Intermolecular Forces of Attraction

Attractive forces that cause atoms or molecules to stick together

Mixtures

- Elements or compounds blended together but not chemically combined

Mixtures

- Can be solid, liquid, or gaseous mixtures
- Solid mixture examples:
  - Jewelry gold, most rocks, steel, alloys
- Liquid mixture examples
  - Beverages, sea water, solutions
- Gaseous mixture examples
  - Air, car exhaust

Mixtures

- Why do they form? What allows the parts to stay mixed? Why do they stay together?
- The components of a mixture are often held together by IMF's – intermolecular forces of attraction

Intermolecular Forces

All intermolecular forces are:

- attractive forces
- *between* molecules
- do not make *new* compounds
- Makes the molecules "sticky"
- weaker than true "bonds"

IMF's

are not

chemical bonds!

but… **IMF's**

<u>are</u>

"Coulombic attractions"

Coulomb's Law

$$F = k\,\frac{Q_1 Q_2}{r^2}$$

F = attractive/repulsive force

Q_1 , Q_2 = charges (size)

r = distance between charges

Types of IMF's

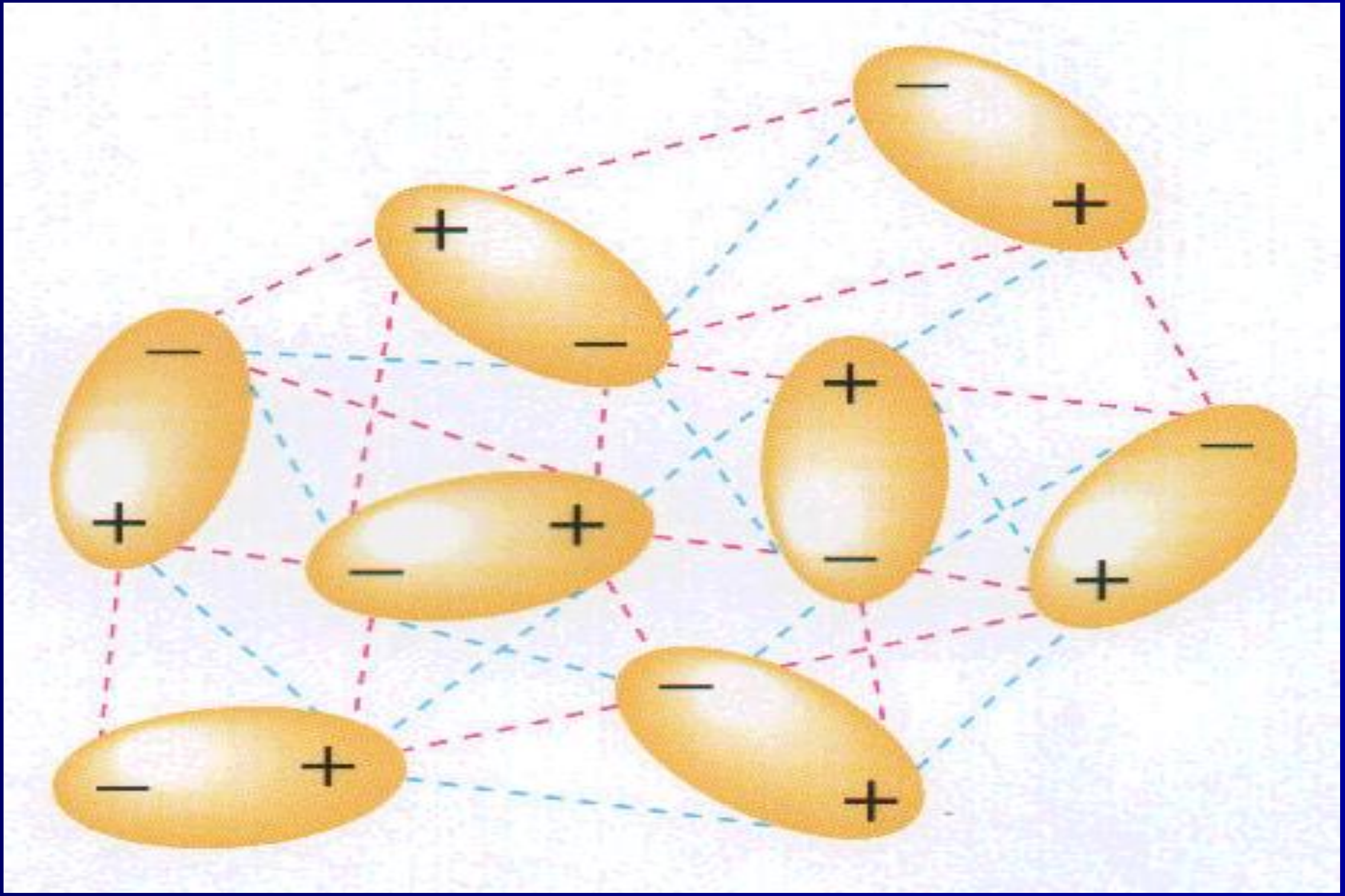
1. London (dispersion) forces
   - all molecules
   - weakest interaction
2. dipole-dipole forces
   - polar molecules
3. hydrogen bonding
   - H atoms w/ O, N, F not covalently bonded to it
   - strongest interaction

- ion-dipole forces
  - Between polar molecules and ions
    - Aqueous solutions of ionic compounds

Polar forces

- “Dipole - Dipole” interactions
- positive ends attract negative ends of other molecules
- about 1% as strong as a covalent bond

