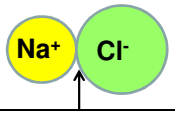
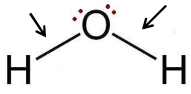
Chemical Bonds

versus

Intermolecular Forces of Attraction (IMF)

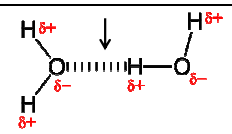
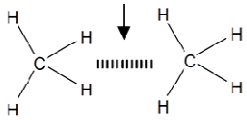
1

Chemical Bonds – bonds ***between atoms*** in a compound

Type of Bond	Diagram of the bond	Approx. bond energy, kJ/mol
Ionic bond		800
Covalent bond		400

Intermolecular Forces of Attraction (IMFs) – attractions ***between molecules*** in a liquid or solid

Type of IMF	Diagram of IMF	Approximate bond energy, kJ/mol
Hydrogen-bonding	(See next slide)	40
Dipole-dipole	(See next slide)	25
London dispersion forces	(See next slide)	10

Chemical Bonds		
Type of Bond		**Approx. bond energy,** kJ/mol
Ionic bond	(See previous slide)	**800**
Covalent bond	(See previous slide)	**400**
Intermolecular Forces of Attraction (IMFs)		
Type of IMF	**Diagram of IMF**	**Approx. bond energy,** kJ/mol
Hydrogen-bonding		**40**
Dipole-dipole		**25**
London dispersion forces		**10**

Chemical Bonds – bonds *between atoms* in a compound

- **Ionic** or
- **Covalent**
  - Difficult to break;
  - Not broken by any physical change (boiling, melting etc.)

Intermolecular Forces of Attraction (IMFs) – attractions *between molecules* in a liquid or solid

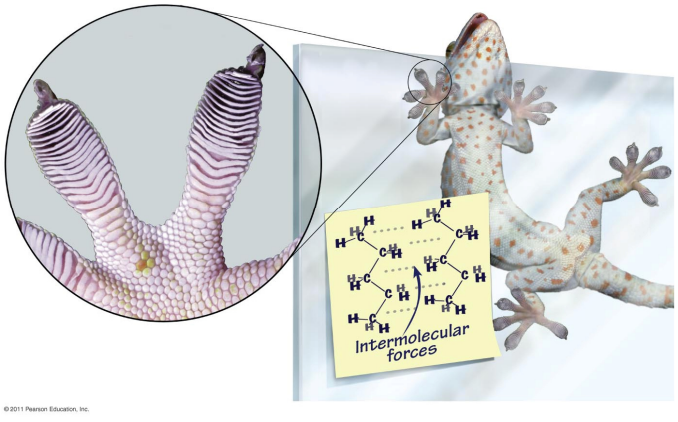
- Easily broken by physical processes (boiling, melting, dissolving etc.)
- Affects boiling point, melting point and solubility of compounds
- Without IMFs, there'll be no DNA

See http://butane.chem.uiuc.edu/pshapley/GenChem1/L20/3.html

4

Chapter 11:
Liquids, Solids, and Intermolecular Forces (IMFs)

5



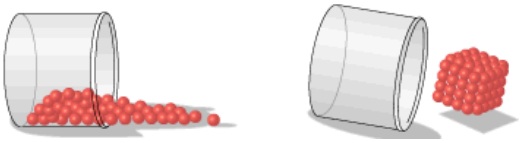
- Geckos can adhere to almost any surface
- This amazing ability is related to intermolecular attractive forces
- Geckos have millions of tiny hairs on their feet that branch out and flatten out on the end
  - allows the gecko to have unusually close contact to the surface

6

Liquids *vs.* Solids

Liquids

- Fixed volume; variable shape; incompressible
- Intermediate *kinetic energy* (KE)
- Intermediate *intermolecular forces* (IMF) of attraction



Solids

- Fixed volume and shape; incompressible
- Low KE (gases > liquids > solids)
- Strong IMF of attraction (solids > liquids > gases)

7

Intermolecular Forces (IMFs)

- Attractions that exist ***between molecules*** in a solid or liquid

Importance: Affects physical properties of matter

- Vapor pressure
- Boiling and melting points (b.p. & m.p.)
- Surface tension
- Solubility

- **Strong IMFs** (attractions) = ***higher b.p.*** (liquids) and ***higher m.p.*** (solids)
  – *assuming about the same molecular size*

8

Why Are Particles Attracted to Each Other?

