Intermolecular Forces

<u>Reading</u>:	Ch 14 sections 3 -6	<u>Homework</u>:	14.3 questions 20, 22*, 24,26

* = 'important' homework question

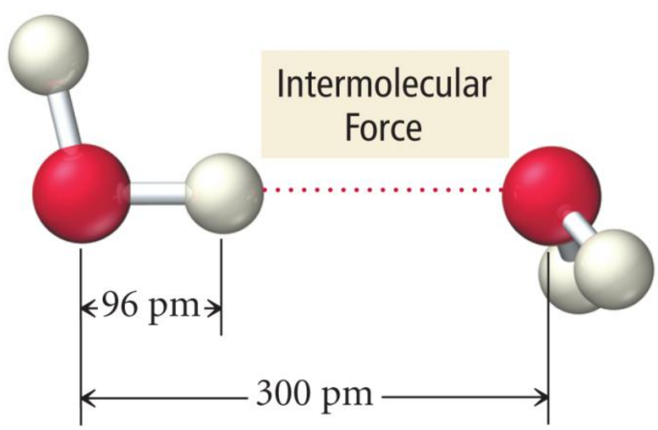
Background

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

<u>*Intra*molecular Force</u>:

<u>*Inter*molecular Force</u>:

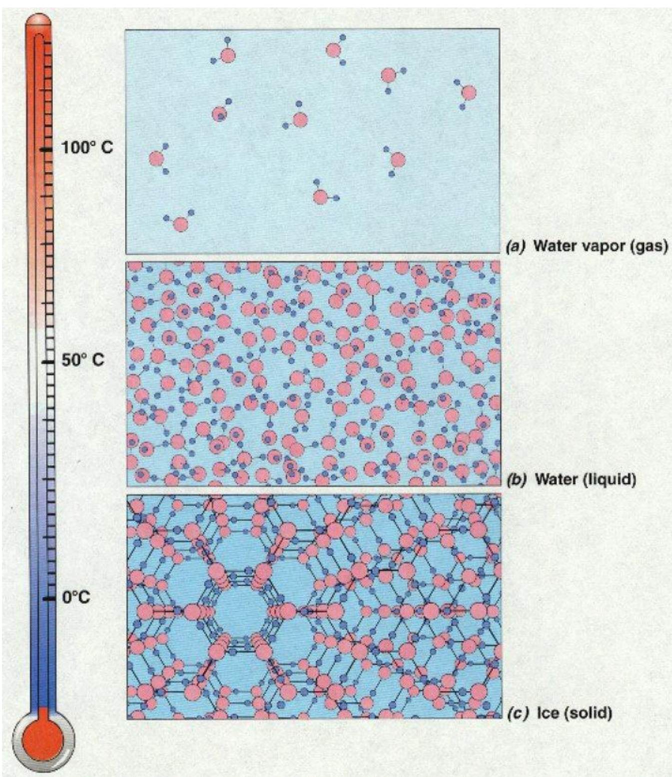
<u>Example</u>: water



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

> **Intermolecular forces are what hold molecular materials together in the liquids 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.

<u>Recap</u>: States of matter



<u>Notes</u>

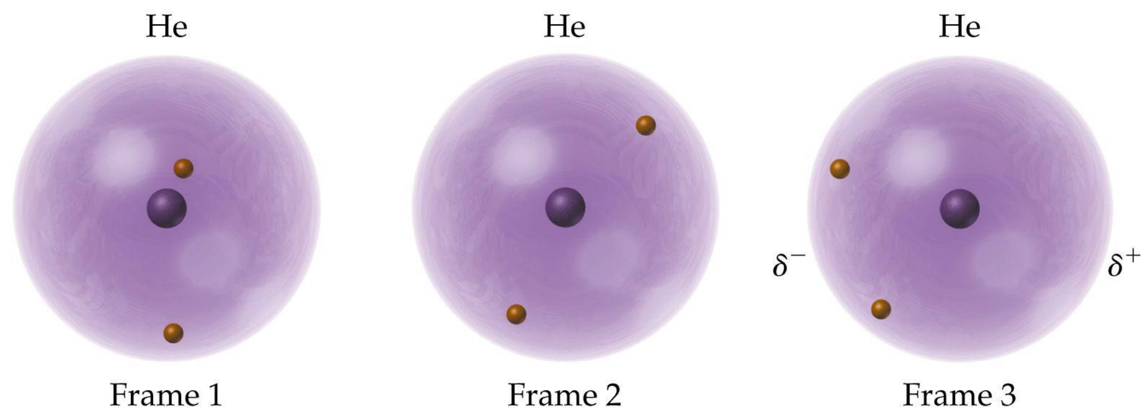
<u>Overview</u>: There are THREE types of intermolecular force (bond):

