# General Chemistry

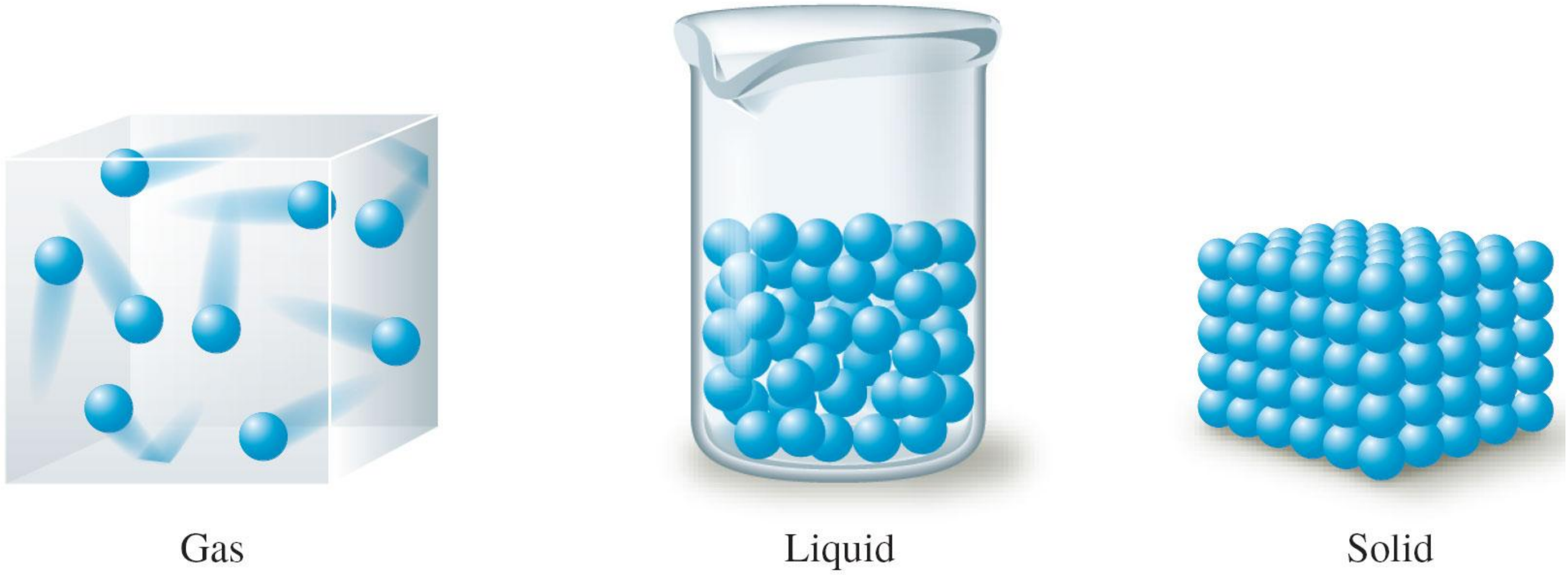
202-SN1-RE

*with Olivia Bibollet-Bahena*

Office: 5th floor

# Unit 7 – Intermolecular Forces

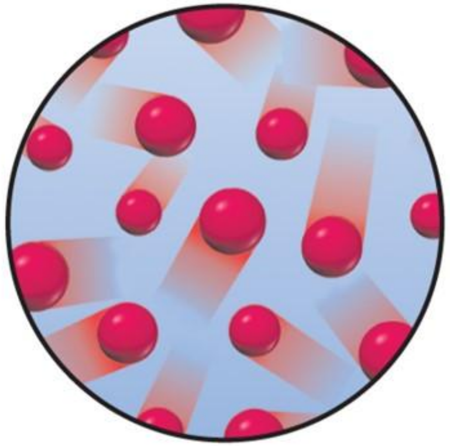
# Three States of Matter



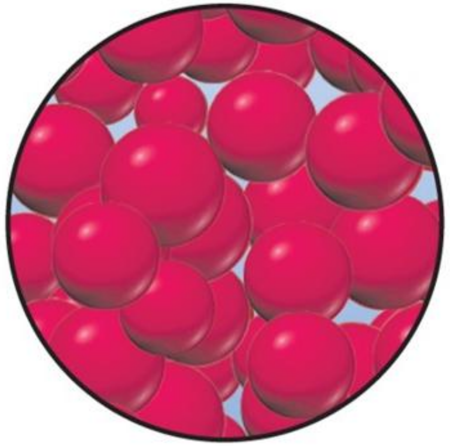

Intramolecular Forces – Interactions that occur *within* a molecule.

Intermolecular Forces – Interactions that occur *between* molecules.

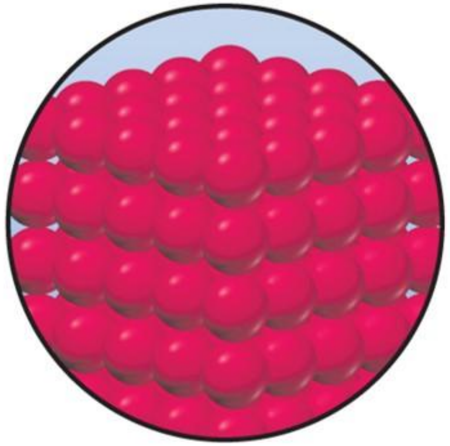
# Intermolecular Forces



In **gases,** the particles feel little attraction for one another and are free to move about randomly.