Recall: **Ionic bond**: (+) ion attracted to (–) ion

- IMFs are due to attractive forces between opposite charges *in molecules*
  - **Polar covalent**: partial positive (δ+) end of polar molecule to partial negative (δ–) end of another polar molecule
    - ✓ H-bonding especially strong
  - **Nonpolar covalent**: Due to temporary charges (dipoles)
- **Larger charge = stronger attraction**
- **Longer distance = weaker attraction**

9

Tro: Chemistry: A Molecular Approach, 2/e

Types of IMFs

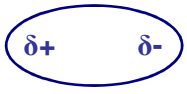
1. **Dipole-dipole attractions** exist between ***polar*** molecules

Dipoles = molecules with partial positive (**δ+**) and partial negative (**δ-**) ends

Recall dipoles in polar HF molecules (Chapter 10 - Polarity)

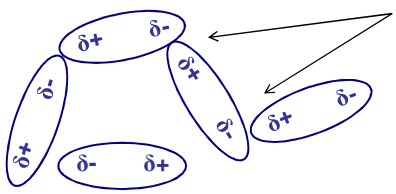
δ+ δ-
H - F

Analogous to



A **"dipole"** (like a magnet with two opposite ends: N & S)

- **δ+** end of one molecule attracts the **δ-** end of another

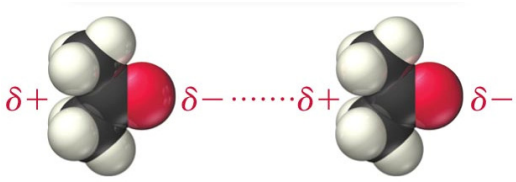


Dipole-dipole attractions

10

Dipole–Dipole Attractions – *Cont.*

- Due to permanent dipole (δ+ and δ– ends) in <u>polar</u> molecules
  - From bond polarity and shape
  - From dipole moment
- The permanent dipole adds to the IMFs between the molecules
  - Raises ***boiling*** and ***melting points*** <u>relative to nonpolar</u> molecules of similar size and shape

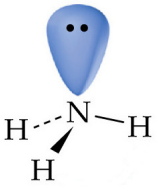


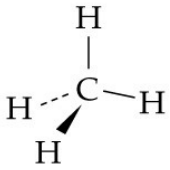
11

Tro: Chemistry: A Molecular Approach, 2/e

Challenge: Which has a higher b.p: NH_3 (molecular mass 17 g/mol) or CH_4 (mol. mass 16 g/mol)

- **NH_3** : IMFs in NH_3 >>> IMFs in CH_4 - Why?





Tetrahedral

NH_3: Trigonal planar - Polar bonds; *Unsymmetrical* molecule **Polar**

CH_4 = Tetrahedral Nonpolar bonds; symmetrical molecule = **Nonpolar**

- <u>Stronger</u> **dipole-dipole IMFs** in <u>polar</u> molecules raises *boiling* and *melting points* relative to nonpolar molecules of similar size and shape

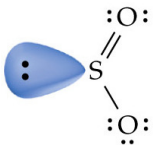
12

Types of IMFs - *Cont.*

Exercise: Circle the molecules below where dipole-dipole attractions exist.

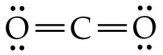
SO_2 **CO_2** **NH_3**

HINT: Draw the Lewis structure first to determine which molecules are **polar** (= exhibits ***dipole-dipole*** attractions)



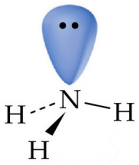
Polar

Polar bonds and not symmetric



Nonpolar

Polar bonds but perfectly *symmetric*



Polar

Polar bonds and not symmetric

13

Types of IMFs - *Cont.*

2. **Hydrogen-bonding** is a strong type of dipole-dipole attraction *seen when H is directly bonded to a small, electronegative atom like **F, O** and **N***

➢ H-bonding: **F—H, O—H, or N—H** (Isn't chemistry **"FON"?)**

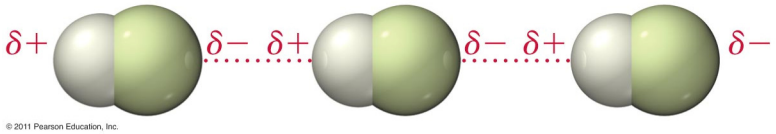
- Highly electronegative atom bonded to H pulls the bonding electrons toward itself

- Very low e^- density around H acts as very strong center of δ+ charge; large e- density around F, O or N acts as strong center of δ - charge

14

H-Bonding in HF

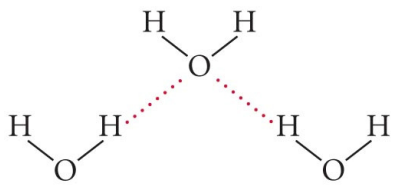
When H bonds directly to F, O, or N, the bonding atoms acquire relatively large partial charges, giving rise to strong dipole–dipole attractions between neighboring molecules.

