Intermolecular Interactions/Forces (IMFs)

IMFs are electrostatic → hence will depend on charge and distance

IMFs are not covalent bonds

typical covalent bond ~ 400 kJ/mol

typical IMF 10-50 kJ/mol

IMFs are much weaker than covalent bonds - but still important
- impact properties and macroscopic behaviors

strong ↓ weak

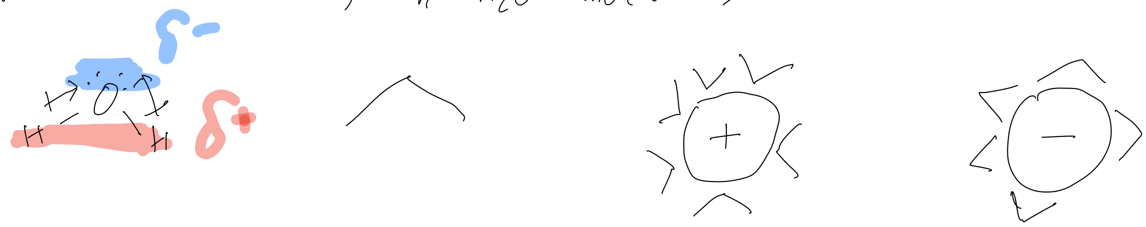
"ion-dipole"
"dipole-dipole"
"dipole-induced dipole"
"induced dipole-induced dipole"

"dipole" = polar molecule

Ion-dipole → interaction btw ion and polar molecule

consider
charge of ion
polarity of molecule
distance

dissolved ion interacting w/ H_2O molecules



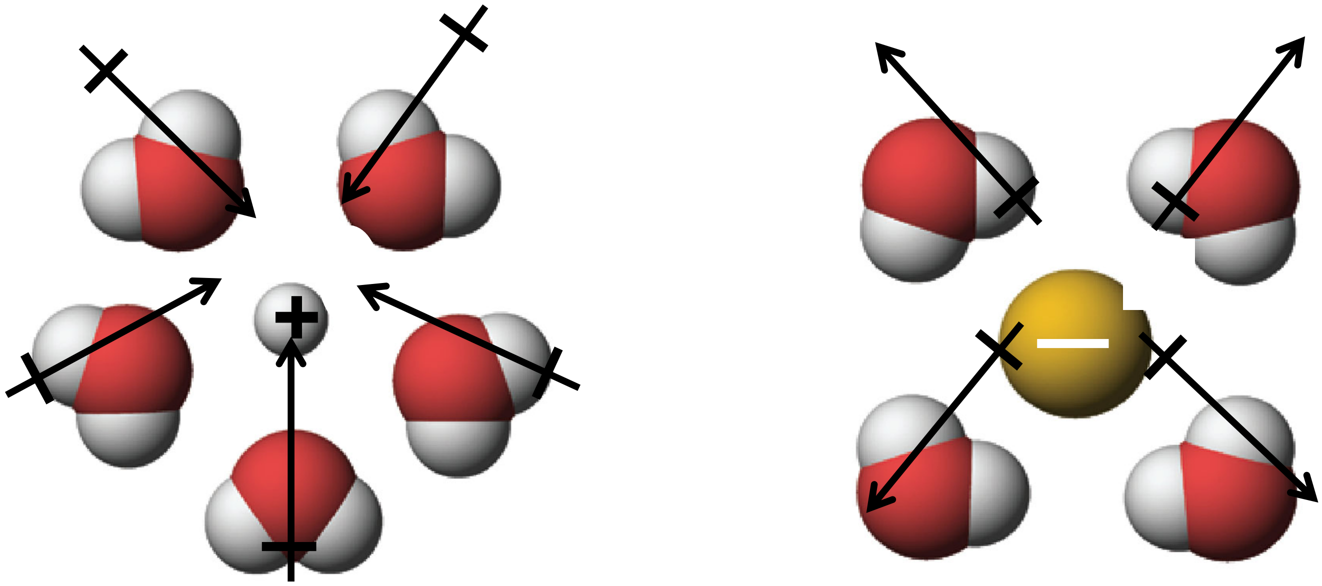
ΔH of solvation (hydration)

gaseous ion → dissolved ion

$K^+_{(g)} \rightarrow K^+_{(aq)}$ $\Delta H_{solv} = -321 \frac{kJ}{mol}$ — per mole of dissolved $K^+_{(aq)}$

each H_2O - ion interaction is less than $-321 \frac{kJ}{mol}$ b/c several H_2O molecules interact w/ each ion

Solvation of Ions



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

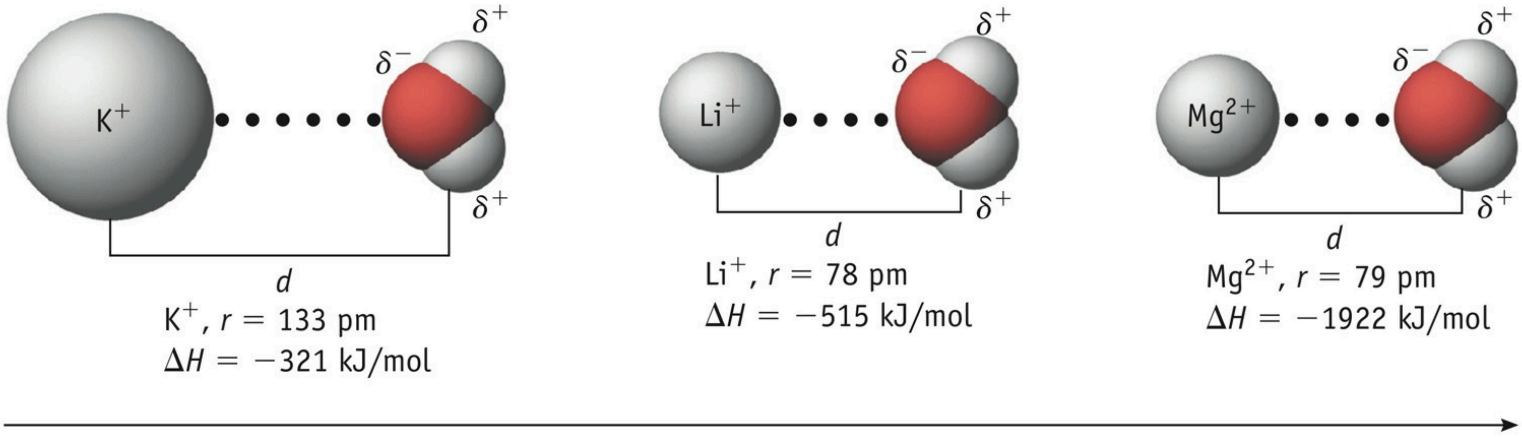
When as *anion* exists in solution, it is surrounded by the *positive* dipole ends of water molecules.

