Intermolecular forces and interactions are all electrostatic – these are weak – but important

covalent bond ~ 400 kJ/mol

intermolecular interaction ~ 10–50 kJ/mol

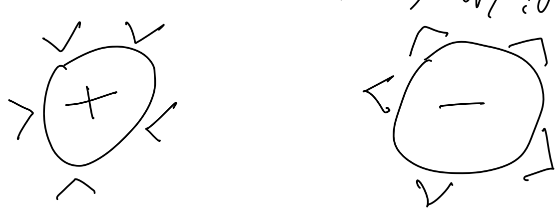
4 types of intermolecular interactions

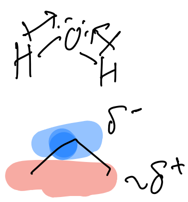
- strong
  - Ion / polar molecule
  - polar/polar
  - polar/nonpolar
  - nonpolar/nonpolar
- weak

Ion/dipole interaction – requires ion and polar ~~molec~~ molecule

– Charge of ion, polarity of molecule, distance ~~all~~ are what strength of interaction depends on

dissolved ionic compounds in water have polar H_2O interacting w/ ions



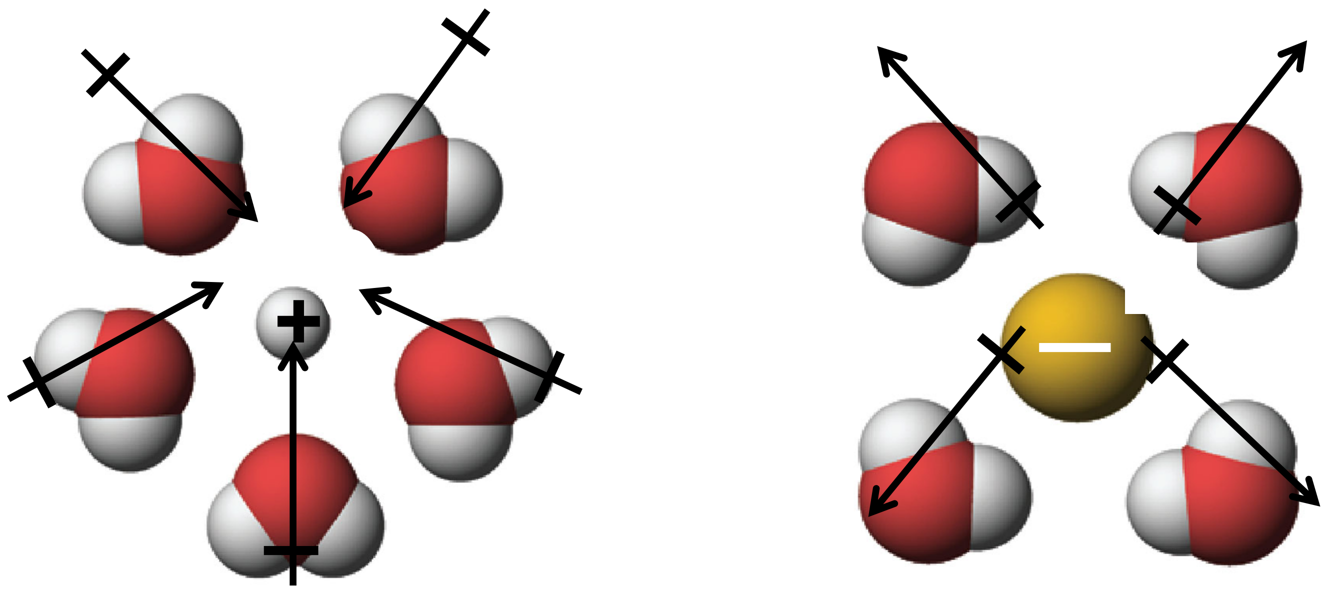


ΔH of solvation or hydration – for process of ~~in~~ interacting ion w/ H_2O molecules

$K^+_{(g)} \xrightarrow[\text{w/ water}]{\text{interact}} K^+_{(aq)}$ $\Delta H_{solv} = -321$ kJ/mol

* typically multiple H_2O molecules interact w/ one ion

Solvation of Ions

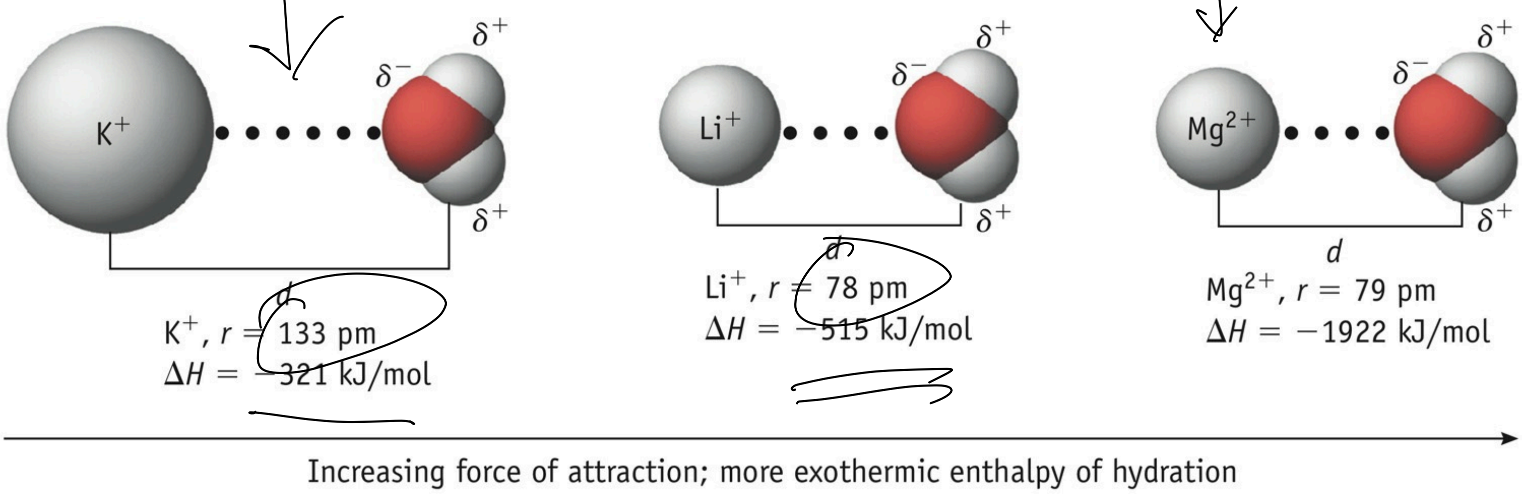


When a *cation* exists in solution, it is surrounded by the *negative* dipole ends of water molecules.