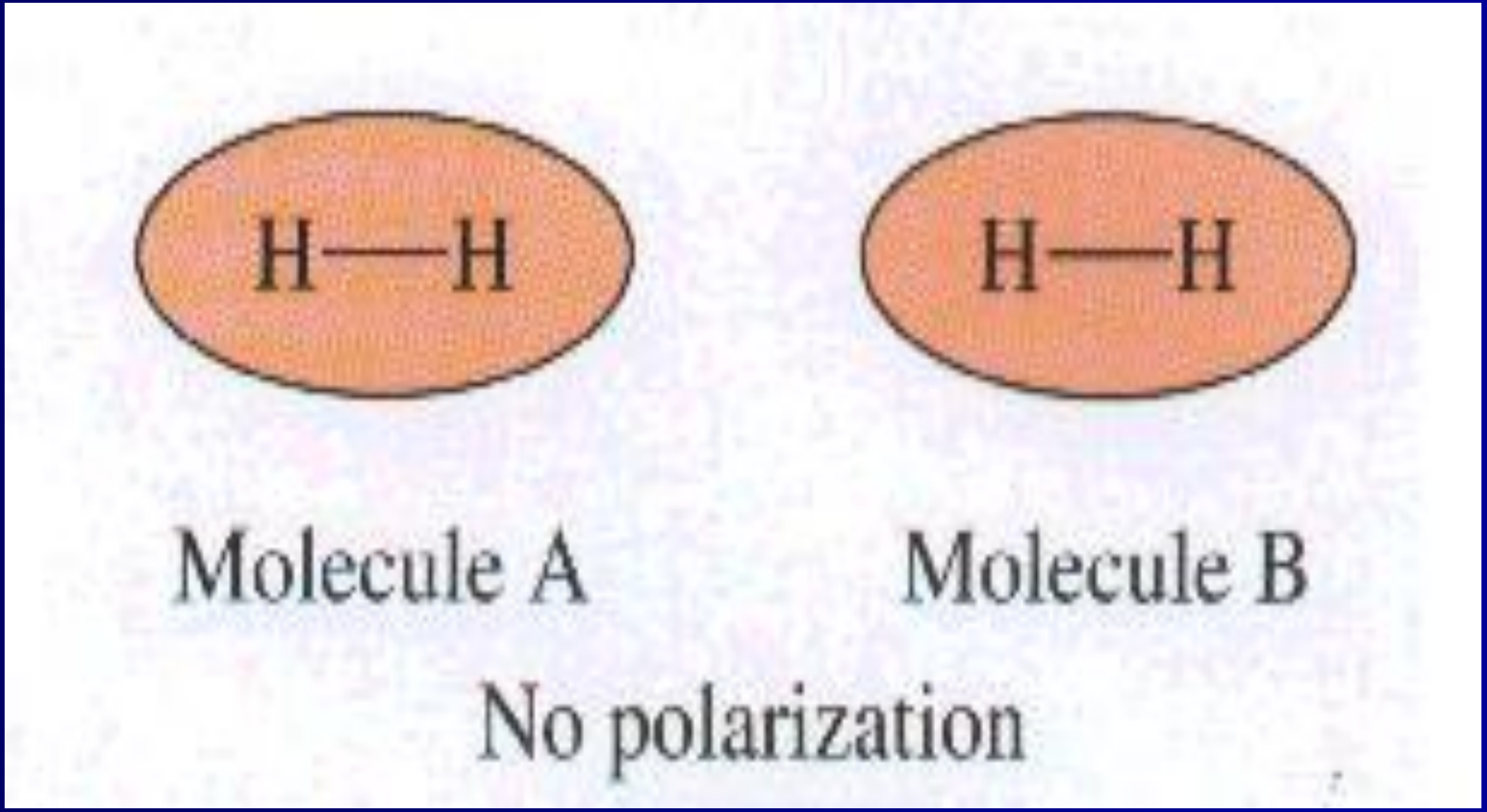
Dipole - Dipole interactions



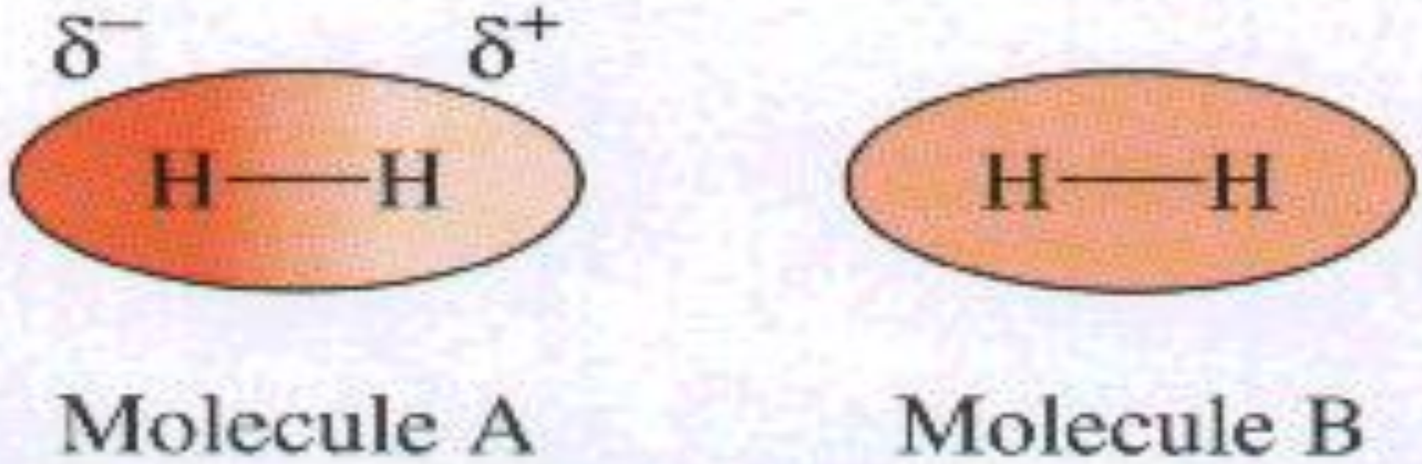
London forces

- Momentary dipole-dipole interaction
- “instantaneous” dipole “induces” a dipole in a neighboring molecule
- brief attractive force results

Step 1

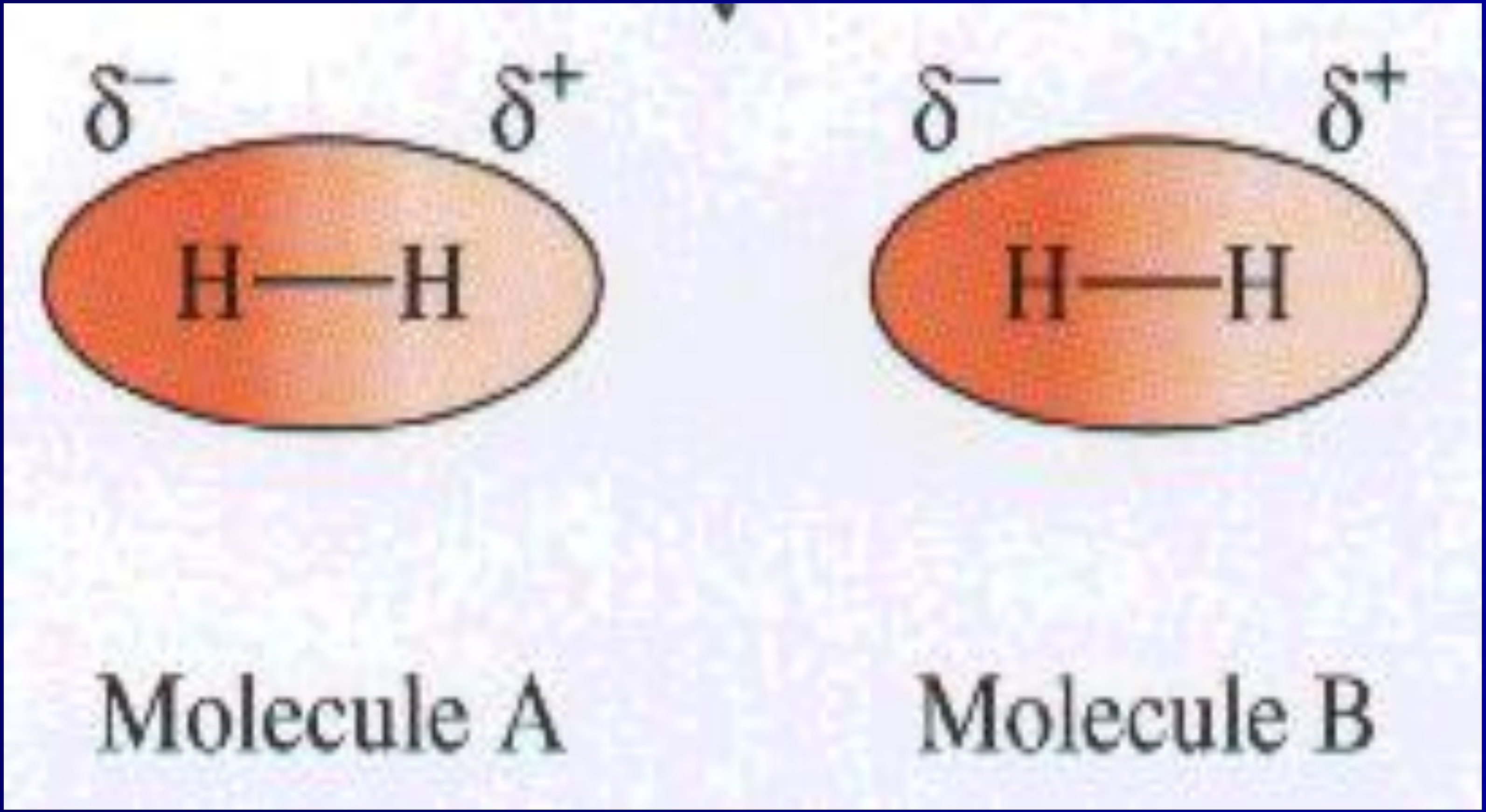


Step 2



Instantaneous dipole on atom A induces a dipole on atom B

Result…



London forces

Strength depends on the **size** of **e^- cloud**

bigger e^- cloud = stronger attraction

The more e-'s, the more "**polarizable**", the stronger the London Forces

How do you get "more" electrons?

1. Bigger atoms
2. More atoms in the molecule

Hydrogen Bonds

- Special case of polar attraction
- H atom is
  - 1) bonded to high EN atom and
  - 2) attracted to a high EN atom it is not bonded to (N, O, F)
- 5 times stronger than regular polar attractions