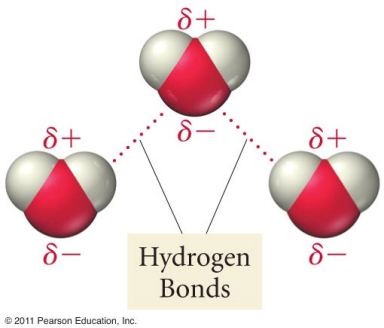


- The *δ- end of one molecule forms H-bonding with the δ+ (hydrogen) end of another.*

15

H-Bonding in Water

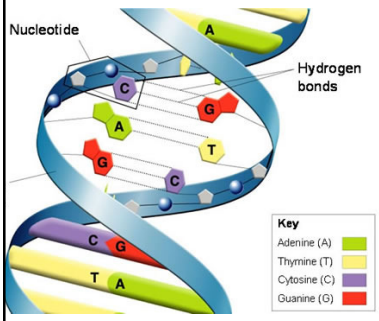


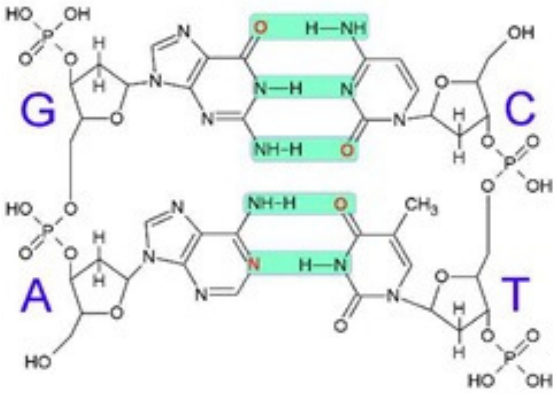


- Notice how a *H atom forms a "bridge" between two electronegative atoms*

16

H-Bonding in DNA





17

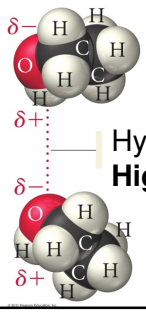
Effect of H-Bonding on Boiling Point

Name	Formula	Molar Mass (amu)	Structure	bp (°C)
Ethanol	C_2H_6O	46.07	CH_3CH_2OH	78.3
Dimethyl Ether	C_2H_6O	46.07	CH_3OCH_3	−22.0

Higher bp

H – O bond; H-bonding

H – C bond; no H-bonding



Hydrogen-bonding in CH_3CH_2**OH; Higher bp** compared to CH_3OCH_3

Tro: Chemistry: A Molecular Approach, 2/e

18

H-Bonding: *Summary*

- Hydrogen bonding is a very strong IMF that exists in polar molecules with H-**F**, H-**O** and H-**N** bonds
  - ***stronger than dipole–dipole*** or dispersion forces (will be discussed next)
- Substances that can hydrogen bond will have higher boiling points and melting points than similar substances that cannot
- Hydrogen bonding is ***not a chemical bond*** and are not nearly as strong as chemical bonds
  - 2 to 5% the strength of covalent bonds

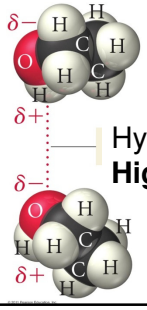
19

For a good 4-minute video summarizing the dipole-dipole and hydrogen-bonding IMFs go to http://www.dnatube.com/video/2114/Organic-Chemistry-Intermolecular-Forces

20

Effect of H-Bonding on Boiling Point

Name	Formula	Molar Mass (amu)	Structure	bp (°C)
Ethanol	C_2H_6O	46.07	CH_3CH_2OH	78.3
Dimethyl Ether	C_2H_6O	46.07	CH_3OCH_3	−22.0

