Types of Intermolecular Forces

- van der Waals forces:
  dipole-dipole
  London dispersion

- Hydrogen bonding

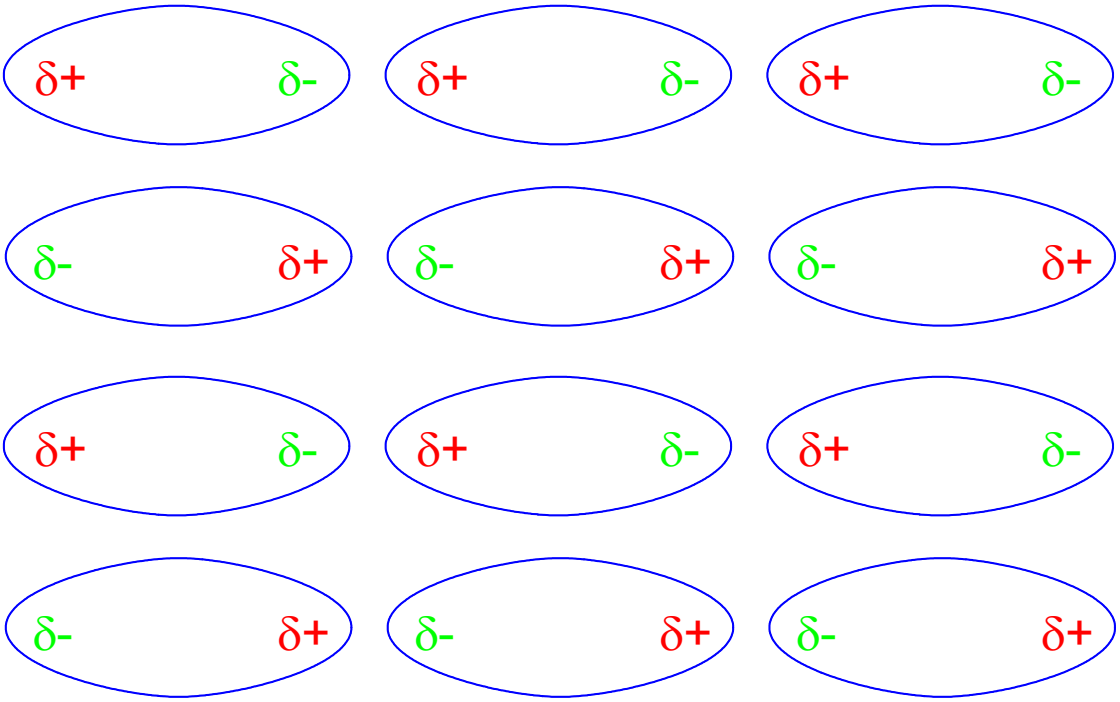
☞ Molecules can have one, two, or all three kinds of intermolecular forces, but all have London dispersion forces.

☞ Substances with stronger overall intermolecular forces, whatever their types, are more likely to have:
  - higher melting points (m.p.)
  - higher boiling points (b.p.)
  - higher enthalpies of vaporization (ΔH_{vap})
  - lower vapor pressures (v.p.)
  - a condensed phase (solid or liquid) at room temperature

☞ Typical intermolecular forces tend to be weaker than typical covalent bond strengths.
  - Covalent bonds: ≈ 50 - 950 kJ/mol
  - Intermolecular forces: ≈ 1 - 50 kJ/mol

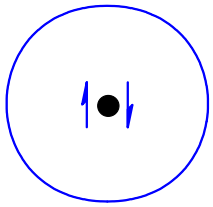
Dipole-Dipole Attractions Between Polar Molecules
Permanent Dipole Moments

$D \approx 1$ - 10 kJ/mol

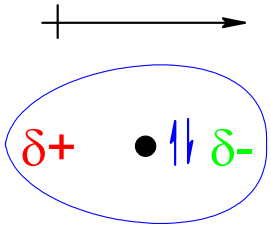


London Dispersion Forces
Transitory Dipole Moments

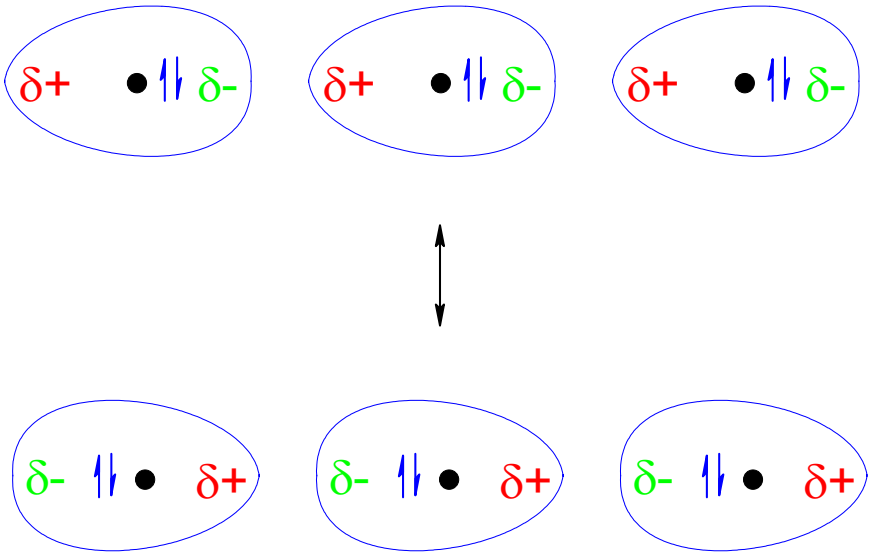
Average Electron Distribution
No Polarity



Momentary Electron Distribution
Temporary Polarity



London Dispersion Forces
Induced Transitory Dipole Moments



- London dispersion forces arise from changing electron distributions.