K^+ vs Li^+ - same charge, different distance (btw nucleus and H_2O)

smaller Li^+ → H_2O can get closer → stronger interaction

Li^+ vs Mg^{+2} - same size, diff charge

- water equally close to both nuclei
- more highly charged Mg^{2+} → stronger interaction



K$^+$, $r = 133$ pm
$\Delta H = -321$ kJ/mol

Li$^+$, $r = 78$ pm
$\Delta H = -515$ kJ/mol

Mg^{2+}, $r = 79$ pm
$\Delta H = -1922$ kJ/mol

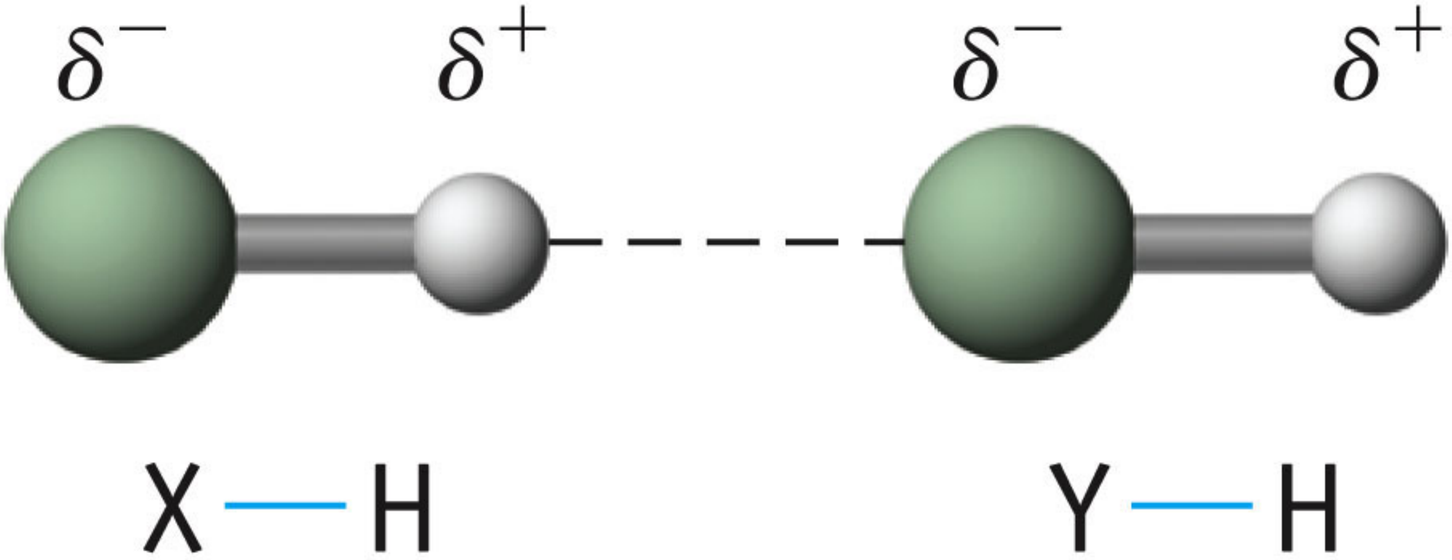
Increasing force of attraction; more exothermic enthalpy of hydration

solubility of ionic compounds is due to competition between ΔH_{solv} and anion/cation interaction in solid

Dipole/Dipole is interaction between 2 polar molecules
- could be 2 of same type or 2 of different type
- more polar molecules have stronger dipole/dipole interactions

- If we only have 1 type of molecule, dipole-dipole interactions are reflected in liquid → gas phase change

to go from liq → gas we need to overcome IMFs holding liquid molecules close



© Brooks/Cole, Cengage Learning

Dipole – Dipole Forces

no dipole-dipole

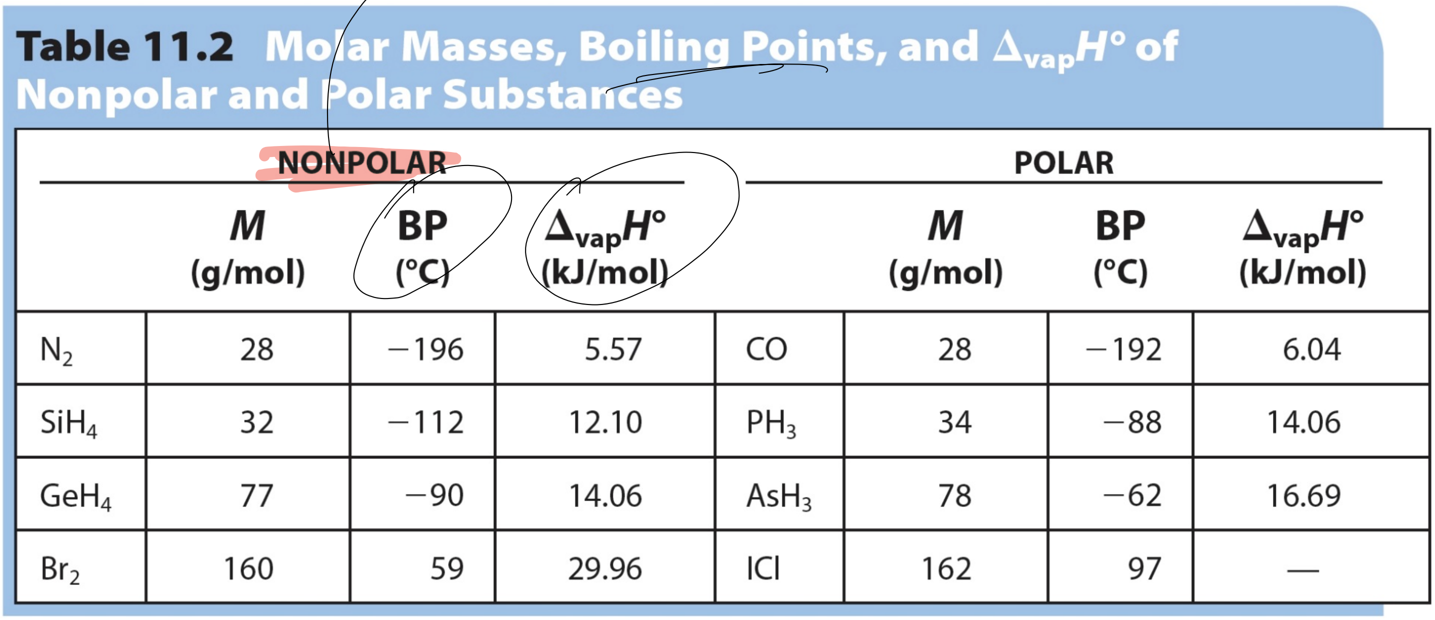


Table 11.2 Molar Masses, Boiling Points, and $\Delta_{vap}H°$ of Nonpolar and Polar Substances

