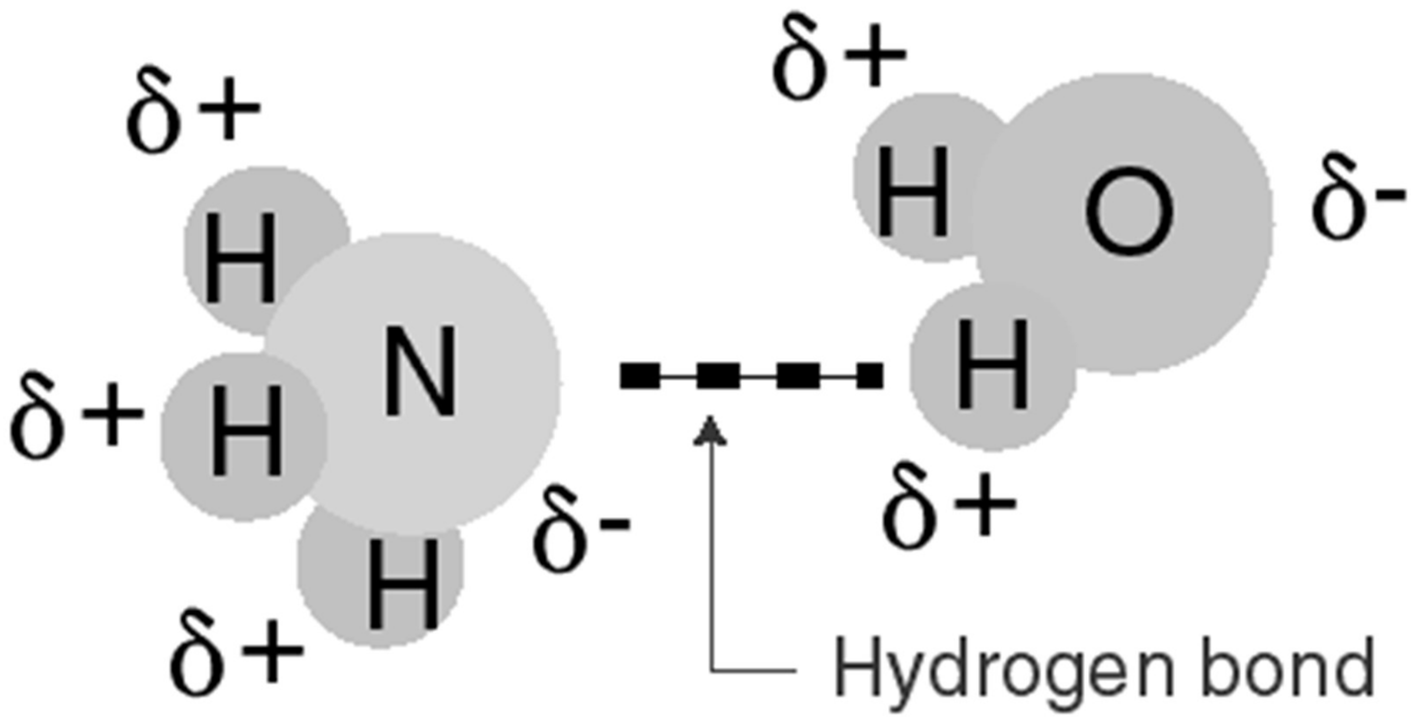
Intermolecular Forces

Going in-depth

Hydrogen Bonding

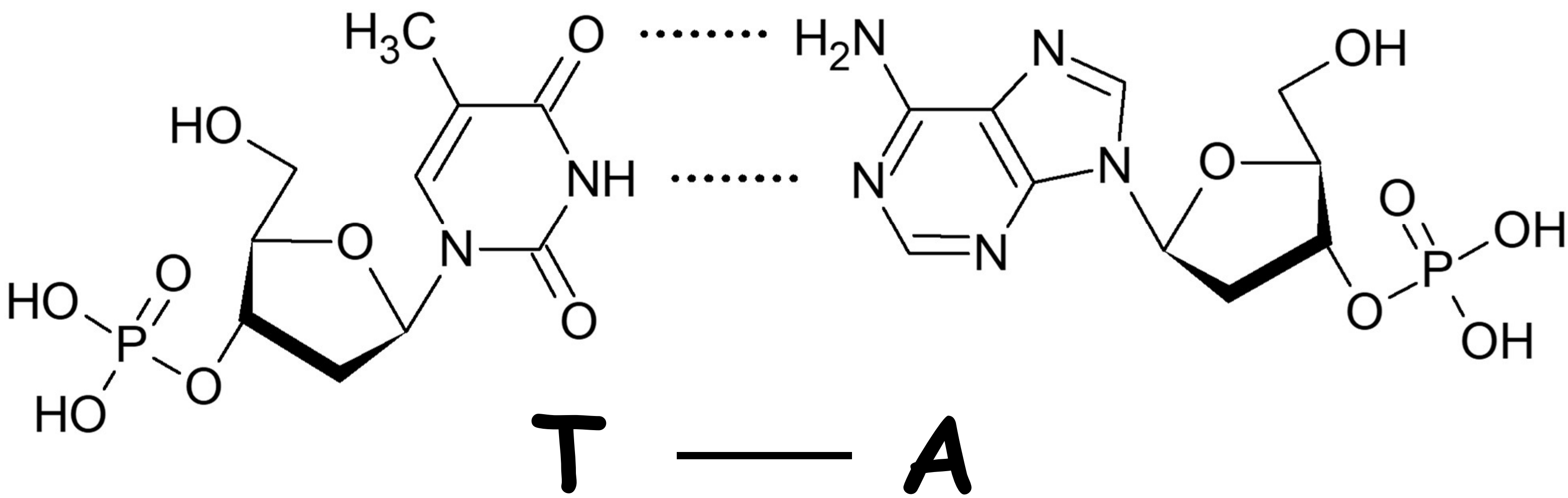
Bonding between hydrogen and more electronegative neighboring atoms such as oxygen and nitrogen



