Intermolecular Forces

Reading:	Ch 11, sections 1-9	Homework:	Chapter 11: 49, 51*, 53*, 59
	Ch 12, section 2		Chapter 12: 29, 31, 33

* = 'important' homework question

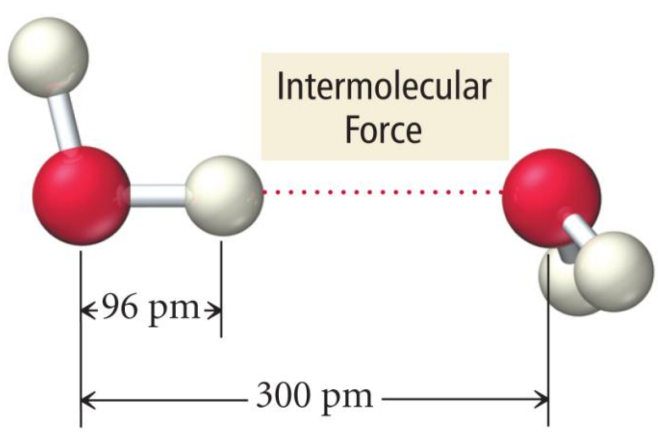
Background

Discussion: What is the difference between an ***inter****molecular* force and an ***intra***molecular force? Hint: Think about the difference between flying to Cleveland and Flying to Europe

*Intra*molecular Force:

*Inter*molecular Force:

Example: water

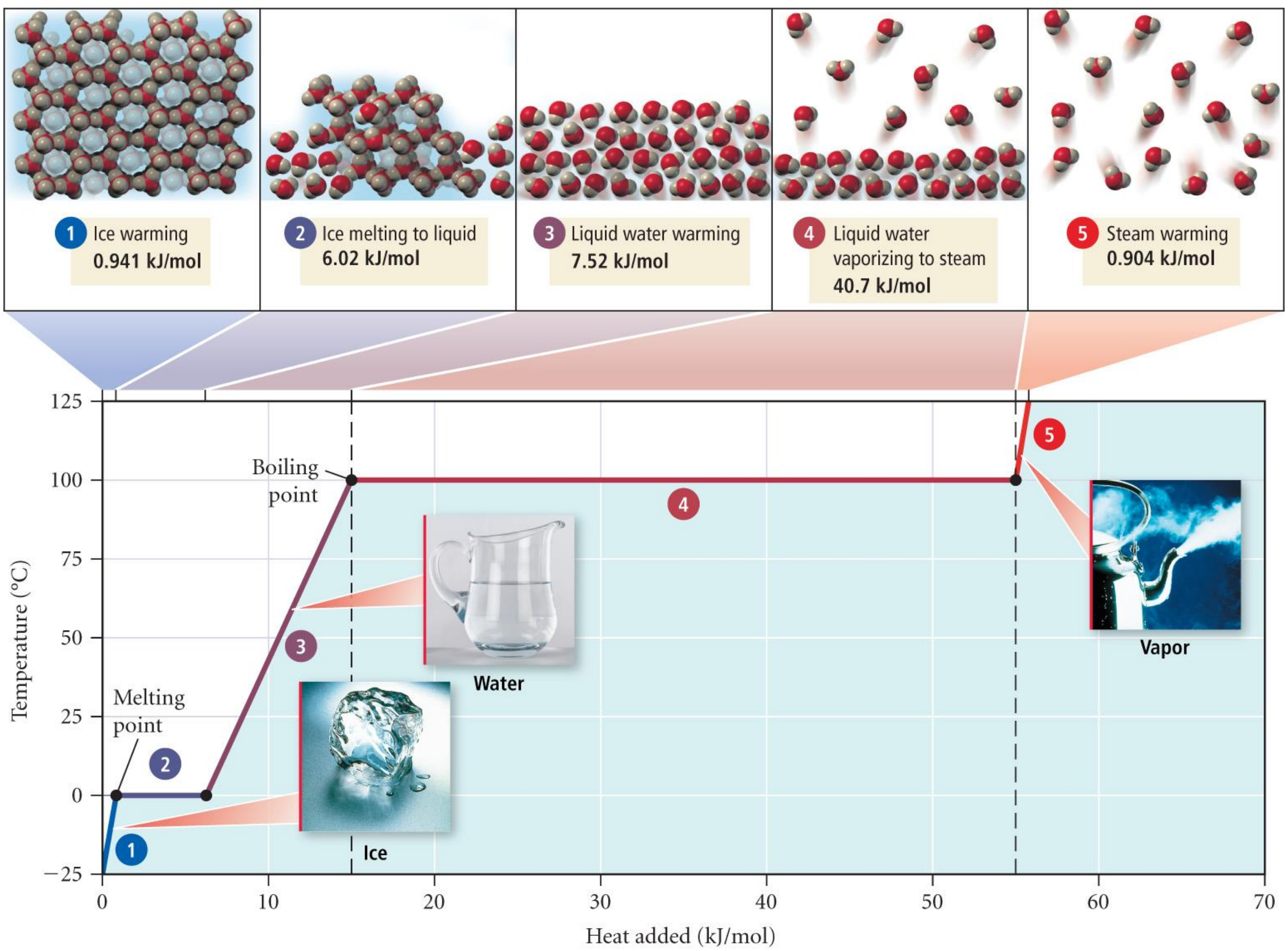


Types of Intermolecular Forces (weak bonds *between* molecules)