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

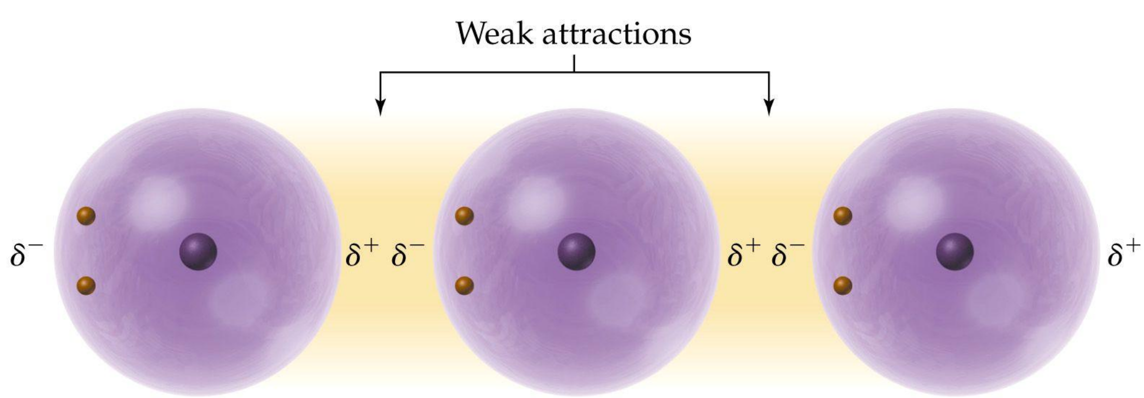
London Dispersion Forces (induced dipole – dipole bonding)

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*

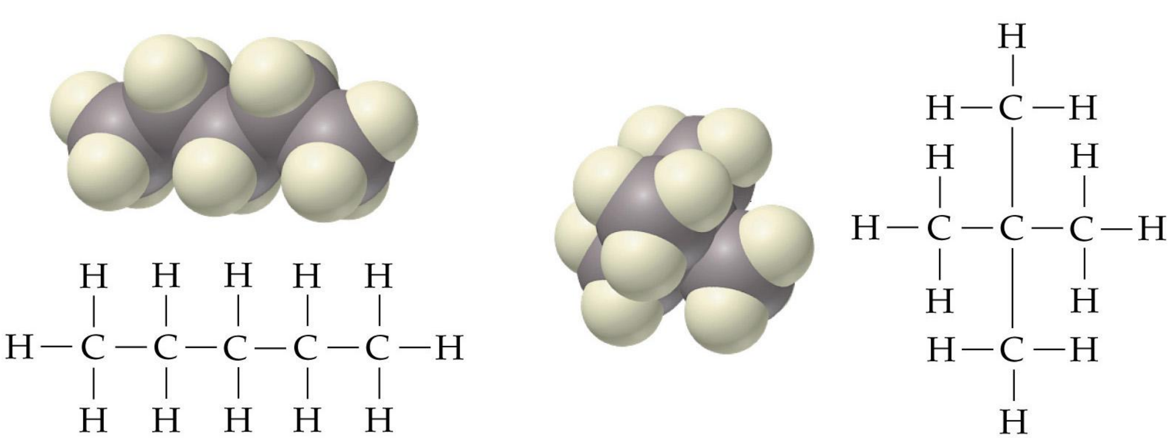
*for atoms and molecules that only have induced dipole-dipole intermolecular forces