Hydrogen bonding between ammonia and water

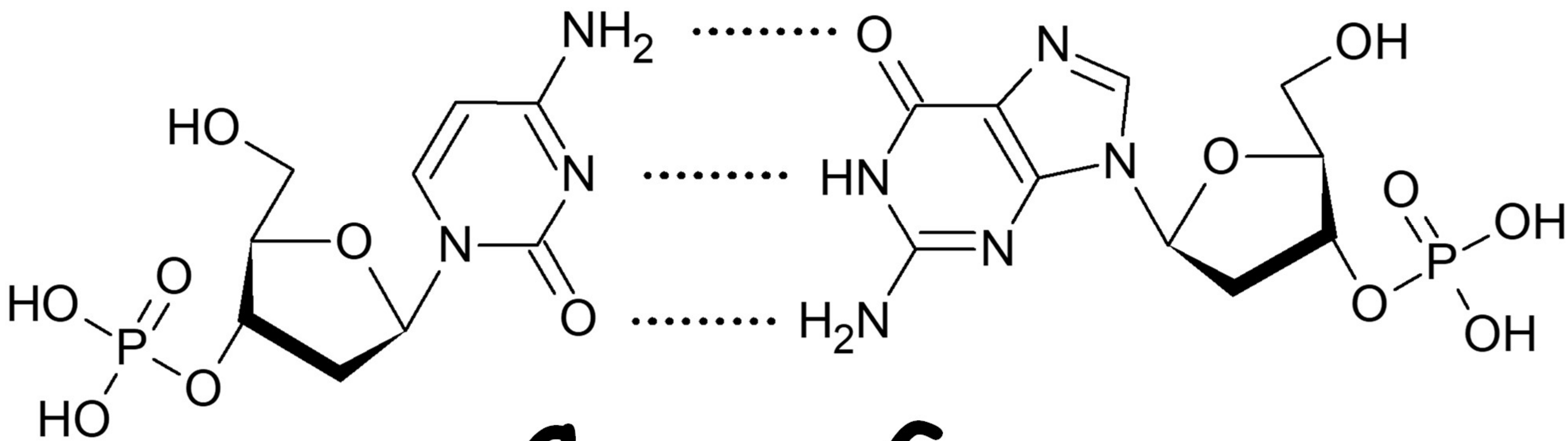
Hydrogen Bonding in DNA

Thymine hydrogen bonds to Adenine



Hydrogen Bonding in DNA

Cytosine hydrogen bonds to Guanine



C —— G

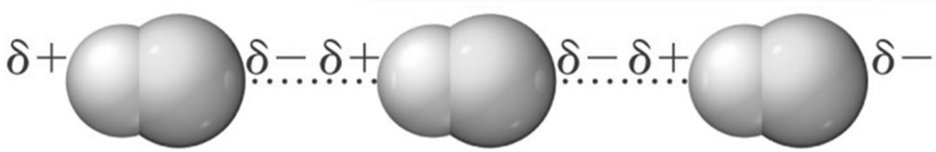
Hydrogen Bonding

- When a very electronegative atom is bonded to hydrogen, it strongly pulls the bonding electrons toward it.
    - :O─H, :N─H, or :F─H
- Because hydrogen has no other electrons, when its electron is pulled away, the nucleus becomes de-shielded, exposing the H proton.
- The exposed proton acts as a very strong center of positive charge, attracting all the electron clouds from neighboring molecules.

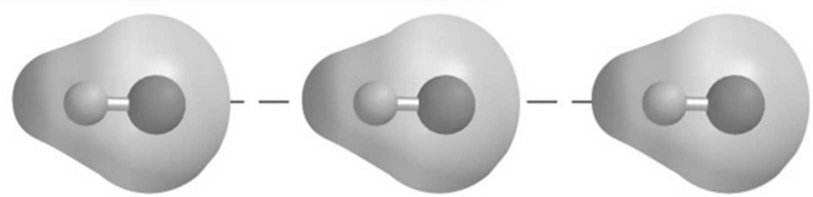
Hydrogen Bonding

Hydrogen Bonding

When H bonds directly to F, O, or N, the bonding atoms acquire relatively large partial charges, giving rise to strong dipole–dipole attractions between neighboring molecules.