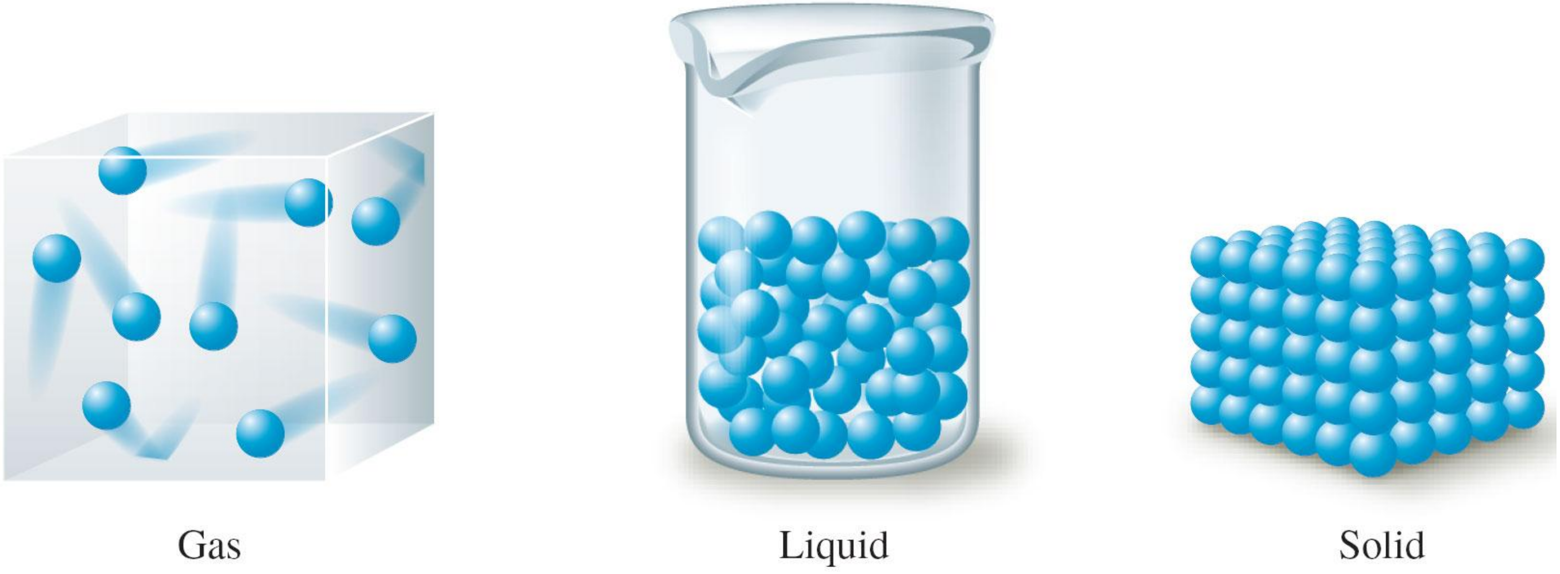


In **liquids,** the particles are held close together by attractive forces but are free to move around one another.



In **solids,** the particles are held in an ordered arrangement.

# Three States of Matter




| State | Density | Shape | Volume | Strength of Intermolecular Forces (Relative to Thermal Energy) |
|---|---|---|---|---|
| Gas | Low | Indefinite | Indefinite | Weak |
| Liquid | High | Indefinite | Definite | Moderate |
| Solid | High | Definite | Definite | Strong |





Tro, N. J. – Chemistry A Molecular Approach, 2008

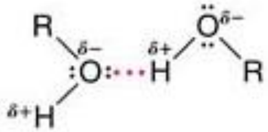
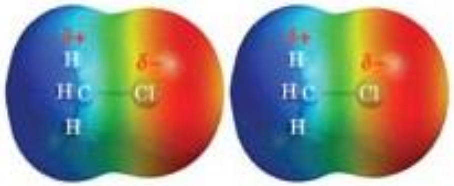
# Intermolecular Forces

# Attractive Electric Forces

***Bonding Forces (Intramolecular)***

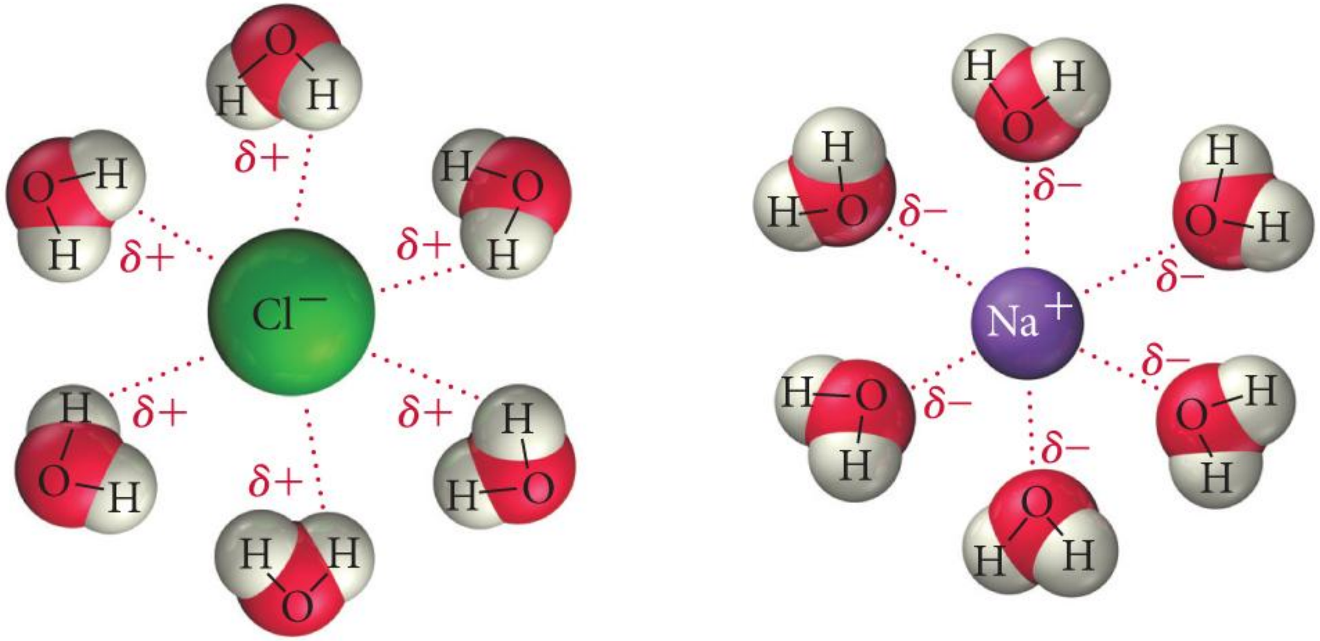
| | | | |
|---|---|---|---|
| Cation–anion (in a crystal) | Very strong |  | Sodium chloride crystal lattice |
| Covalent bonds | Strong (140–523 kJ mol$^{-1}$) | Shared electron pairs | H—H (436 kJ mol$^{-1}$)<br>$CH_3$—$CH_3$ (378 kJ mol$^{-1}$)<br>I—I (151 kJ mol$^{-1}$) |

***Intermolecular Forces (Van der Waals Forces)***

| | | | |
|---|---|---|---|
| Hydrogen bonds | Moderate to weak (4–38 kJ mol$^{-1}$) | $-\overset{\delta-}{Z}:\cdots\overset{\delta+}{H}-$ |  |
| Dipole–dipole<br>(Debye Forces) | Weak | $\delta+\cdots\delta-$ |  |
| London Dispersion Forces | Variable | Transient dipole | Interactions between methane molecules |

# Ion-Dipole Interactions
# (also important to consider)

The positively charged end of a polar molecule such as $H_2O$ is attracted to negative ions and the negatively charged end of the molecule is attracted to positive ions.



