Intermolecular Forces / Interactions (IMF)

IMFs are electrostatic in nature

IMFs are not bonds

Avg covalent bond ~ 400 kJ/mol

IMFs 10-50 kJ/mol – much weaker than covalent - but still can affect molecule properties

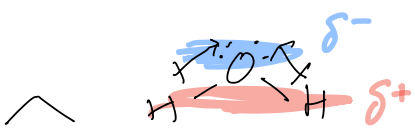
strong ↓ weaker

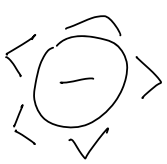
- Ion/polar molecule "ion-dipole"
- polar molec/polar molec "dipole-dipole"
- polar molec/nonpolar molec "dipole-induced dipole"
- nonpolar/non polar "induced dipole-induced dipole"

Ion dipole interaction – ion interacting w/ polar molecule

- Factors that determine strength
  - charge of ion
  - polarity of molecule
  - distance

Interaction btw dissolved ions and the water in which they are dissolved



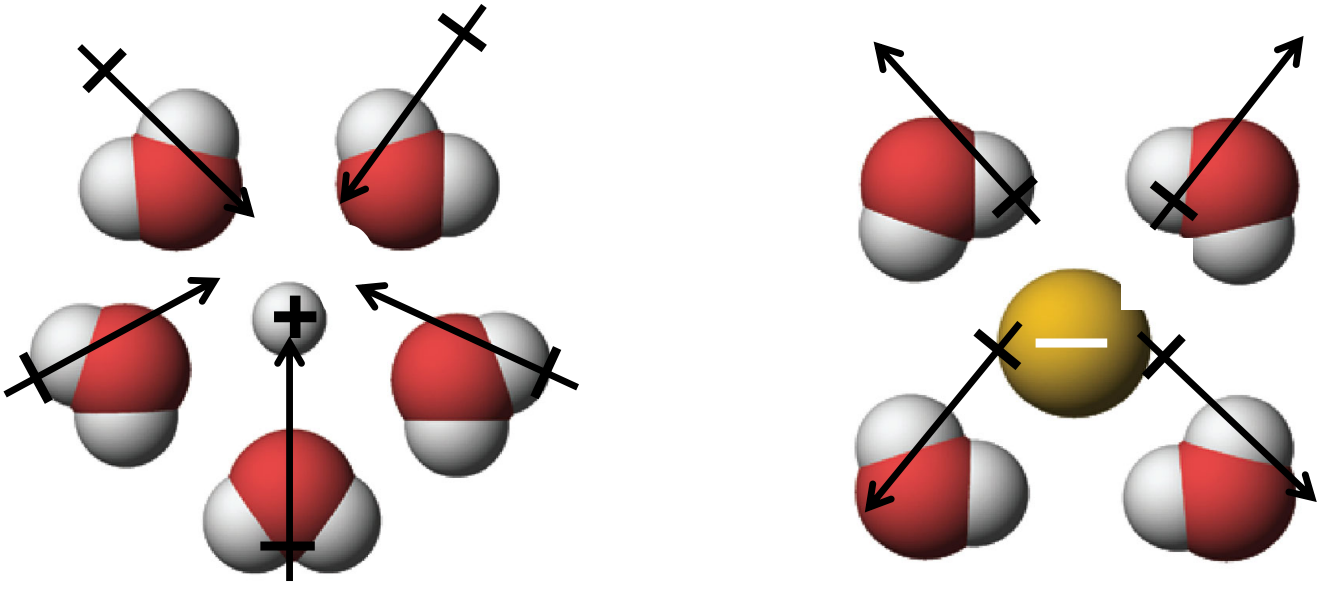


ΔH of solvation – ΔH for gaseous ion to a dissolved (solvated) ion

$K^+_{(g)} \longrightarrow K^+_{(aq)}$ $\Delta H_{solv} = -321 \frac{kJ}{mol}$ of K^+

* Many H_2O molecules per ion, the individual H_2O–ion interaction much smaller than $-321 \frac{kJ}{mol}$

Solvation of Ions

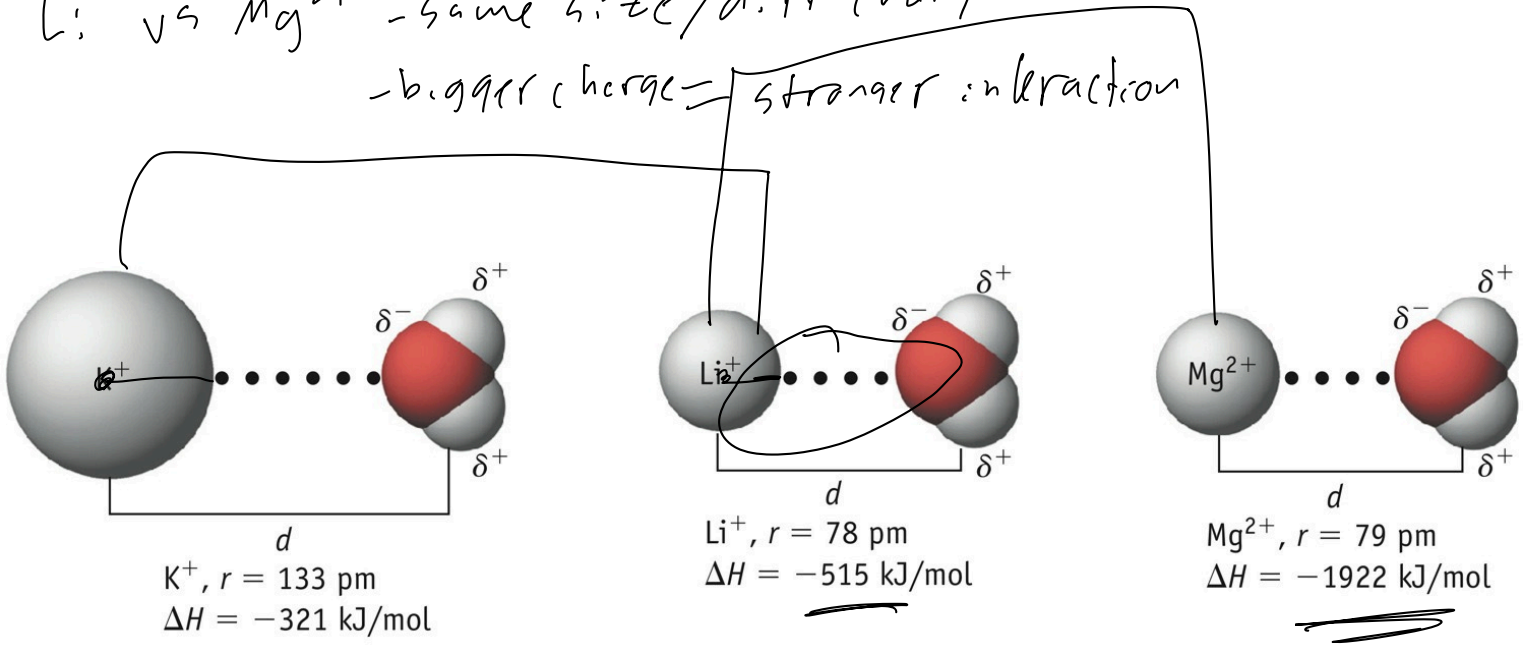


When a *cation* exists in solution, it is surrounded by the *negative* dipole ends of water molecules.