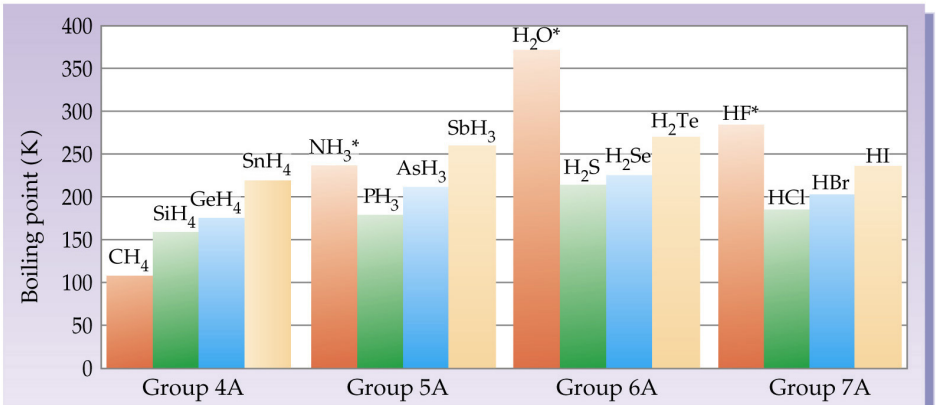


Hydrogen-bonding in …
Higher bp compared to …

Tro: Chemistry: A Molecular Approach, 2/e

21

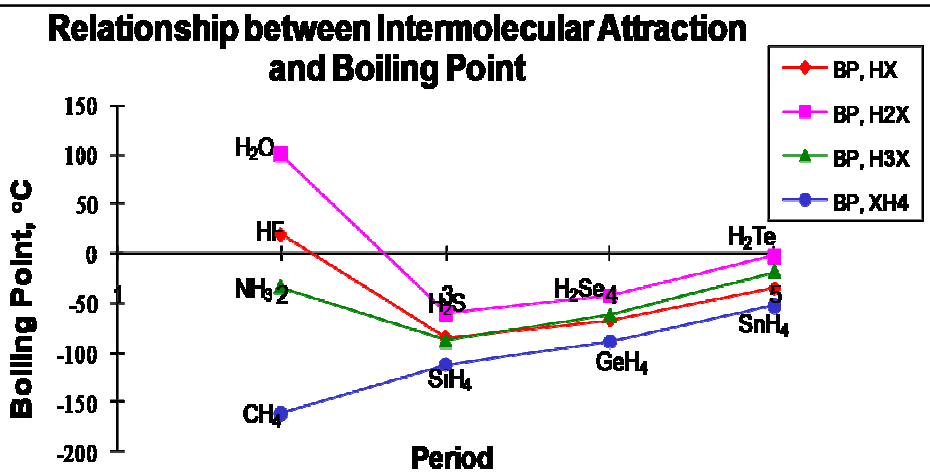
IMFs and Boiling Point: Trend within a Group



*The boiling points generally increase with increasing molecular mass down a group of the periodic table, but the hydrides of nitrogen (NH_3), oxygen (H_2O), and fluorine (HF) have abnormally high boiling points because these molecules form hydrogen bonds.

http://wps.prenhall.com/wps/media/objects/602/616516/Chapter_10.html

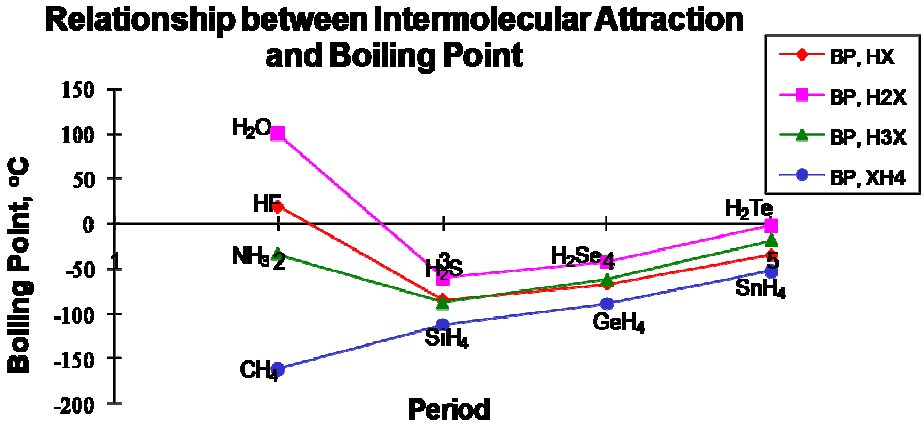
22



Polar molecules, such as the hydrides of Groups 15–17 (**XH_3, XH_2 and XH**), have ***dipole–dipole*** attractions. Therefore they have higher boiling points than the corresponding Group 14 molecules.

23

Tro: Chemistry: A Molecular Approach, 2/e



For **nonpolar molecules**, such as the **hydrides of Group 14 (XH_4),** the IMFs are due to dispersion forces. Dispersion forces increase down the column as size increases, causing the boiling point to increase.