# Dipole-Dipole Forces

- Dipole moment – molecules with polar bonds often behave in an electric field as if they had a center of positive charge and a center of negative charge.

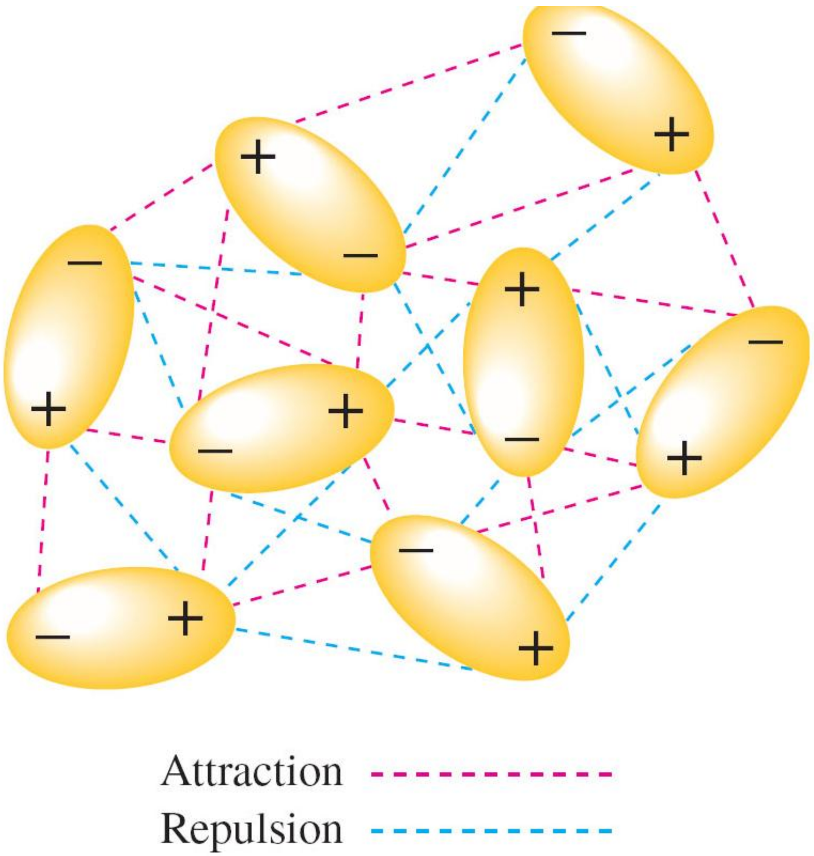
- Molecules with dipole moments can attract each other electrostatically. They line up so that the positive and negative ends are close to each other.

- Only about 1% as strong as covalent or ionic bonds, and they become weaker as distance between the dipoles increases.

# Dipole-Dipole Forces

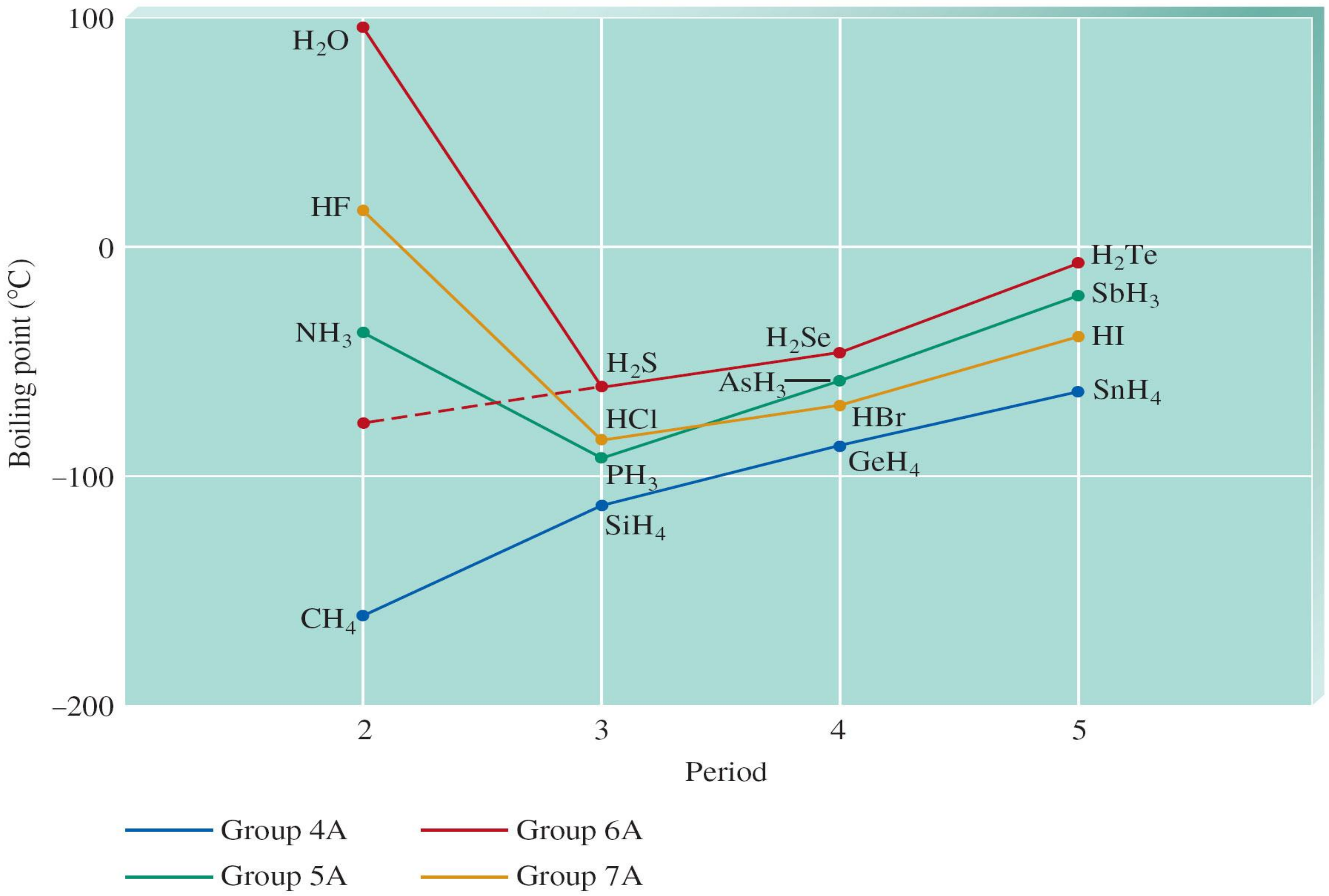

- Polar molecules (molecules with net dipoles) have dipole-dipole forces.
- These forces are very distance dependent, thus in the gas phase are less important.
- In liquids and solids, they can be very important.