When as *anion* exists in solution, it is surrounded by the *positive* dipole ends of water molecules.

K^+ vs Li^+ - same charge / diff size
- smaller ion = closer distance = stronger interaction

Li^+ vs Mg^{2+} - same size / diff charge
- bigger charge = stronger interaction

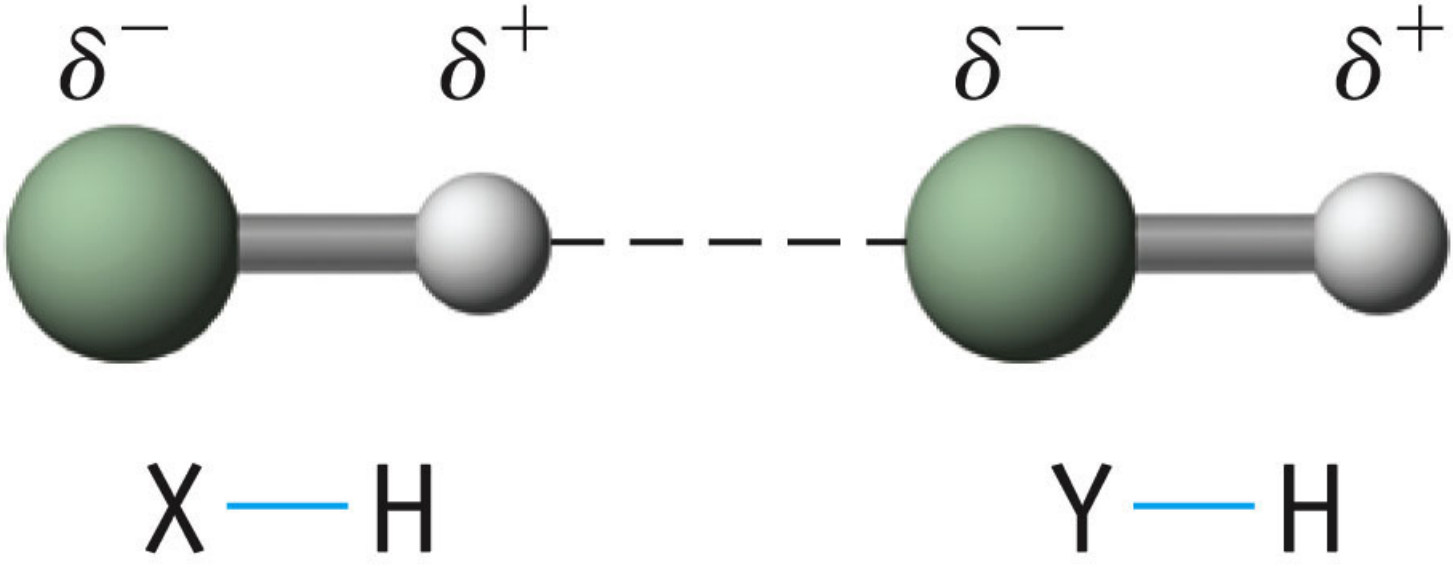


solubility of ionic compounds

competition btw ionic bond stability and stability from solvation of individual ions

Dipole / Dipole interactions

- between polar molecules of same type or of different types
- More polar molecules → stronger interactions
- If looking at single substance, strength of dipole/dipole interaction is reflected in liq → gas phase change



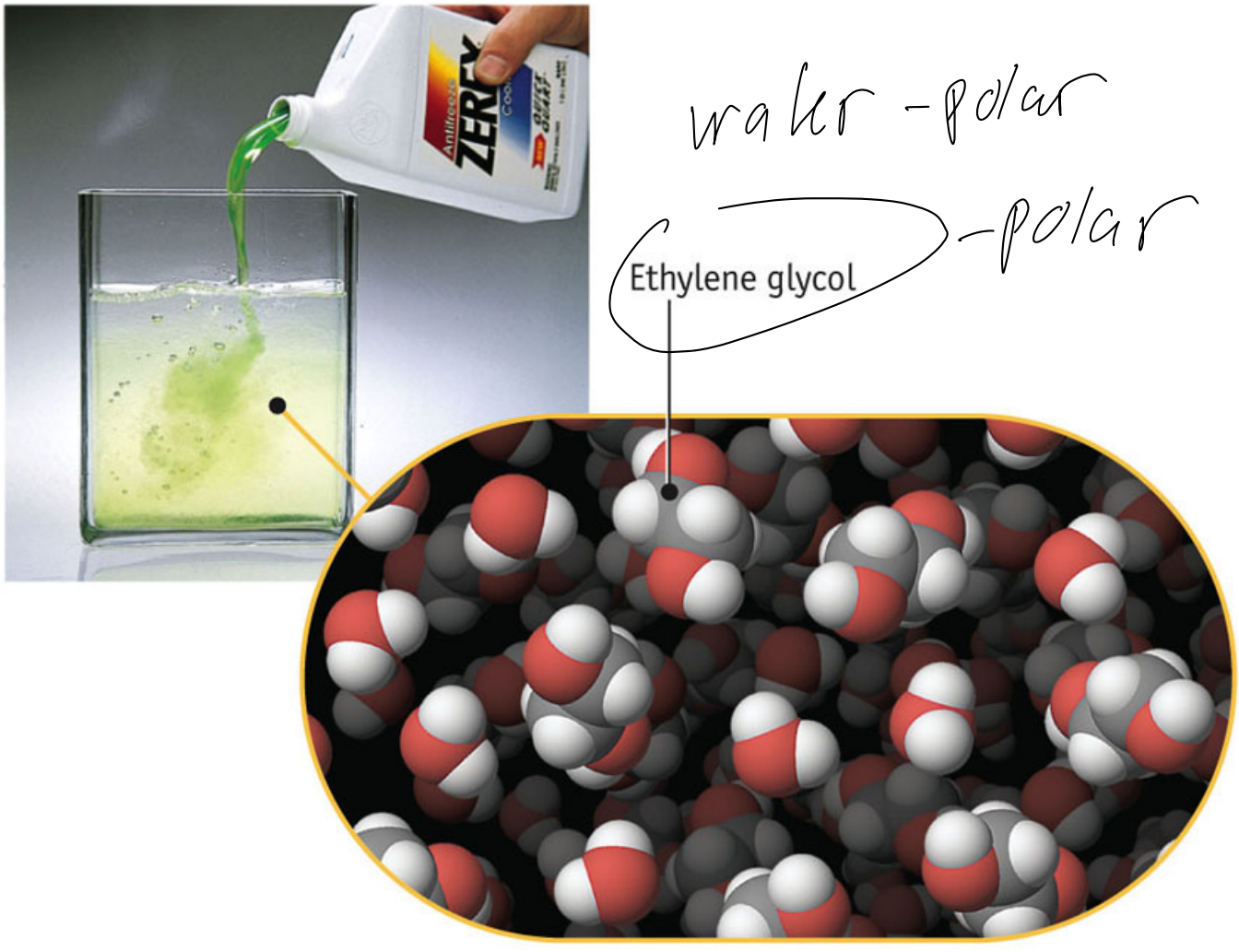
Dipole – Dipole Forces

Table 11.2 Molar Masses, Boiling Points, and $\Delta_{vap}H°$ of Nonpolar and Polar Substances