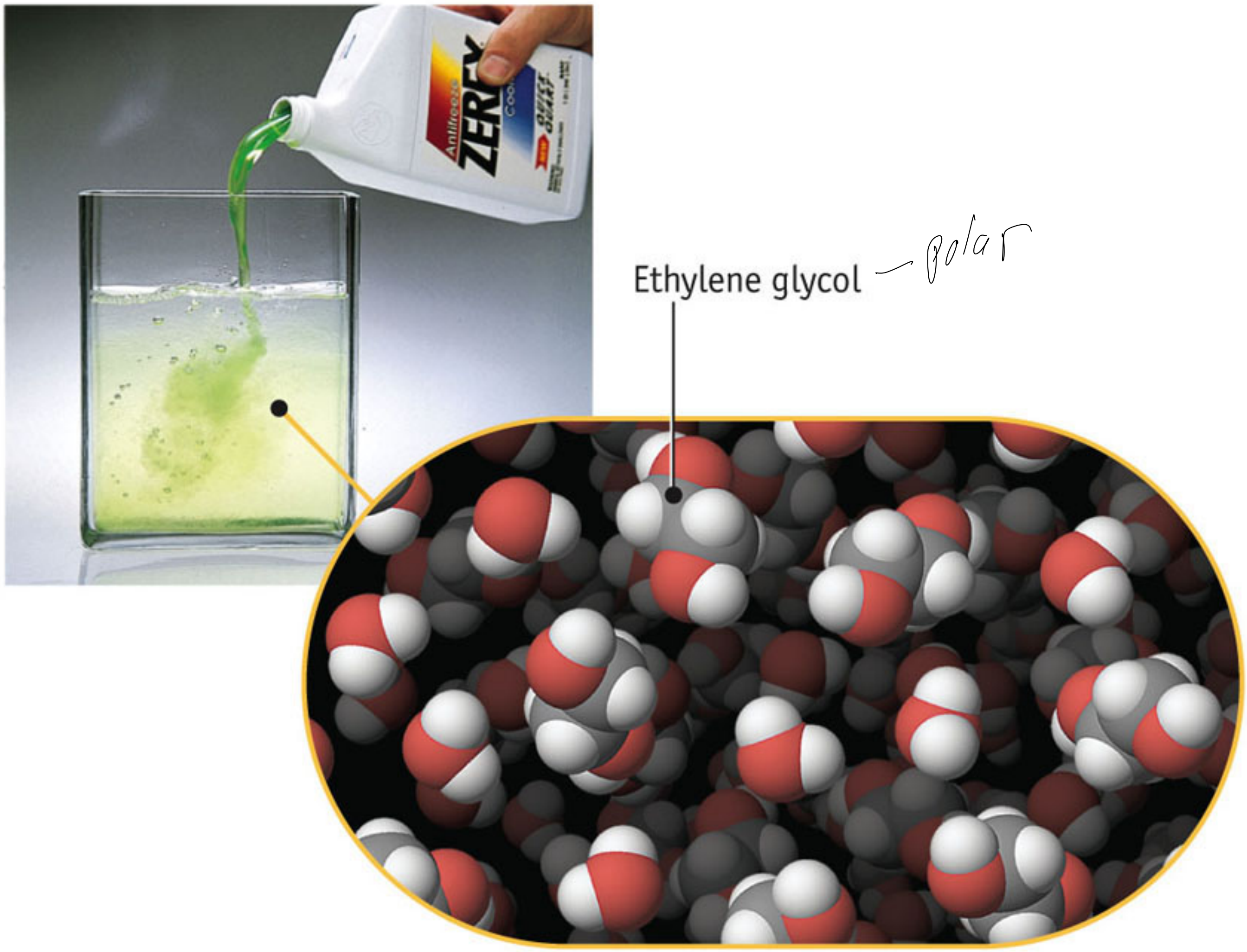
	NONPOLAR				POLAR		
	M (g/mol)	BP (°C)	$\Delta_{vap}H°$ (kJ/mol)		M (g/mol)	BP (°C)	$\Delta_{vap}H°$ (kJ/mol)
N_2	28	−196	5.57	CO	28	−192	6.04
SiH_4	32	−112	12.10	PH_3	34	−88	14.06
GeH_4	77	−90	14.06	AsH_3	78	−62	16.69
Br_2	160	59	29.96	ICl	162	97	—

polar molecules → higher bp, larger ΔH_{evap}
b/c stronger interactions

Miscibility of liquids is related to dipole-dipole interactions

water – polar

oil – non polar



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

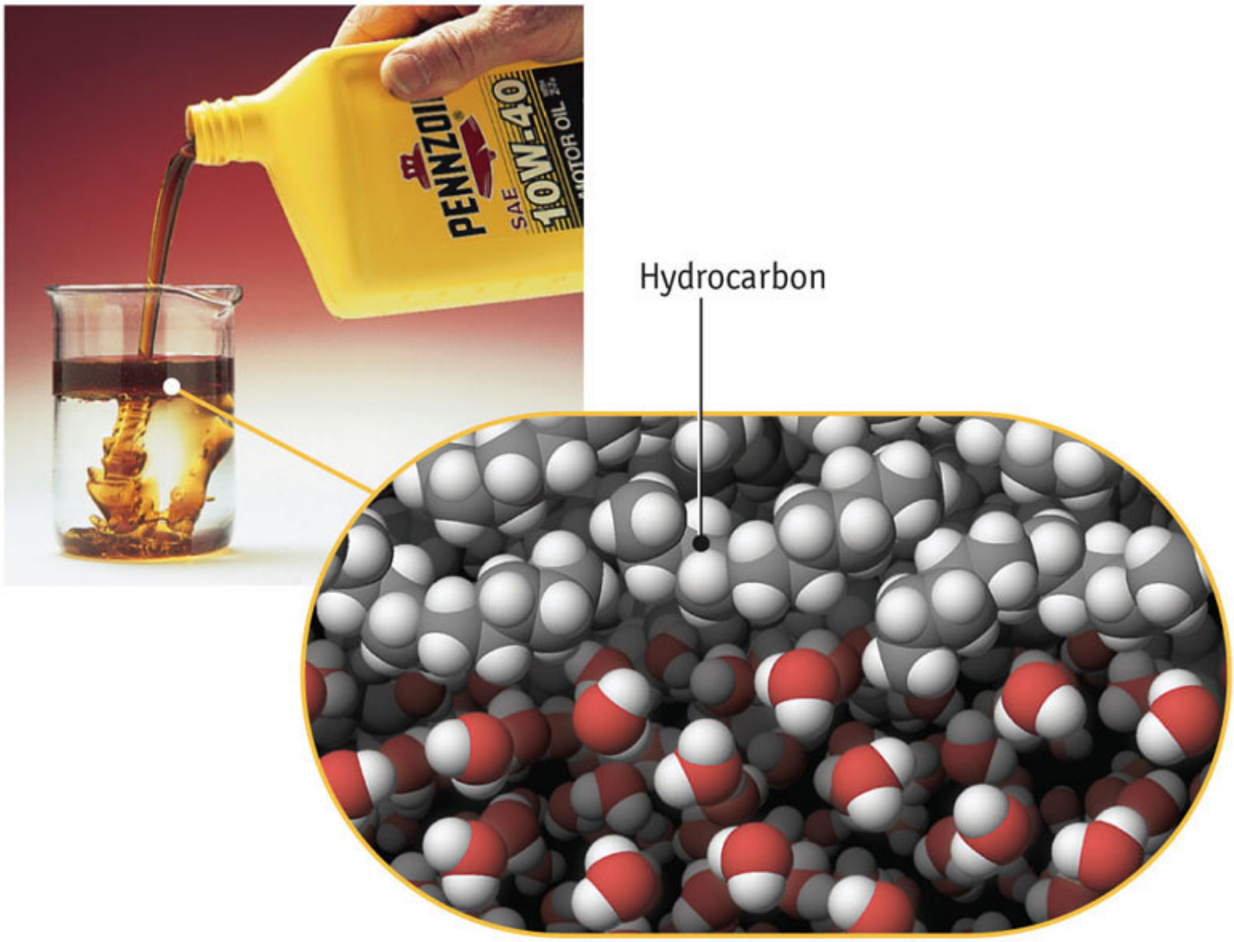
"Like dissolves like"