Intermolecular forces are what hold *molecular* materials together in the liquid or solid state (gases experience no intermolecular forces so are free to fill the container in which they are placed)

Intermolecular bonds are broken when energy (heat) greater than the intermolecular bond strength is applied to the material. This is why materials have specific melting and freezing points.

States of Matter and Heating / Cooling Curves



Notes:

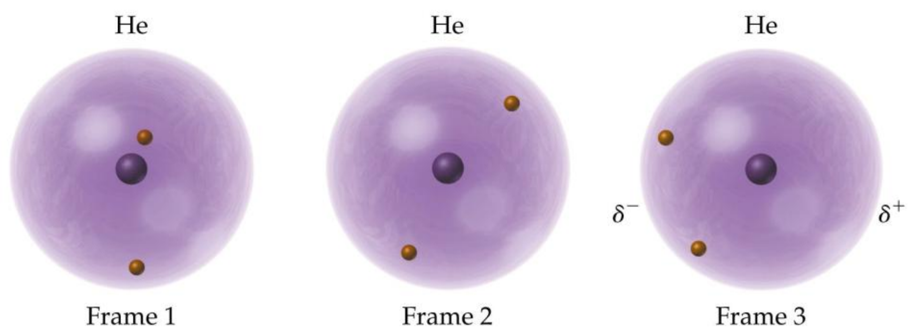
Overview: There are THREE types of intermolecular force (bond):

Type of Force	Strength	Notes
London Dispersion Forces (induced dipole - dipole)	weak - strong	Common to ***all*** molecular materials
Dipole - Dipole	strong	Only for polar molecules
Hydrogen Bonding	very strong	Only for specific molecules

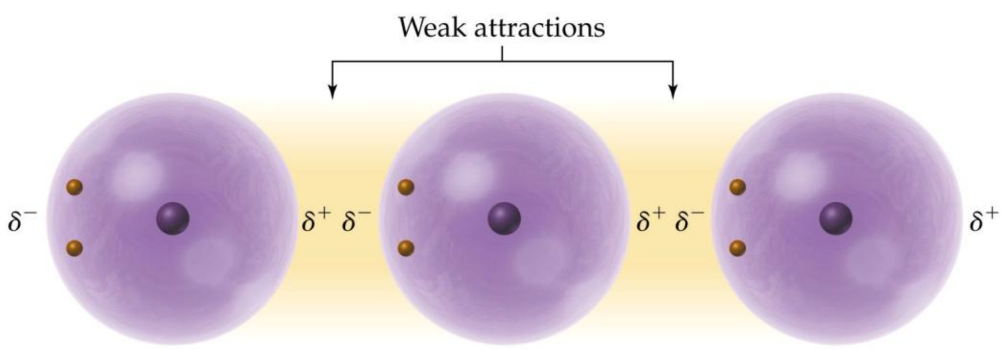
London Dispersion Forces (induced dipole – dipole bonding)

Theory:

1. Short lived *time dependant dipoles* are being created in atoms (and molecules) continually as electrons move around their respective orbital(s). Recall that a dipole is a special separation of charge. Since all atoms and molecules contain electrons, they all do this.



2. At close to the condensation point (gas - liquid), the atoms or molecules are moving slowly enough for an *induced dipole* to form between adjacent atoms or molecules. This spreads throughout the material, turning it to a liquid (or solid).



Analogy: Induced Dipole interactions are much like the ‘wave’ - seen at various sporting events when the crowd becomes ‘bored’ (like at Sox games).

CLASS DEMO: ‘Helium in the house’

Likely Exception: British soccer – extreme boredom

“Com’on lads, let’s see how they like the taste of this pointy metal fence”

The strength of London Dispersion Forces

Discussion: What basic property of an atom or molecule results in the formation of induced dipole – dipole bonding (London forces)? How then can the degree dipole – dipole bonding be increased? What *macroscopic* affect would this have?