<u>Boiling Points and Molar masses ($\mathcal{M}$) of the Nobel gases</u>

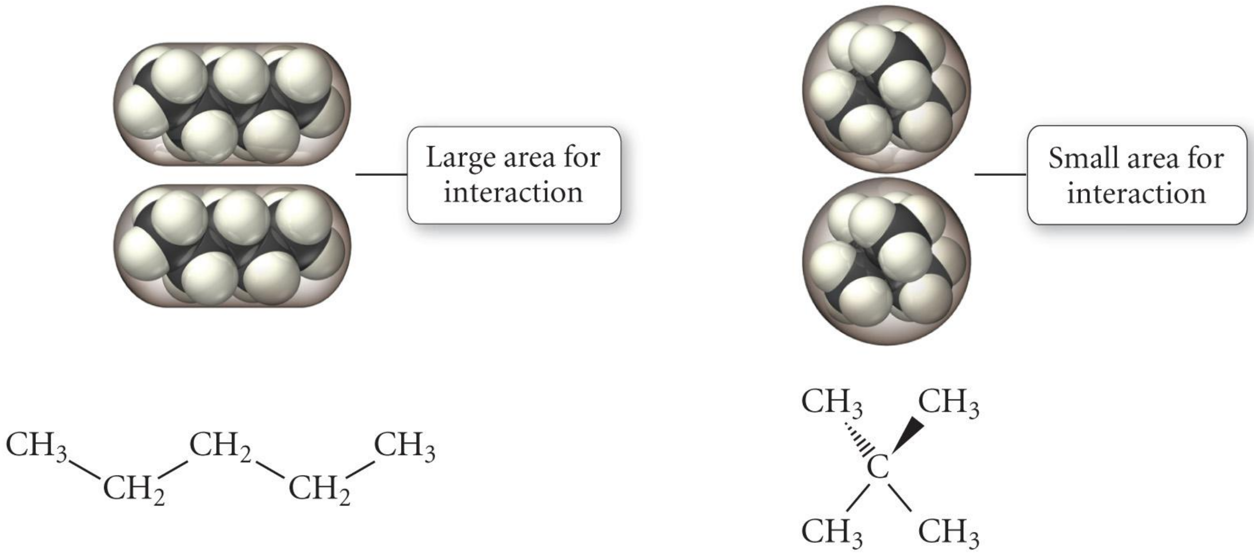
Nobel Gas	$\mathcal{M}$ (g/mole)	Bpt. (K)
He	4.0	4.6
Ne	20.2	27.3
Ar	39.9	87.5
Kr	83.8	120.9

<u>Molecular shape considerations</u>

<u>Discussion</u>: 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**

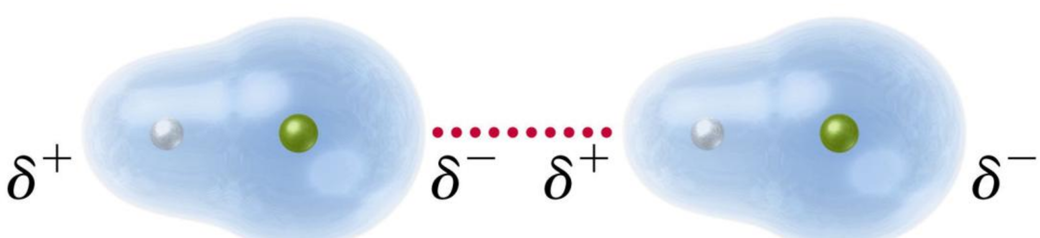
<u>Dipole-Dipole and Dipole – Ion interaction</u>