# Dipole-Dipole Forces

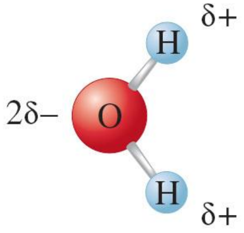


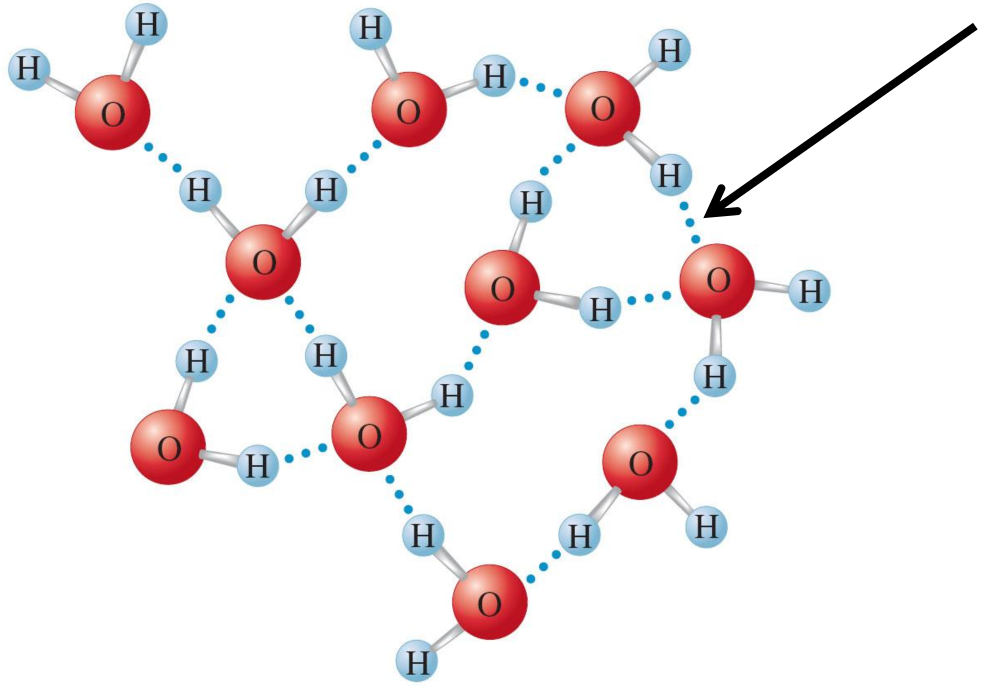

In the liquid phase, dipoles find the best compromise between attraction and repulsion.

# Hydrogen Bonding:
# A Special Type of Dipole-Dipole



# Hydrogen Bonding: A Special Type of Dipole-Dipole

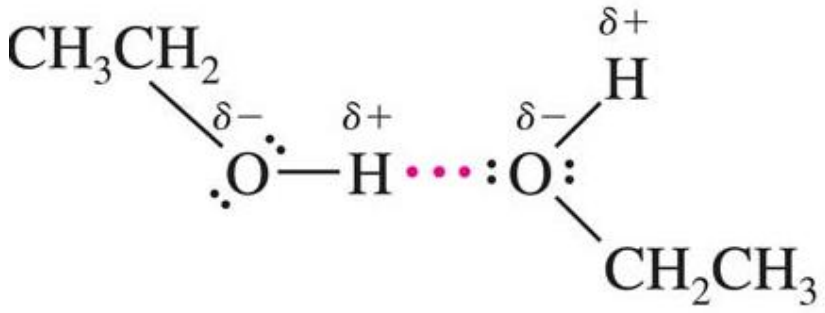


Hydrogen bonding between partially positive H atoms and the lone pairs on O.

Hydrogen bonding is a very strong dipole-dipole attraction.
Occurs most when hydrogen is attached to highly electronegative atoms.