Hydrogen Bonding

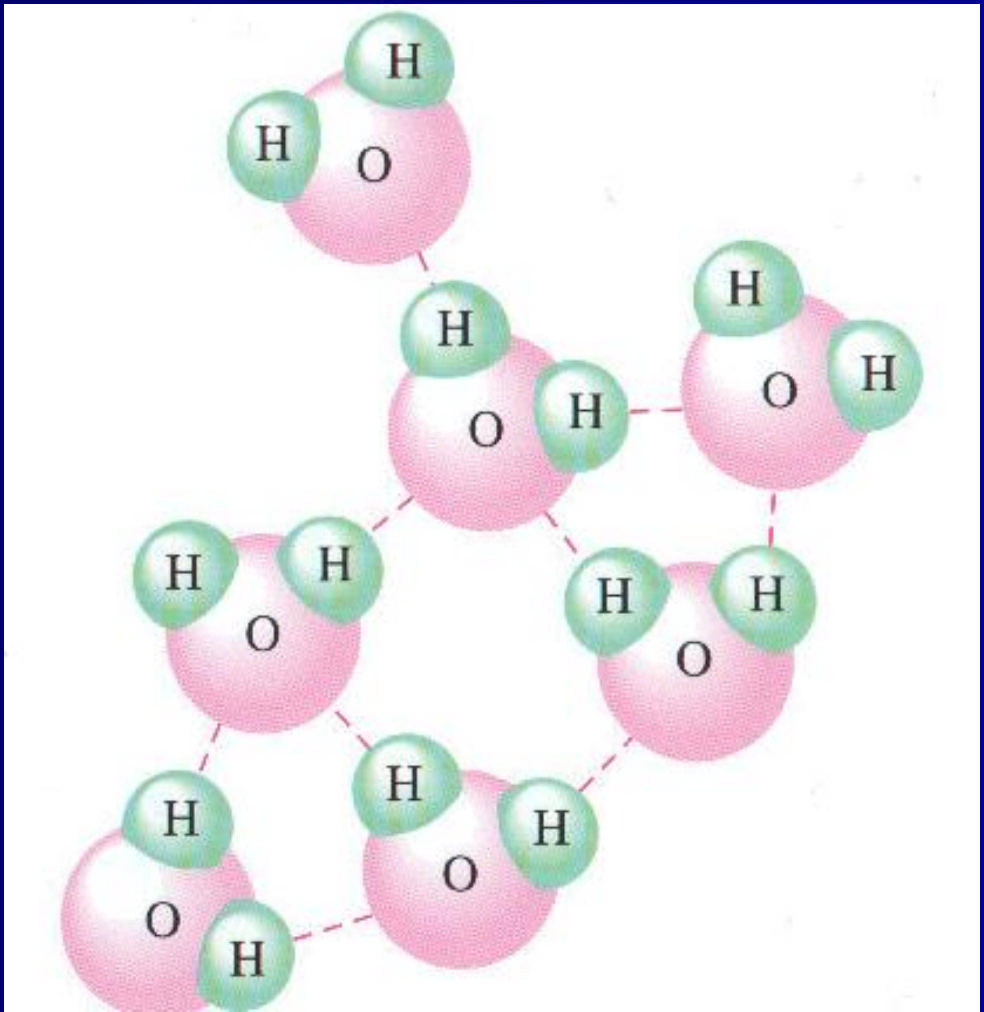
The strongest type of dipole-dipole interaction involving a hydrogen on one molecule (attached to a F, O, or N) and either F, O, or N on another molecule.

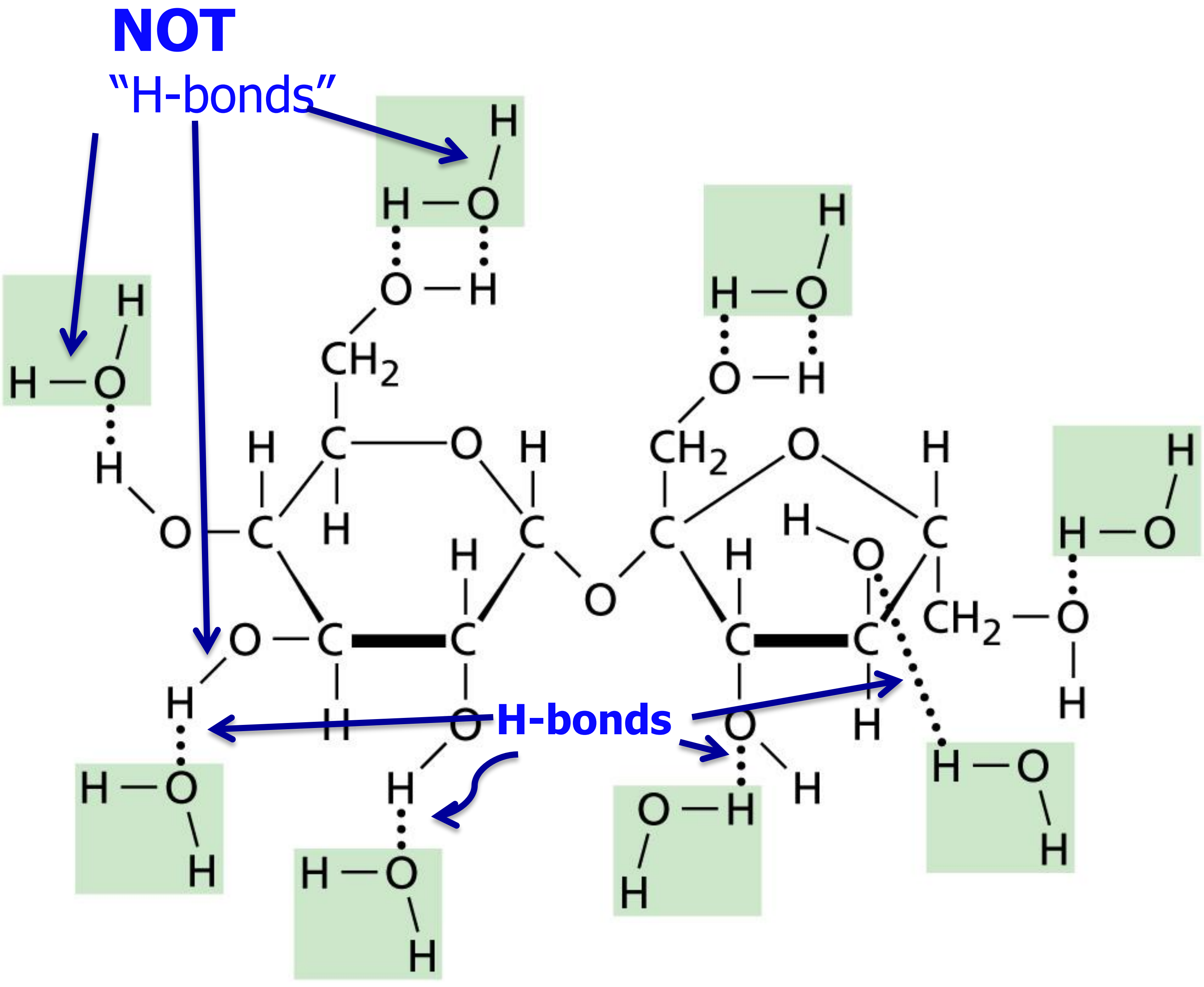
Types of Hydrogen Bonds

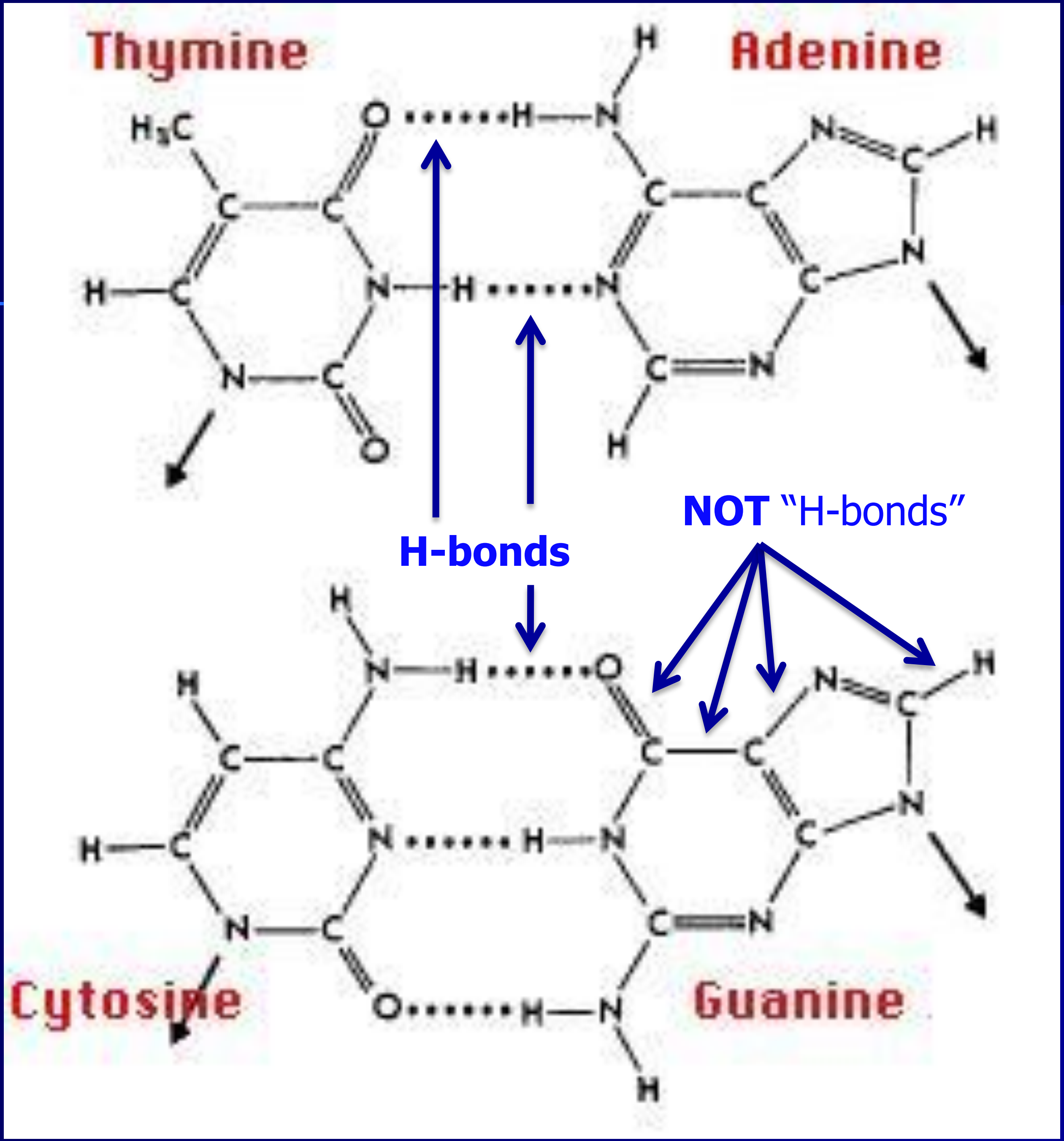
N—H···N—	O—H···N—	F—H···N—
N—H···O—	O—H···O—	F—H···O—
N—H···F—	O—H···F—	F—H···F—

About 10 % as strong as an ordinary covalent bond so approximately 15-40 kJ/mol.