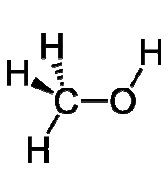
24

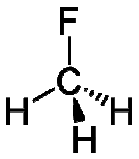
Tro: Chemistry: A Molecular Approach, 2/e

Practice – Choose the substance in each pair that is a liquid (i.e. has stronger IMFs) at room temperature (the other is a gas)

a) CH_3OH and CH_3F

can H-bond





b) CH_3-O-CH_2CH_3 $CH_3CH_2CH_2NH_2$

can H-bond

Tro: Chemistry: A Molecular Approach, 2/e

25

Types of IMFs - *Cont.*

3. **London dispersion forces** = weak attractive forces between nonpolar molecules due to *instantaneous induced dipoles*

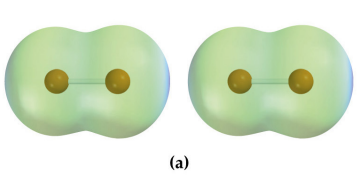
- ***Temporary dipoles*** result from fluctuations in the electron distribution in atoms and molecules
  - not due to polar bonds (unlike permanent dipoles in polar bonds)
  - Region with excess e^- density develop temporary δ- charge; region with depleted e^- density develop temporary δ+ charge
- The attractive forces caused by these temporary dipoles are called ***London dispersion force***

26

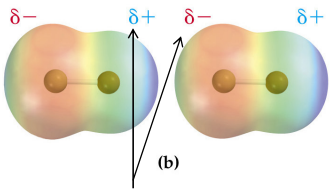
Image available at http://wps.prenhall.com/

London dispersion forces - *Cont.*

Illustration: Each Br_2 molecule has zero polarity (a). However, due to the motion of electrons at any given instant a temporary dipole would arise that would then induce a dipole in an adjacent molecule (b), causing a weak attraction between them called ***London dispersion forces***



No dipoles = no attraction



Instantaneous dipoles

- London dispersion forces *increase with increasing molecular size*

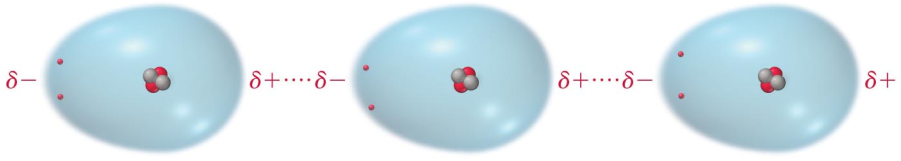
27

Image available at http://wps.prenhall.com/

London dispersion forces - *Cont.*

Dispersion Force

An instantaneous dipole on any one helium atom induces instantaneous dipoles on neighboring atoms, which then attract one another.



28

Tro: Chemistry: A Molecular Approach, 2/e

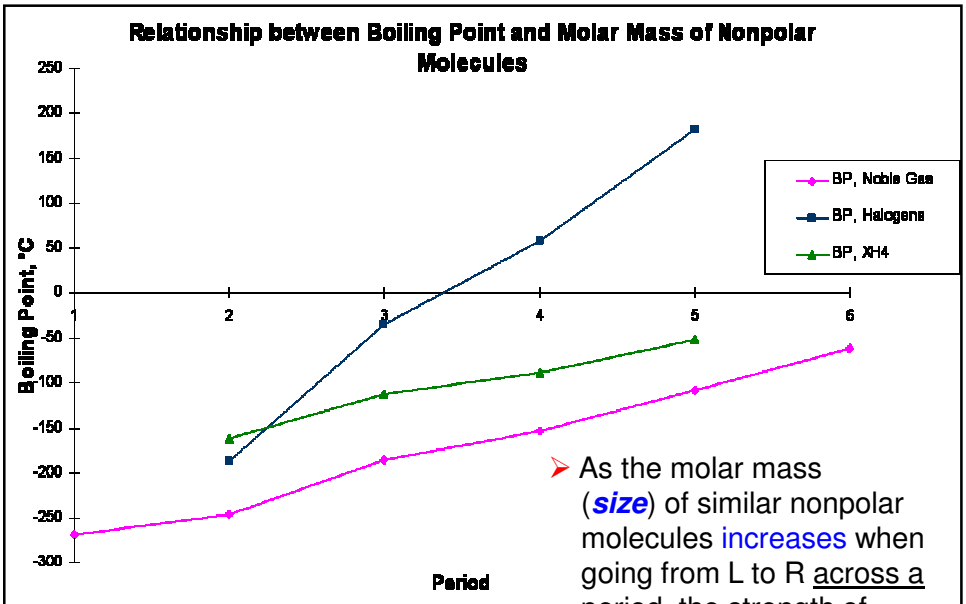
Effect of Molecular Size on Dispersion Force