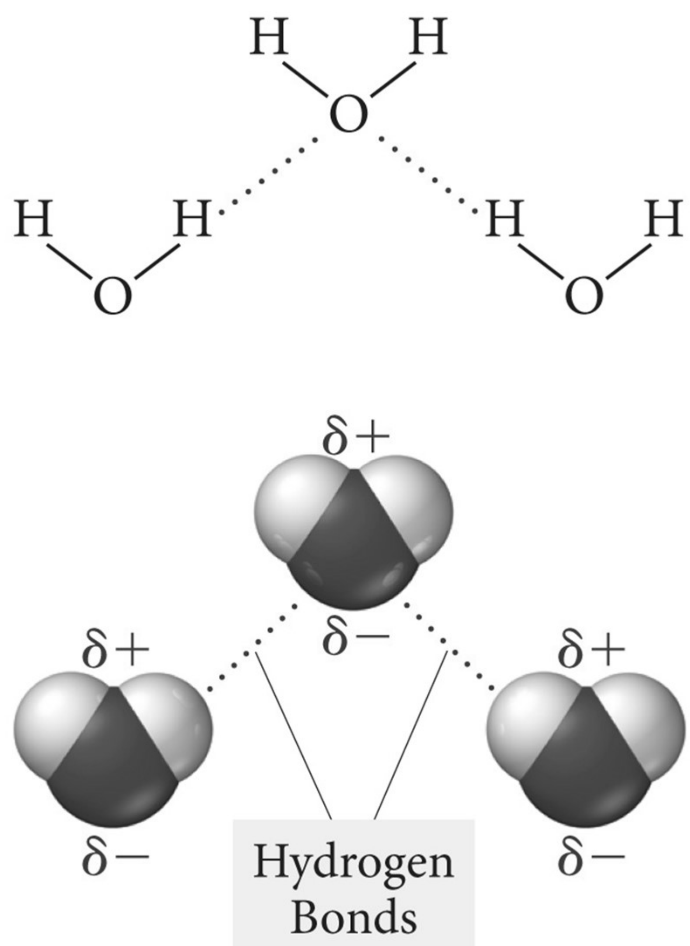
Space-filling model



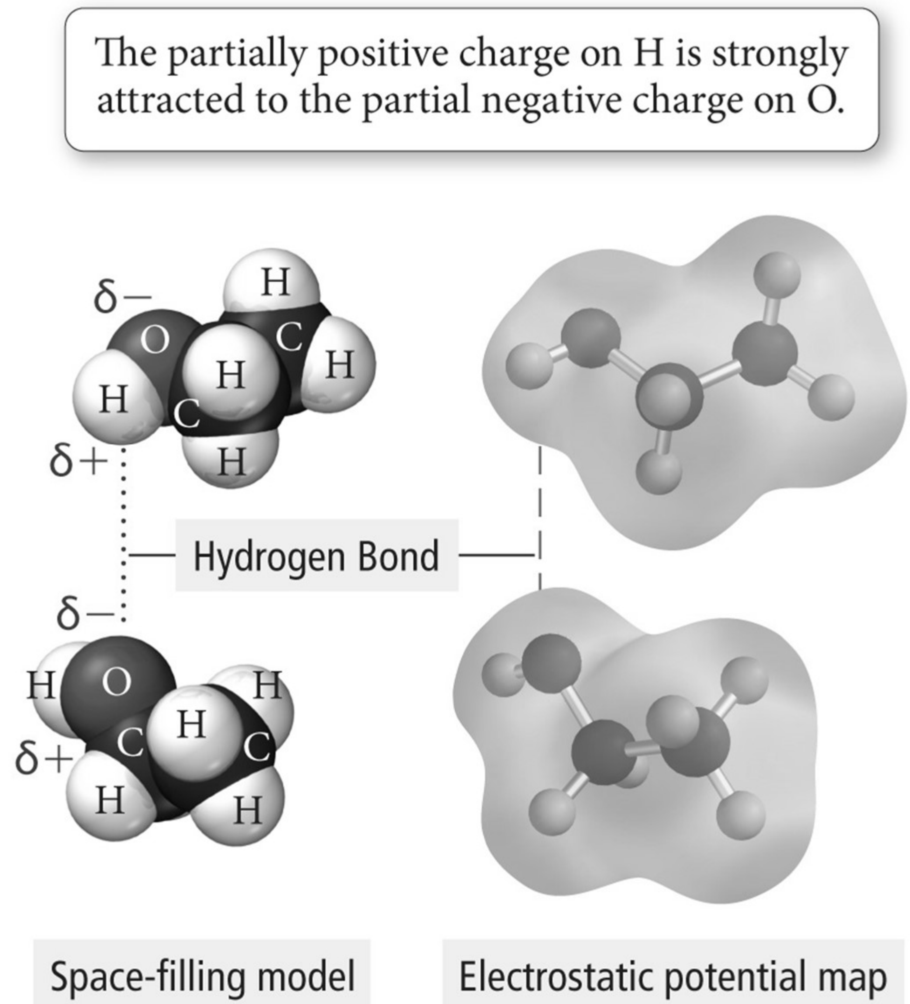
Electrostatic potential map

H–Bonding in Water and Ethanol

Hydrogen Bonding in Water



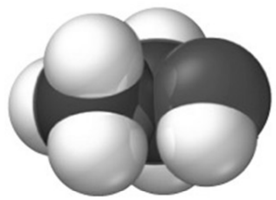
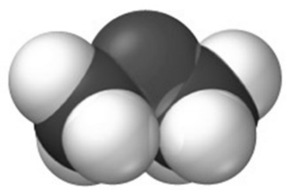
Hydrogen Bonding in Ethanol



Hydrogen Bonds

- Hydrogen bonds are very strong intermolecular attractive forces.
  - Stronger than dipole–dipole or dispersion forces
- Substances that can hydrogen bond will have higher boiling points and melting points than similar substances that cannot.
- But hydrogen bonds are not nearly as strong as chemical bonds.
  - 2–5% the strength of covalent bonds