# Hydrogen Bonding:
# A Special Type of Dipole-Dipole



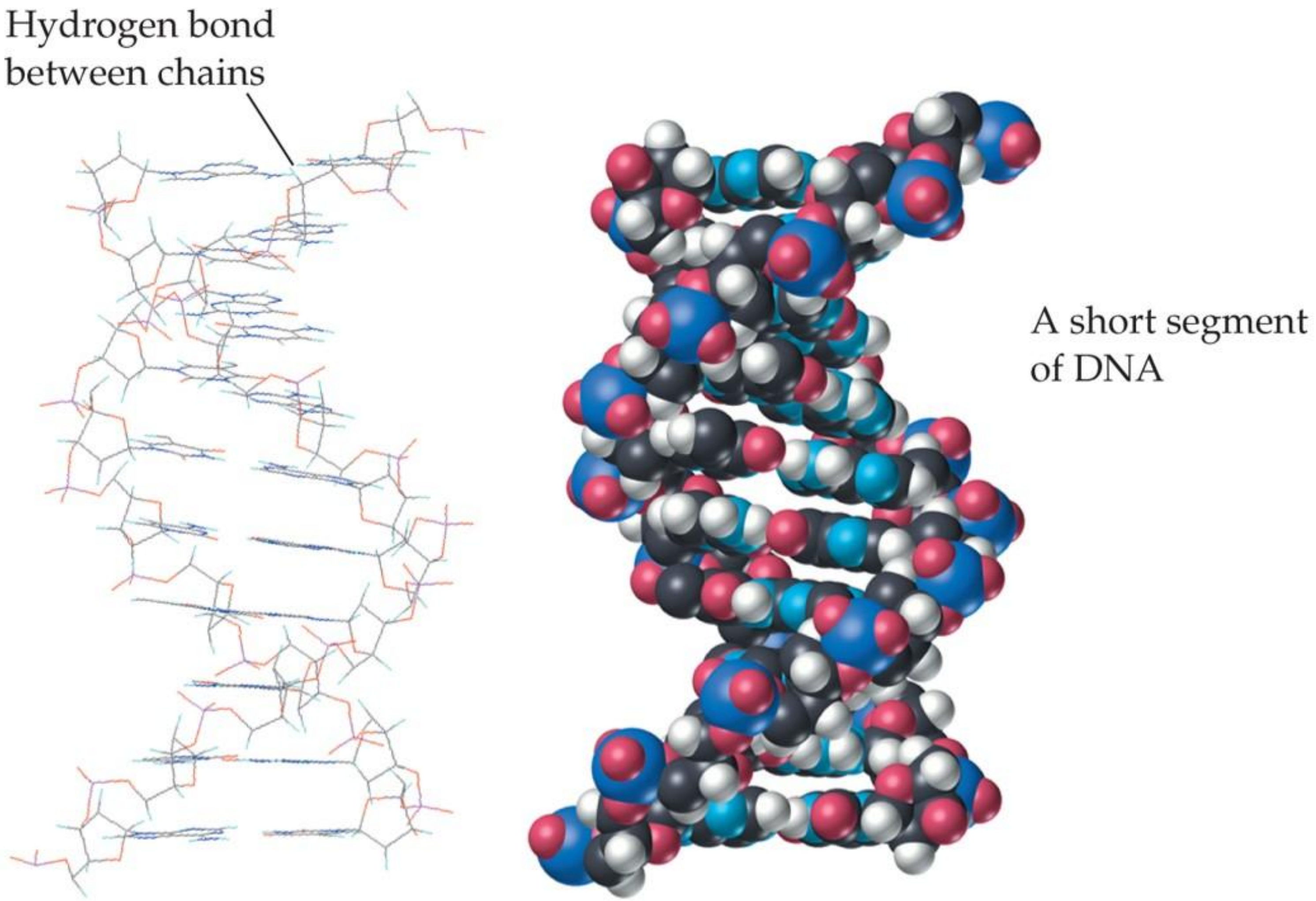

<u>Factors Involved in Hydrogen Bonding:</u>

1) Hydrogen bonding occurs in O-H, N-H, and F-H bonds (highly polarized bonds).

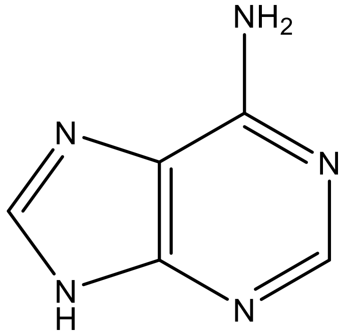
2) Very small size of hydrogen allows close approach of dipoles.

3) Specific angle required.