NONPOLAR				POLAR			
	M (g/mol)	BP (°C)	$\Delta_{vap}H°$ (kJ/mol)		*M* (g/mol)	BP (°C)	$\Delta_{vap}H°$ (kJ/mol)
N_2	28	−196	5.57	CO	28	−192	6.04
SiH_4	32	−112	12.10	PH_3	34	−88	14.06
GeH_4	77	−90	14.06	AsH_3	78	−62	16.69
Br_2	160	59	29.96	ICl	162	97	—

polar – higher bp, larger ΔH_{evap}
b/c stronger interactions
holding together molecules in liquid

Dipole-dipole interaction affect miscibility of liquids



(a) Ethylene glycol ($HOCH_2CH_2OH$), a polar compound used as antifreeze in automobiles, dissolves in water.

Fig. 12-5, p. 560

W-W interactions

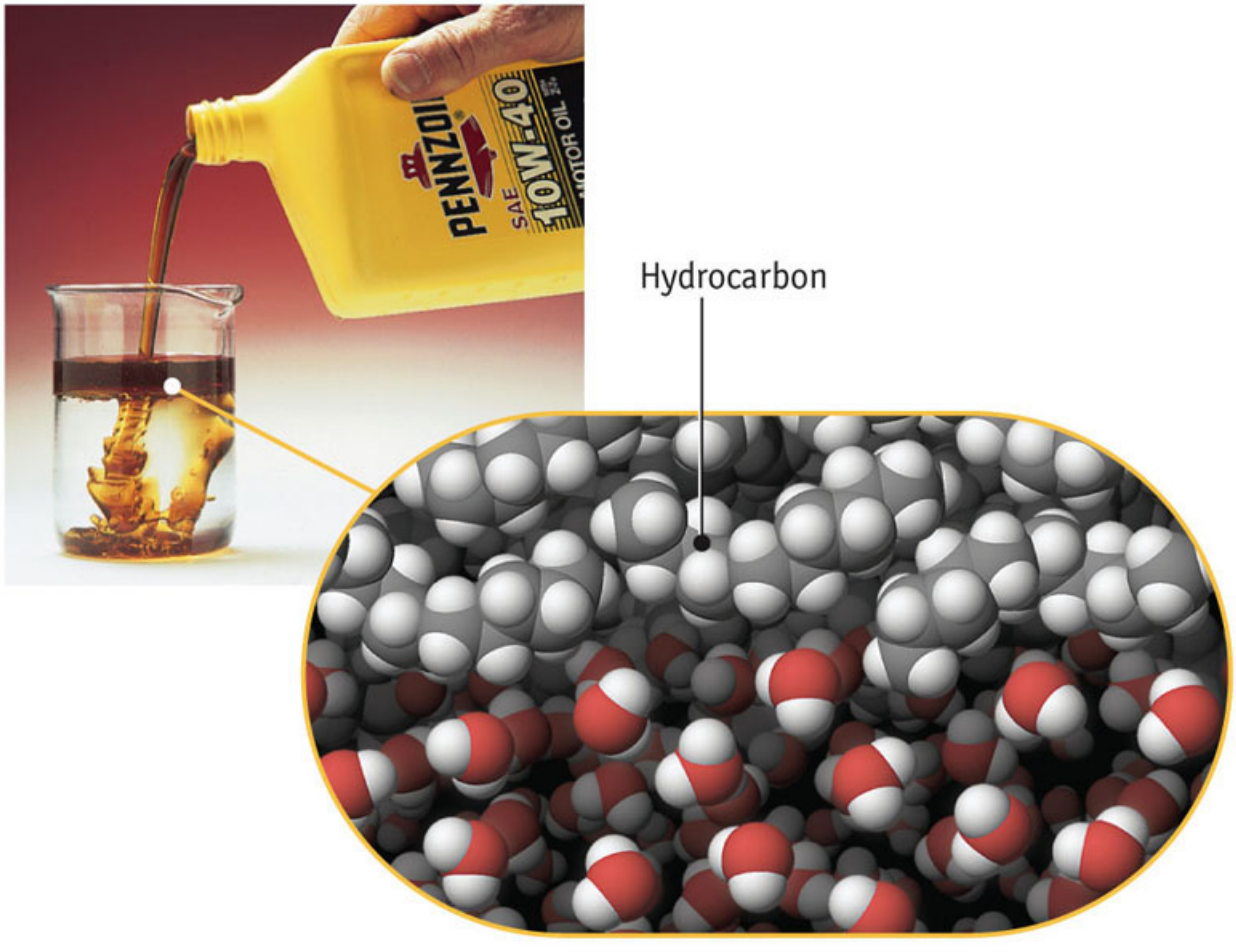
EG-EG interactions

W-EG interactions → causes them to be able to mix

water - polar

oil - non polar

no interactions btw oil and water



(b) Nonpolar motor oil (a hydrocarbon) dissolves in nonpolar solvents such as gasoline or CCl_4. It will not dissolve in a polar solvent such as water, however. Commercial spot removers use nonpolar solvents to dissolve oil and grease from fabrics.

Fig. 12-5, p. 560

2 non polar things will mix

b/c no one has strong interactions

"like dissolves like"

Dipole – Dipole Forces

Table 11.2 Molar Masses, Boiling Points, and $\Delta_{vap}H°$ of Nonpolar and Polar Substances

NONPOLAR				POLAR			
	M **(g/mol)**	**BP (°C)**	**$\Delta_{vap}H°$ (kJ/mol)**		***M*** **(g/mol)**	**BP (°C)**	**$\Delta_{vap}H°$ (kJ/mol)**
N_2	28	−196	5.57	CO	28	−192	6.04
SiH_4	32	−112	12.10	PH_3	34	−88	14.06
GeH_4	77	−90	14.06	AsH_3	78	−62	16.69
Br_2	160	59	29.96	ICl	162	97	—