The strength of an induced dipole – dipole bond is proportional to the number of electrons an atom or molecule has. Since atomic mass scales with the number of electrons:

Strength of London of Forces ∝ Molecular mass ∝ boiling point*

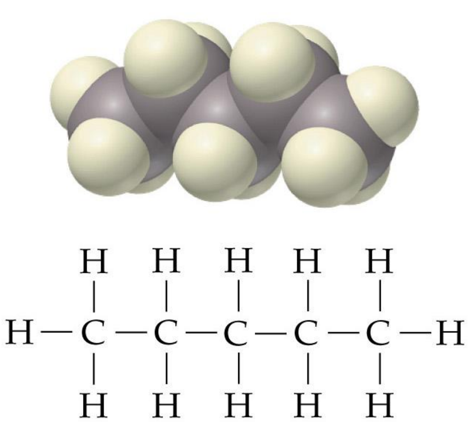
*for atoms and molecules that only have induced dipole-dipole intermolecular forces

Boiling Points, # electrons and Molar masses ($\mathcal{M}$) for the Nobel gases

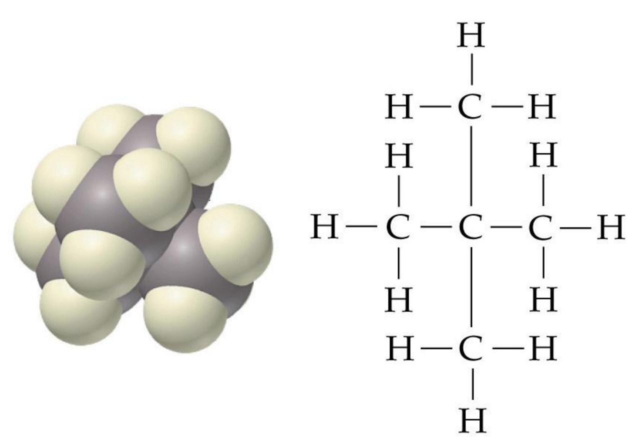
Nobel Gas	# electrons	$\mathcal{M}$ (g/mole)	Bpt. (K)
He	2	4.0	4.6
Ne	10	20.2	27.3
Ar	18	39.9	87.5
Kr	36	83.8	120.9

Molecular shape considerations

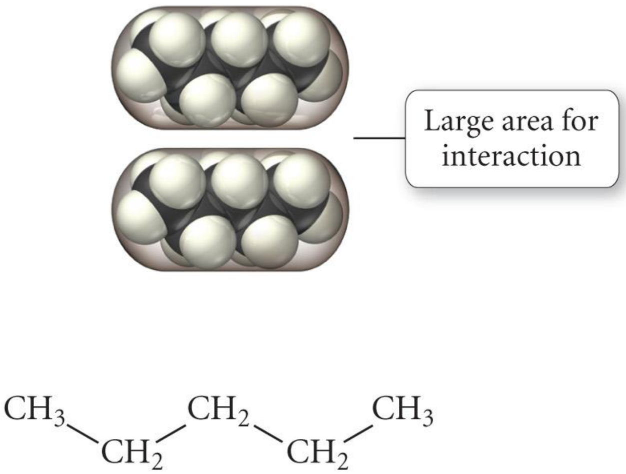
Discussion: Pentane (a) and isopentane (b) have identical molecular weights and molecular formulas. However, their shapes and boiling points are different. Explain.



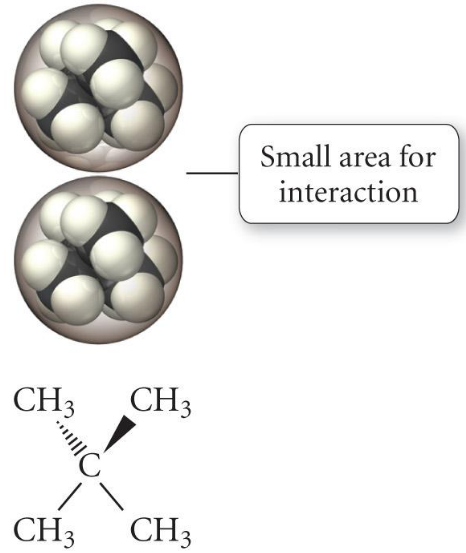
(a) Pentane (bp = 309.4 K)



(b) 2,2-Dimethylpropane (bp = 282.7 K)



(a) *n*-Pentane



(b) Neopentane

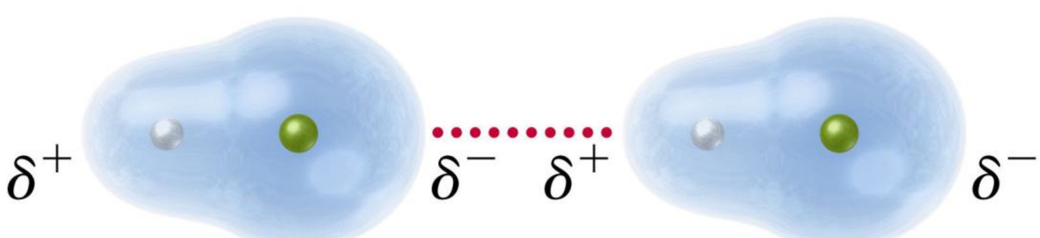
<u>Dipole-Dipole and Dipole – Ion interaction</u>

A number of molecules have *permanent* dipoles, so experience stronger dipole–dipole interactions *in addition* to London dispersion forces.

