of the three IMFs mentioned so far
- molecules that can hydrogen bond typically have higher boiling points and melting points than molecules that only exhibit dipole-dipole interactions
  - dimethyl ether (BP = –22 °C) vs. ethanol (BP = 78 °C)
  - acetone (BP = 56 °C) vs. acetic acid (BP = 118 °C)