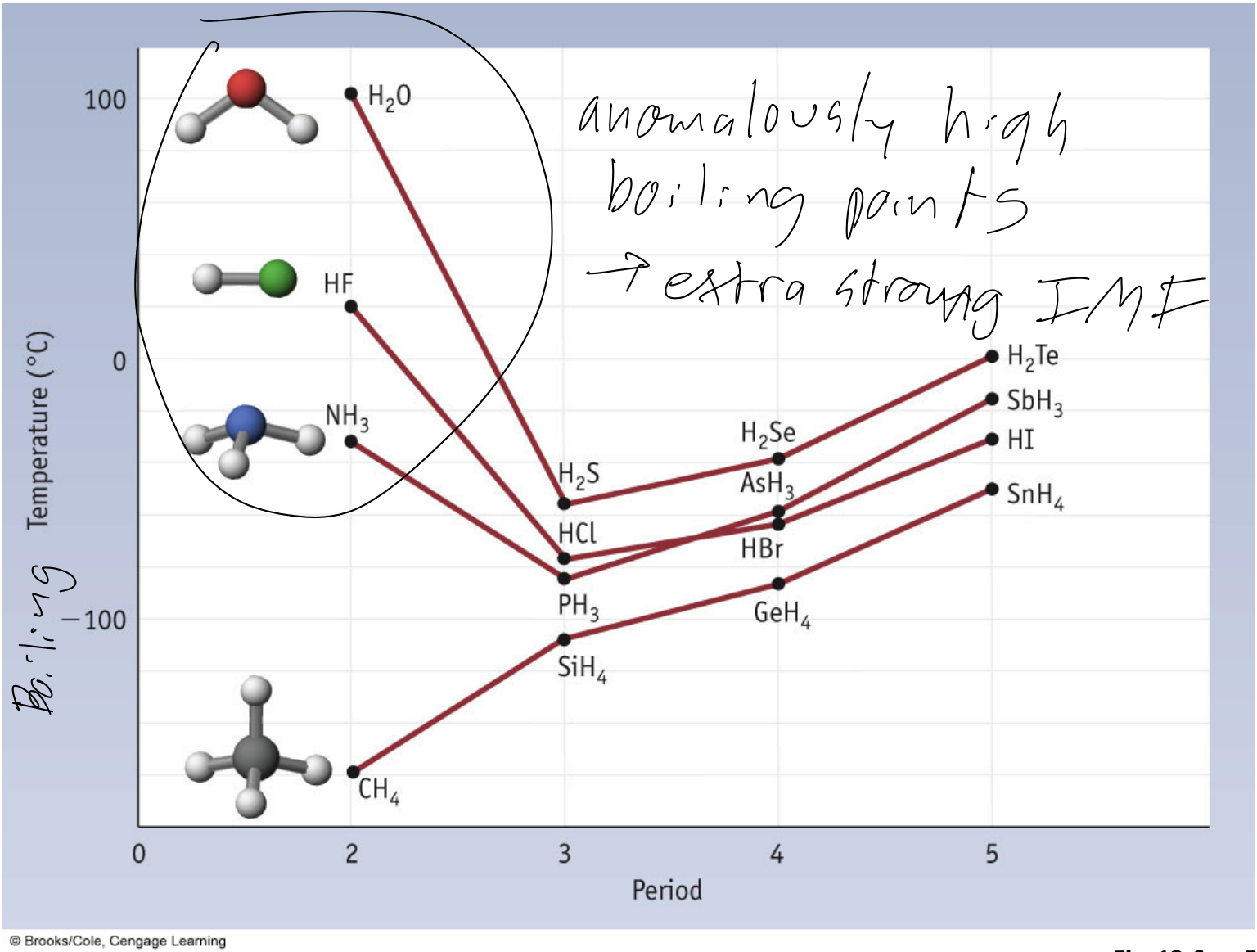
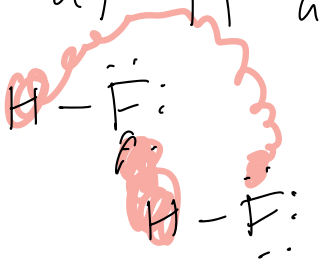


Fig. 12-6, p. 561

Hydrogen bonding - special case of dipole-dipole - only for really polar bonds

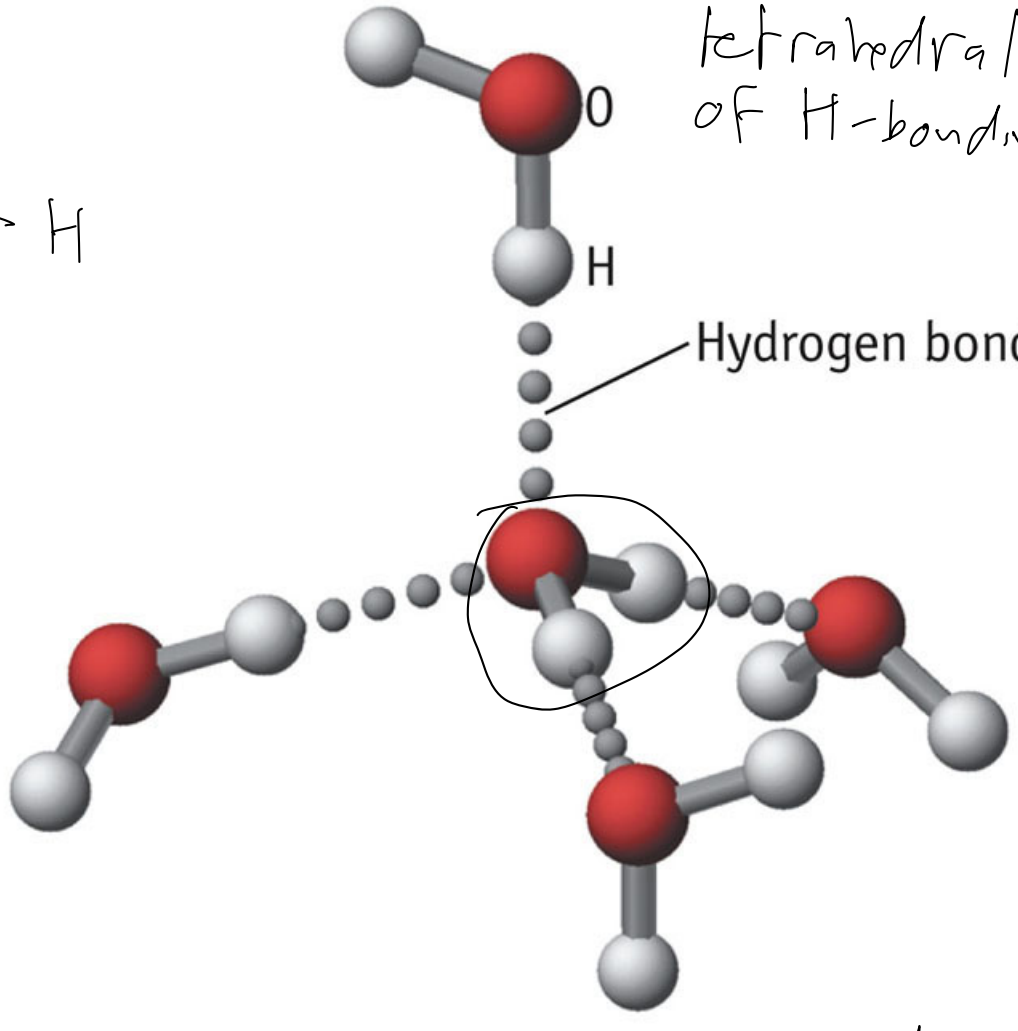
* Need H bonded to F, O, N (very polar bond)
* Need lone pair on F, O, N