- All molecules have electrons, so all have London dispersion forces, regardless of whether they are polar or non-polar.

- **Polarizability** - Molecules with higher molecular weights have more electrons, generally more loosely held, resulting in electron distributions that are more susceptible to deformation from adjacent charges.

- Heavier molecules have higher London dispersion forces.

Effects of London Dispersion Forces on Properties

Group VI Hydrides, H_2X

Compound	H_2S	H_2Se	H_2Te
b.p. (^oC)	-60.33	-41.3	-2

Halogens, X_2

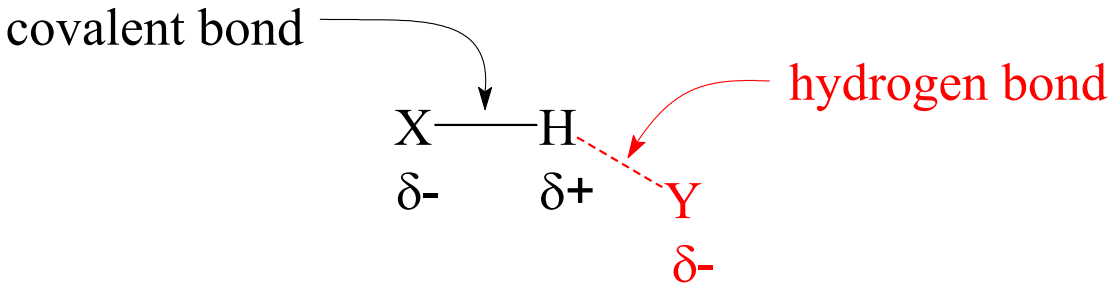
Element	F_2	Cl_2	Br_2	I_2
m.p. (^oC)	-220	-101	-7.3	114
b.p. (^oC)	-188	-34	58.8	184
At 25 ^oC	gas	gas	liquid	solid

Alkanes (C_nH_{2n+2}) at Room Temperature

n	Phase	Examples
1 - 4	gas	methane, ethane, propane, butane
5 - 17	liquid	pentane, hexane, heptane, octane, ...
18 - ∞	solid	paraffin waxes

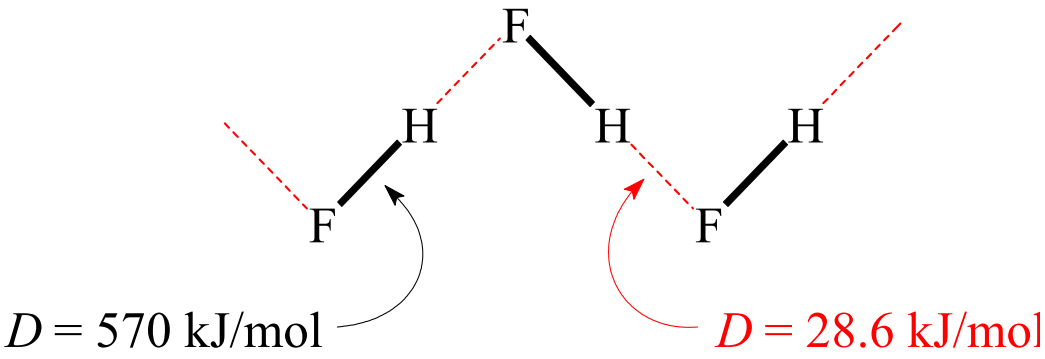
Hydrogen Bonding

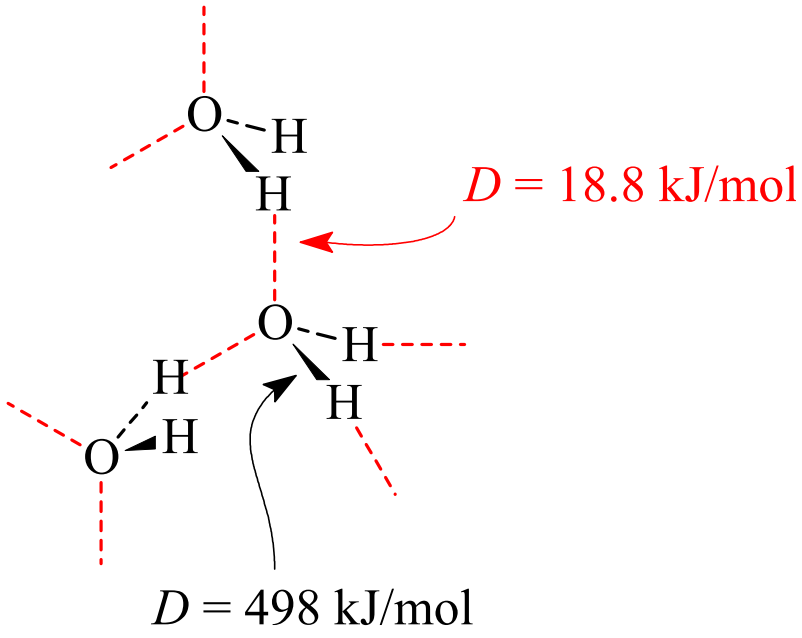
☞ A hydrogen bond is a non-covalent attraction between a hydrogen that is covalently bonded to a very electronegative atom (X) and another very electronegative atom (Y), most often on an adjacent molecule. (X and Y may be the same or different elements.)