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

smaller dist b/c smaller ion

+2 ion interacts more strongly

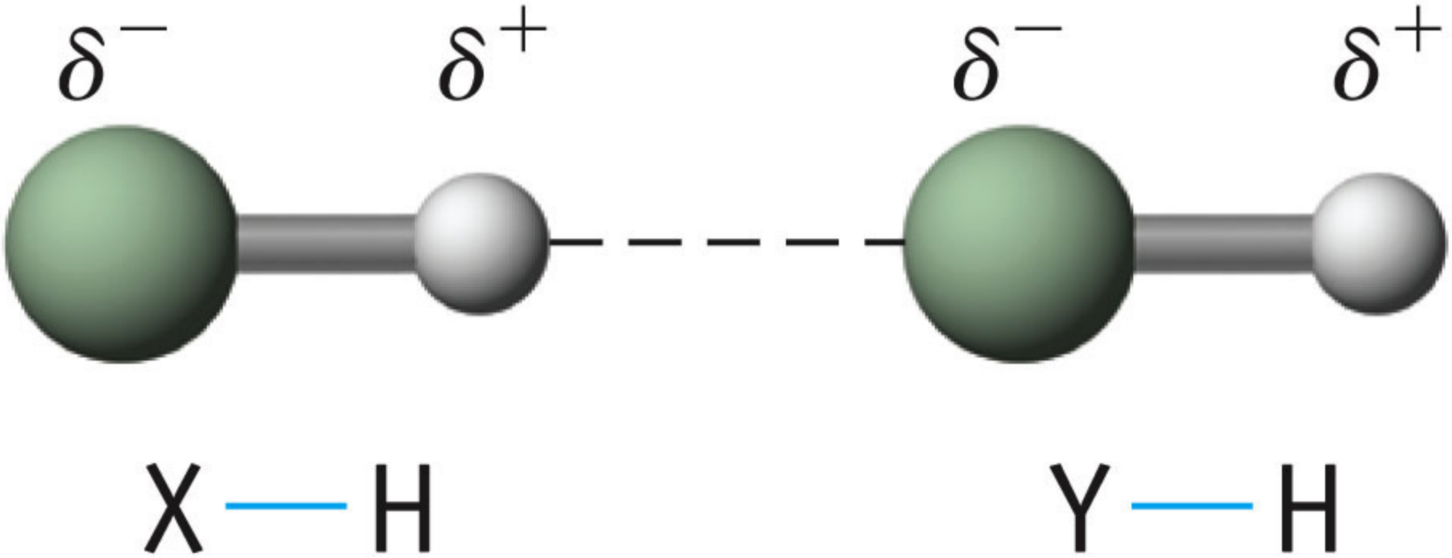


~~sol~~ solubility of ionic compounds
competition btw stability from interaction w/counterion vs stability from interaction with water

Dipole/Dipole interaction - between 2 polar molecules

- could be 2 of same polar molecule
- could be 2 different polar molecules

For a single substance w/ polar molecules strength of dipole/dipole interactions will be reflected in liq → gas phase change


δ⁻
δ⁺
δ⁻
δ⁺
X—H
Y—H

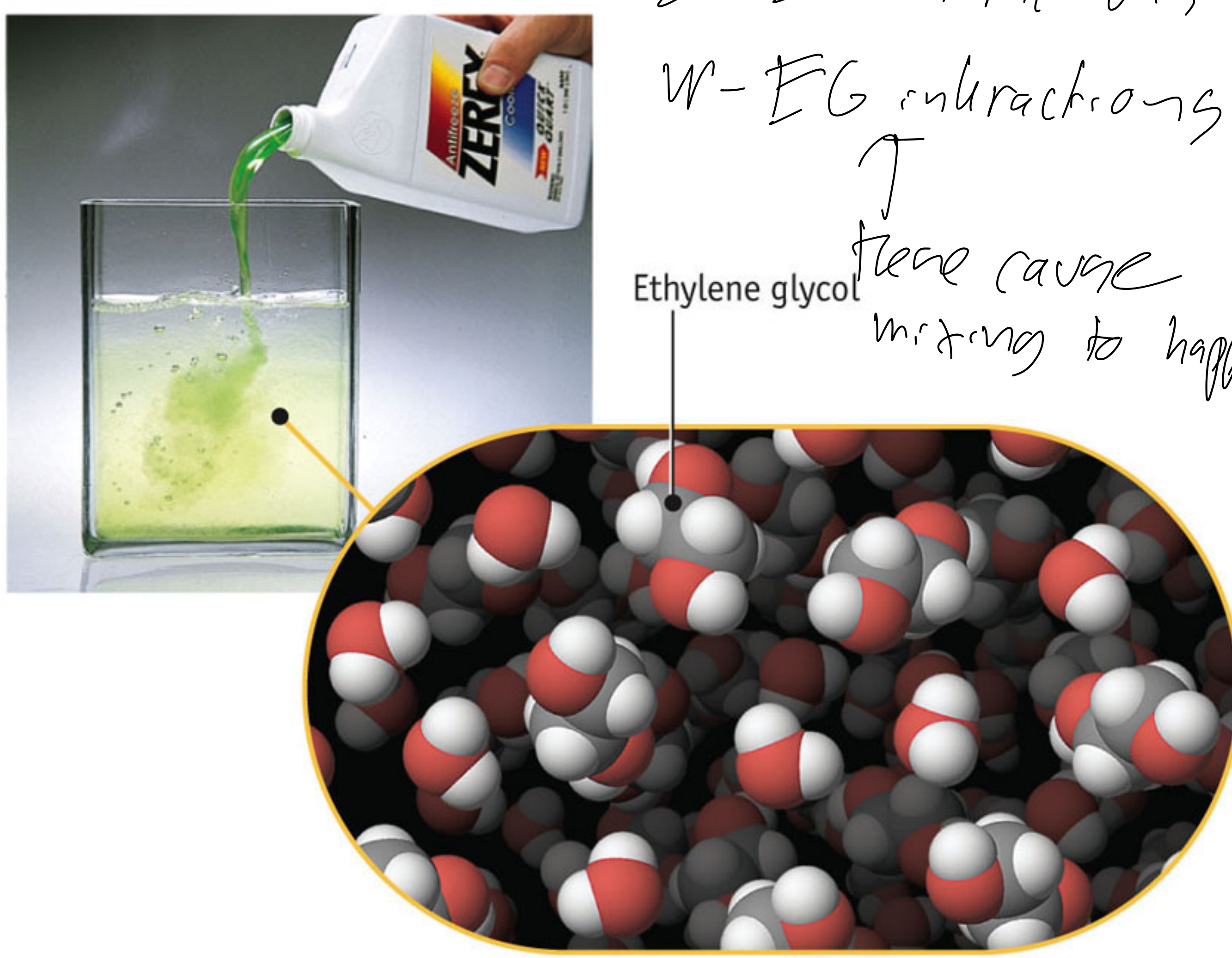
Miscibility of liquids is related to dipole-dipole interactions