Effect of H–Bonding on BP

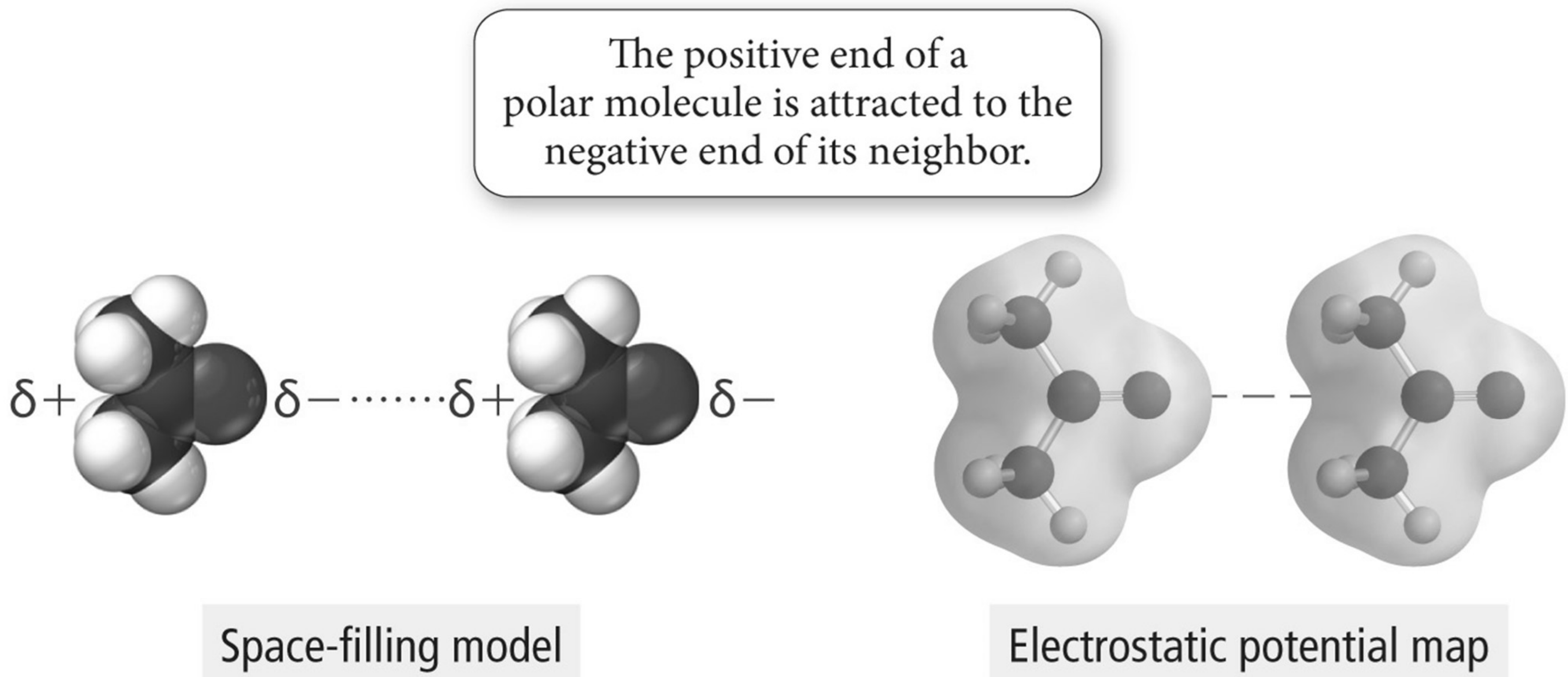
Name	Formula		Molar Mass (amu)	Structure	bp (°C)	mp (°C)
Ethanol	C_2H_6O		46.07	CH_3CH_2OH	78.3	−114.1
Dimethyl Ether	C_2H_6O		46.07	CH_3OCH_3	−22.0	−138.5

Dipole–Dipole Attractions

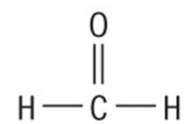
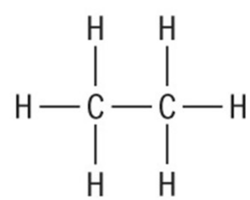
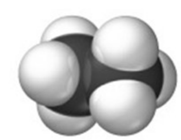
- Polar molecules have a permanent dipole.
  - Bond polarity and shape
  - Dipole moment
  - The always present induced dipole
- The permanent dipole adds to the attractive forces between the molecules, raising the boiling and melting points relative to nonpolar molecules of similar size and shape.