Hydrogen Bonds

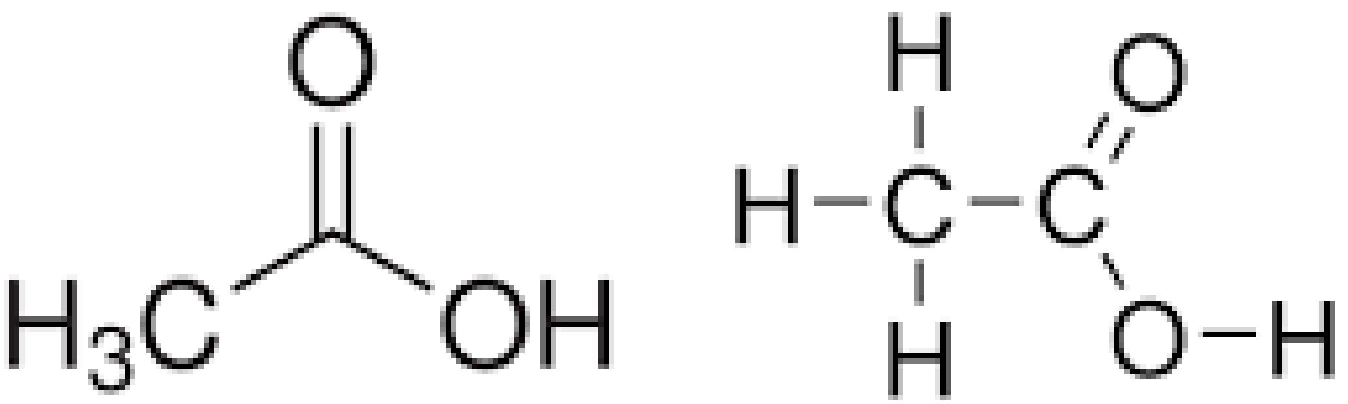



NOT
"H-bonds"
H-bonds



http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/B/BasePairing.html

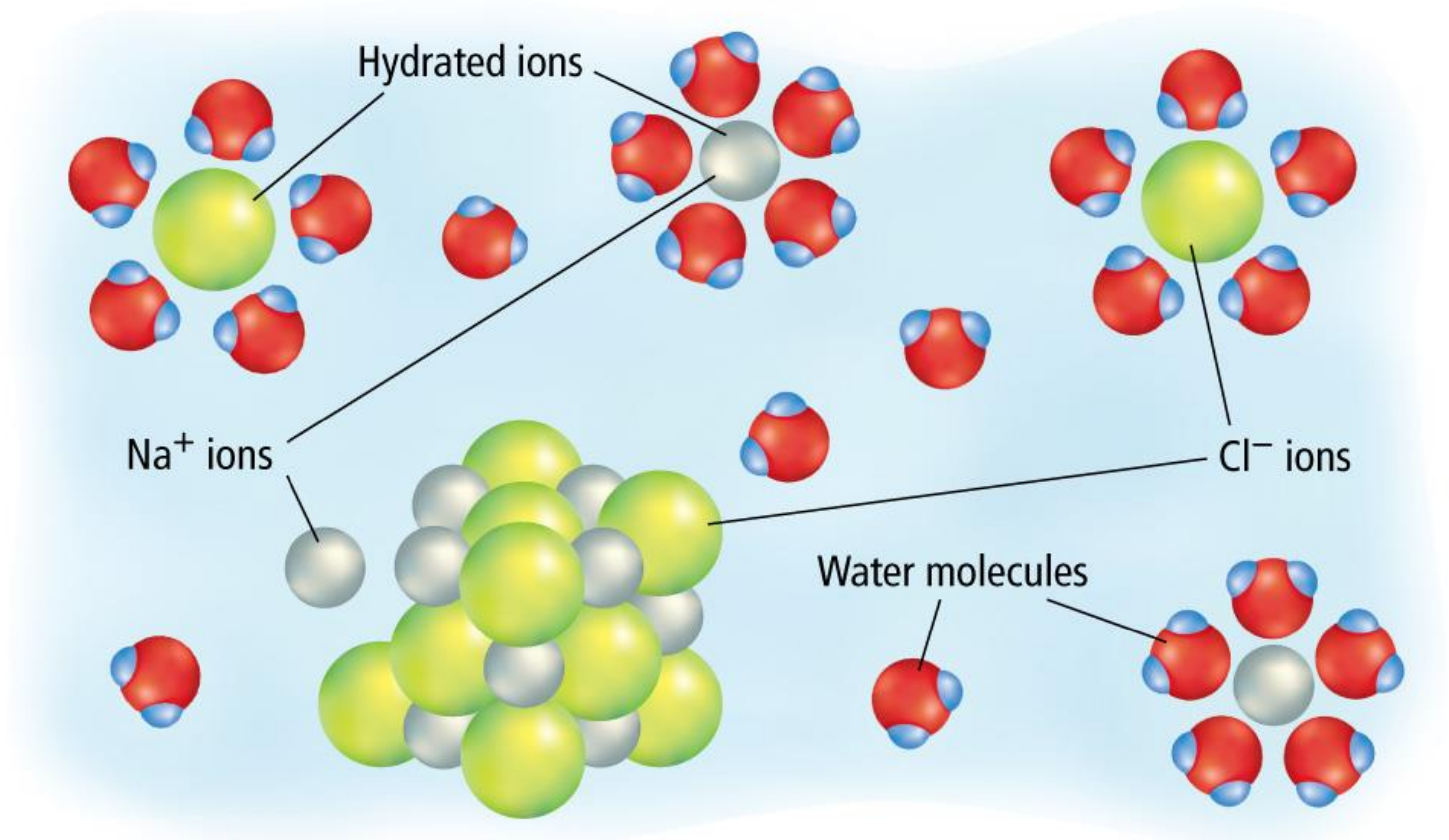
Which atoms can H bond?



Ion – dipole forces

- Between polar molecules and ions
  - Aqueous solutions of ions
- Positive ends of polar molecules attract negative ions
- Negative ends attract positive ions
- Important in aqueous solutions

Solvation Process of NaCl



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Physical property effects of Intermolecular Forces of Attraction

…all come down to how sticky the molecules are toward each other…

The Key Idea…

- ✓The stronger the IMF's, the tighter the molecules cling to each other, the harder it is to separate them.