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

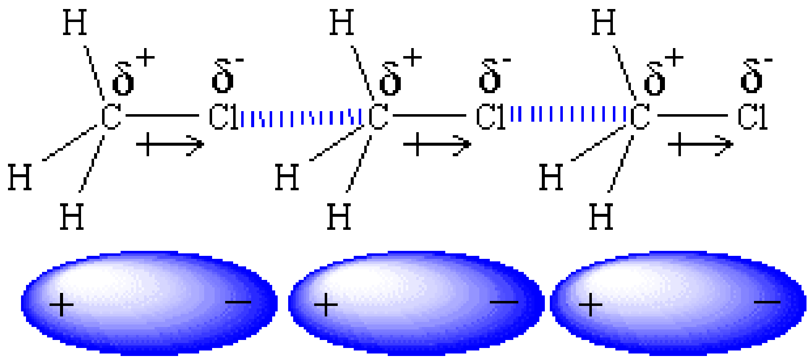
<u>Recall</u>: Polar molecules have a net dipole (separation of charge). HCl is a good example of a polar molecule.

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_3Cl (polar C-Cl bond)



The strength of a dipole-dipole intermolecular interaction is related to the strength of a molecule's permanent dipole (dipole moment).

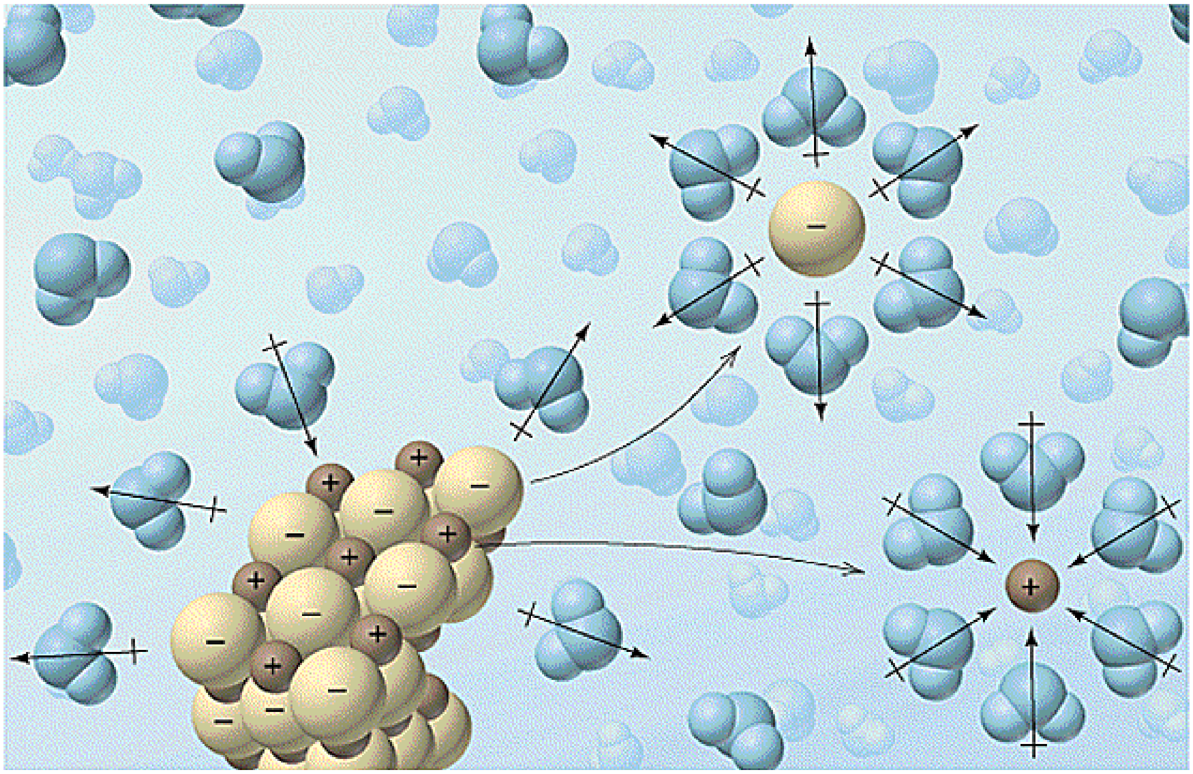
Strength of dipole-dipole force $\propto$ Dipole moment $\propto$ boiling point

Boiling Points, Dipole moments and Molar masses ($\mathcal{M}$) of some molecules

Compound	Formula	$\mathcal{M}$ (g/mole)	Dipole moment (μ)	Bpt. (K)
Propane	$CH_3CH_2CH_3$	44	0.1	231
Ethanal	CH_3CHO	44	2.7	294
Acetonitile	CH_3CN	41	3.9	355

Discussion: Table salt (NaCl) is very soluble in water – what type of intermolecular interaction is responsible for this fact?