Hydrogen bonding is interaction between that H and lone pair



Isn't a covalent bond

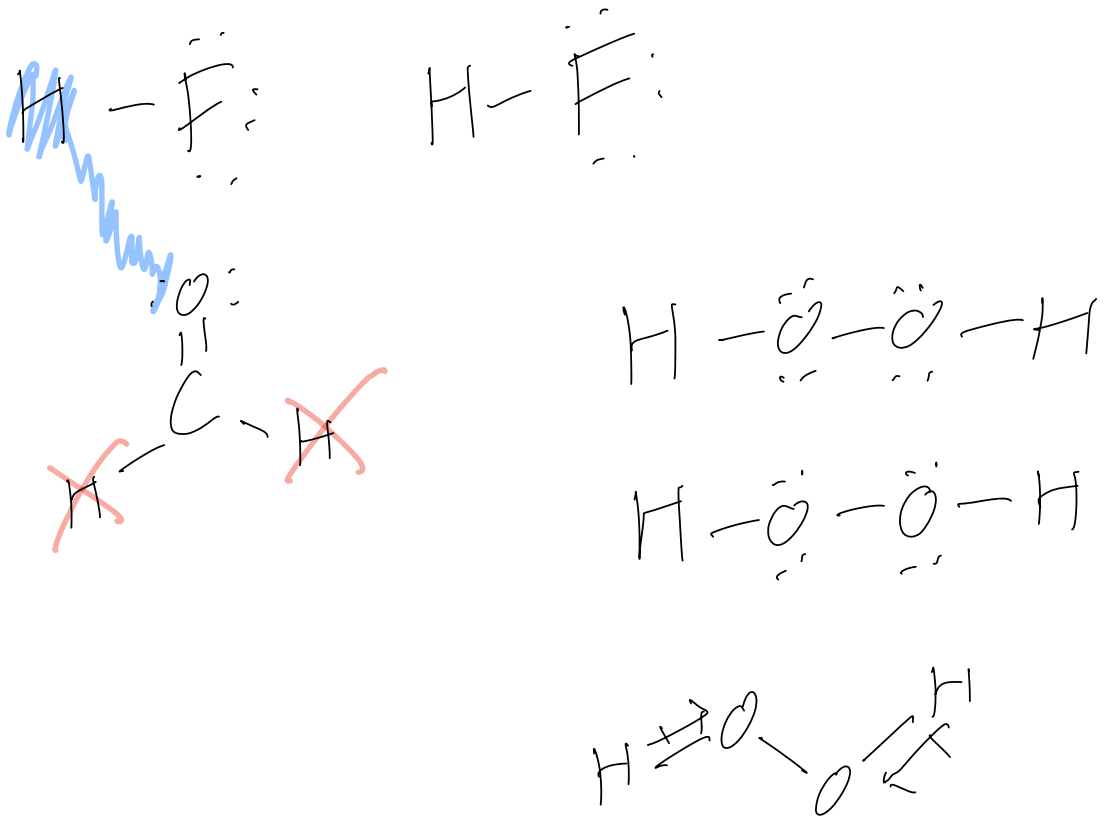
each H_2O has tetrahedral arrangement of H-bonding interactions



(a)

solid water keeps the tetrahedral H-bonding arrangement - lots of void space

Fig. 12-8, p. 564



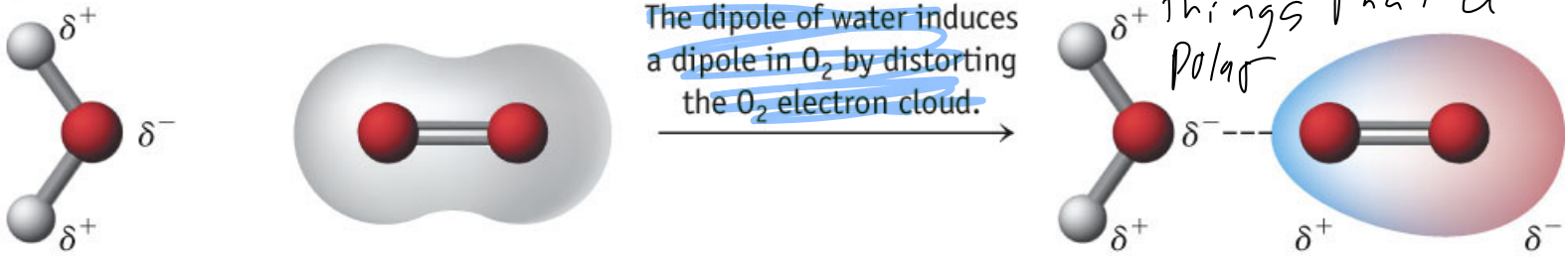
Polar/non polar

$:\ddot{O}=\ddot{O}:$ - non polar → but O_2 dissolves in water

$H-\ddot{O}-H$ - polar

H_2O induces O_2 to be a bit polar and then you have interactions btw 2 things that a polar

(a)



(b)