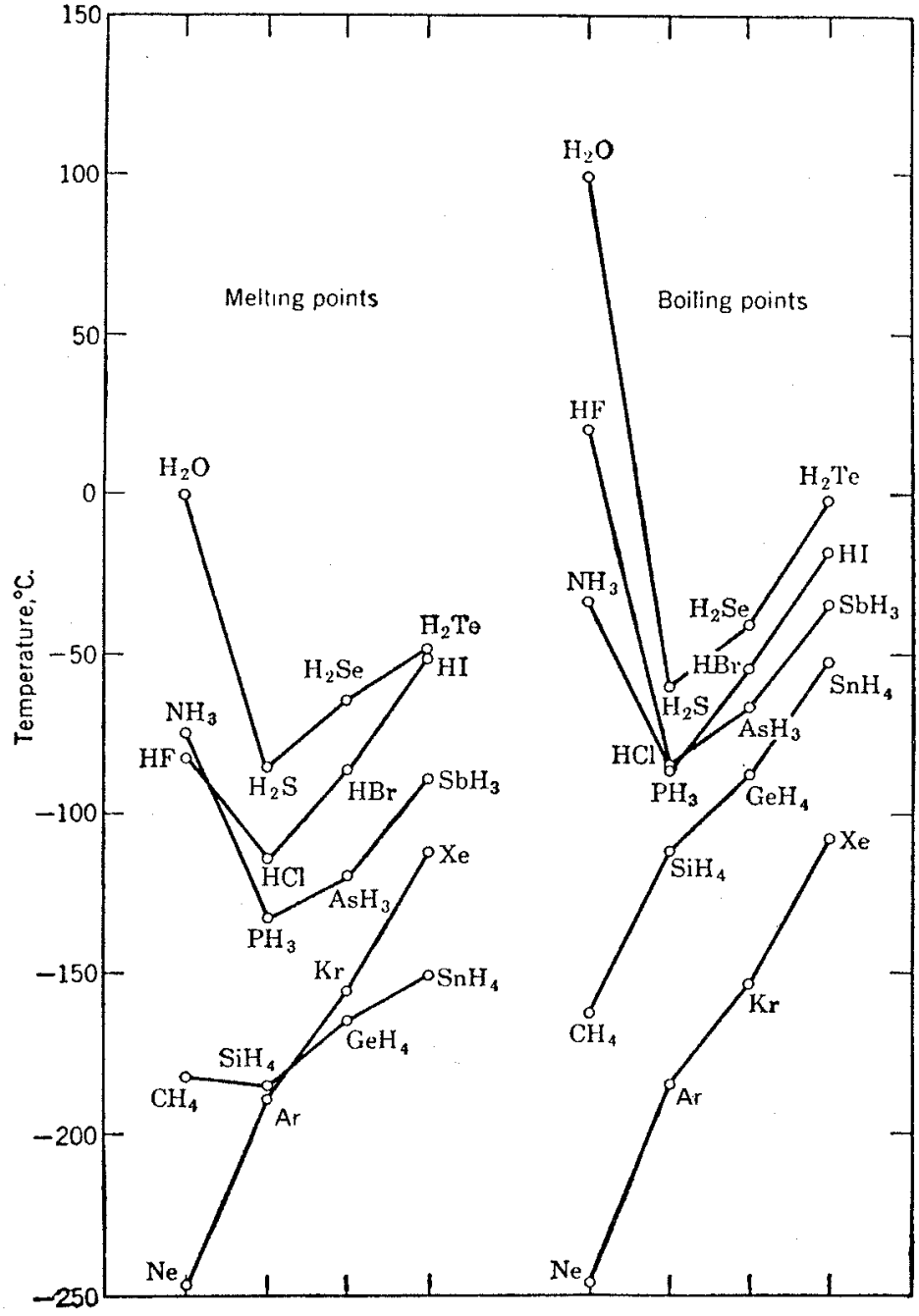
- X and Y are typically O, N, or F.
- The X–H covalent bond must be very polar.
- The hydrogen bond H···Y is mainly electrostatic.
- Hydrogen bond strengths typically are in the range 4 - 46 kJ/mol.

Hydrogen Bonding in Solid HF and H_2O





Melting Points and Boiling Points of Hydrides, XH_n (n = 1, 2, 3, 4)



Structure of Ice