Fig. 12-5, p. 560

Polar-Polar – mixing b/c interactions A/A
B/B
A/B

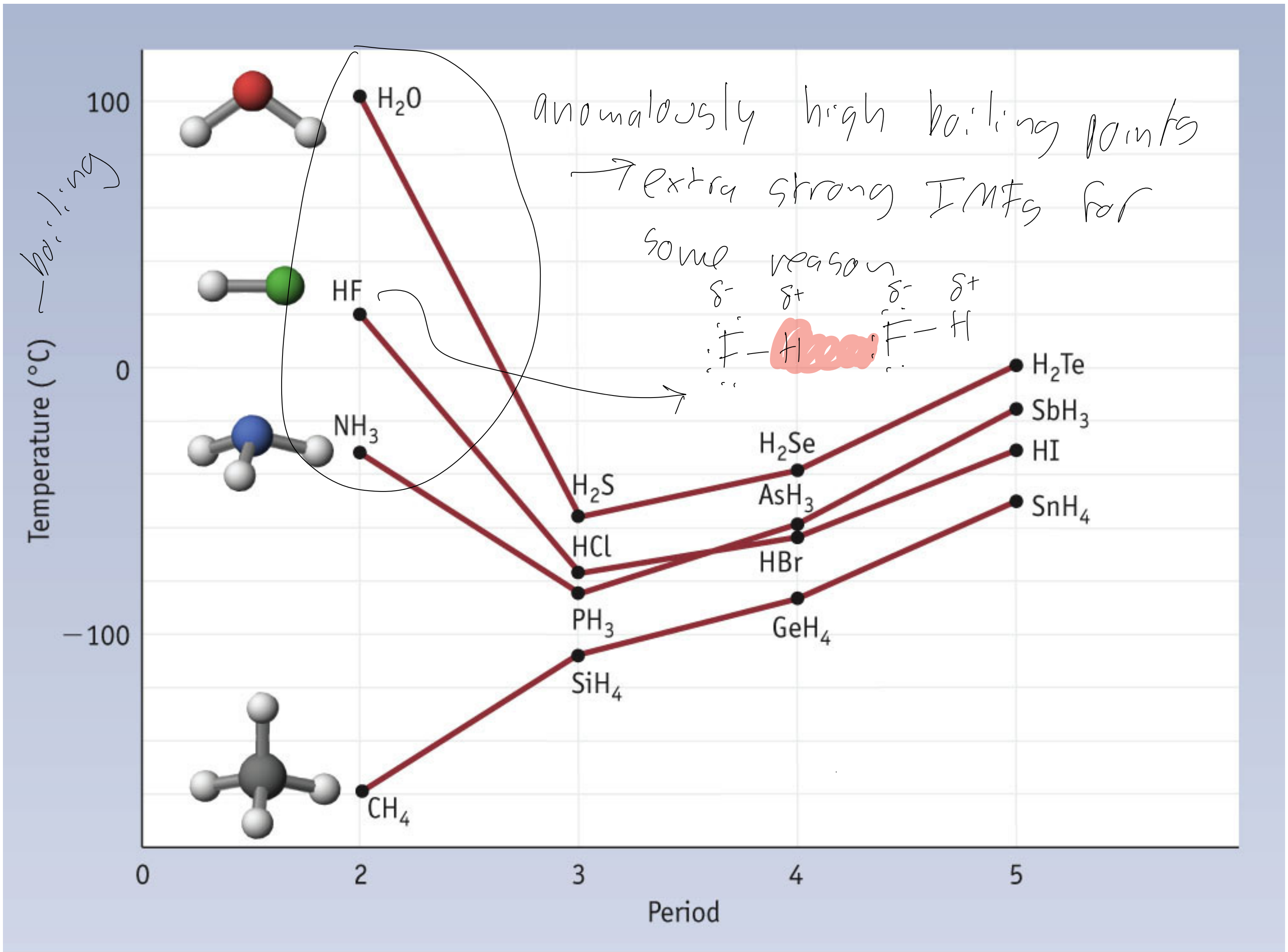
Polar – nonpolar – no mixing b/c there are not interactions between different types

Nonpolar-nonpolar – mixing



(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



—boiling

anomalously high boiling points
→ extra strong IMFs for some reason

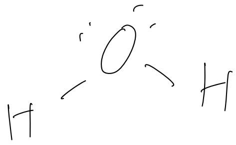
δ^- δ^+ δ^- δ^+
F—H···F—H

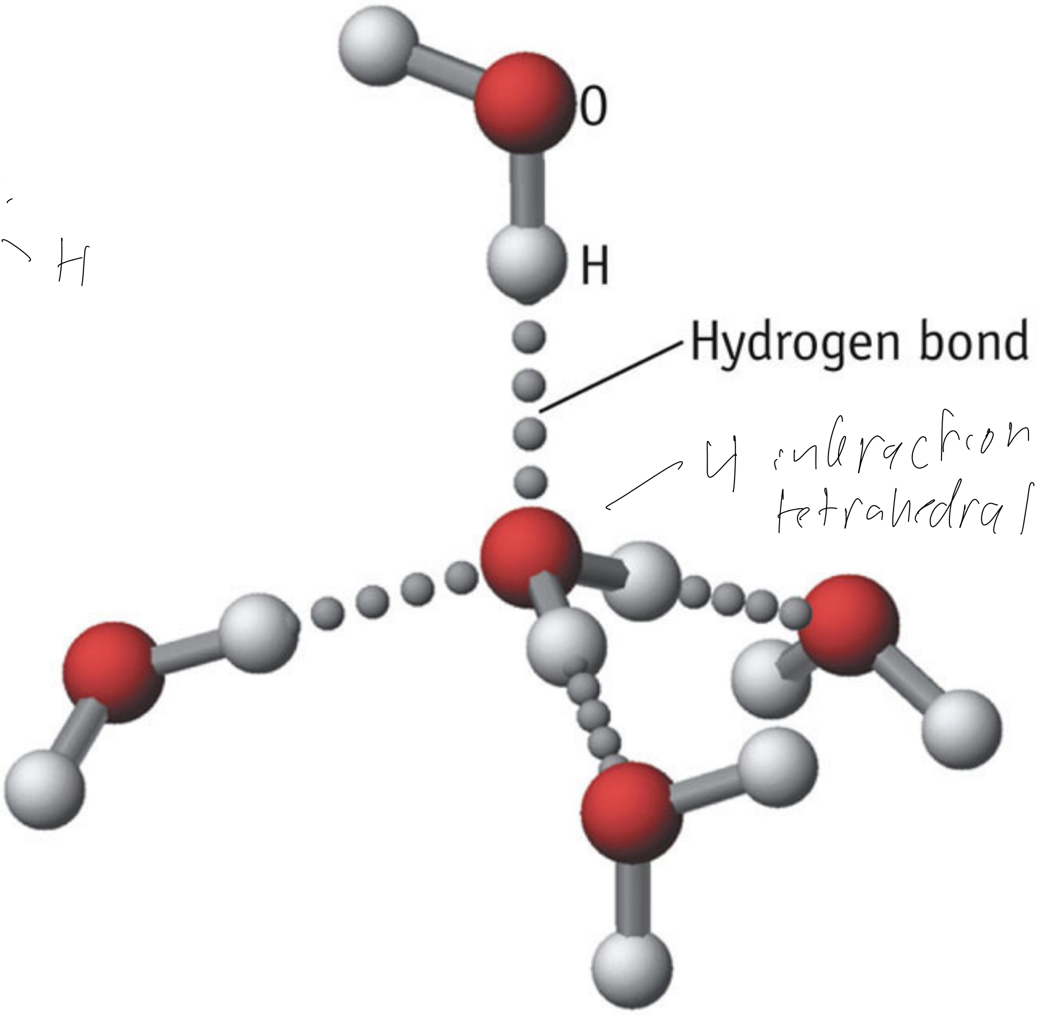
Fig. 12-6, p. 561

Hydrogen bonding – special case of dipole/dipole that only happens with very polar bonds

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

Not a covalent bond - just a very strong dipole/dipole interaction

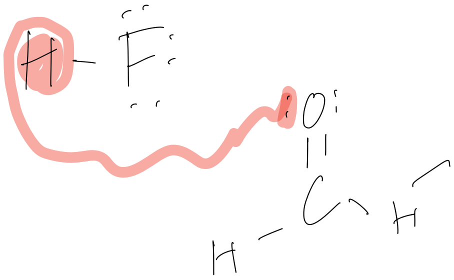




4 interactions tetrahedral

(a)