W-W interactions

EG-EG interactions

W-EG interactions

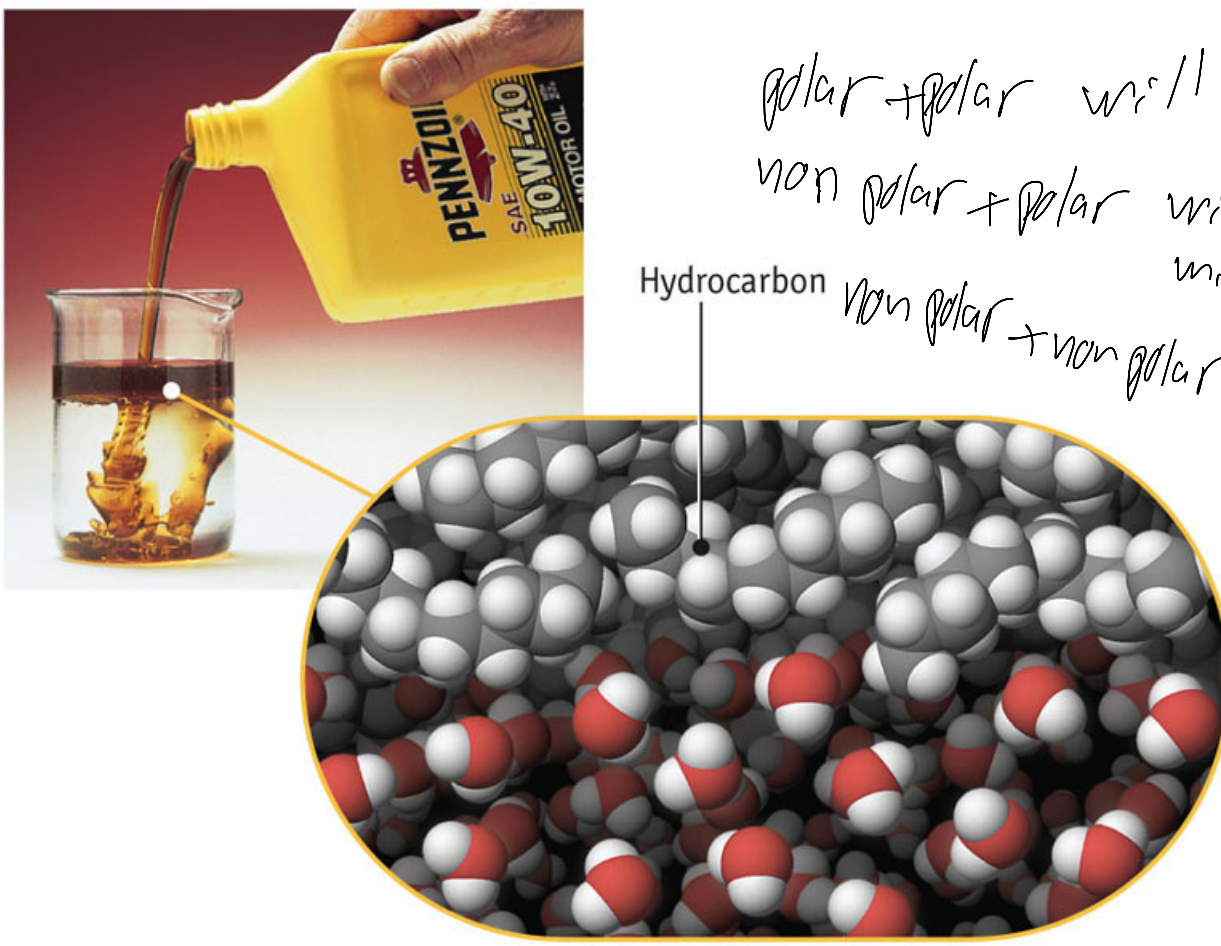
↑ these cause mixing to happen



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

Fig. 12-5, p. 560

Water and nonpolar oil
can't mix b/c water can't interact
with oil b/c oil isn't polar



polar + polar will mix
nonpolar + polar will not mix
nonpolar + nonpolar will mix
"like dissolves like"