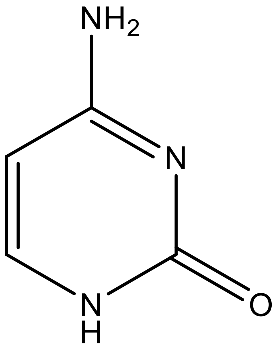
# Intermolecular Forces



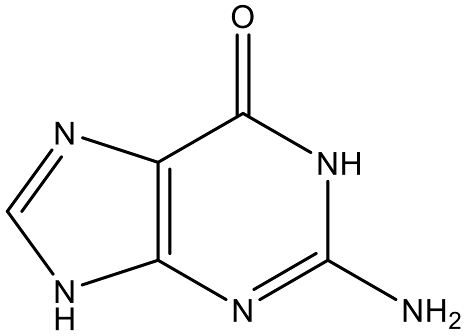
# DNA and IMFs



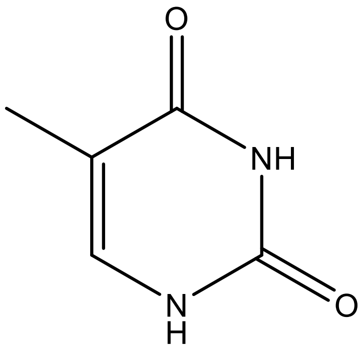
Adenine



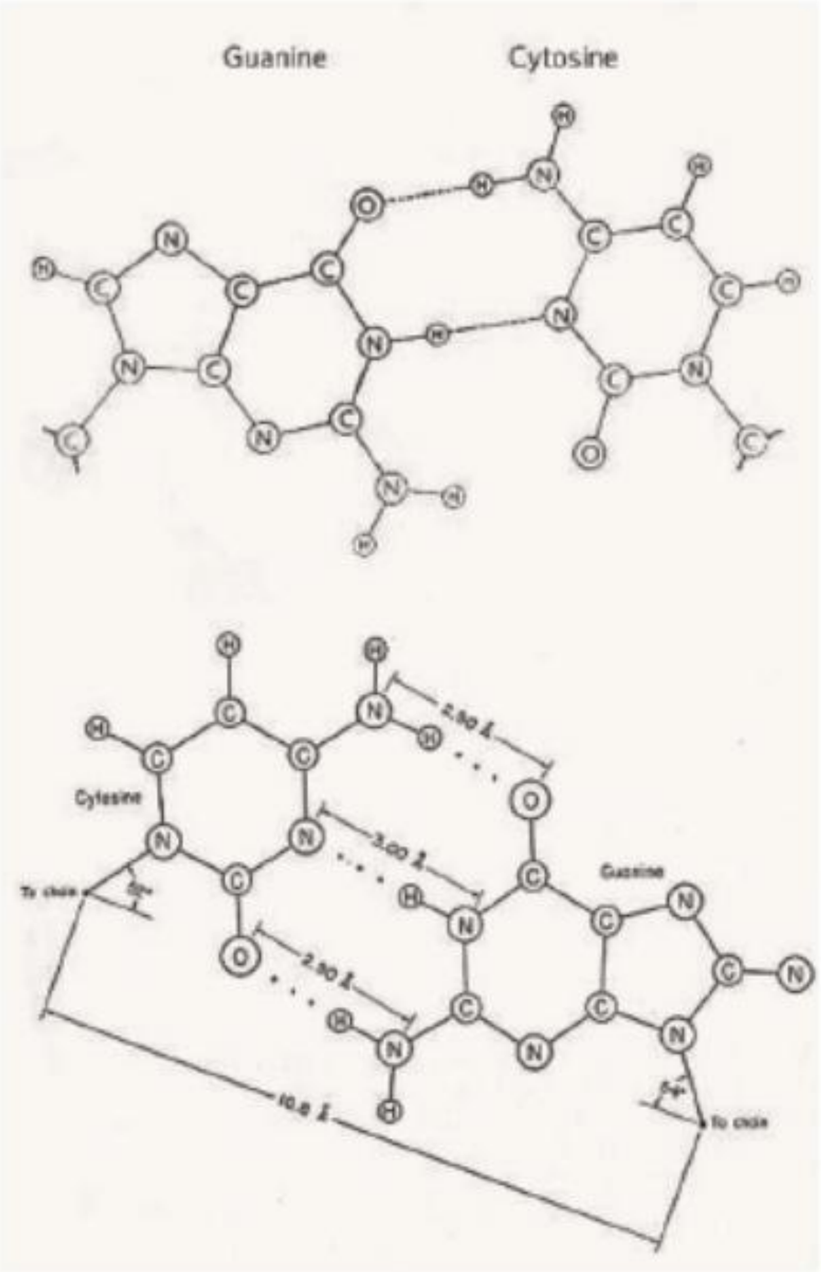
Cytosine



Guanine



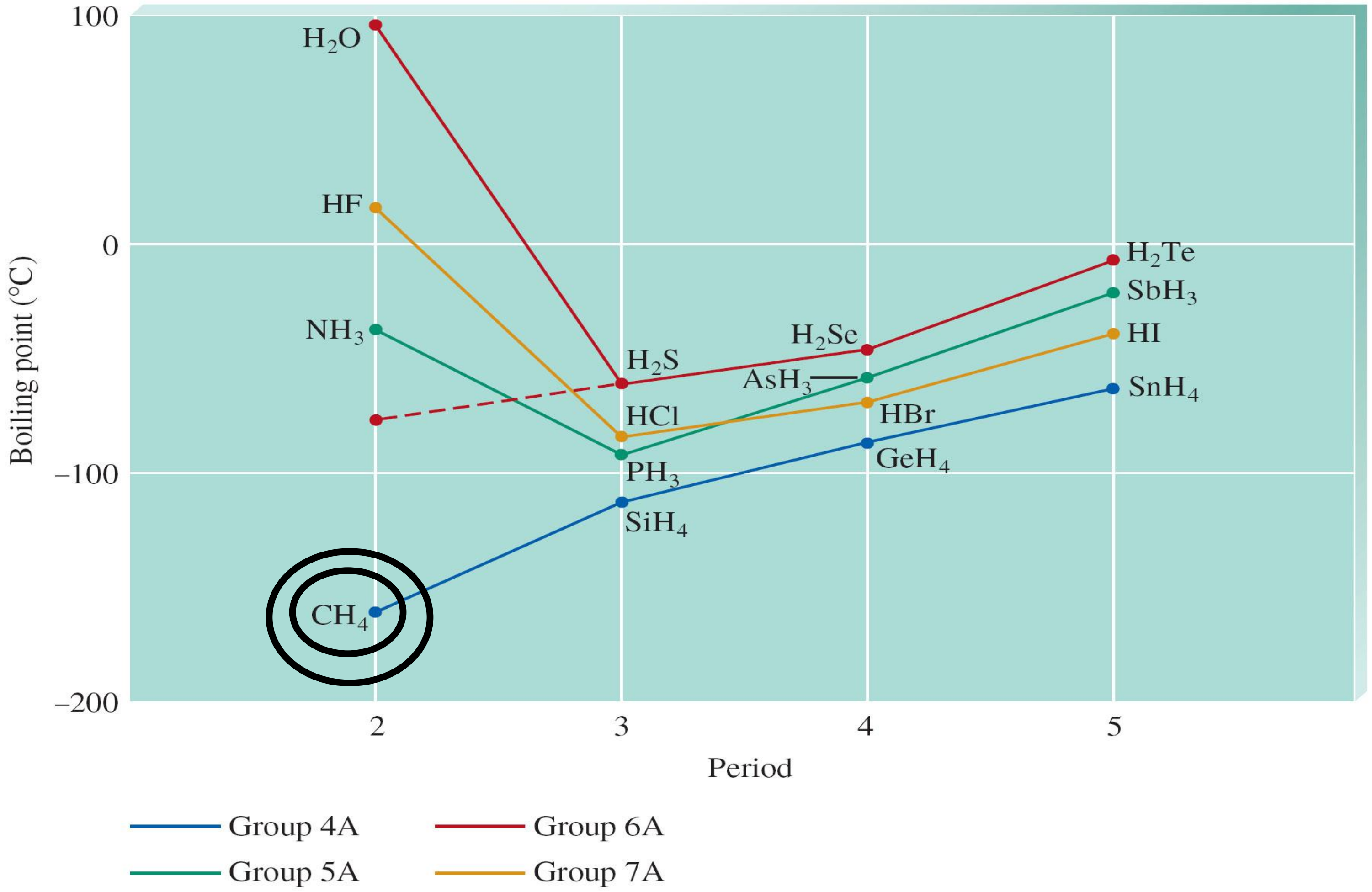
Thymine




**The third hydrogen bond in a guanine–cytosine base pair (bottom) was missed in the 1953 description of DNA (top).**

Wain-Hobson, S. The third Bond. *Nature* **439**, 539 (2006).
https://doi.org/10.1038/439539a

# London Dispersion Forces



# London Dispersion Forces

*Methane does not have a dipole…*

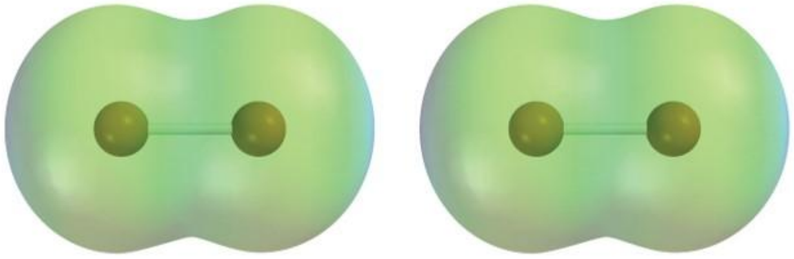
bp = -162 ºC

*Why does methane ever become a solid or a liquid?*

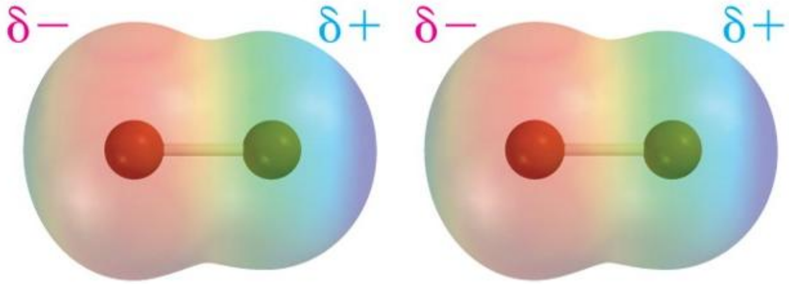
$CH_4$ is nonpolar, the main form of attraction between the molecules is through London dispersion forces.

# London Dispersion Forces

The result of the motion of electrons that gives the molecule a short-lived dipole moment. This induces temporary dipoles in neighboring molecules.