Fig. 12-8, p. 564



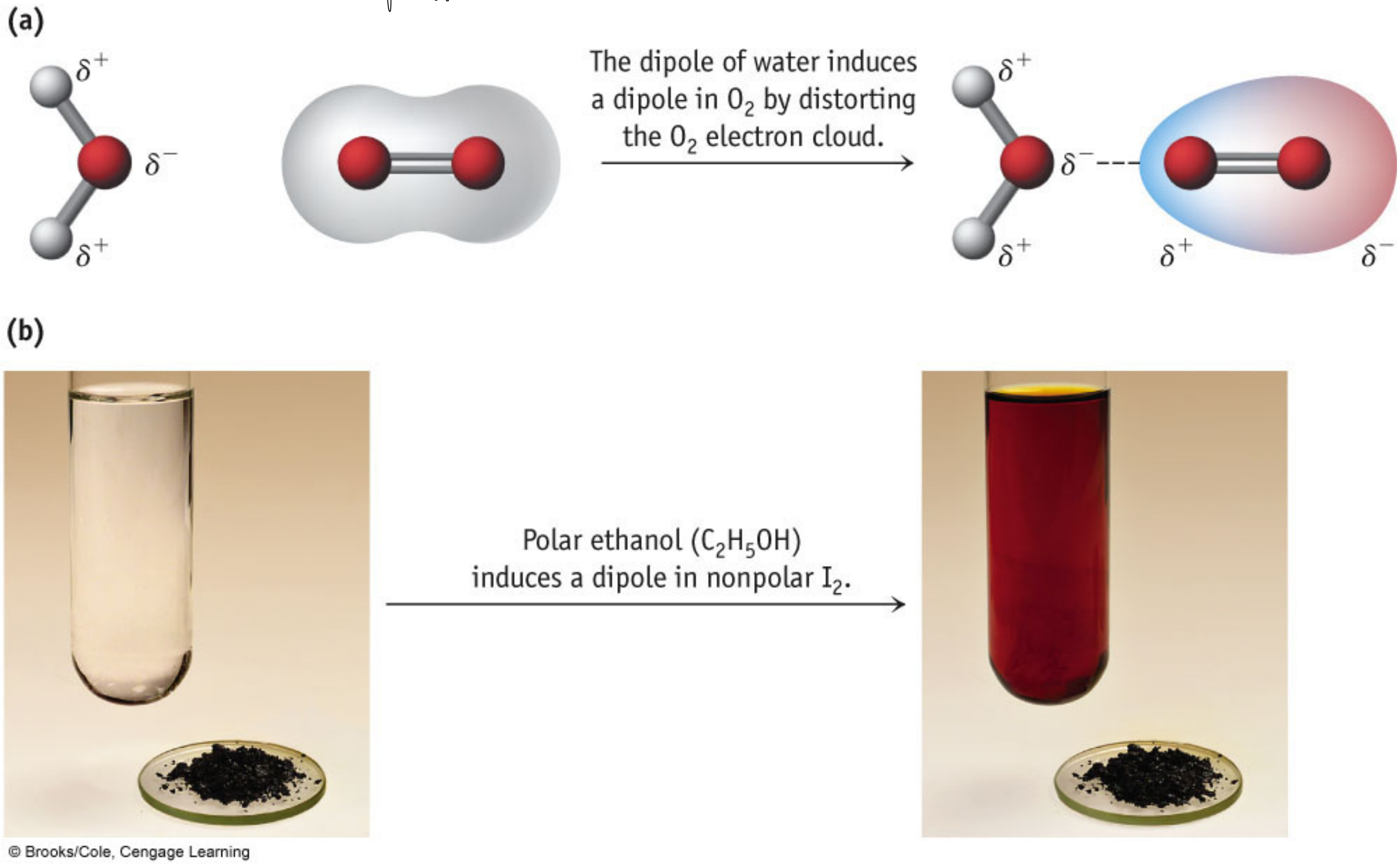
can't hydrogen bond b/c not connected to N, O, F

Polar/non polar interaction (dipole - induced dipole)

H_2O - polar → but they do mix - how?

$\ddot{O}=\ddot{O}$ - non polar

induced dipole is when electrons in non polar molecule are moved around by presence of polar molecule, making the non-polar molecule a bit polar



The dipole of water induces a dipole in O_2 by distorting the O_2 electron cloud.

Polar ethanol (C_2H_5OH) induces a dipole in nonpolar I_2.

Fig. 12-10, p. 566

works best with more polar dipoles

and with more polarizable non polar molecules

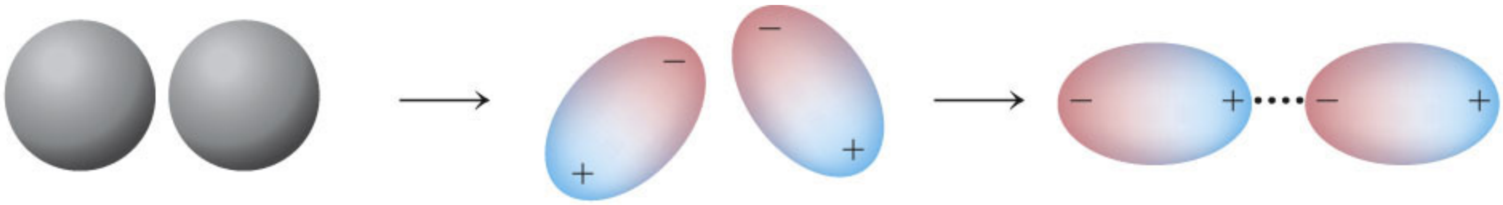
[able to have electron distribution distorted

larger molecules w/ lots of e^- → more polarizable

electrons farther from nuclei

Non polar/non polar (induced dipole/induced dipole)
Van der Waals
dispersion force

"non polar" molecules are nonpolar on time averaged basis but there are always momentary fluctuations in electron density