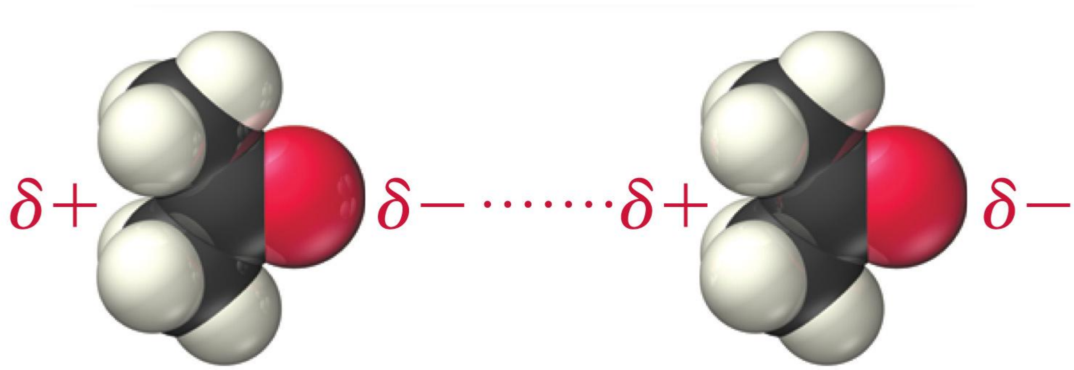
<u>Recall</u>: Polar molecules have a net dipole (separation of charge). HCl is a good example of a polar molecule.

The δ^+ and δ^- ‘ends’ of polar molecules are attracted to one another – this is a dipole- dipole intermolecular force.

<u>Example</u>: HCl



Any molecule with a *permanent dipole* will undergo dipole-dipole intermolecular bonding. Example, CH_3COCH_3 (polar C=O bond)



> The strength of a dipole-dipole intermolecular interaction is related to the strength of a molecule's permanent dipole (dipole moment).
>
> **Strength of dipole-dipole force ∝ Dipole moment ∝ boiling point**

Boiling Points, Dipole moments for some similar Mwt. ($\mathcal{M}$) molecules

(see appendix / slide)

Compound	Formula	$\mathcal{M}$ (g/mole)	Dipole moment (μ)	Bpt. (K)
Propane	$CH_3CH_2CH_3$	44	0.1	231
Dimethyl ether	CH_3OCH_3	46	1.3	254
Ethylene oxide	$(CH_2)_2O$	44	1.9	284
Acetaldehyde	CH_3CHO	44	2.7	294
Acetonitrile	CH_3CN	41	3.9	355

Hydrogen Bonding

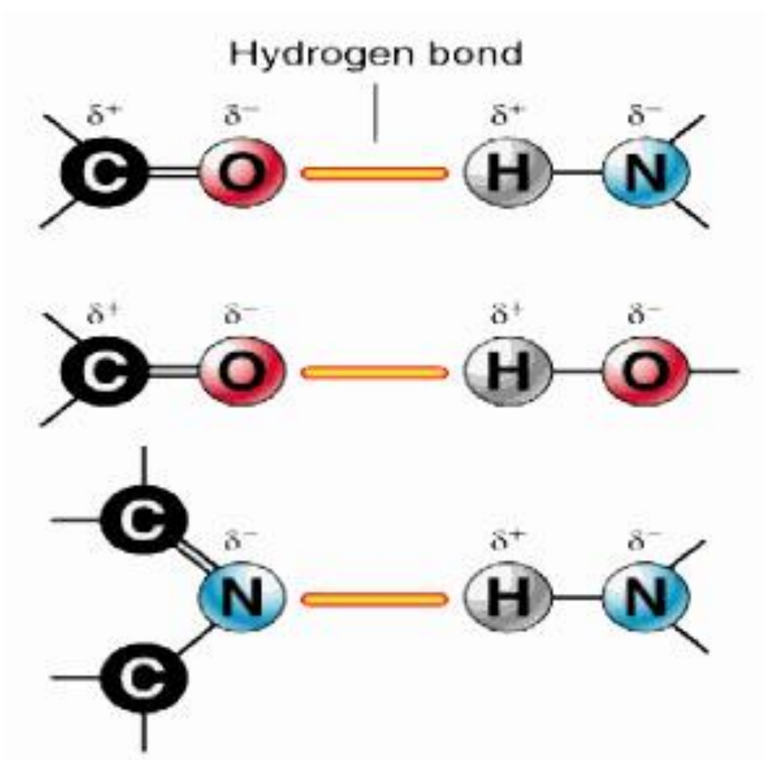
Hydrogen bonding is a 'special' form of strong dipole-dipole interaction.