The Key Idea…

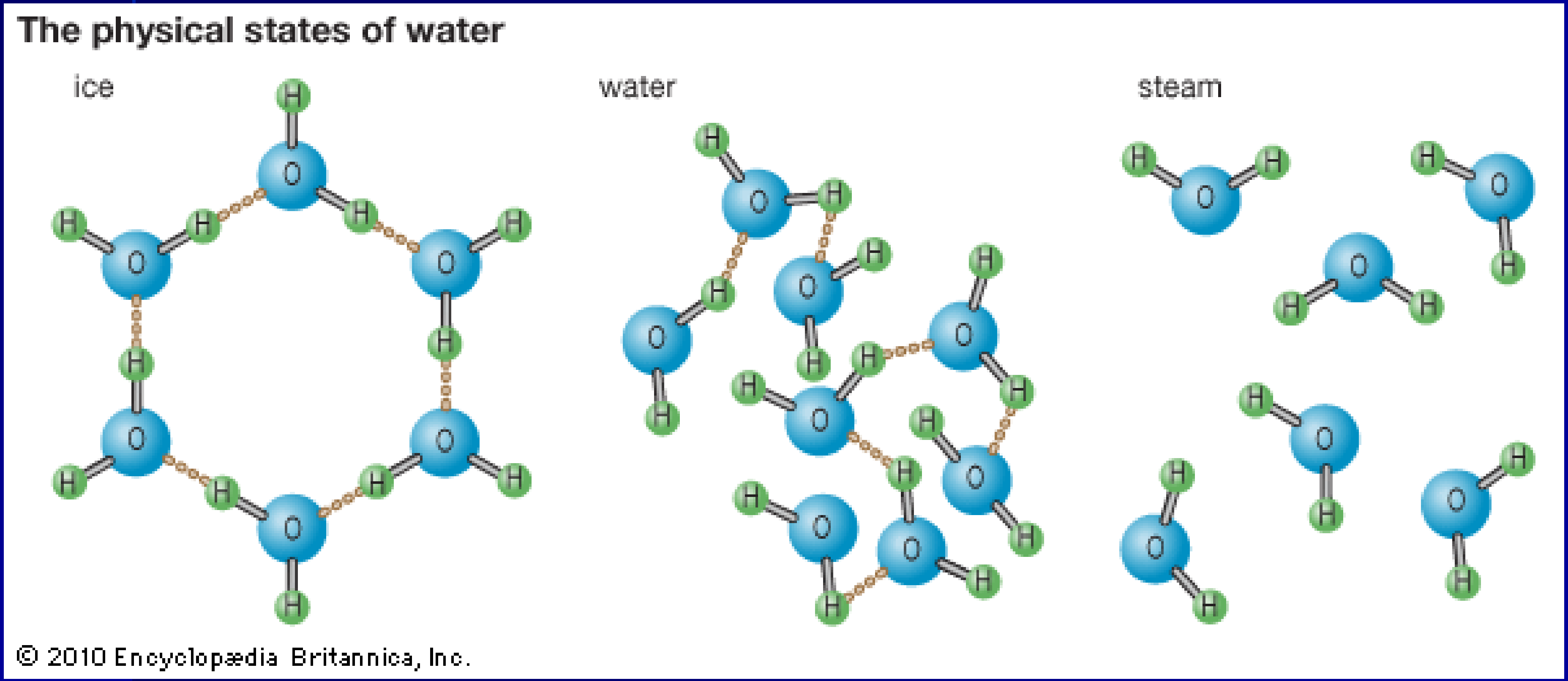
- ✓In other words, the harder it is to separate molecules, the stronger their IMF's

What does that mean… "separate the molecules"?

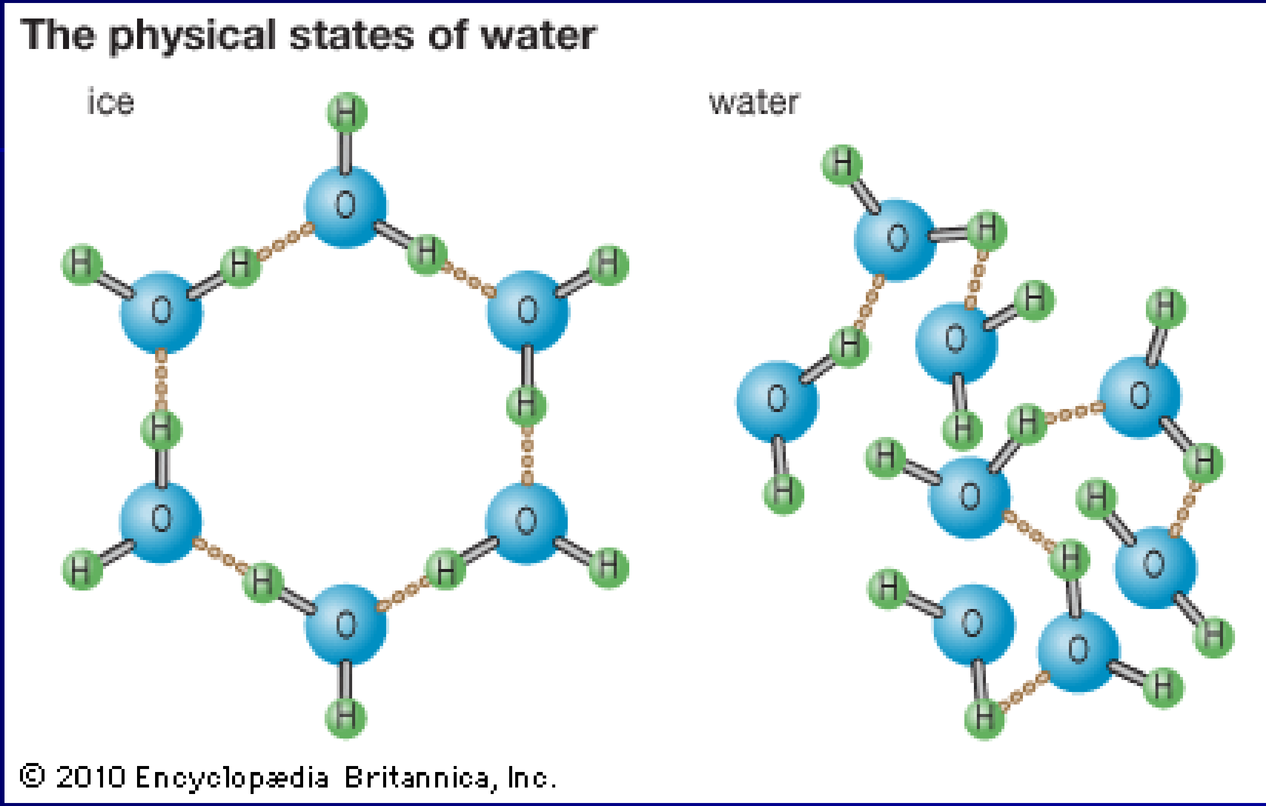
Pull them apart from each other (but not **<u>break</u>** them!):

- ✓Melting
- ✓Boiling
- ✓Physically move them apart
  - ✓Peel them away. Wipe them off, etc…

Separating = breaking the attraction holding the molecules to each other



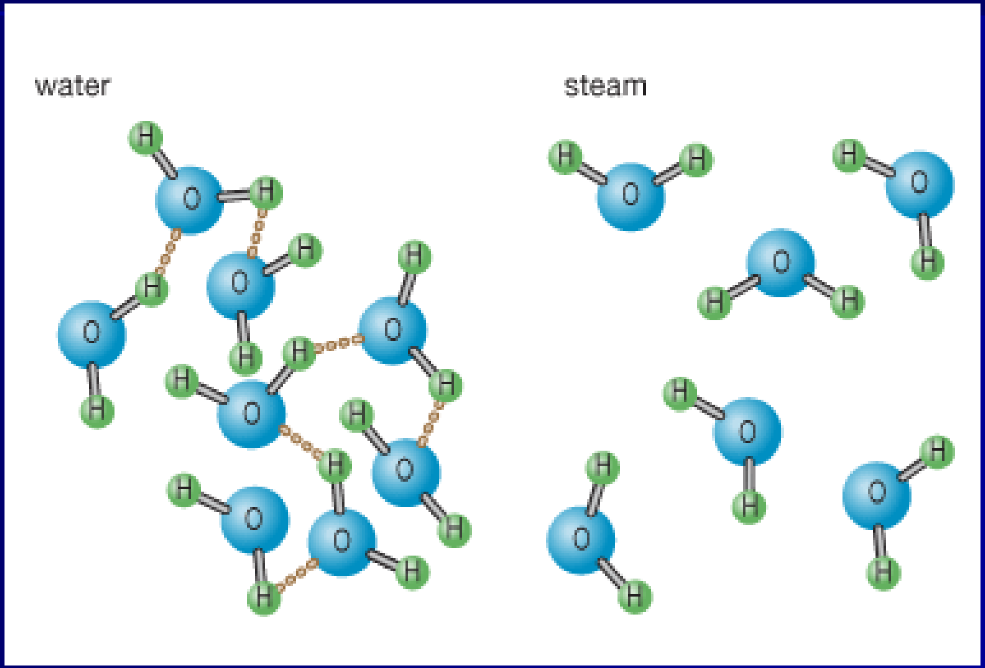
What is happening when ice melts?



The IMF's (H-bonds) are being *disrupted*

The covalent bonds are NOT breaking

What is happening when water vaporizes?