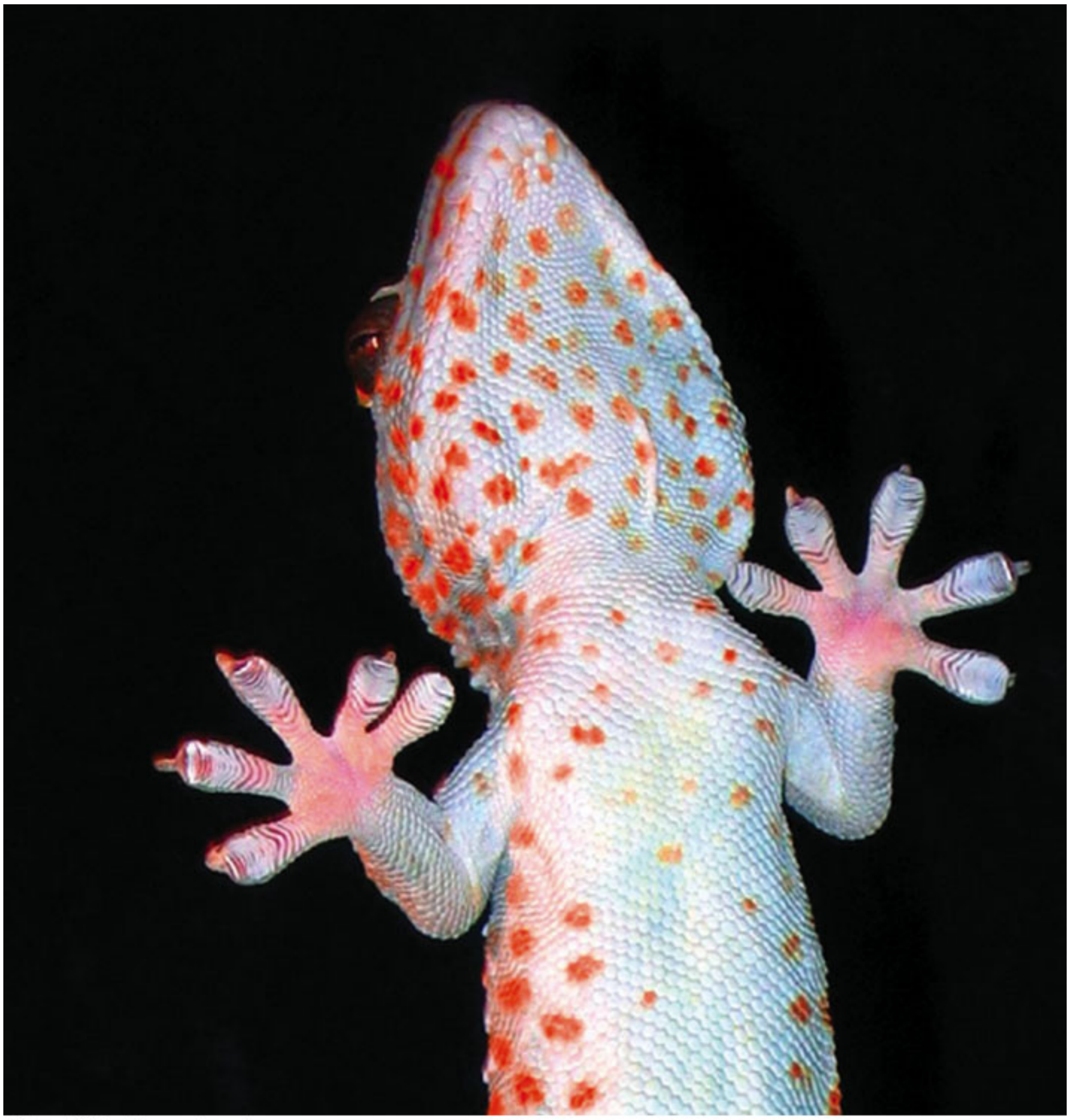


Two nonpolar atoms or molecules (depicted as having an electron cloud that has a time-averaged spherical shape).

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



© Brooks/Cole, Cengage Learning

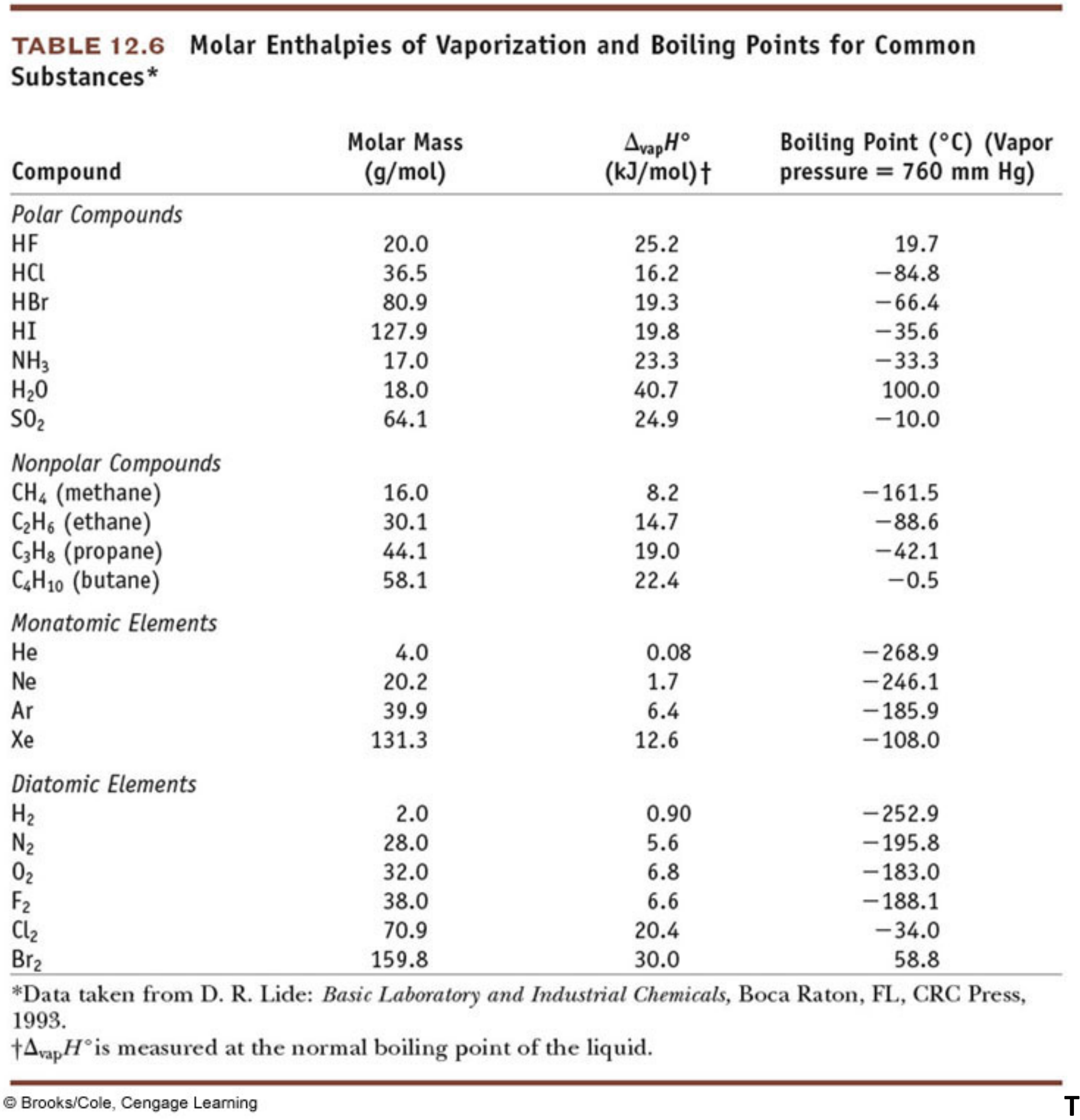


TABLE 12.6 **Molar Enthalpies of Vaporization and Boiling Points for Common Substances***