Dipole–Dipole Attractions

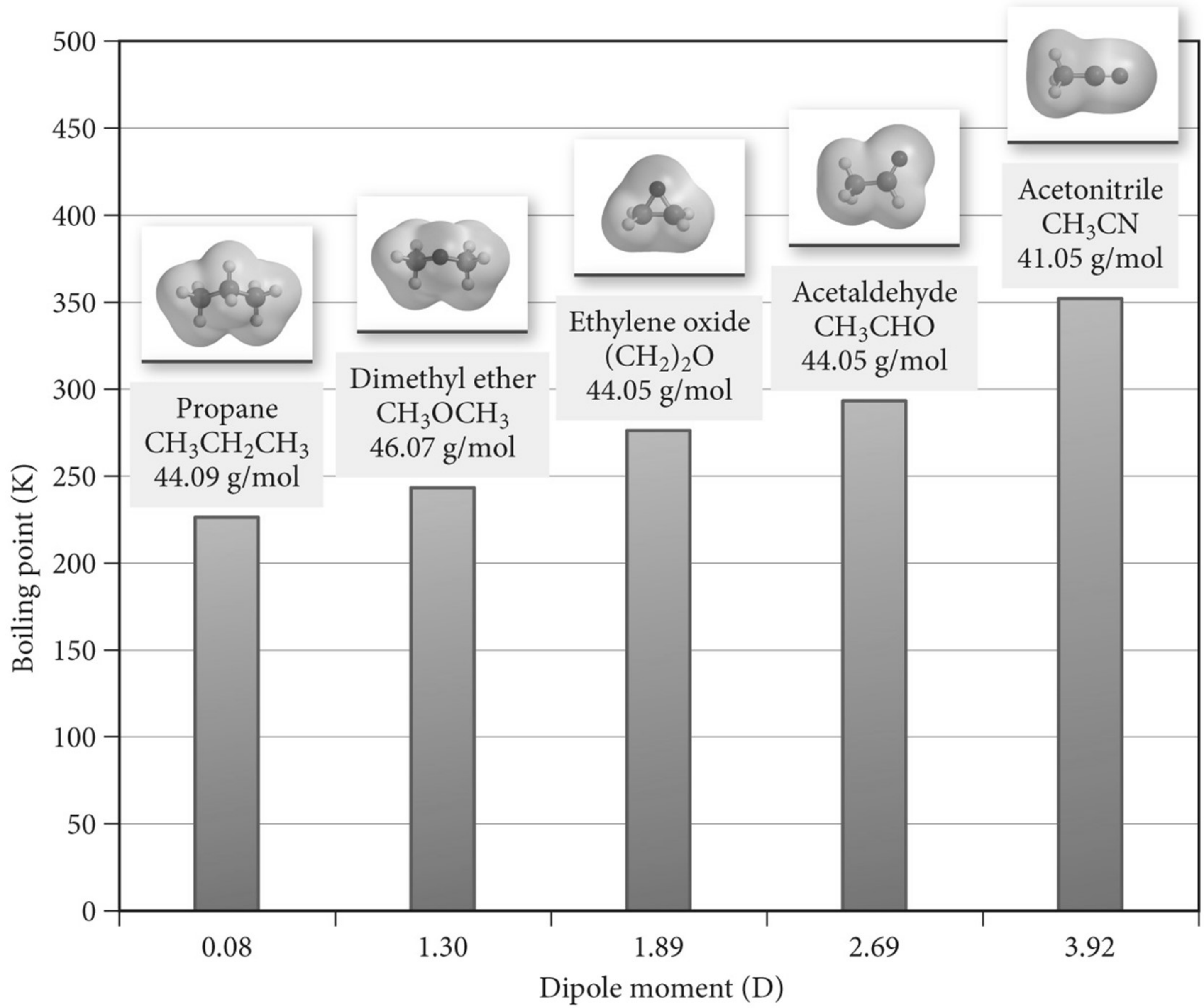
Dipole–Dipole Interaction



Effect of Dipole–Dipole Attraction on BP and MP

Name	Formula	Molar Mass (amu)	Structure	bp (°C)	mp (°C)
Formaldehyde	CH_2O	30.03	 	−19.5	−92
Ethane	C_2H_6	30.07	 	−88	−172

Dipole Movement and Boiling Point



London Dispersion Forces

Fritz London
1900-1954

The temporary separations of charge that lead to the London force attractions are what attract one nonpolar/noble gas molecule to its neighbors.

London forces increase with the size of the molecules and increase in number of e-'s.

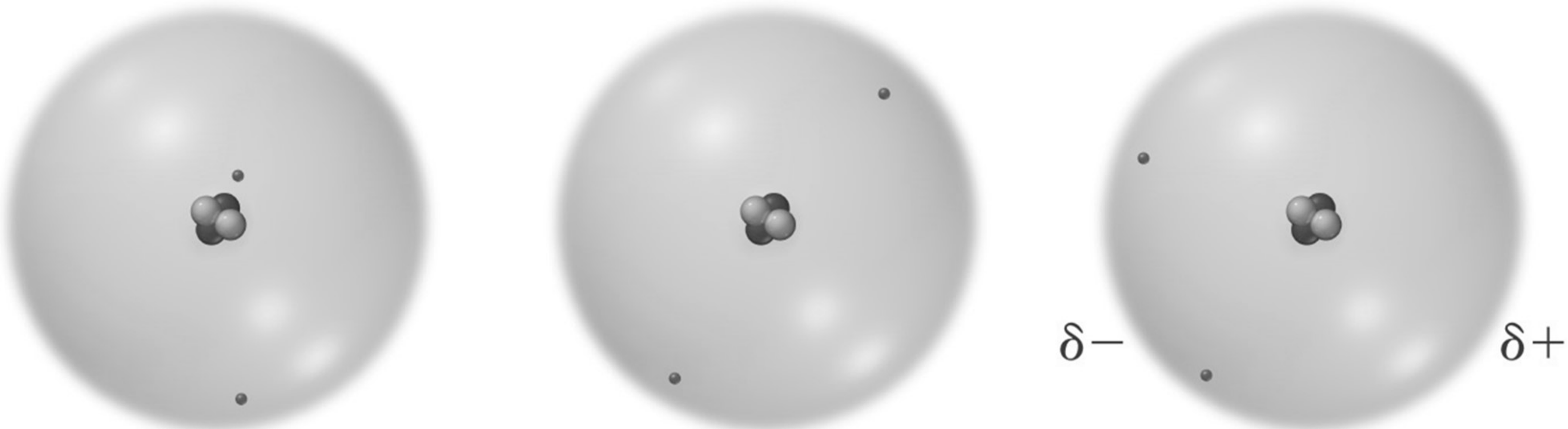
Dispersion Forces

- Fluctuations in the electron distribution in atoms and molecules result in a temporary dipole.
  - Region with excess electron density has partial (–) charge
  - Region with depleted electron density has partial (+) charge
- The attractive forces caused by these temporary dipoles are called dispersion forces.
  - Aka London Forces

Dispersion Forces

- All molecules and atoms will have them.
- As a temporary dipole is established in one molecule, it induces a dipole in all the surrounding molecules.