The IMF's (H-bonds) are being **ELIMINATED**
The covalent bonds are NOT breaking

Boiling Point Effects

- ✓ The stronger the IMF's, the higher the boiling point

Boiling Point Effects

Formula	Boiling point	Polar?	IM force
HCl	-85°C	Polar	Dipole-dipole
H_2S	-60.7°C	Polar	Dipole-dipole
H_2O	100°C	Polar	H-bonding
Ar	-185.7°C	Nonpolar	london

Boiling Point Effects

Formula	Boiling Point	Polar?	IM force
F_2	-188.1^{o}C	Nonpolar	London
Cl_2	-34.6^{o}C	Nonpolar	London
Br_2	58.8^{o}C	Nonpolar	London
I_2	184.4^{o}C	Nonpolar	London

Boiling Point Effects

Formula	Boiling point	Polar?	IM force
CH_4	-161.5^{o}C	Nonpolar	London
C_2H_6	-88.6^{o}C	Nonpolar	London
C_3H_8	-42.1^{o}C	Nonpolar	London
C_4H_{10}	-0.5^{o}C	Nonpolar	London
C_5H_{12}	36.1^{o}C	Nonpolar	london

Diffusion

- The intermingling of molecules with each other
- gases = rapid ⇨ much empty space
- liquids = slowly ⇨ more closely packed
- solids = negligible ⇨ locked in place

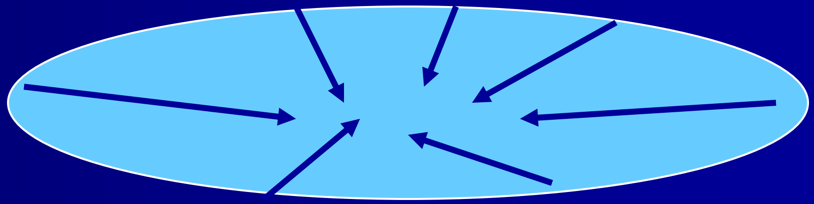
Solubility of a solid in liquid

General rule: **Like dissolves Like**

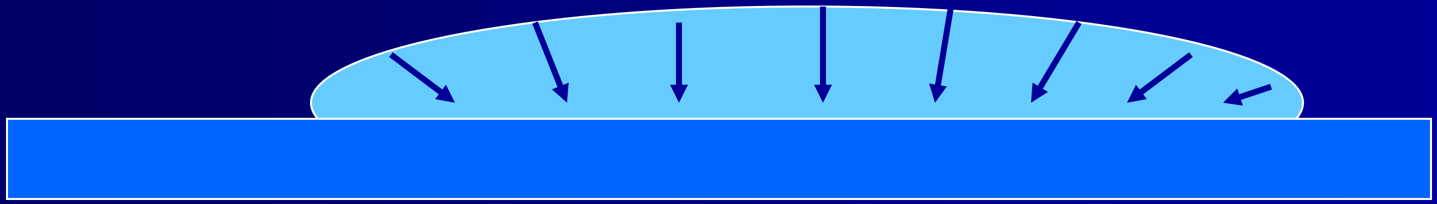
- Polar solutes dissolve in polar solvents
  - *Sugar* (polar solute) in H_2O (polar solvent)
- Ionic solids dissolve in polar solvents
  - *NaCl* (ionic solid) in H_2O (polar solvent)
- Nonpolar solutes dissolve in nonpolar solvents
  - *Dried paint* (nonpolar solute) in *paint stripper – turpentine, etc.* (nonpolar solvent)

Cohesion/Adhesion

- ✓ Cohesion = molecules sticking together



- ✓ Adhesion = molecules sticking to a substrate

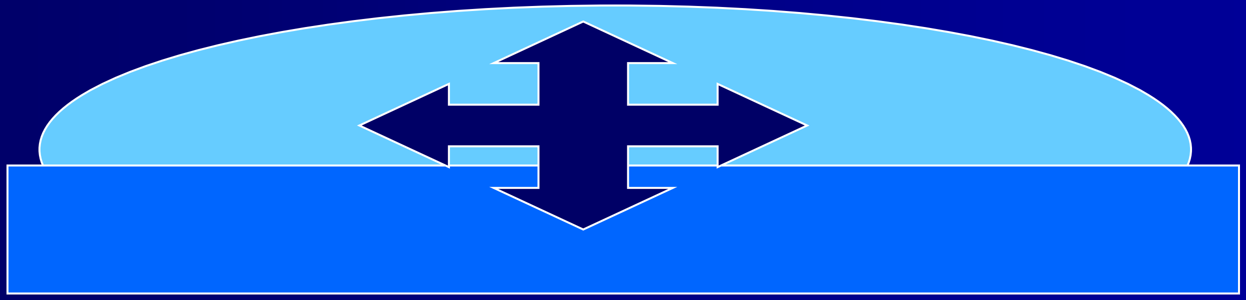


Viscosity

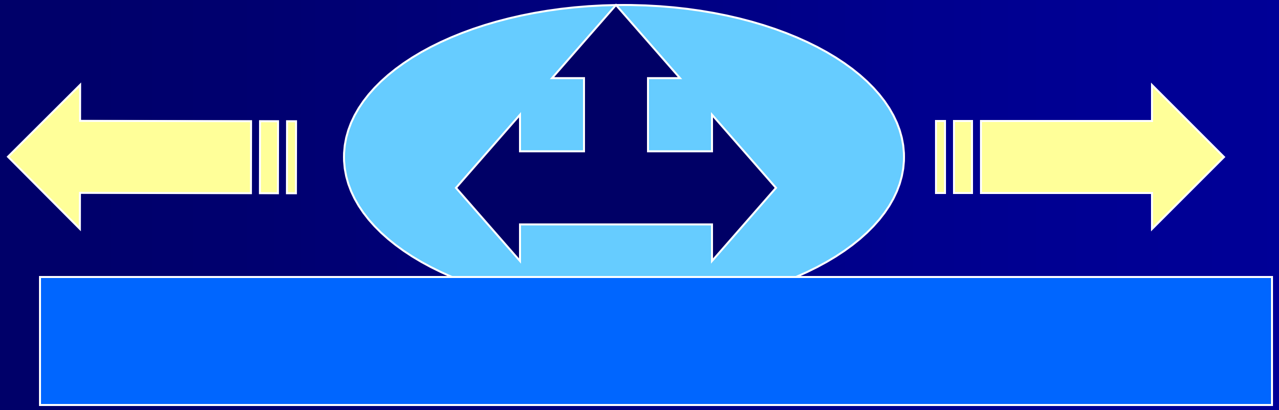
- The resistance of a fluid to flow.
- The stronger the IMF's, the higher the viscosity

Surface Wetting

- The spreading of a liquid across a surface
- must have adhesion ≈ cohesion

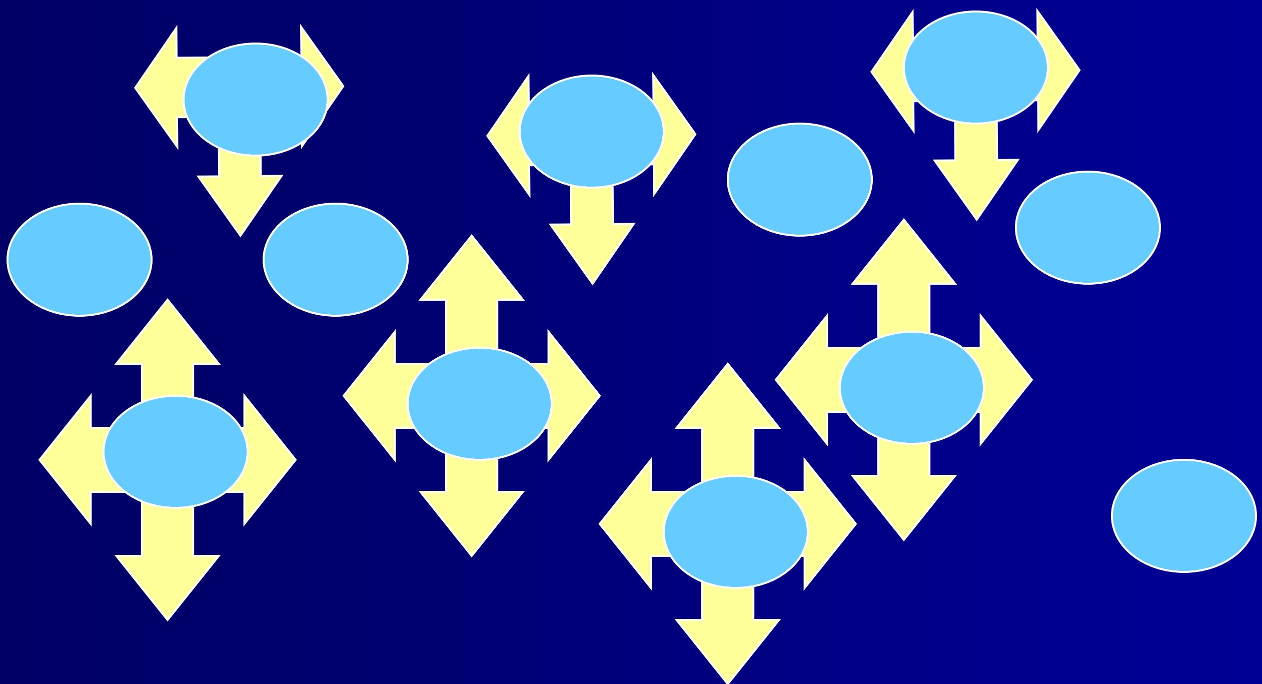


- Water beads on greasy glass
  - *eliminates H-bonding to glass*
  - *low adhesion*