Hydrogen bonds are the strongest form of intermolecular force. A hydrogen bond is ~10% the strength as an intramolecular covalent bond.

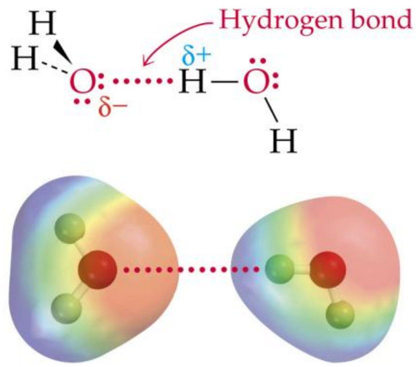
<u>Requirements of a hydrogen bond</u>: the **-X:**$^{\delta-}$ · · · · · $^{\delta+}$**H –**$^{\delta-}$**Y- coordinate**

<u>Diagram</u>

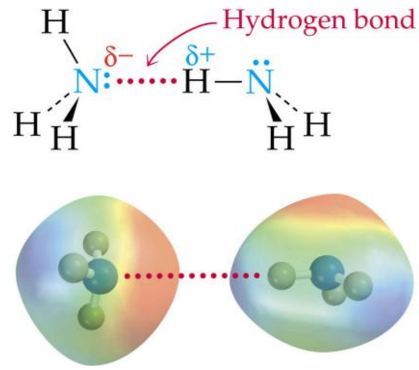
<u>Typical H-bond coordinates</u>



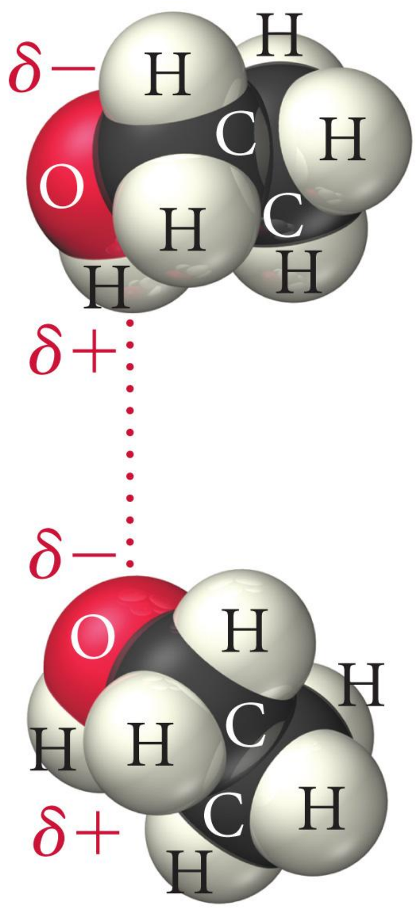
Examples:



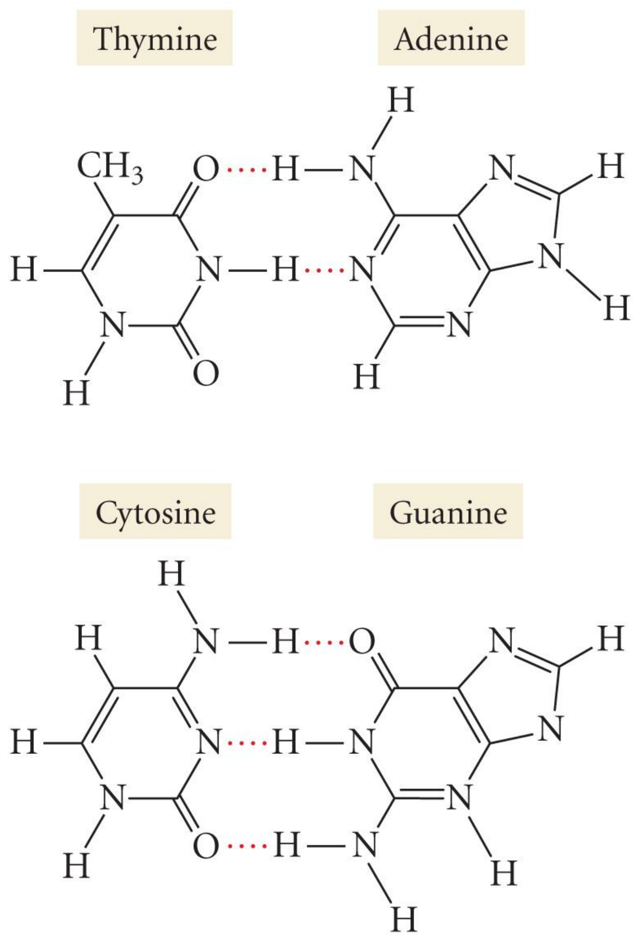
Water (H_2O)



Ammonia (NH_3)