(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

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	—

non polar – lower bp, lower ΔH_{evap}

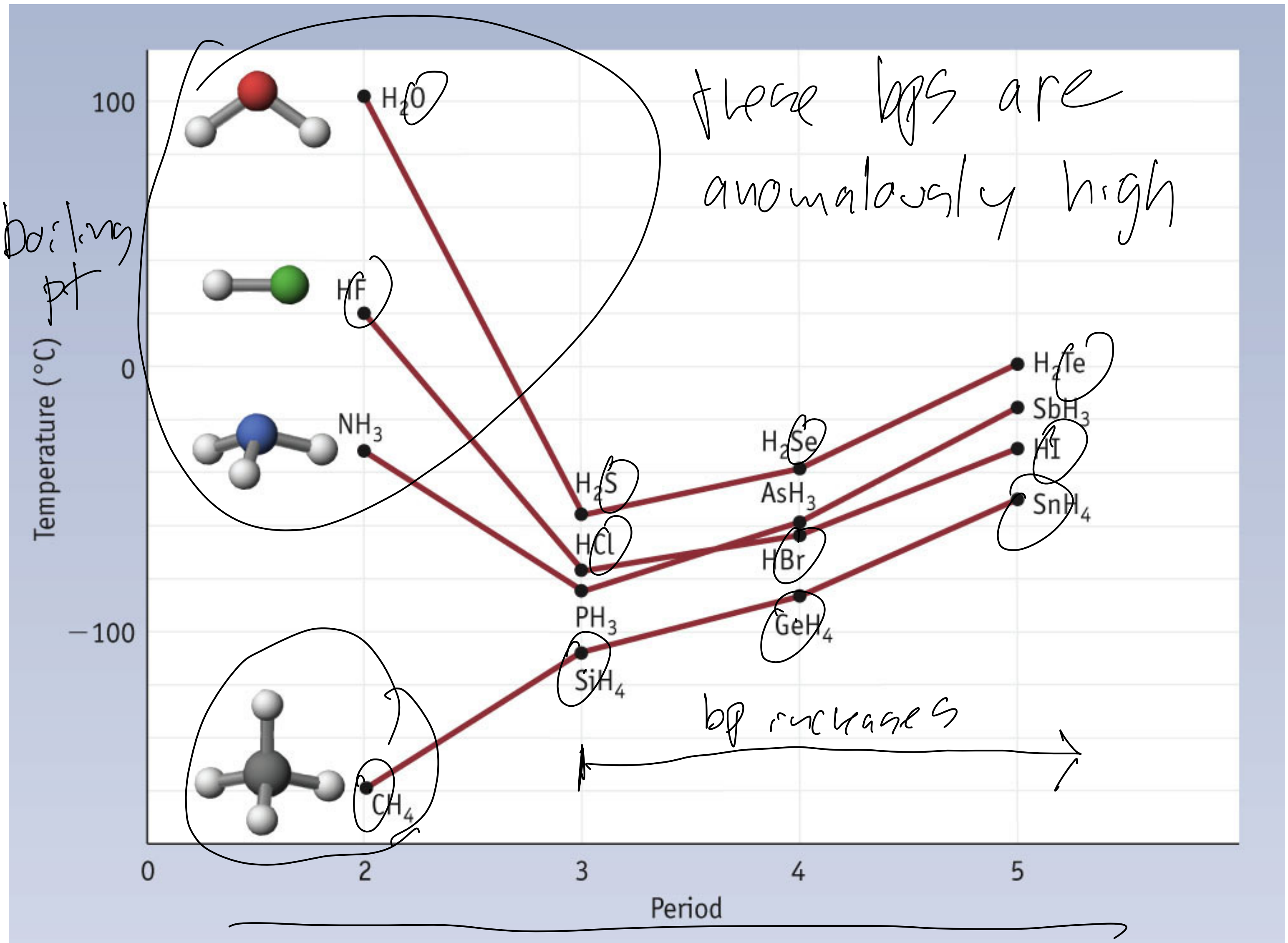
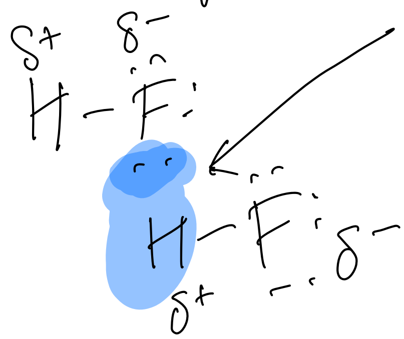


Fig. 12-6, p. 561

Hydrogen bonding is special case of dipole-dipole interaction

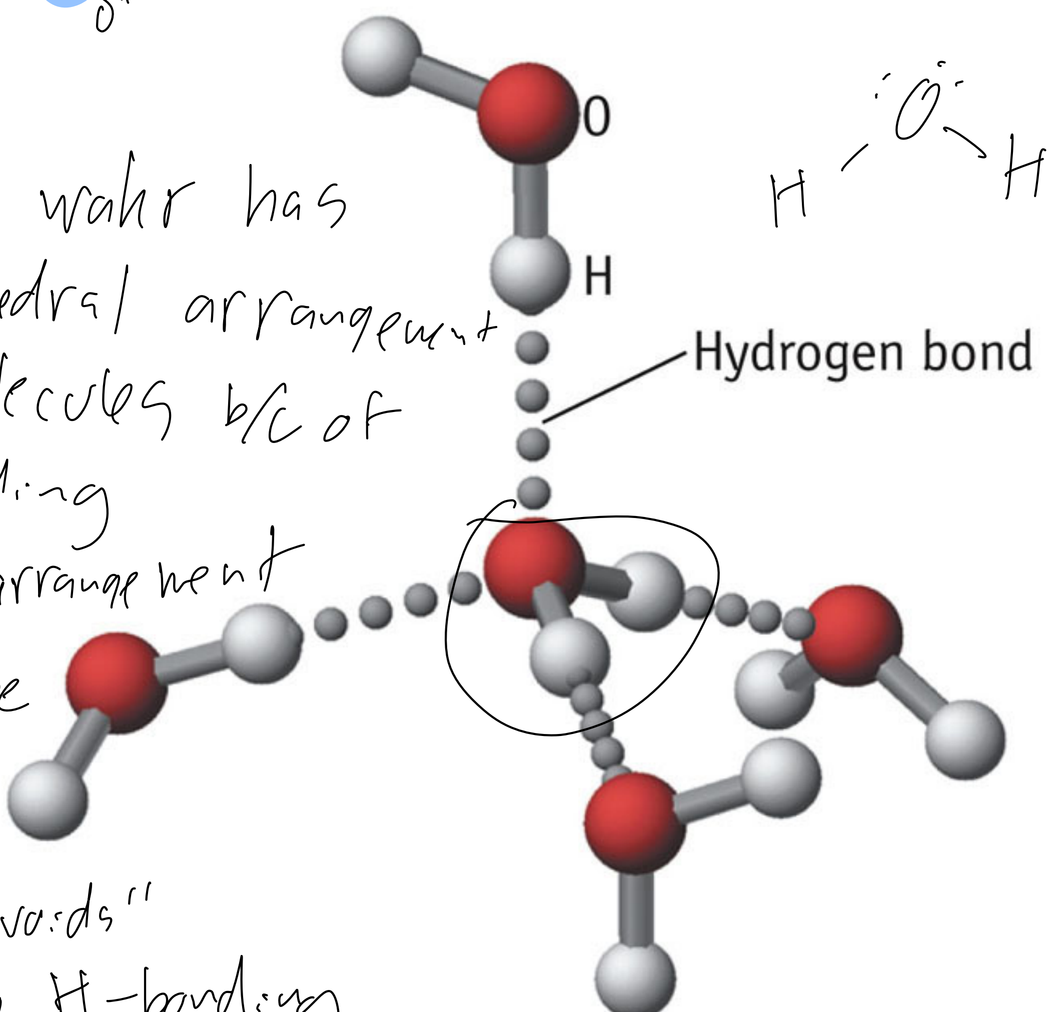
* Requires H connected to F, O, N (very polar bond)
* Requires lone pair on a F, O, N