Dispersion Force

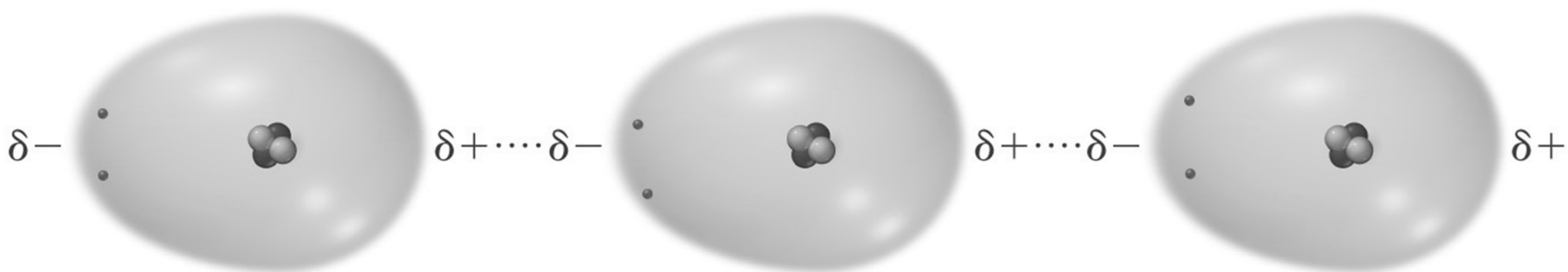


Frame 1 Frame 2 Frame 3

Dispersion Force

Dispersion Force

An instantaneous dipole on any one helium atom induces instantaneous dipoles on neighboring atoms, which then attract one another.



Size of the Induced Dipole

- The magnitude of the induced dipole depends on several factors.
- Polarizability of the electrons
  - Volume of the electron cloud
  - Larger molar mass = more electrons = larger electron cloud = increased polarizability = stronger attractions
- Shape of the molecule
  - More surface-to-surface contact = larger induced dipole = stronger attraction

Effect of Molecular Size on Size of Dispersion Force

- The Noble gases are all nonpolar atomic elements.