The **noble gases** are all nonpolar atomic elements

- As the molar mass (size) increases, the number of e⁻s increases.
  - strength of dispersion forces also increases.
  - stronger IMF, higher bp

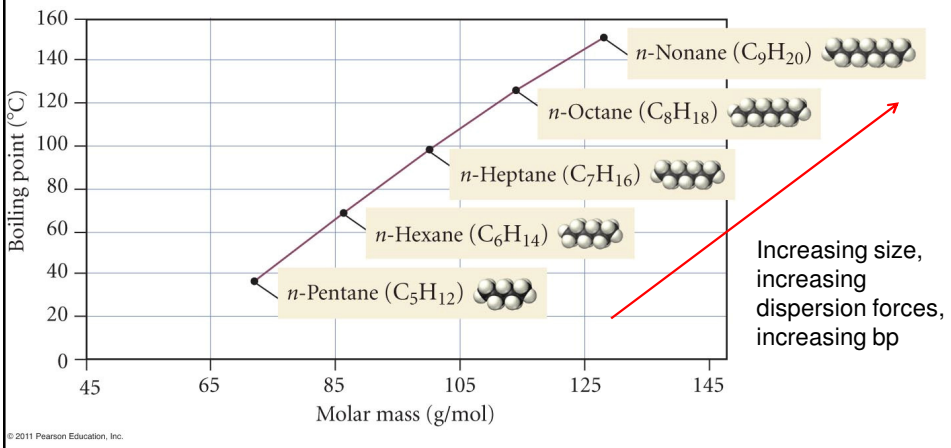
TABLE 11.3 Boiling Points of the Noble Gases

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



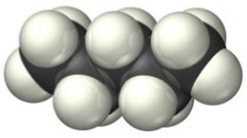
- As the molar mass (***size***) of similar nonpolar molecules increases when going from L to R across a period, the strength of dispersion forces also increases and so does bp

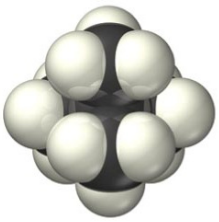
Boiling Points of *Hydrocarbons**



* Petroleum products typically used as fuel (gasoline)

Molecular Shape Effect on Dispersion Force

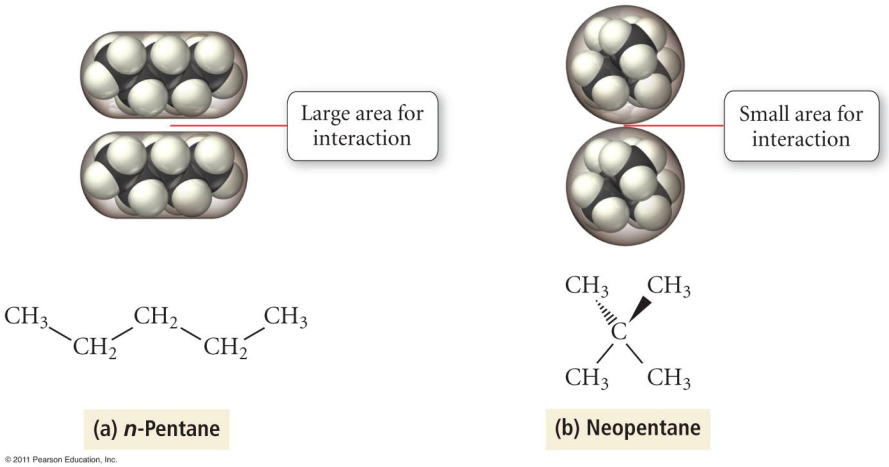




***n*-Pentane**
molar mass = 72.15 g/mol
boiling point = 36.1 °C

Neopentane
molar mass = 72.15 g/mol
boiling point = 9.5 °C

Molecular Shape Effect on Dispersion Force



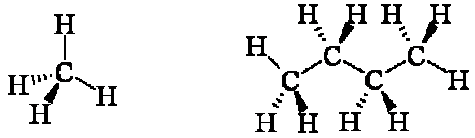
The larger surface-to-surface contact between molecules in *n*-pentane results in stronger dispersion force attractions