Interaction btw H (connected to F, O, N) and lone pair (on F, O, N) is "hydrogen bonding"



hydrogen bonding interaction

* Not covalent bond

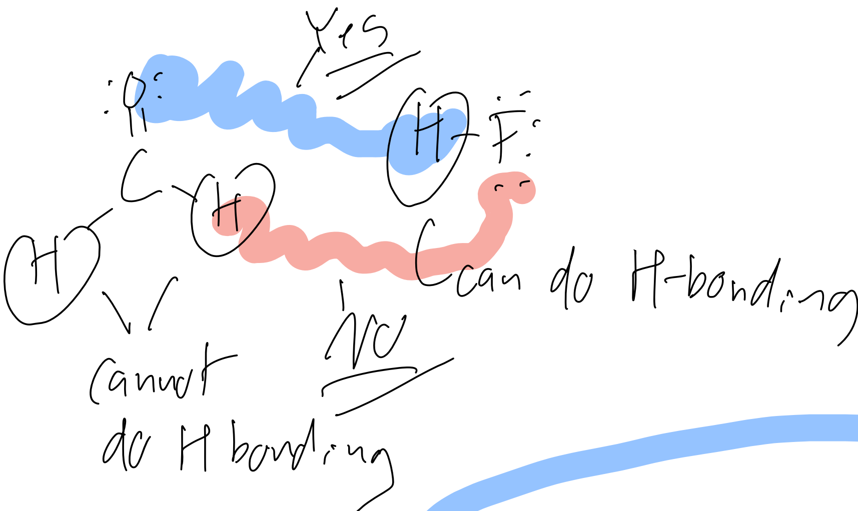


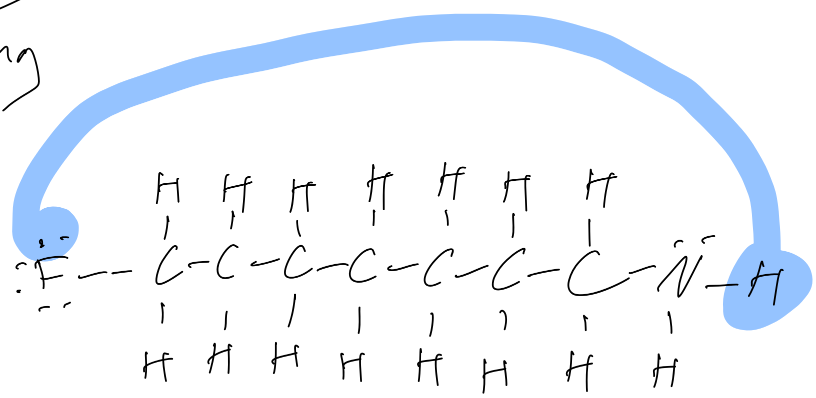
* solid water has tetrahedral arrangement of molecules b/c of H bonding

* solid arrangement less dense than liquid b/c of "voids" due to H-bonding

(a)

Fig. 12-8, p. 564


Yes
NO
cannot do H bonding
can do H-bonding



Polar/Nonpolar or Dipole/Induced dipole

$\ddot{O}=\ddot{O}$: - non polar molecule - but it dissolves in water

Presence of polar thing "induces" non polar thing to become a bit polar. Then you can have interactions

(a)