- The stronger the attractive forces between the molecules, the higher the boiling point will be.

TABLE 11.3 Boiling Points of the Noble Gases

Noble Gas		Molar Mass (g/mol)	Boiling Point (K)
He		4.00	4.2
Ne		20.18	27
Ar		39.95	87
Kr		83.80	120
Xe		131.30	165

Effect of Molecular Size on Size of Dispersion Force

- As the molar mass increases, the number of electrons increases. Therefore, the strength of the dispersion forces increases.

- The stronger the attractive forces between the molecules, the higher the boiling point will be.

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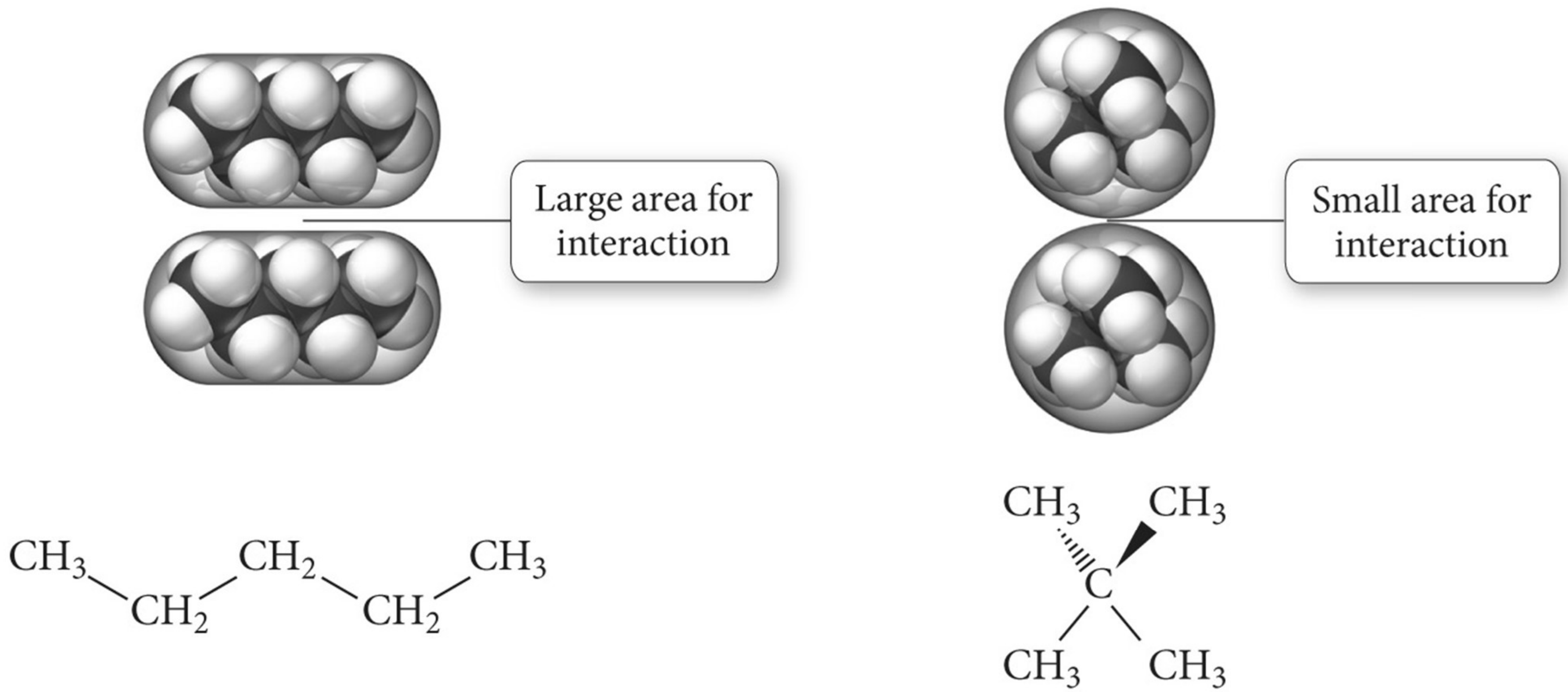
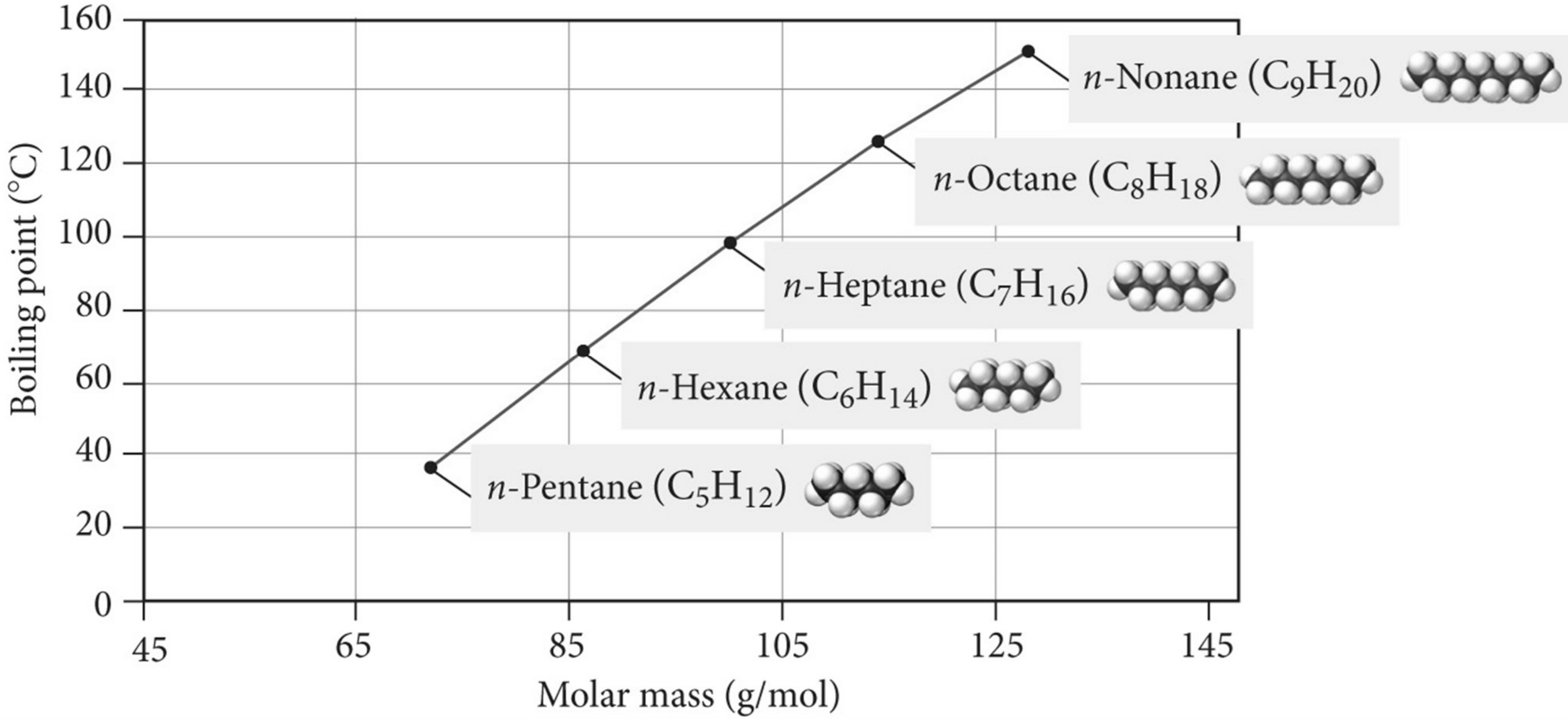
Effect of Molecular Shape on Size of Dispersion Force