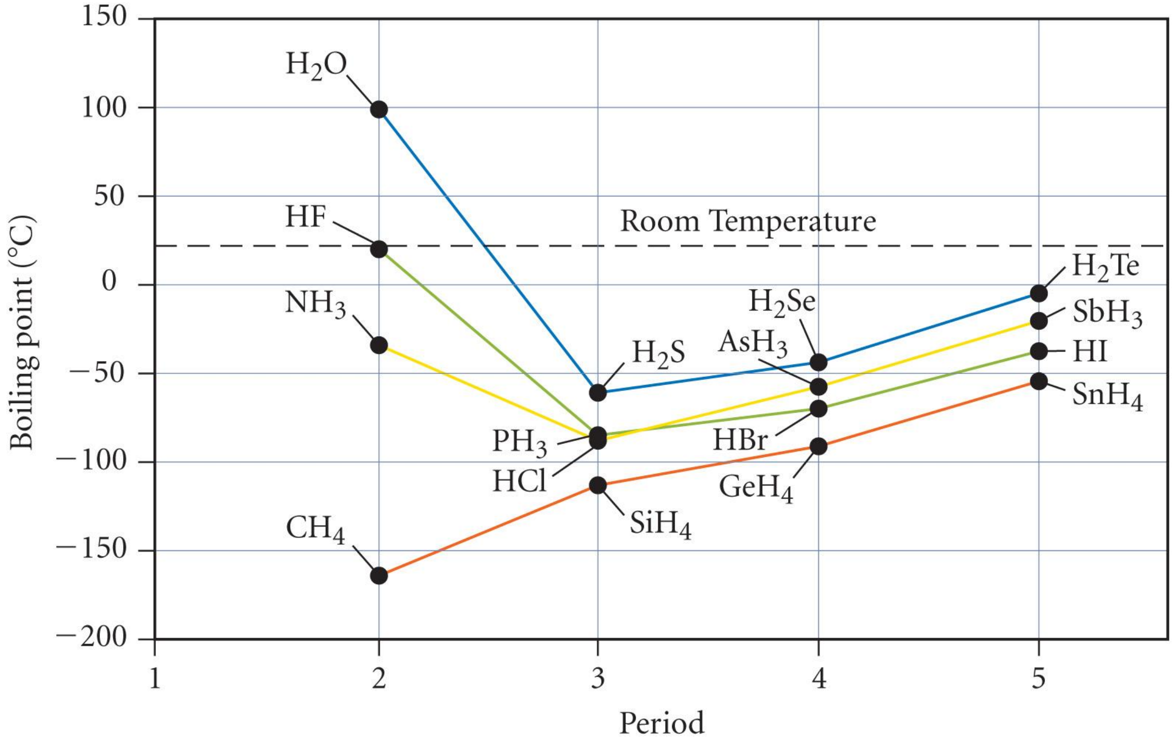


Ethanol

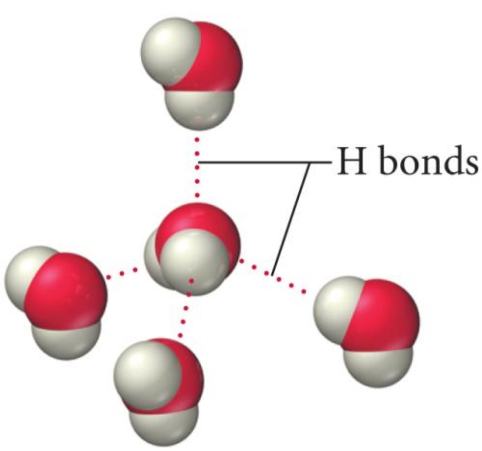


DNA Base Pairs (see appendix)

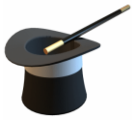
Hydrogen bonding greatly increases the boiling points of H-bonded materials. See figure.



Discussion: ‘*Amazing* water’: Based on the above graph, what s the projected boiling point of water based *only* on induced dipole-dipole forces? Why is the actual boiling point of water so high? What consequences does this have for, oh, let’s say, *the emergence of life on earth*??