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

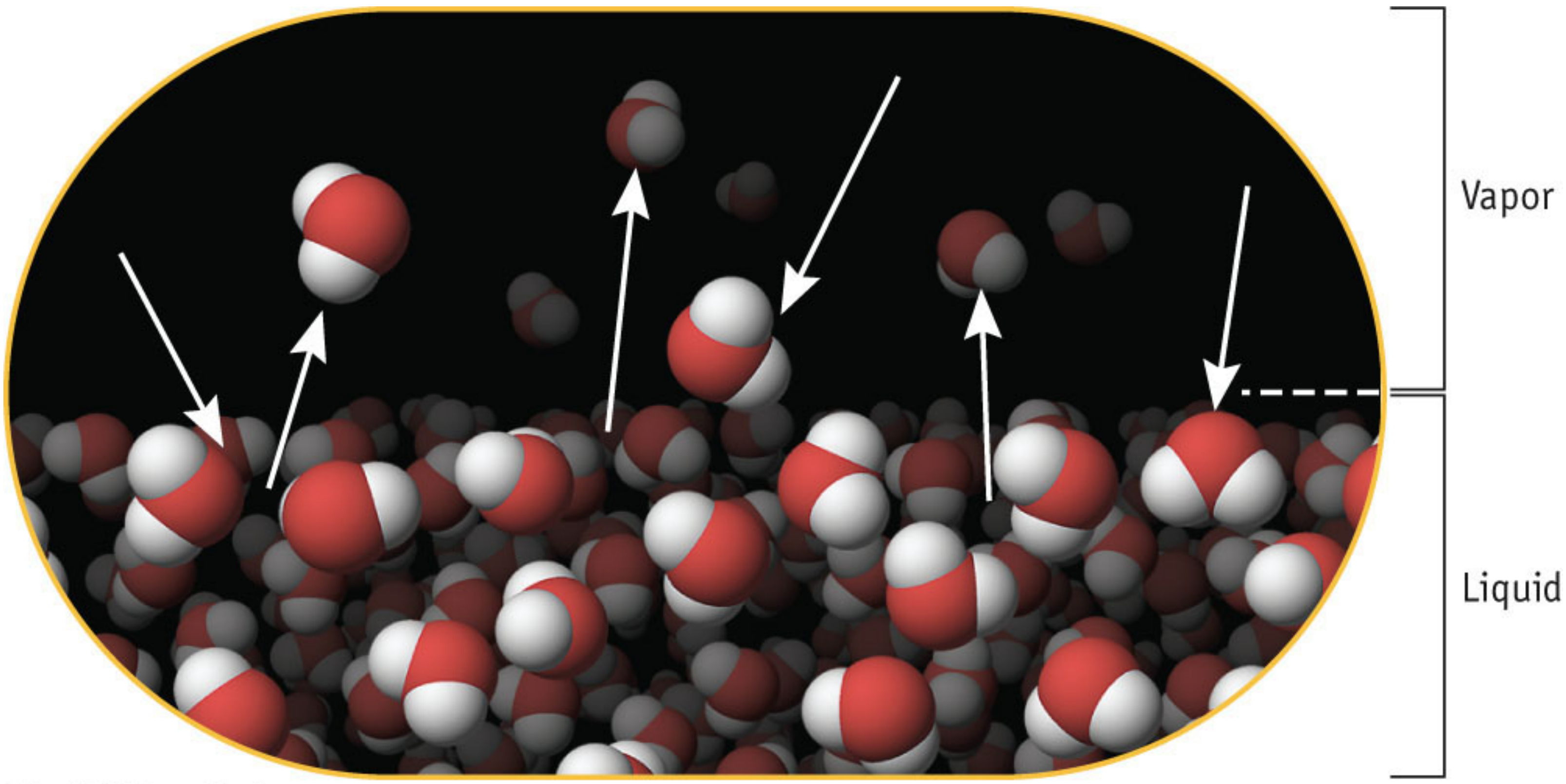
*Data taken from D. R. Lide: *Basic Laboratory and Industrial Chemicals,* Boca Raton, FL, CRC Press, 1993.