33

Tro: Chemistry: A Molecular Approach, 2/e

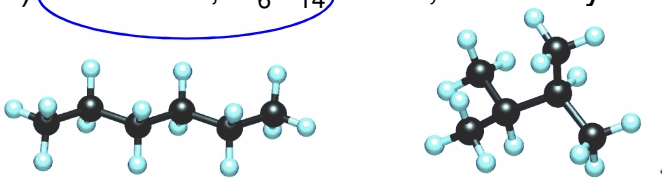
Practice: Which substance in each pair below has the higher boiling point?

a) CH_4 or C_4H_{10}



Both molecules are *nonpolar, so* larger molar mass has higher bp

b) n-hexane, C_6H_{14} or *2,3*-dimethylbutane, C_6H_{14}



Both are *nonpolar,* but the n-hexane has a larger surface-to-surface contact, *so it has a* higher bp

34

For a good 5-minute video summarizing the three IMFs go to
http://www.youtube.com/watch?feature=endscreen&v=S8QsLUO_tgQ&NR=1

35

Intermolecular Forces and Solubility

36

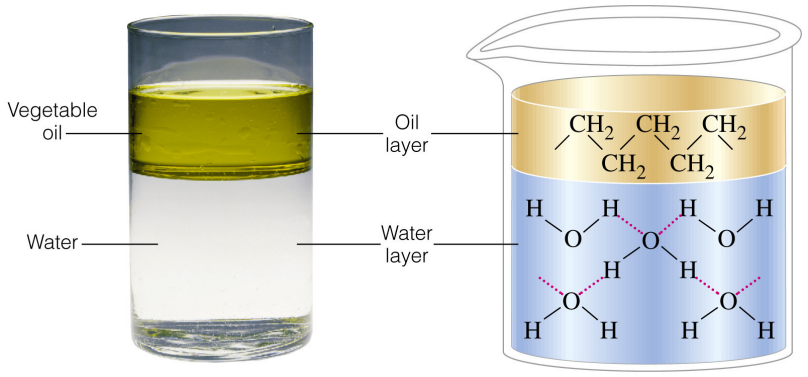


Image available at http://www.jonescollegeprep.org/

37

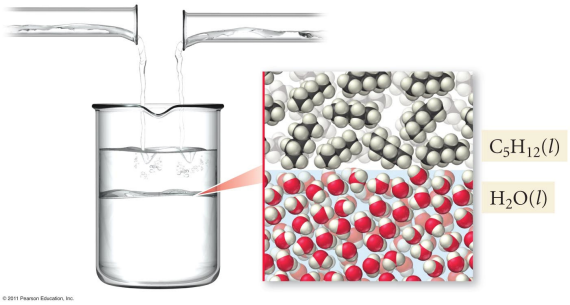
IMFs and Solubility

- Solubility depends, in part, on the attractive forces of the solute and solvent molecules
  - **like dissolves like**
  - **miscible liquids will always dissolve in each other**
- Polar substances dissolve in polar solvents
  - **H-bonding – H-bonding or dipole-dipole attractions**
- Nonpolar molecules dissolve in nonpolar solvents
  - **Dispersion forces-dispersion forces**
- Many molecules have both polar and nonpolar parts
  - **solubility in water depends on competition between solute-solute IMFs and solute-solvent IMFs**

38

Tro: Chemistry: A Molecular Approach, 2/e

Immiscible (not soluble) **Liquids**



- Pentane, C_5H_{12} is nonpolar; water is polar = ***polar does not dissolve nonpolar***
- Solvent-to-solvent (H_2O-H_2O) IMFs >> Solvent (H_2O)-solute (pentane) IMFs
  - **LDF**
  - **H-bonding**
- The result is the liquids are **immiscible**.

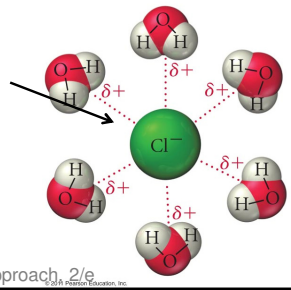
39

Tro: Chemistry: A Molecular Approach, 2/e

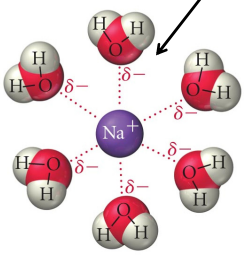
IMFs – *Cont.*
(4) Ion–Dipole Attractions

- In a mixture (e.g. salt-water), ions from an ionic compound (salt) are attracted to the dipole of polar molecules like water
- The strength of the ion–dipole attraction is one of the main factors that *determines the solubility of ionic compounds in water*