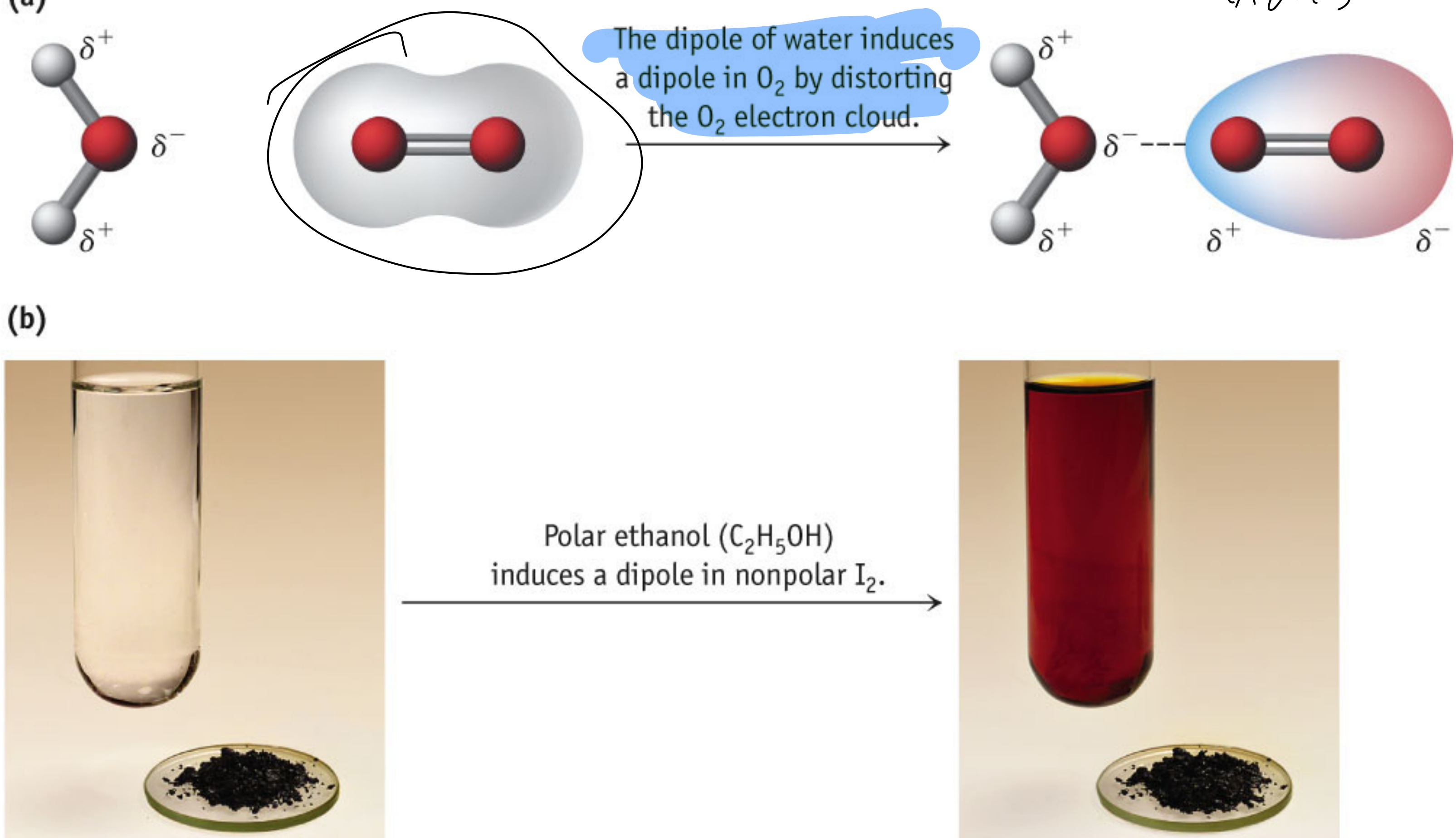


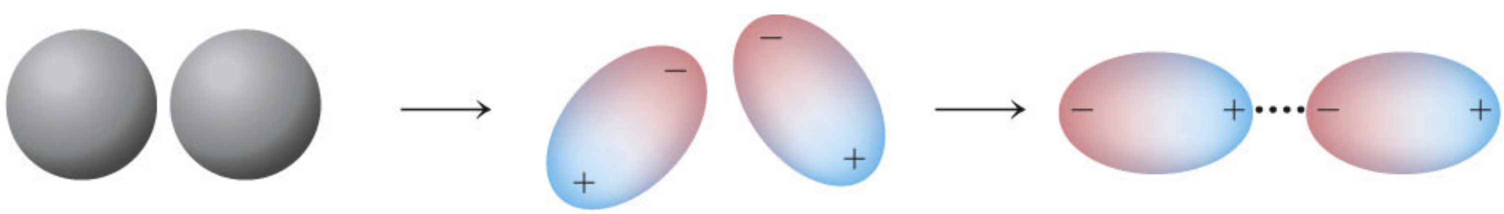
Fig. 12-10, p. 566

Polarizability - how likely/easy it is to induce a dipole in a "non-polar" molecule

- larger molecules with more electrons are "fluffier" and more easily polarized

Nonpolar/nonpolar Induced dipole/Induced dipole

electron density - even of nonpolar molecule - is dynamic - so at any instant the molecule might be slightly ~~nonpolar~~ polar → and then induce a slight dipole in another "nonpolar" molecule



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

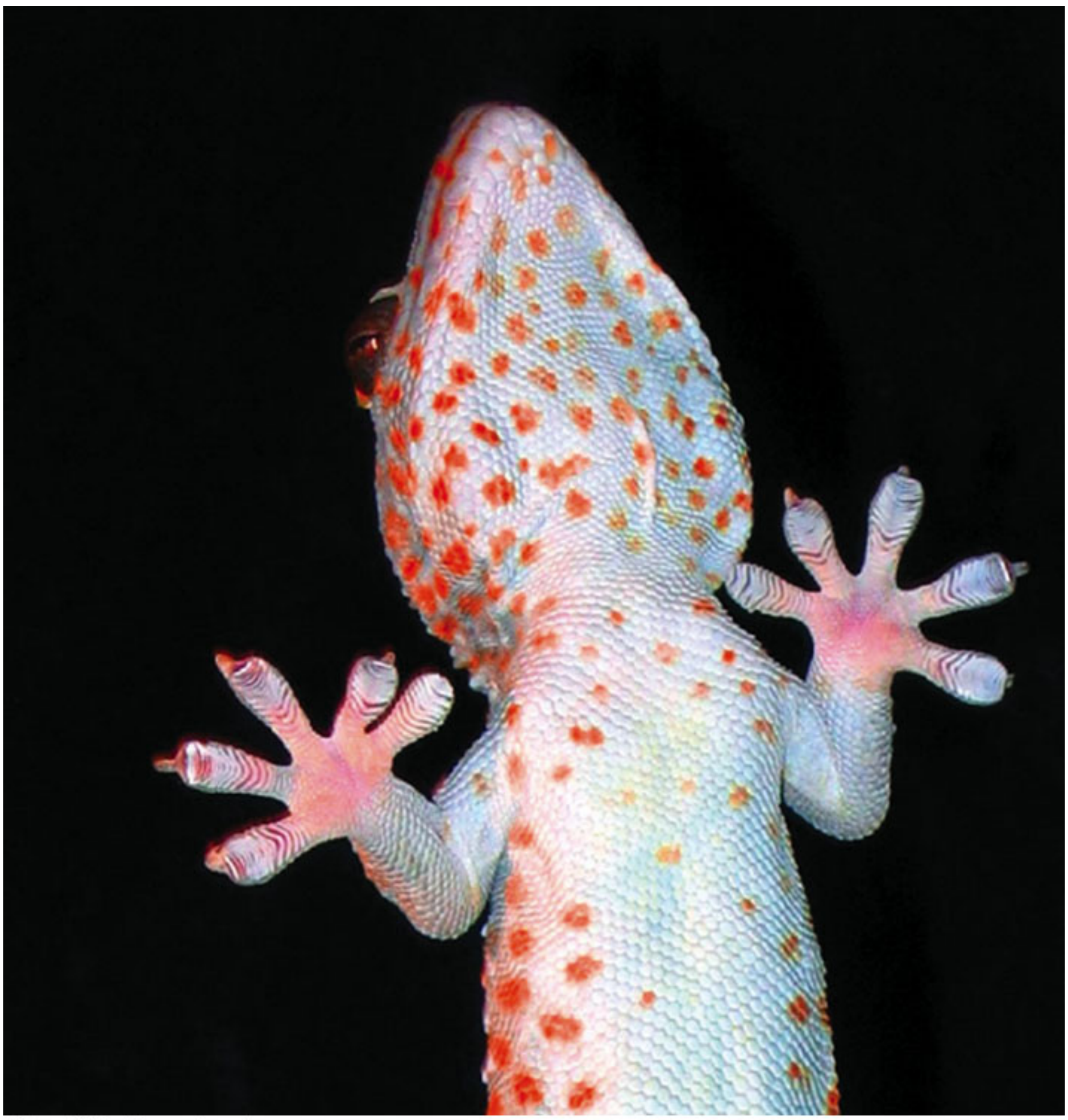


TABLE 12.6 **Molar Enthalpies of Vaporization and Boiling Points for Common Substances***

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.