Dipole – Ion interactions: NaCl (aq)



Hydrogen Bonding

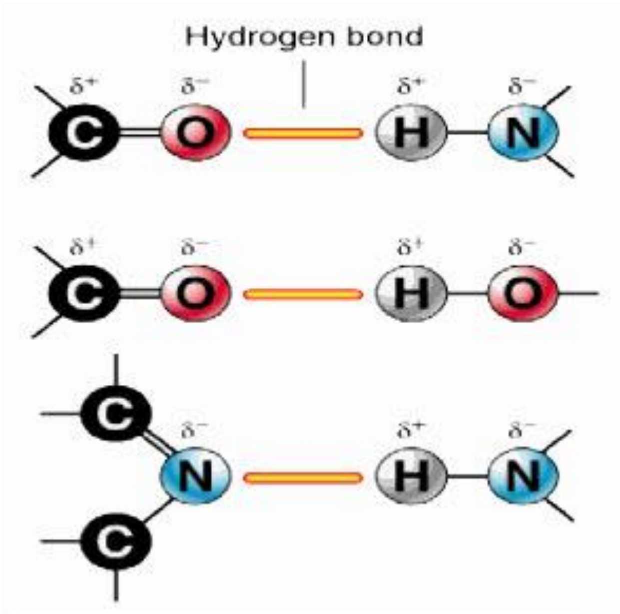
Hydrogen bonding is a 'special' form of strong dipole-dipole interaction.

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

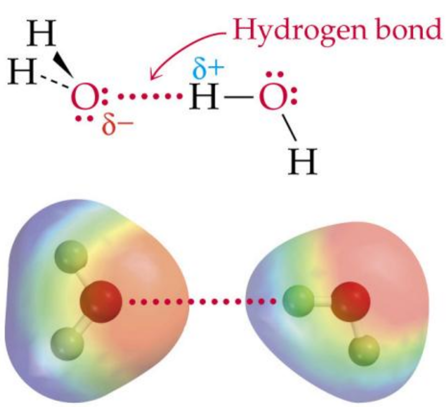
Requirements of a hydrogen bond: the **-X:**$^{\delta-}$ · · · · · $^{\delta+}$**H—**$^{\delta-}$**Y- coordinate**