Surface Tension

- Intermolecular attractions at the surface are only inward towards the substance



Surface Tension, continued

- Molecules at the surface of a liquid act as a “skin”
- the greater the IMF’s, the more pronounced the effect
- liquids seek to lower their surface tension
- water drops are spherical

Surface Tension, continued

- **Surfactants**, used in soaps and detergents, drastically lower the surface tension of water
  - soapy water spreads more easily over dirty surfaces

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Boiling Point Effects

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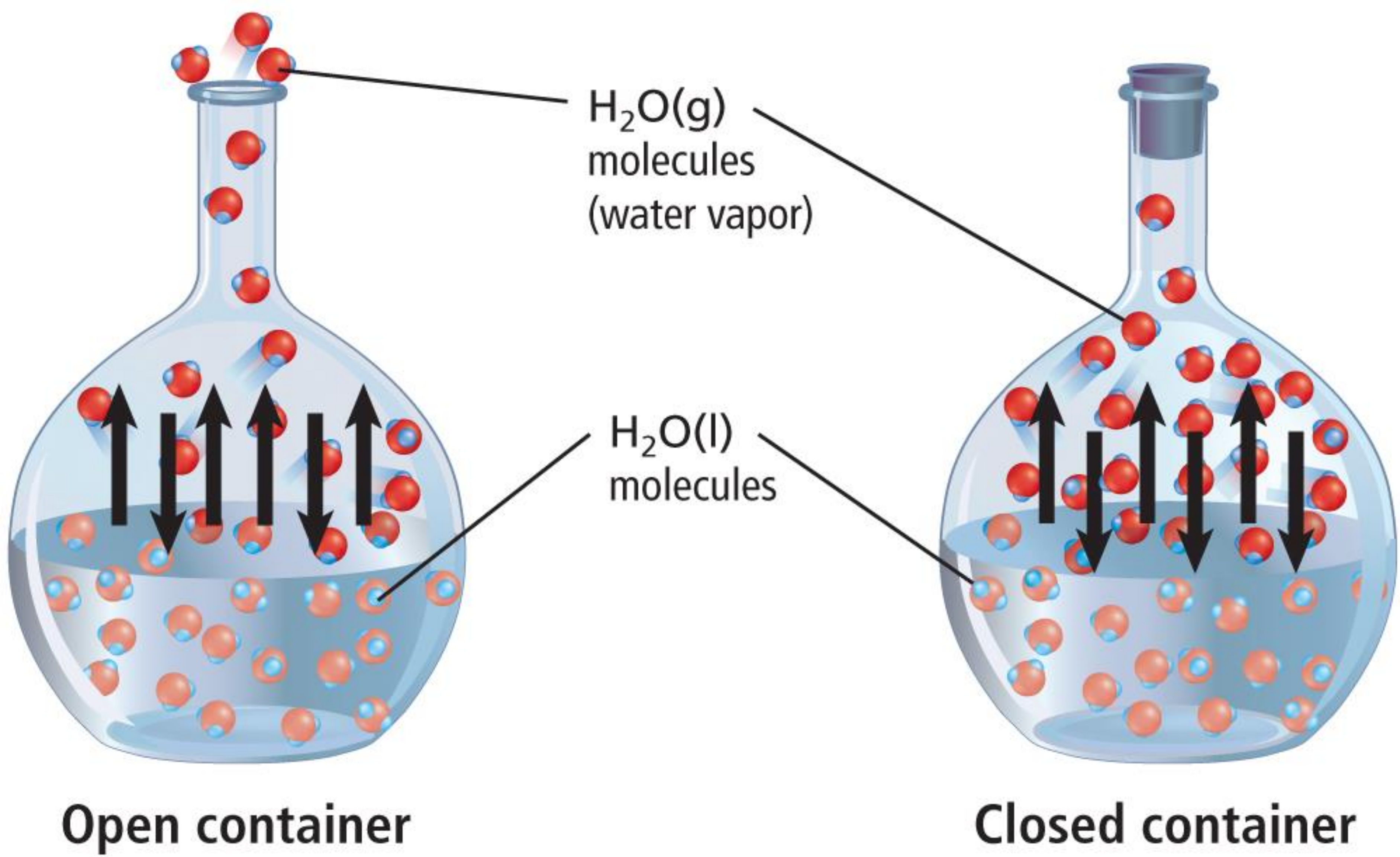
Vaporization

- The change of a liquid → gas is called *vaporization*
  - an example of separating molecules
- Evaporation: happens at the exposed surface of a liquid
- Boiling: happens within the liquid itself

Evaporation

- Evaporated liquids are gases – and so exert pressure
- **vapor pressure**
- The stronger the IMF's, the slower the evaporation rate, the lower the vapor pressure for a given temperature

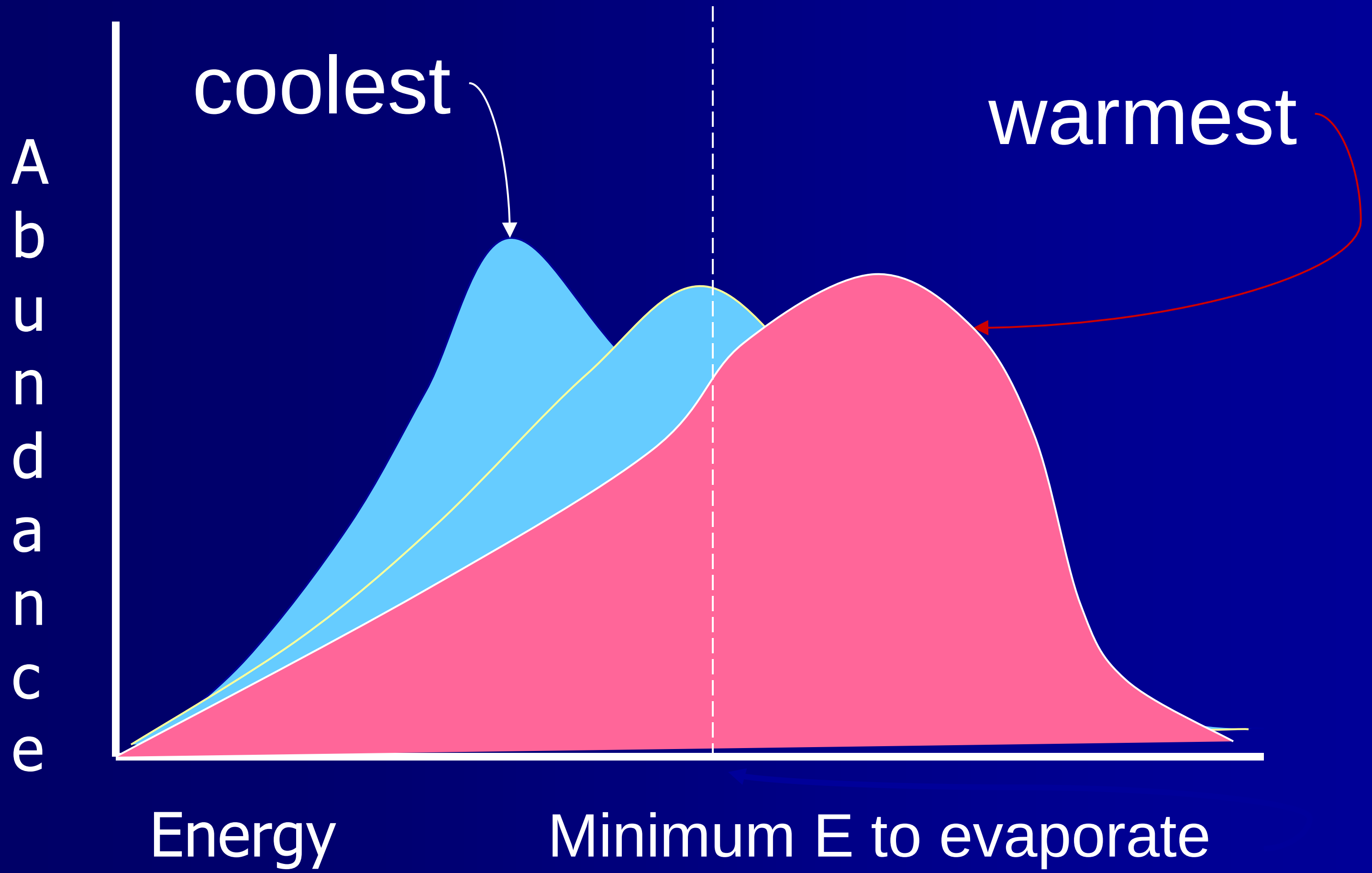


$H_2O(g)$
molecules
(water vapor)
$H_2O(l)$
molecules
Open container
Closed container