Ion-dipole:
(-) charge on Cl^- ion is attracted to the δ+ H end of water molecule



Ion-dipole attraction b/w
(+) Na^+ and δ- O in H_2O



40

Tro: Chemistry: A Molecular Approach, 2/e

- Ion–dipole attractions are present when a soluble ionic compound dissolves in water (polar solvent)
- Ion–dipole attractions are the strongest IMFs
- Ion–dipole attractions are especially important in aqueous solutions of ionic compounds

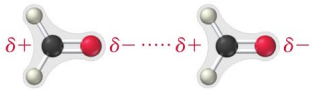
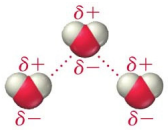
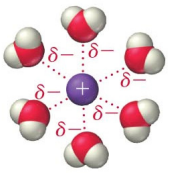
Relative strengths of IMFs:

Ion-dipole > H-bonding > dipole-dipole > London dispersion forces

41

Tro: Chemistry: A Molecular Approach, 2/e

TABLE 11.4 Types of Intermolecular Forces

Type	Present in	Molecular perspective	Strength
Dispersion	All molecules and atoms		
Dipole–dipole	Polar molecules		
Hydrogen bonding	Molecules containing H bonded to F, O, or N		
Ion–dipole	Mixtures of ionic compounds and polar compounds		

Tro: Chemistry: A Molecular Approach, 2/e

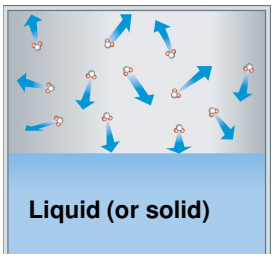
Vapor Pressure and Boiling Point

43

Vapor Pressure and Boiling Point

Vapor pressure, P_{vap} = pressure exerted by gas molecules on top of a liquid or solid

- Apply heat to increase P_{vap} (more gas molecules to exert pressure)
- When P_{vap} equals atmospheric pressure, the liquid boils



Boiling point, b.p. = temperature at which the vapor pressure of a liquid equals the atmospheric pressure

- b.p. generally increases with increasing size of molecules
- Recall that b.p. is also affected by IMFs

44

Vapor Pressure and Boiling Point - *Cont.*

Q: How do IMFs affect P_{vap} and b.p.?

A: ***Stronger IMFs***, fewer gas molecules escape the liquid = ***lower P_{vap}*** and ***higher b.p.***

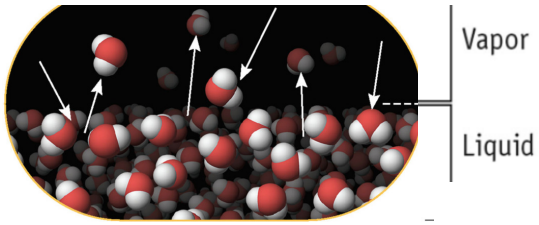
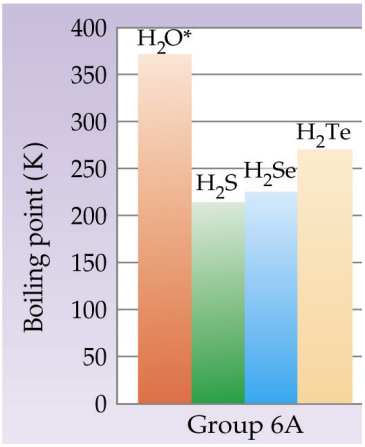


Image available at
http://www.uwec.edu/boulteje/Boulter103Notes/11December.htm

45

Q: Arrange the following in order of increasing boiling point: **H_2O, H_2S, H_2Se** and **H_2Te**

Hint: Look at both molecular size and IMFs



46

IMFs and Surface Tension

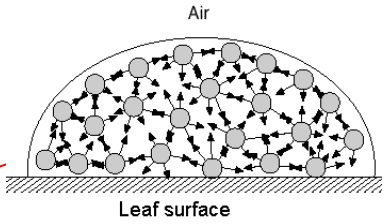


Image above from http://quest.nasa.gov/space/teachers/microgravity/image/66.gif

Intermolecular forces create the surface tension that causes these water droplets on leaves to bead up and form the smallest surface possible. The water molecules at the surface are pulled in by the intermolecular force between themselves and molecules inside the droplet.

Multimedia from Encarta at http://encarta.msn.com/encnet/refpages/mediacenter.aspx

47