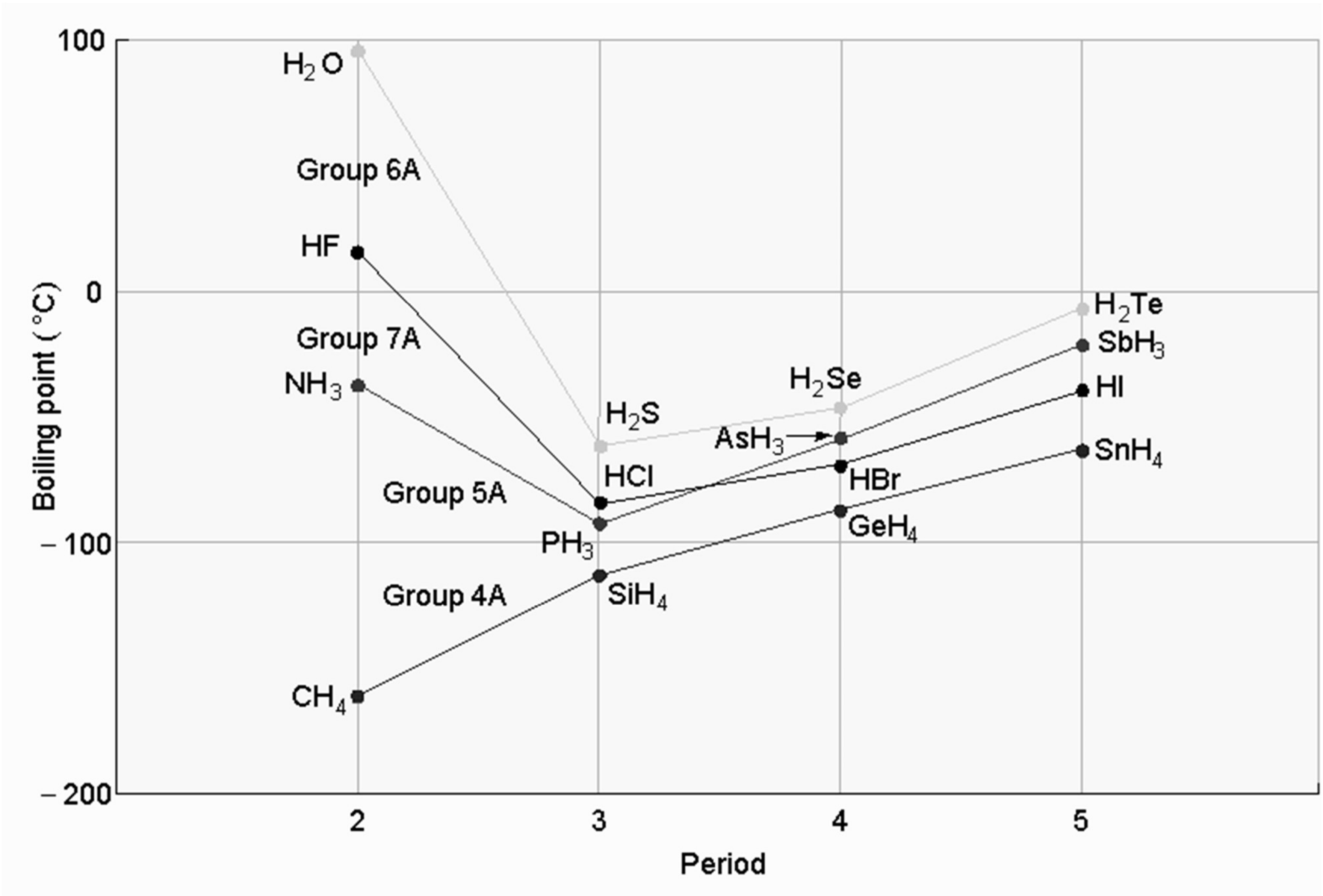


(a) *n*-Pentane (b) Neopentane

Boiling Points of *n*-Alkanes

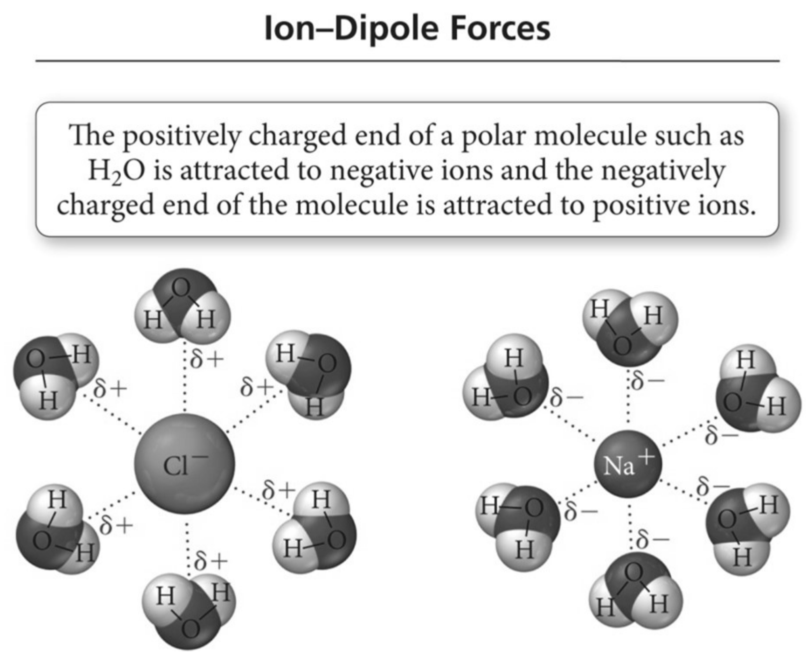


Boiling point as a measure of intermolecular attractive forces



Ion–Dipole Attraction

- In a mixture, ions from an ionic compound are attracted to the dipole of polar molecules.
- The strength of the ion–dipole attraction is one of the main factors that determines the solubility of ionic compounds in water.



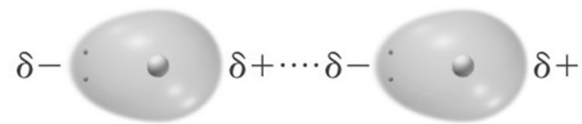
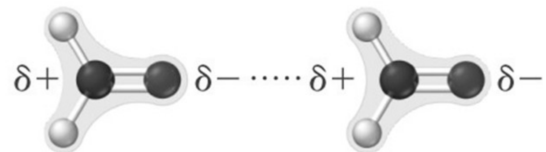
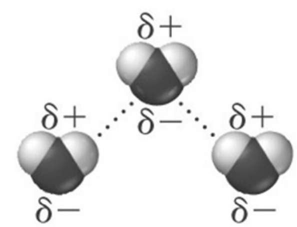
Summary

- Dispersion forces are the weakest of the intermolecular attractions.
- Dispersion forces are present in all molecules and atoms.
- The magnitude of the dispersion forces increases with molar mass.
- Polar molecules also have dipole–dipole attractive forces.

Summary (cont.)

- Hydrogen bonds are the strongest of the intermolecular attractive forces a pure substance can have.
- Hydrogen bonds will be present when a molecule has H directly bonded to either O, N, or F atoms.
  - The only example of H bonded to F is HF.
- Ion–dipole attractions are present in mixtures of ionic compounds with polar molecules.
- Ion–dipole attractions are the strongest intermolecular attraction.
- Ion–dipole attractions are especially important in aqueous solutions of ionic compounds.

TABLE 11.4 Types of Intermolecular Forces

Type	Present in	Molecular perspective	Strength
Dispersion	All molecules and atoms		
Dipole–dipole	Polar molecules		
Hydrogen bonding	Molecules containing H bonded to F, O, or N		
Ion–dipole	Mixtures of ionic compounds and polar compounds