Evaporation

- The higher the T of a substance, the more molecules with enough energy to overcome cohesive forces/surface tension and evaporate
- As liquid T ↑, vapor P ↑

Temperature is ~ the average KE of a sample



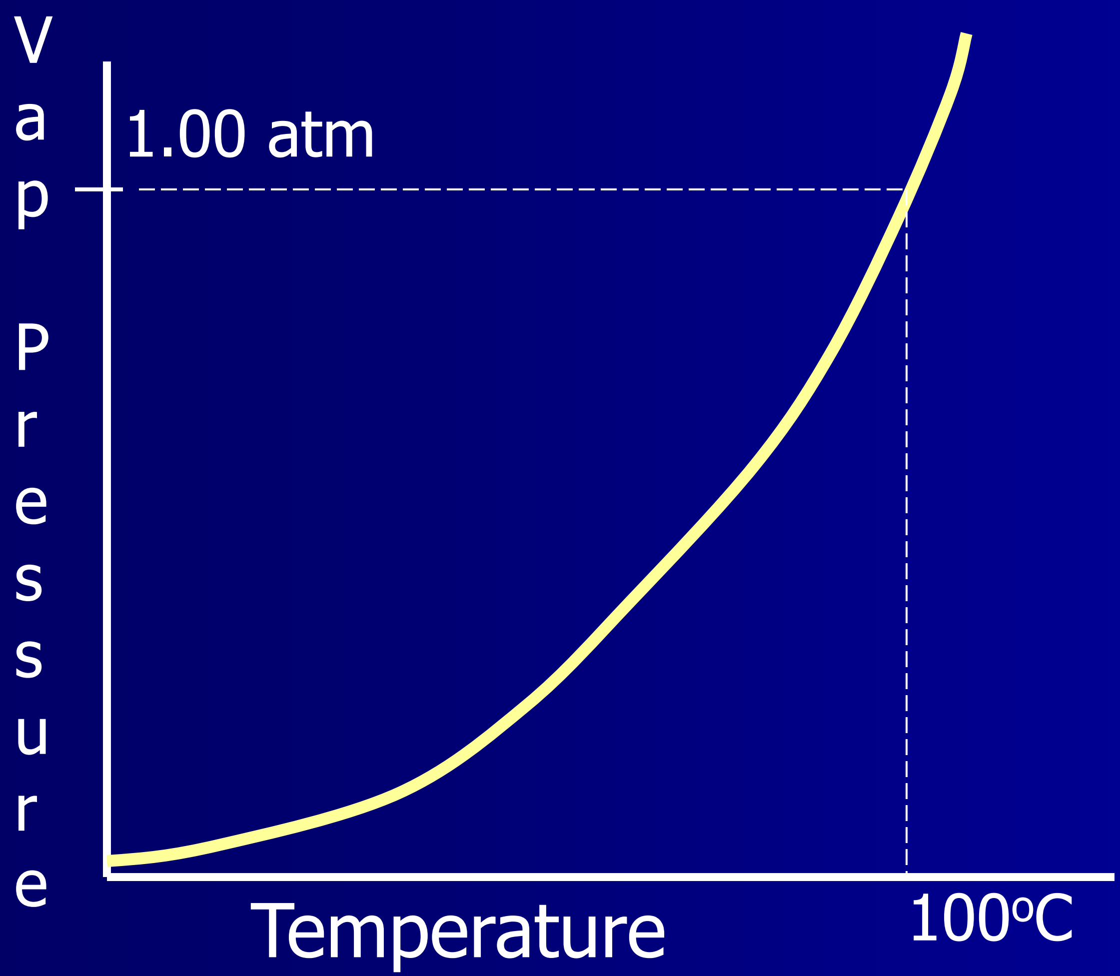
What happens...

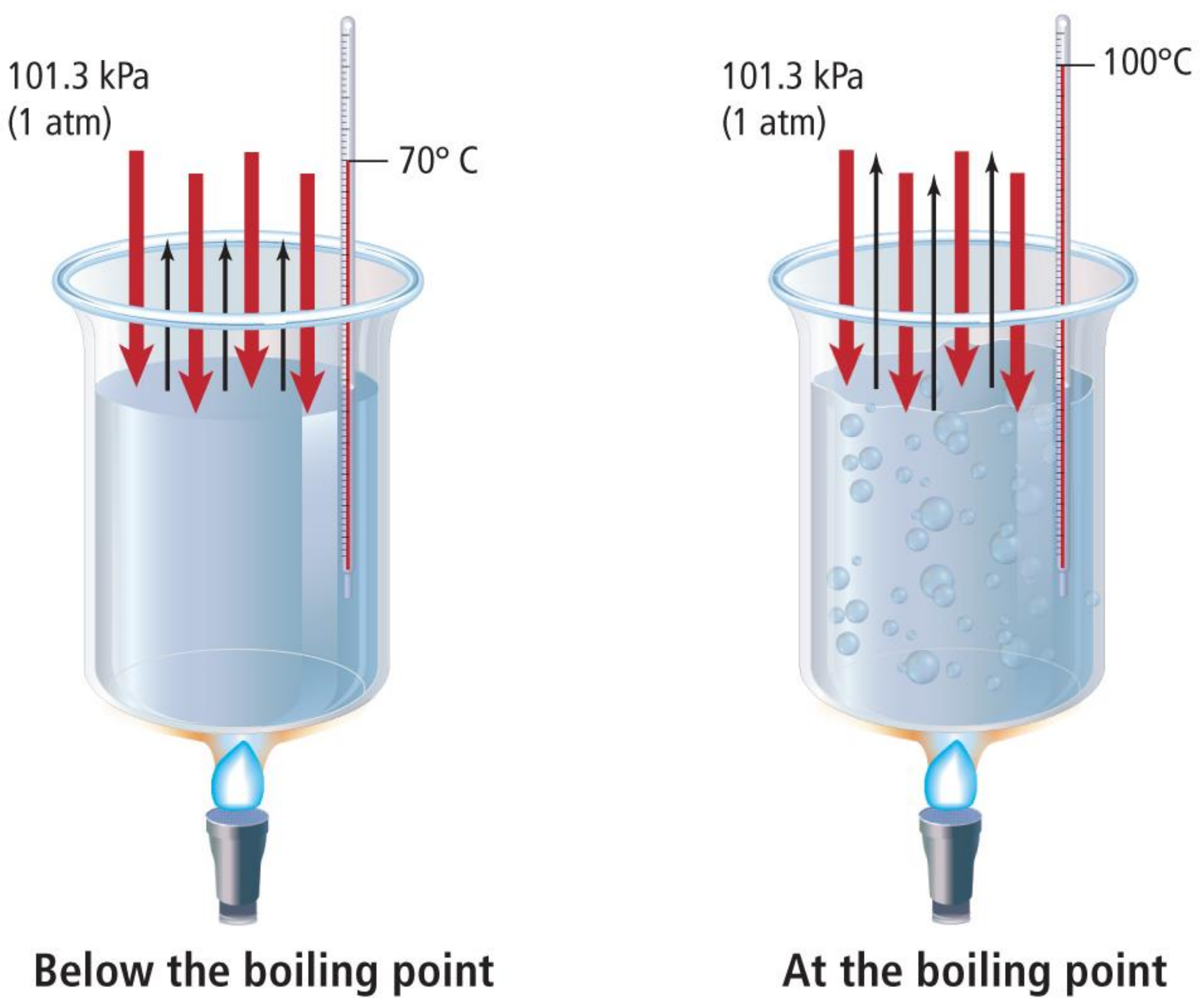
- To the evaporation rate
  - if the temperature = the boiling point ?
- **All** the molecules, on average, have enough energy to vaporize
  - the liquid boils

What happens...

- If the vapor pressure equals the atmospheric pressure ?
- All the molecules, on average, have enough energy to vaporize
  - –the liquid boils

T vs Vapor Pressure




101.3 kPa
(1 atm)
70° C
Below the boiling point
101.3 kPa
(1 atm)
100°C
At the boiling point

How can you boil a liquid?

1) Heat it to its boiling point
   - vapor P = air P
2) Reduce the air P above it to equal the vapor P of the liquid at that temperature
   - air P = vapor P

The stronger the IMF…

- The *higher* the melting point
- The *higher* the boiling point
- The *higher* the viscosity
- The *higher* the surface tension

- The lower the *vapor pressure*

Intermolecular Forces of Attraction

Forces of attraction between molecules