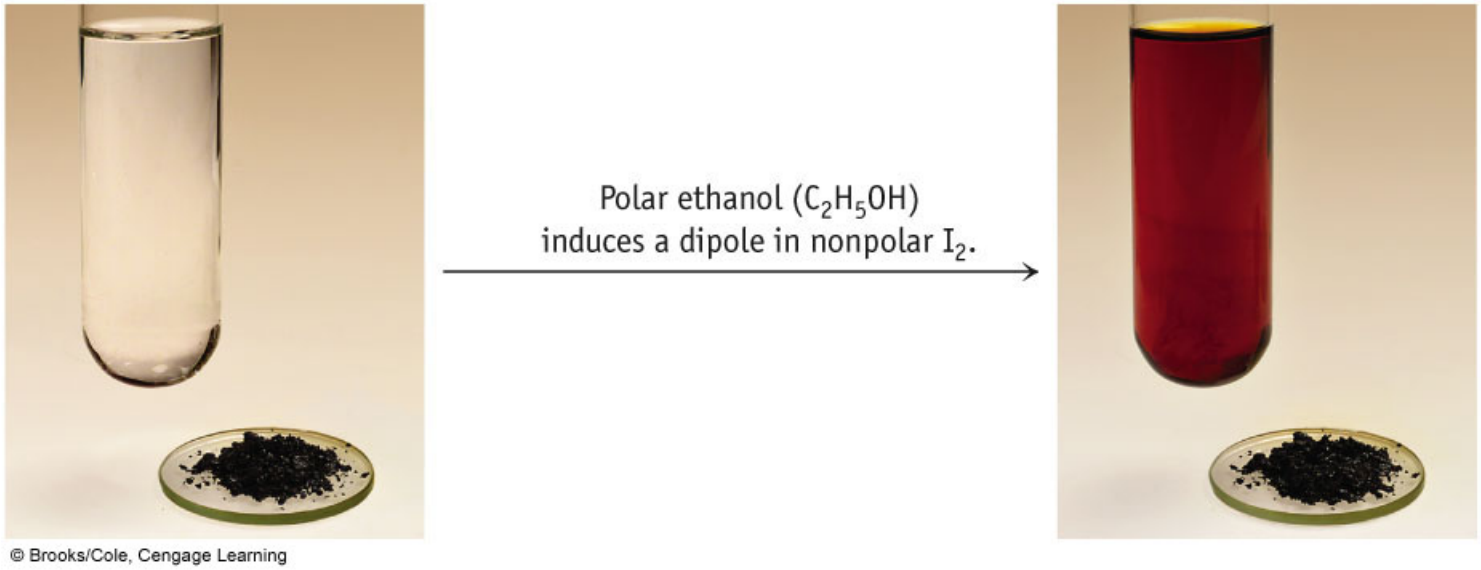


Fig. 12-10, p. 566

works best for polarizable molecule

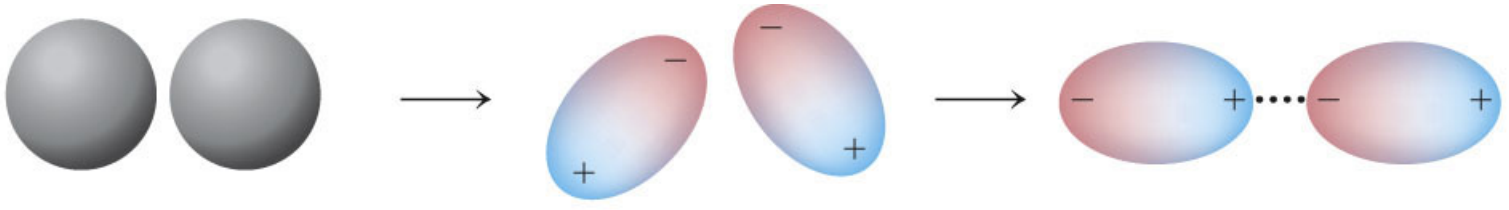
↓

where electron cloud is easily distortable

larger molecules w/ more e^- are more polarizable

non polar/non polar

non polar things are non polar on time averaged basis but electron distribution is always in flux so "non polar" molec is momentarily polar



Two nonpolar atoms or molecules (depicted as having an electron cloud that has a time-averaged spherical shape).

Momentary attractions and repulsions between nuclei and electrons in neighboring molecules lead to induced dipoles.

Correlation of the electron motions between the two atoms or molecules (which are now dipolar) leads to a lower energy and stabilizes the system.

Fig. 12-11, p. 567

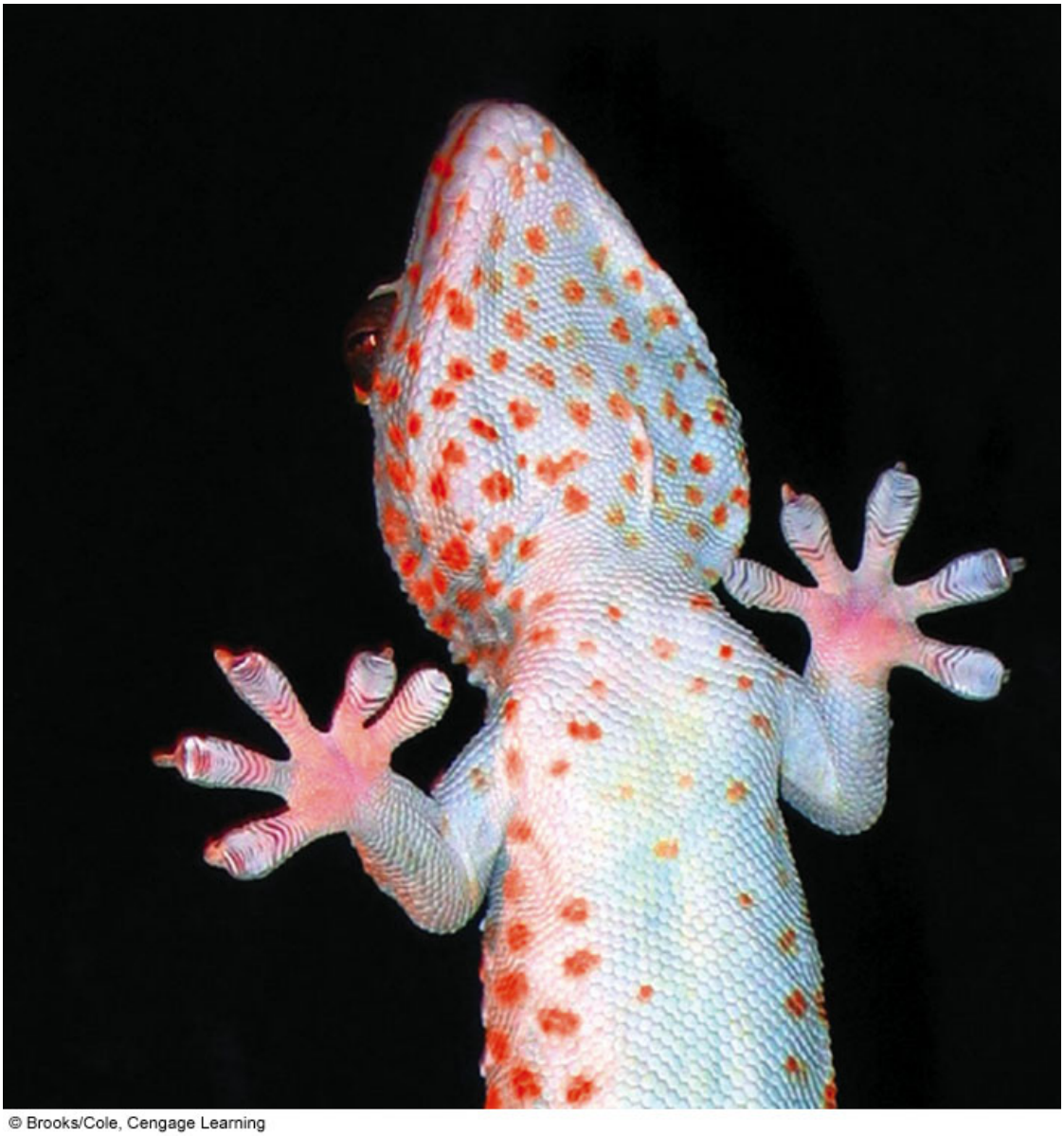


TABLE 12.6 Molar Enthalpies of Vaporization and Boiling Points for Common Substances*

Compound	Molar Mass (g/mol)	$\Delta_{vap}H°$ (kJ/mol)†	Boiling Point (°C) (Vapor pressure = 760 mm Hg)
Polar Compounds			
HF	20.0	25.2	19.7
HCl	36.5	16.2	−84.8
HBr	80.9	19.3	−66.4
HI	127.9	19.8	−35.6
NH_3	17.0	23.3	−33.3
H_2O	18.0	40.7	100.0
SO_2	64.1	24.9	−10.0
Nonpolar Compounds			
CH_4 (methane)	16.0	8.2	−161.5
C_2H_6 (ethane)	30.1	14.7	−88.6
C_3H_8 (propane)	44.1	19.0	−42.1
C_4H_{10} (butane)	58.1	22.4	−0.5
Monatomic Elements			
He	4.0	0.08	−268.9
Ne	20.2	1.7	−246.1
Ar	39.9	6.4	−185.9
Xe	131.3	12.6	−108.0
Diatomic Elements			
H_2	2.0	0.90	−252.9
N_2	28.0	5.6	−195.8
O_2	32.0	6.8	−183.0
F_2	38.0	6.6	−188.1
Cl_2	70.9	20.4	−34.0
Br_2	159.8	30.0	58.8

*Data taken from D. R. Lide: *Basic Laboratory and Industrial Chemicals*, Boca Raton, FL, CRC Press, 1993.