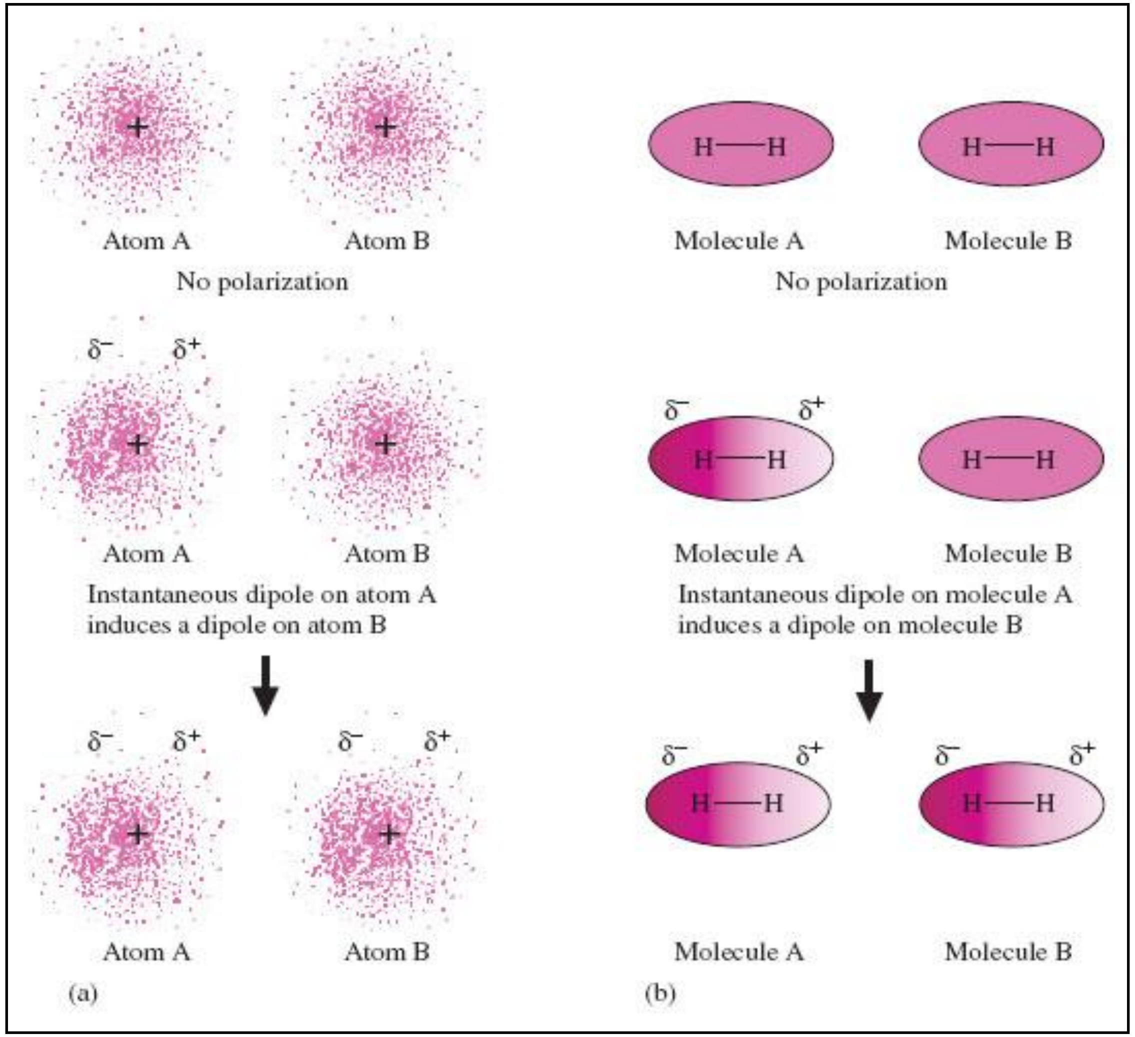
Averaged over time, the electron distribution in a $Br_2$ molecule is **symmetrical**.




At any given instant, the electron distribution in a molecule may be **unsymmetrical**, resulting in a temporary dipole and inducing a complementary attractive dipole in neighboring molecules.

# London Dispersion Forces

Dispersion forces arise from instantaneous dipole-induced dipole forces.



# Dispersion Forces

$I_2$

Boiling point = 184 °C


$F_2$

Boiling point = - 188 °C

At room temperature, $I_2$ is a solid and $F_2$ is a gas.

# Dispersion Forces

$I_2$

Boiling point = 184 °C


$F_2$

Boiling point = - 188 °C

Larger atoms don't hold their electrons as tightly and so the electron cloud can be distorted with greater ease - They have greater "polarizability" and so their dispersion forces are higher.

# Intermolecular Forces

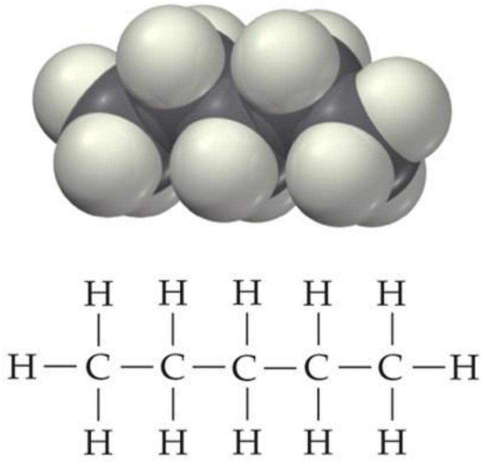
- **London Dispersion Forces**

**Table 8.4** Melting Points and Boiling Points of the Halogens

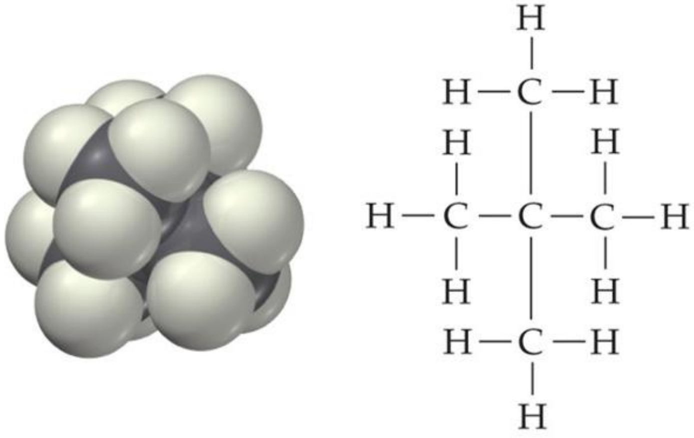
| Halogen | mp (K) | bp (K) |
|---|---|---|
| $F_2$ | 53.5 | 85.0 |
| $Cl_2$ | 171.6 | 239.1 |
| $Br_2$ | 265.9 | 331.9 |
| $I_2$ | 386.8 | 457.5 |

- As the **dispersion forces** increase, the **intermolecular forces** increase.
- As the **intermolecular forces** increase, the **boiling point** increases.