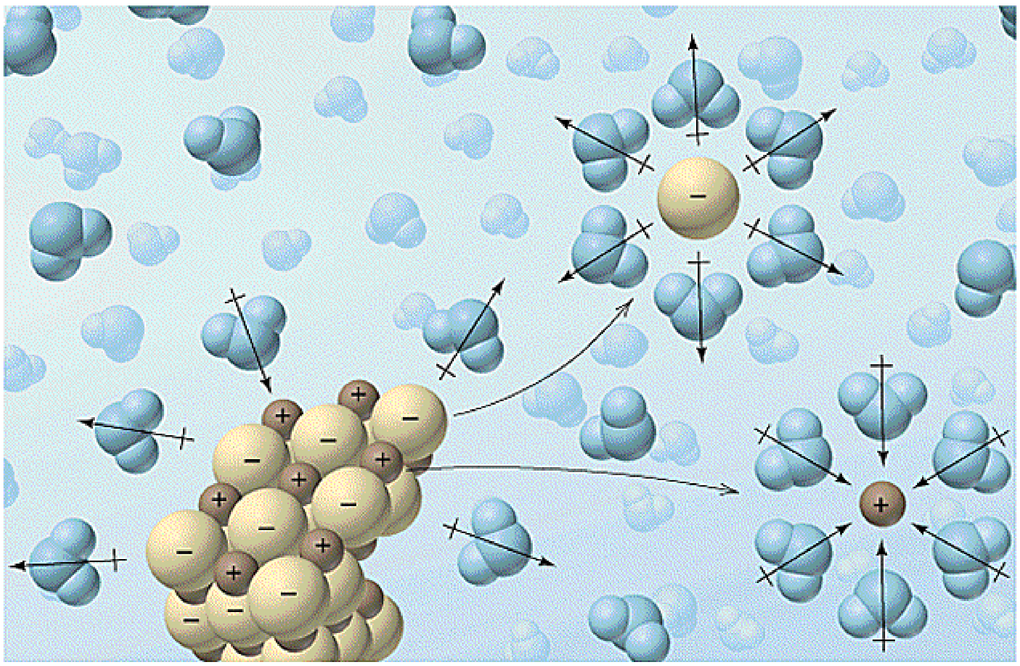
Discussion: Table salt (NaCl) is very *soluble* in water, while 'oil' (e.g. pentane) and water are *immiscible* – what types of intermolecular interaction(s) are responsible for these facts? (See appendix).



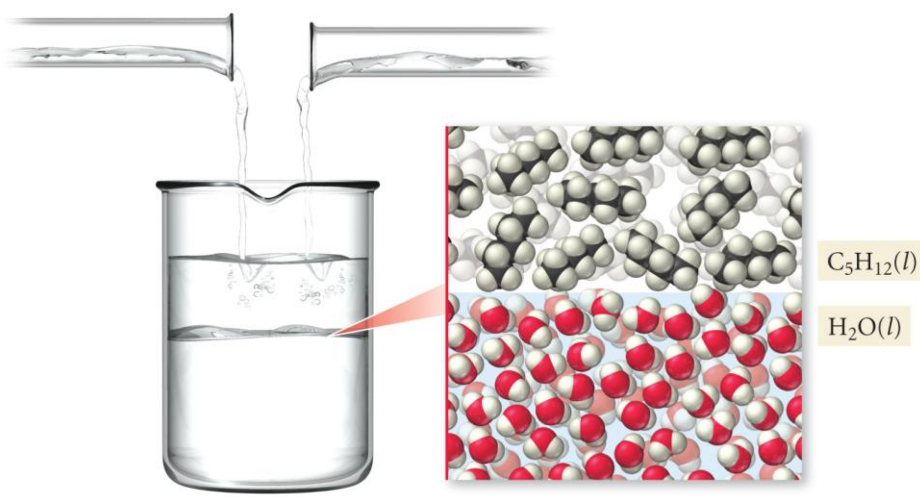
Recall the Chemist's stock phrase regarding solubility / immiscibility:

"LIKE DISSOLVES IN LIKE"

Dipole – Ion interactions: NaCl (aq)



Polar- Polar vs non-Polar – non Polar interactions: 'oil and water'

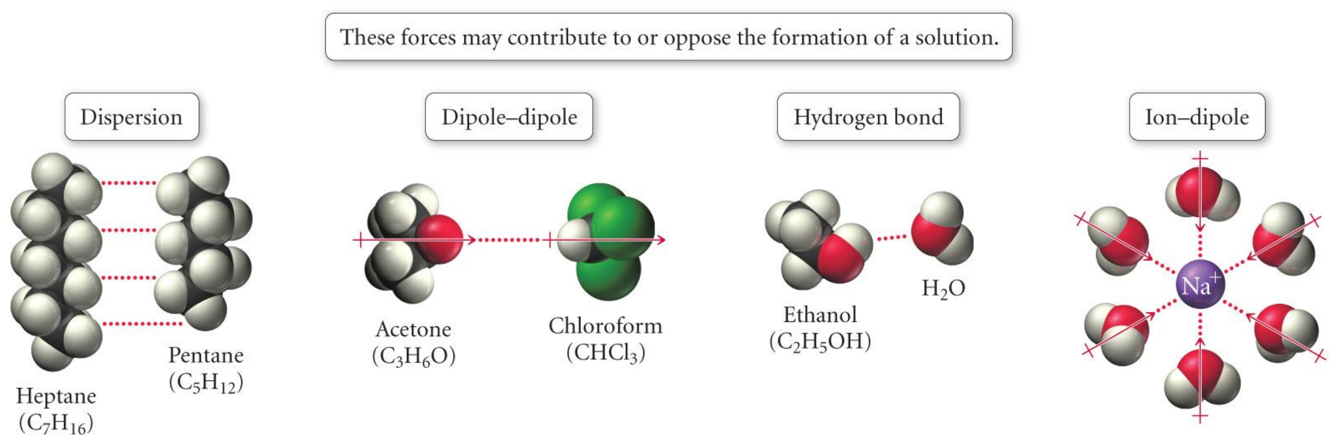


Summary

- All materials have *induced* dipole –dipole / London Dispersion forces (they all have electrons)
- Additional permanent dipole – dipole or H- bonding interactions occur for a small subset of molecules with the necessary molecular features
- H-bonded materials have *much* greater boiling points that predicted using only London dispersion force trends (see above figure)