†$\Delta_{vap}H°$ is measured at the normal boiling point of the liquid.

Table 12-6, p. 572

Vapor pressure is partial pressure of gas above a liquid

Vapor pressure depends on strength of IMFs

Vapor pressure depends on temp

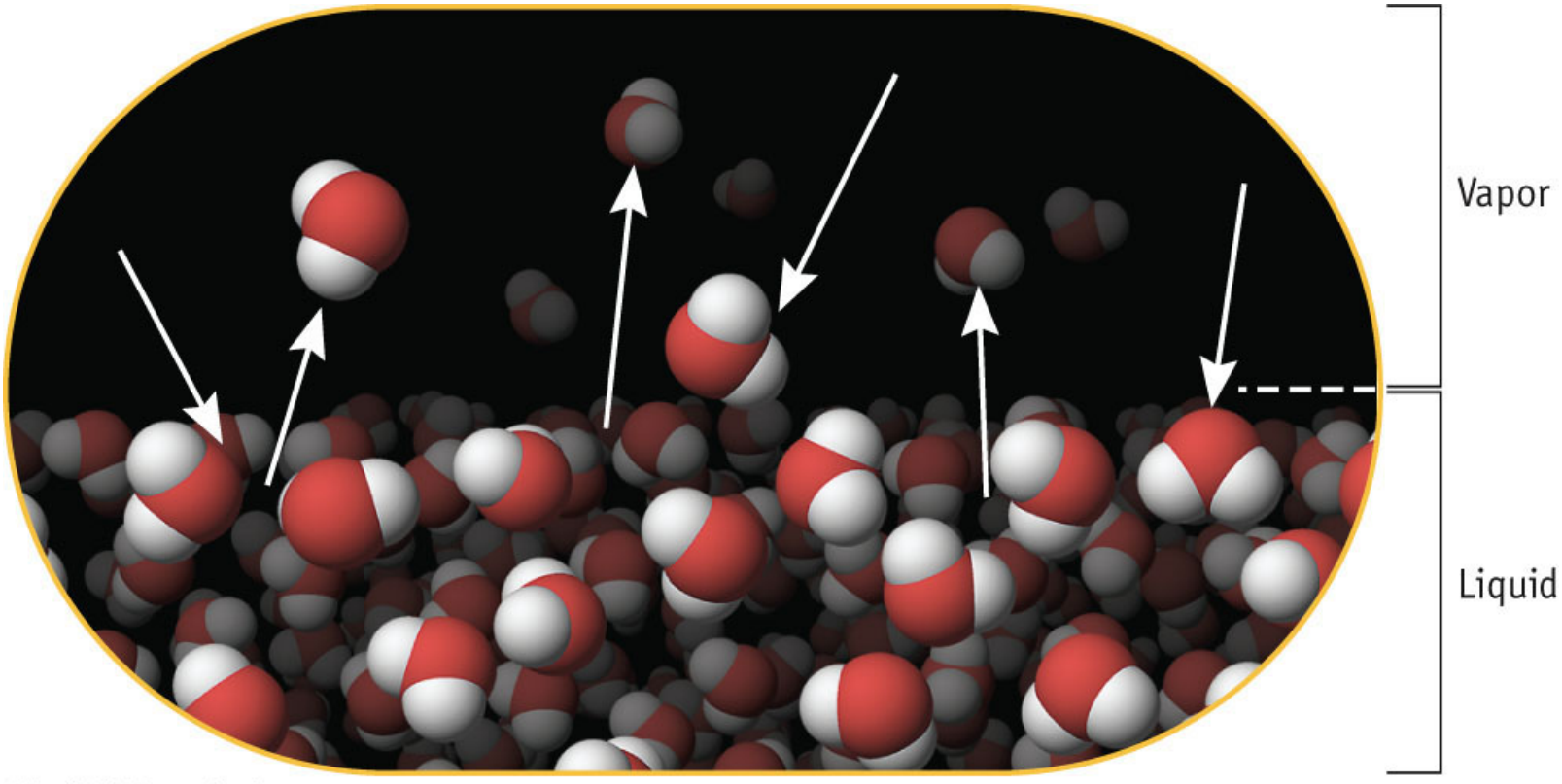


Fig. 12-14, p. 571

Boiling = when vapor pressure = atmospheric pressure

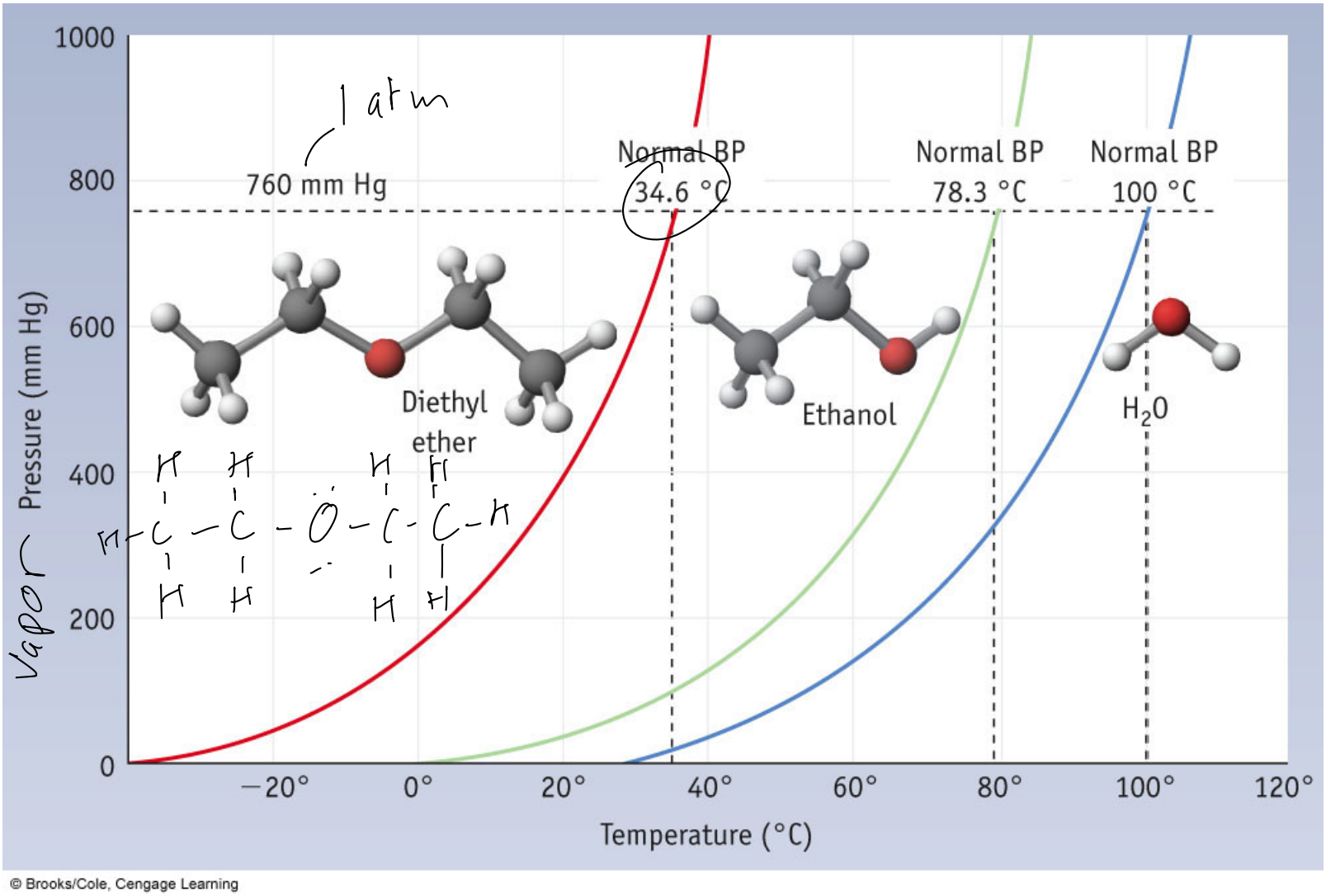


Fig. 12-17, p. 574

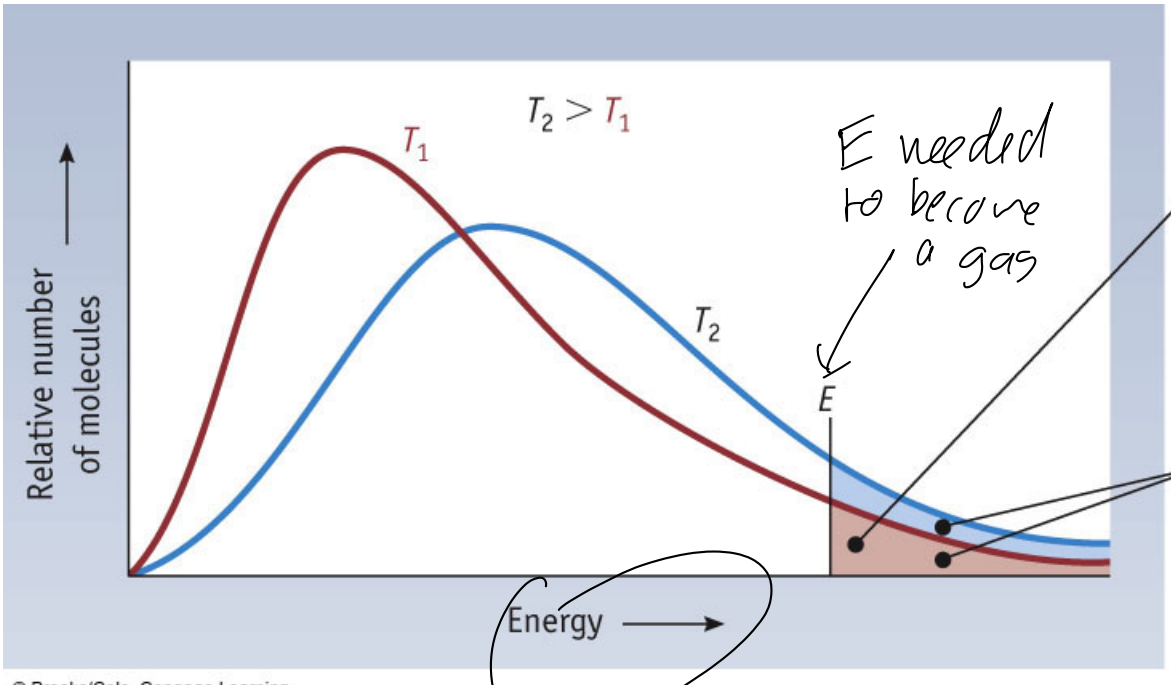
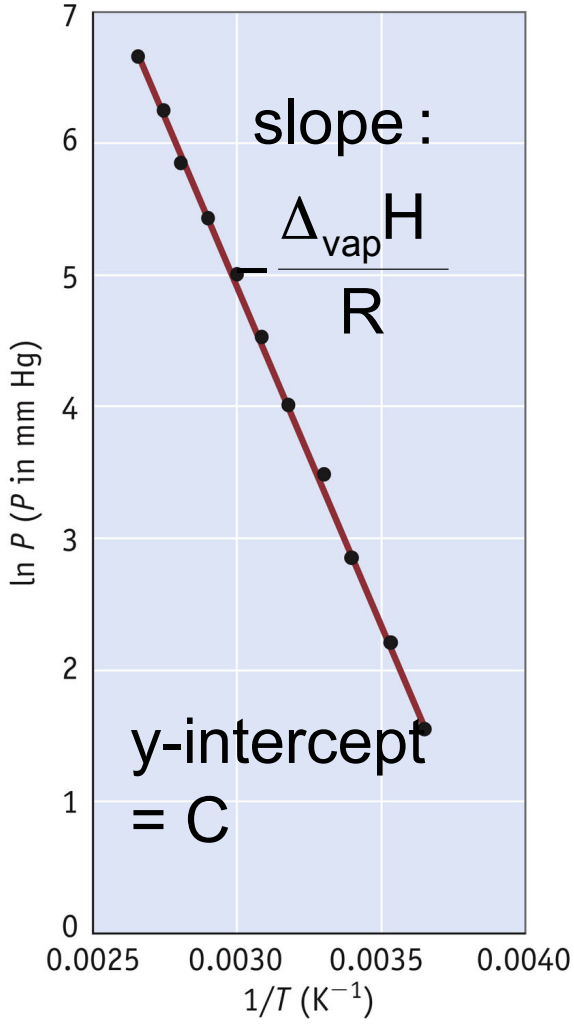


Fig. 12-13, p. 571

The Temperature Dependence of Vapor Pressure Goes As:

$$\ln P_{vap} = -\frac{\Delta_{vap}H^\circ}{RT} + C$$

A plot of $\ln P_{vap}$ vs. $\frac{1}{T}$ yields a slope of:



$\Delta_{vap}H^\circ$ is related to *T* and *P* by the *Clausius-Clapeyron* equation

$$\ln\left(\frac{P_2}{P_1}\right) = -\frac{\Delta H_{evap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Phase diagram shows P, T at which various phases exist

Critical Temperature and Pressure for CO_2