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

Table 12-6, p. 572

Vapor pressure – partial pressure of gas above a liquid

partial pressure of gaseous water is vapor pressure of water



© Brooks/Cole, Cengage Learning

Vapor pressure depends on strength of IMFs
Vapor pressure depends on temperature

Fig. 12-14, p. 571

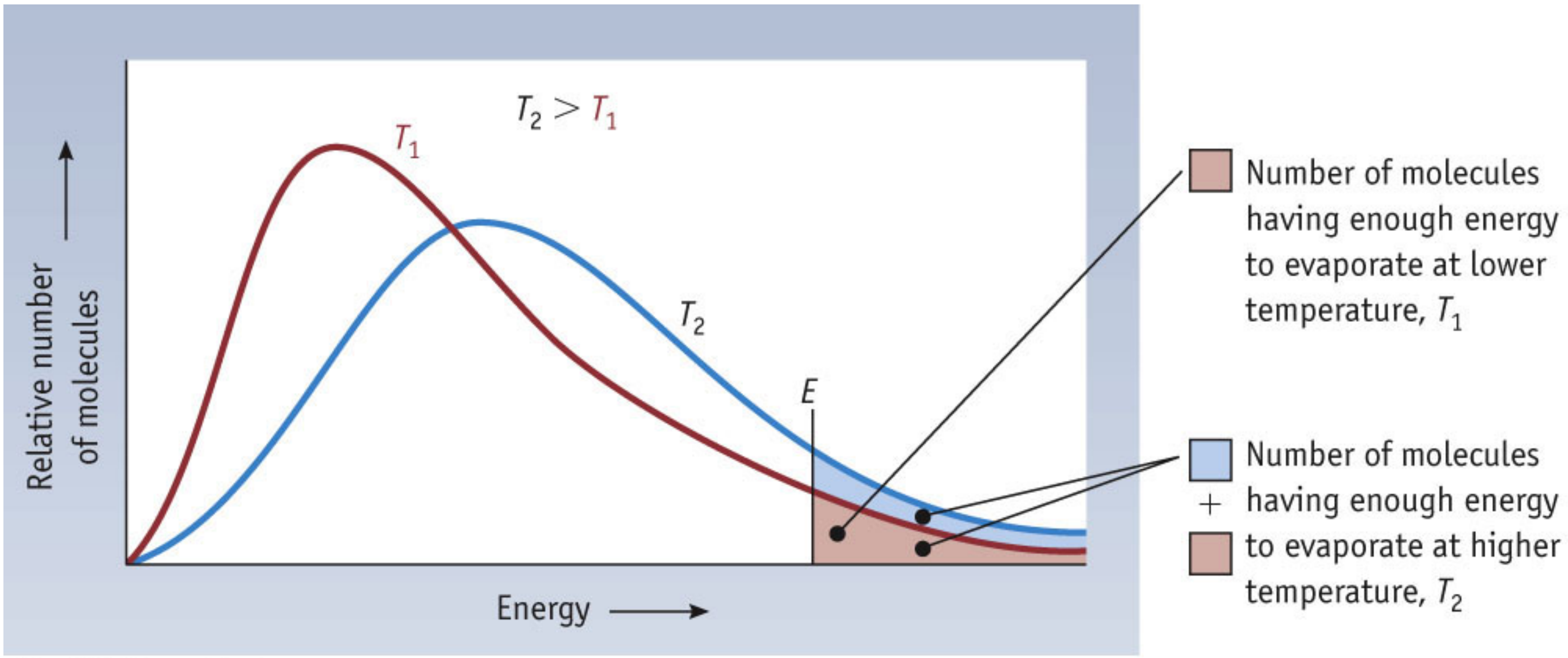


Fig. 12-13, p. 571

Boiling is when vapor pressure equals atmospheric pressure

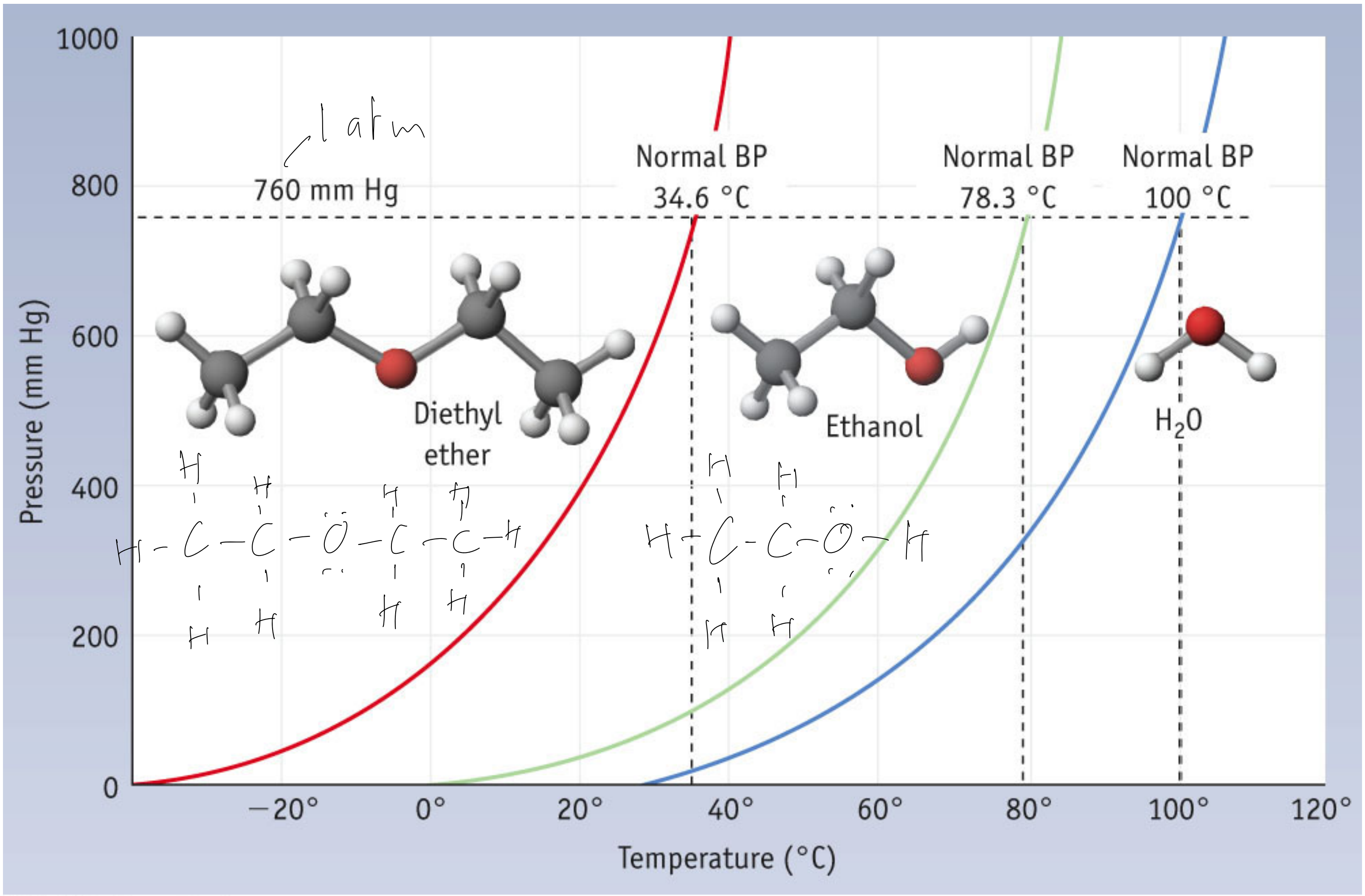


Fig. 12-17, p. 574

differences in vapor pressure reflects IMFs

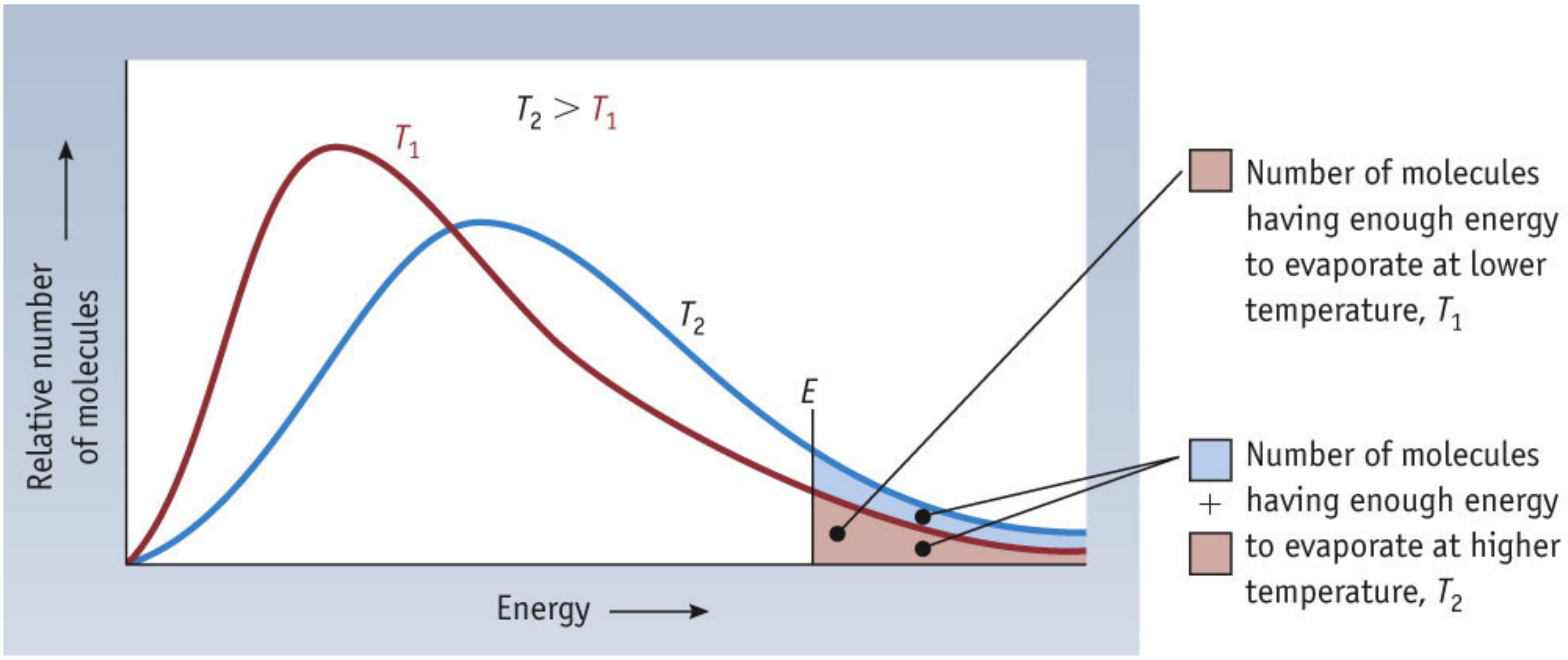
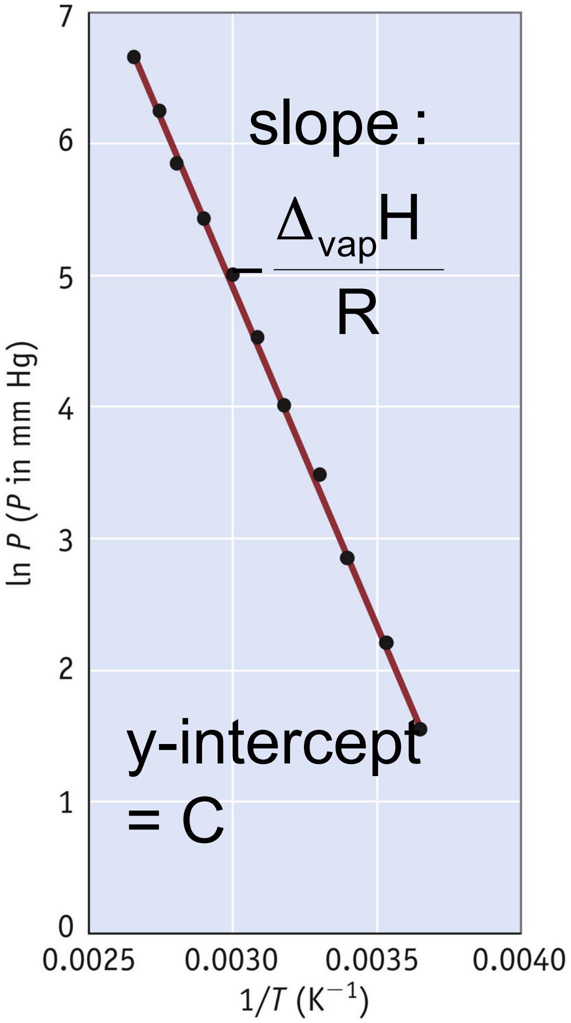


Fig. 12-13, p. 571

The Temperature Dependence of Vapor Pressure Goes As:

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



slope : $-\frac{\Delta_{vap}H}{R}$

y-intercept = 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

T_1 P_1 T_2 P_2

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

gas constant

$0.08206 \frac{L\,atm}{mol\,K}$ doesn't work

$8.314 \frac{J}{mol\,K}$