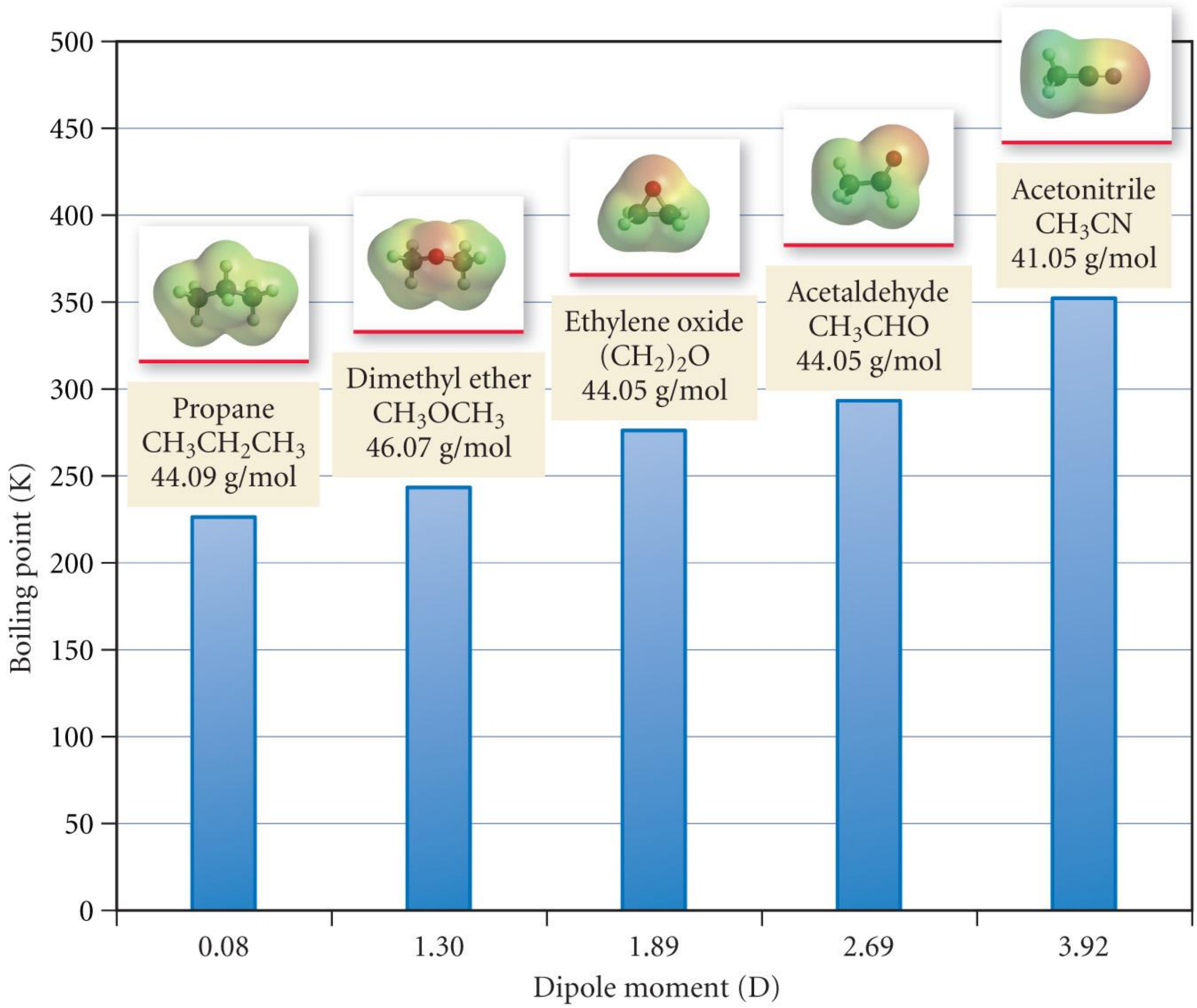
H-bonding >> **Dipole - Dipole** > **London dispersion**
strongest → *weakest*

- Recall that 'like dissolves in like' due to complementary intermolecular forces (and vice versa):



Appendix

Boiling Point vs Dipole moment for similar Mwt. Compounds



<u>DNA replication</u>