## London Dispersion Forces



Pentane (bp = 309.2 K)



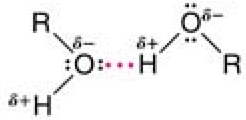
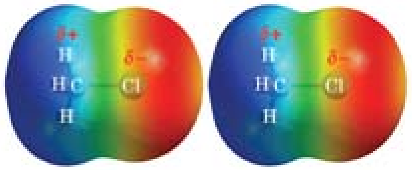
2,2-Dimethylpropane (bp = 282.6 K)

Longer, **less compact molecules** like pentane feel stronger dispersion forces and consequently have higher boiling points.

**More compact molecules** like 2,2-dimethylpropane feel weaker dispersion forces and have lower boiling points.

# Attractive Electric Forces

## Intermolecular Forces (Van der Waals Forces)

| | | | |
|---|---|---|---|
| Hydrogen bonds | Moderate to weak ($4-38\ kJ\ mol^{-1}$) | $-\overset{\delta-}{Z}:\cdots\overset{\delta+}{H}-$ |  |
| Dipole–dipole | Weak | $\delta+\cdots\delta-$ |  |
| Dispersion | Variable | Transient dipole | Interactions between methane molecules |

*Hydrogen bonds > Dipole-dipole forces > Dispersion forces*

Dispersion forces become significant with larger molar mass differences (>10 g/mol, LDF dominates).

# Intermolecular Forces

**Table 8.7** A Comparison of Intermolecular Forces

| Force | Strength | Characteristics |
|---|---|---|
| Ion–dipole | Highly variable (10–70 kJ/mol) | Occurs between ions and polar molecules |
| Dipole–dipole | Weak (3–4 kJ/mol) | Occurs between polar molecules |
| London dispersion | Weak (1–10 kJ/mol) | Occurs between all molecules; strength depends on size, polarizability |
| Hydrogen bond | Moderate (10–40 kJ/mol) | Occurs between molecules with O—H, N—H, F—H bonds |

# Exercise

Which molecule is capable of forming stronger intermolecular forces?

$N_2$ $H_2O$

Explain.

# Exercise

Which molecule is capable of forming stronger intermolecular forces?

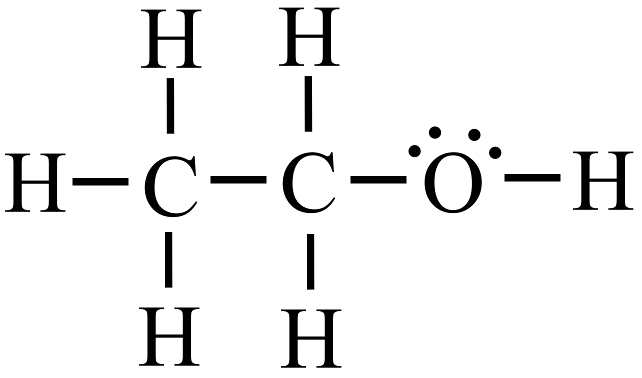
$N_2$ $H_2O$

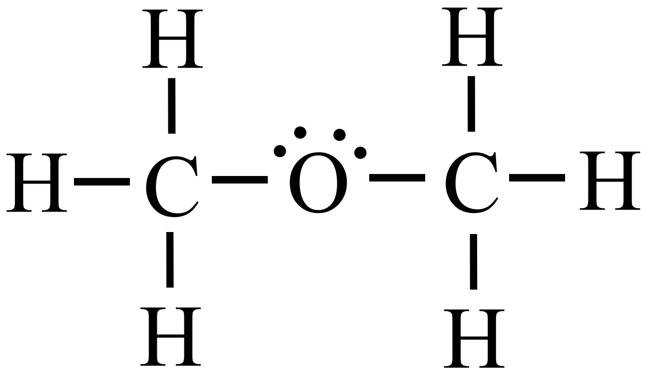
Explain.

$H_2O$ has the stronger intermolecular forces because it exhibits hydrogen bonding, whereas $N_2$ only exhibits London dispersion forces.

# Exercise

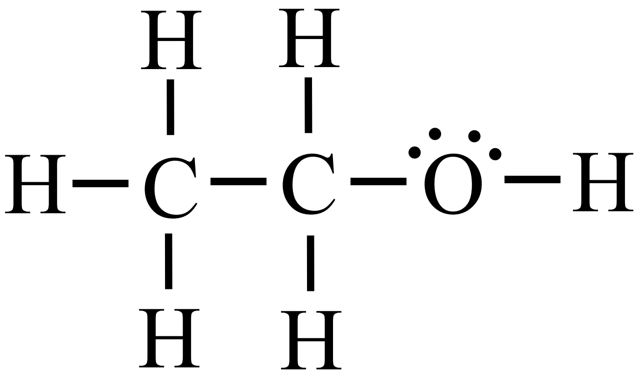
Consider the two possible Lewis structures for the formula $C_2H_6O$ and compare the boiling points of the two molecules.



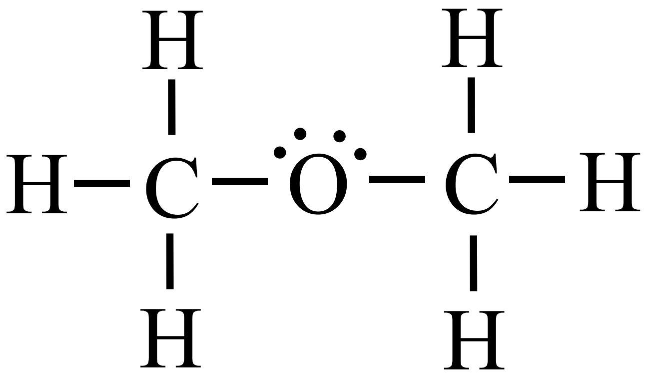


# Exercise

Consider the two possible Lewis structures for the formula $C_2H_6O$ and compare the boiling points of the two molecules.



Ethanol



Dimethyl ether

One Lewis structure is ethanol and the other is dimethyl ether. Ethanol will have a higher boiling point than dimethyl ether because ethanol exhibits hydrogen bonding and dimethyl ether exhibits dipole-dipole interactions. Hydrogen bonding is an especially strong type of dipole-dipole interaction and will thus raise the boiling point of ethanol.

# Exercise

1. What is the important type of intermolecular force that exists for each of the chemical species?

$HBr$

$CBr_4$

$CH_3OH$

2. Rank the intermolecular forces in order of increasing strength (weakest to strongest) when compared one to one.

# Exercise

1. What is the important type of intermolecular force that exists for each of the chemical species?

HBr – Dipole-dipole forces

$CBr_4$ – London dispersion forces

$CH_3OH$ – Hydrogen bonds

2. Rank the intermolecular forces in order of increasing strength (weakest to strongest) when compared one to one.

*Hydrogen bonds > Dipole-dipole forces > Dispersion forces*

$CH_3OH$ > HBr > $CBr_4$