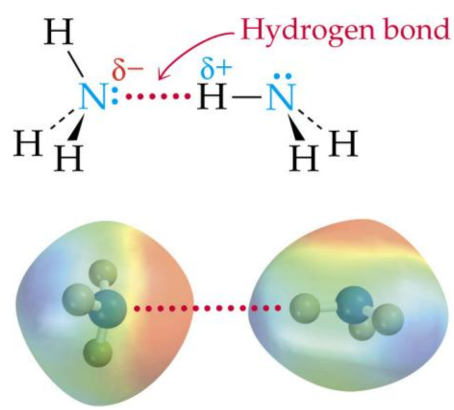
Diagram

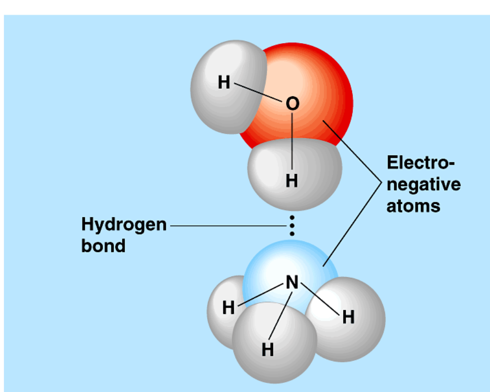
Typical H-bond coordinates

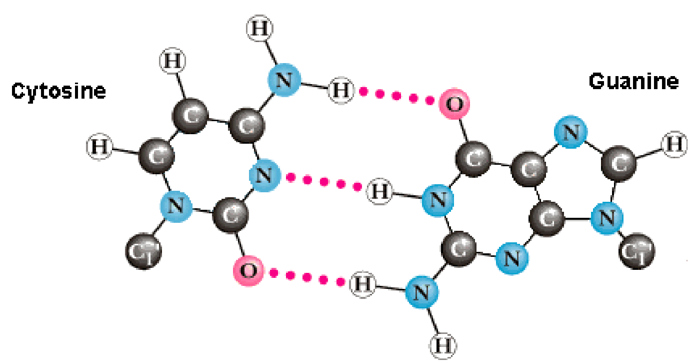


Examples:

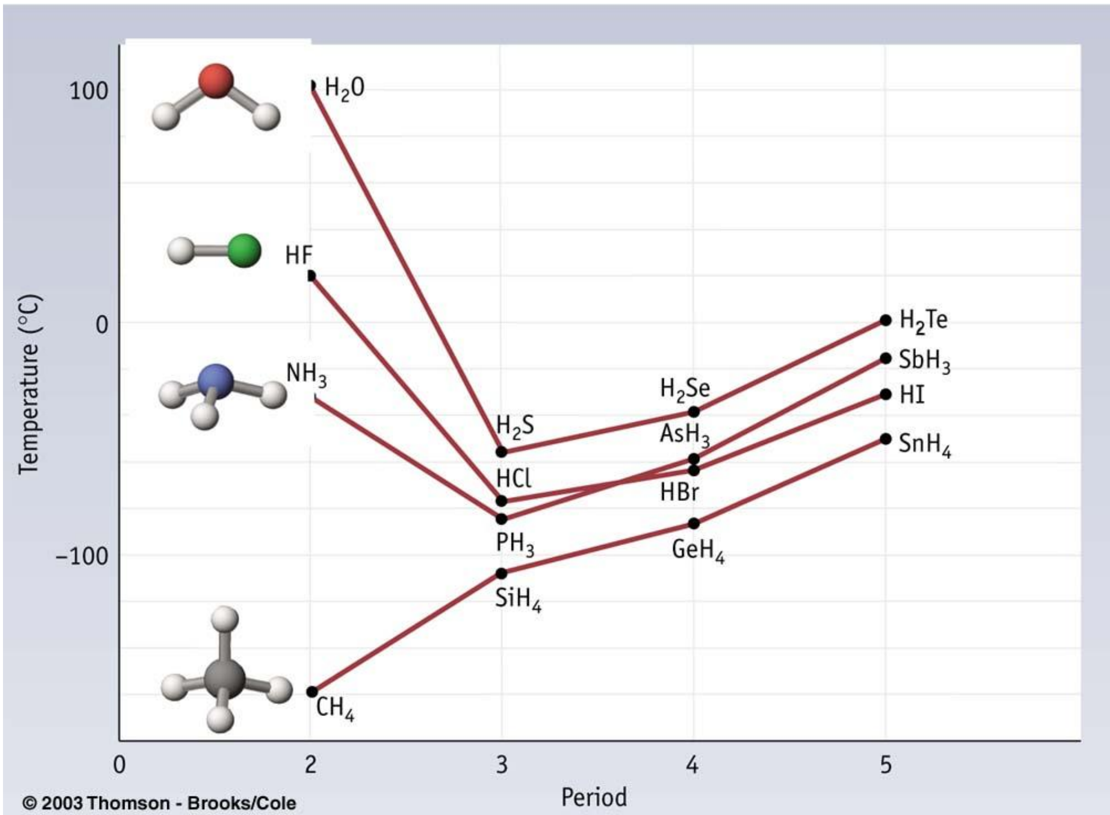








Hydrogen bonding greatly increases the boiling points of H-bonded materials. See figure.



<u>Summary</u>

- 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*