ID/ID only

ID/ID depends on "size" → # of e- polarizability

Table 12-6, p. 572

Vapor pressure also tells us about intermolec. interactions

Vapor pressure = partial pressure of a gas above a liquid

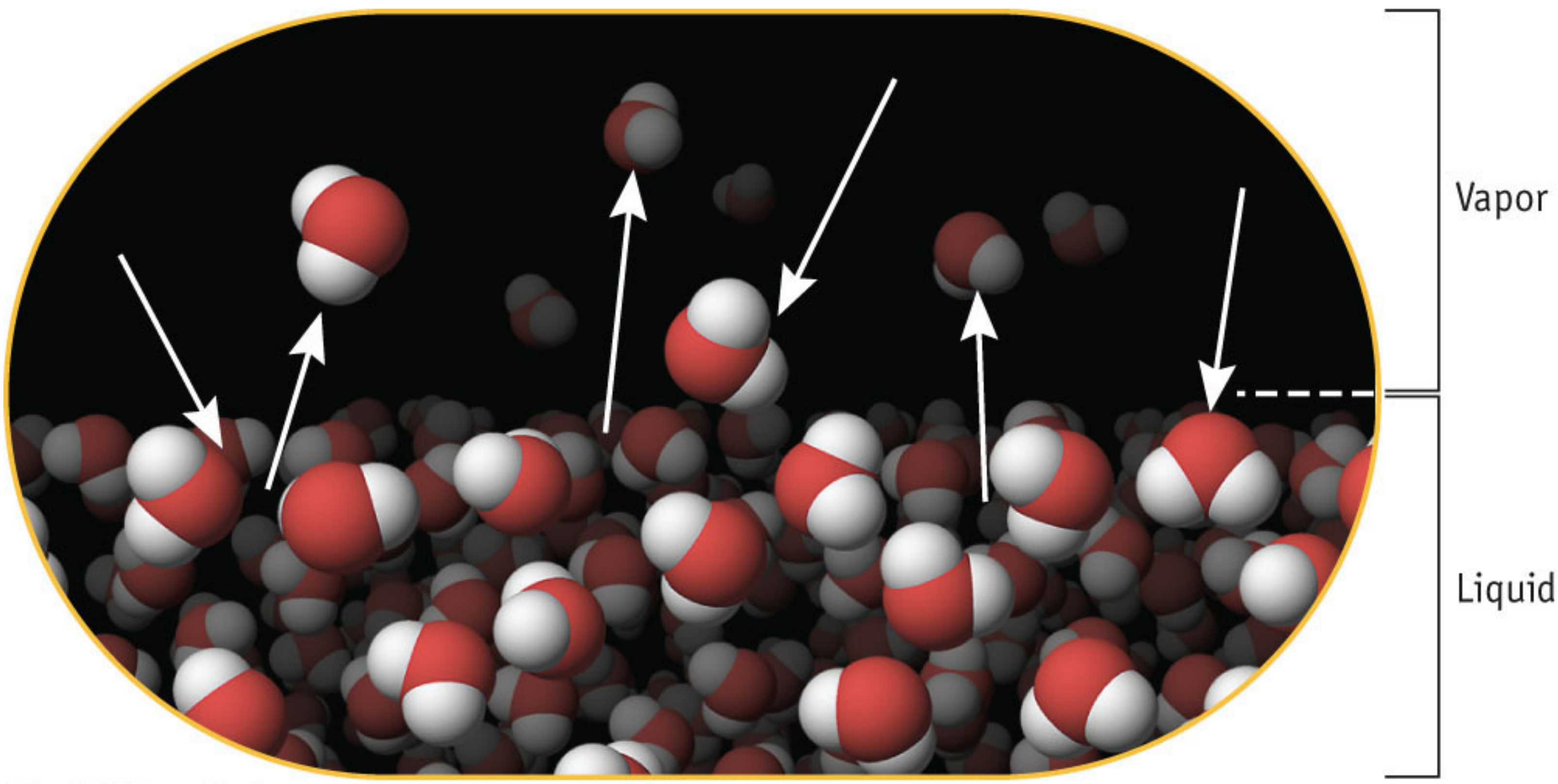


Fig. 12-14, p. 571

Vapor pressure depends on strength of interaction and on temp

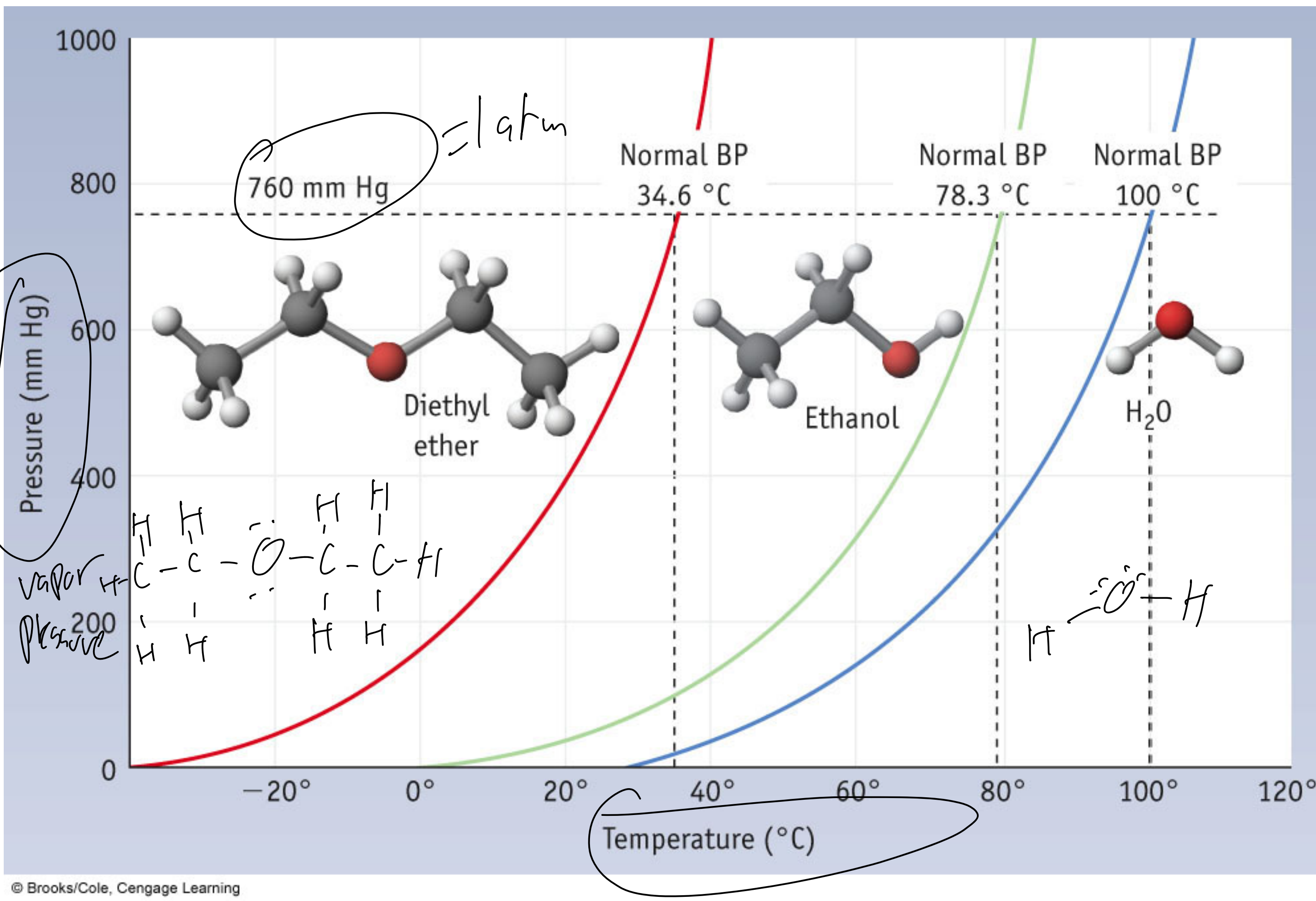


Fig. 12-17, p. 574

Boiling → when vapor pressure = atmospheric pressure

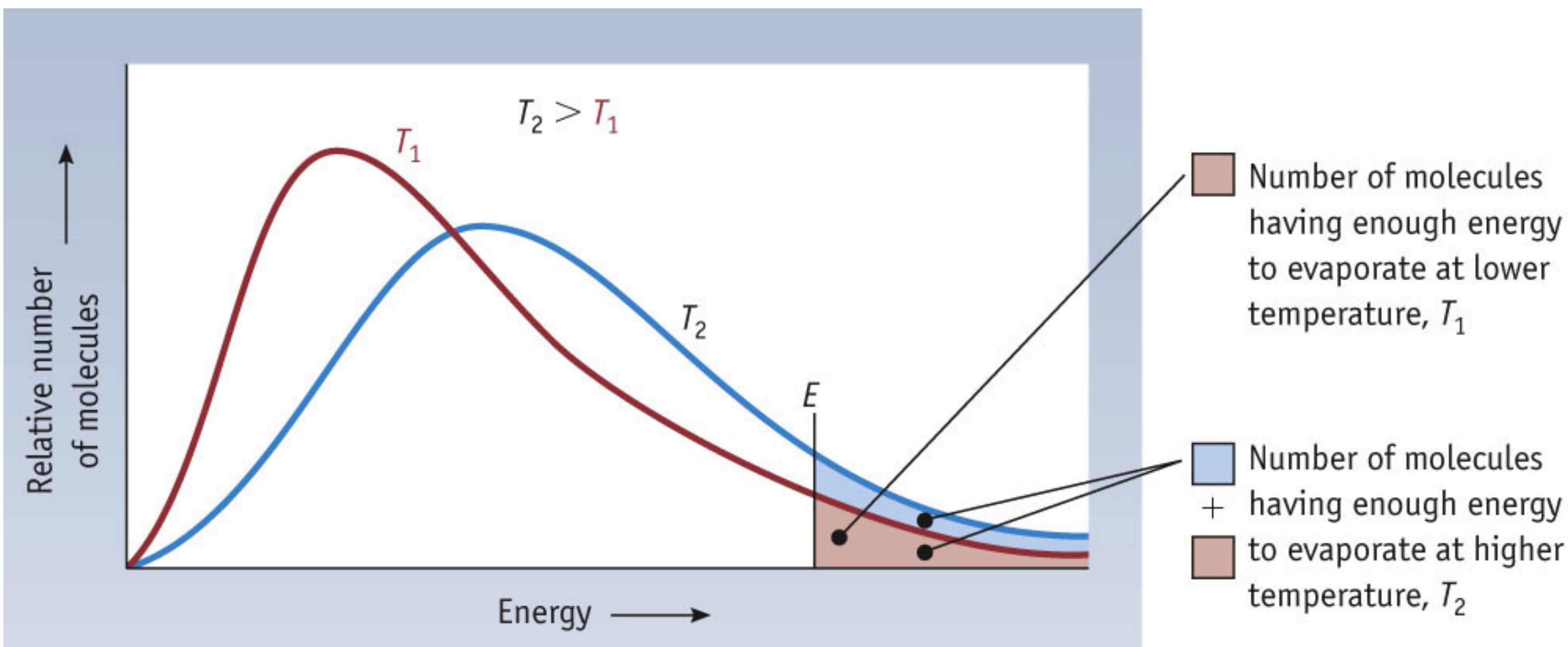
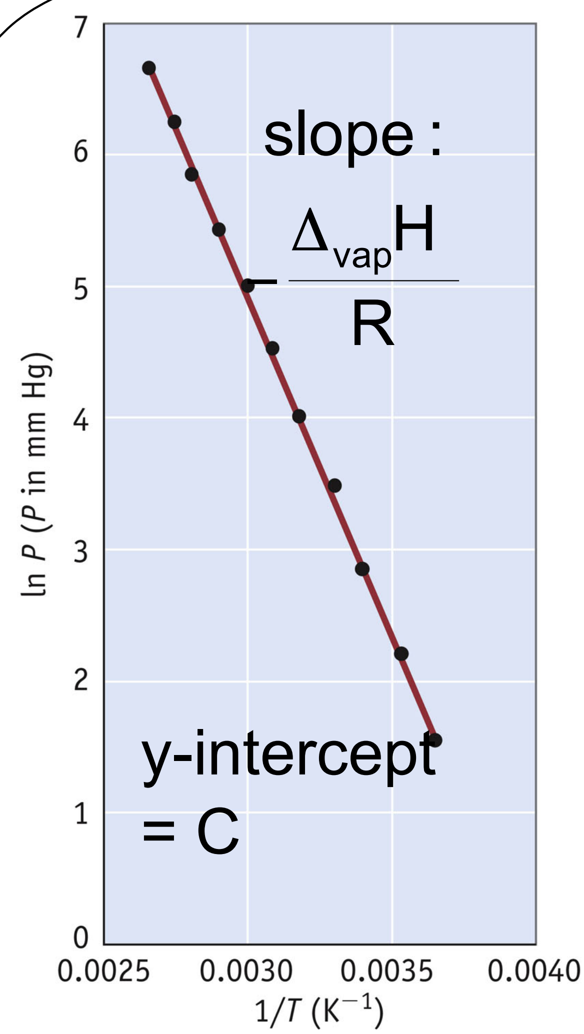


Fig. 12-13, p. 571

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

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

↓ vap pressure

Critical Temperature and Pressure for CO_2

The separate phases of CO_2 are seen through the window in a high-pressure vessel.

As the sample warms and the pressure increases, the meniscus becomes less distinct.

Once the critical T and P are reached, distinct liquid and vapor phases are no longer in evidence. This homogeneous phase is "supercritical CO_2."