

Periodic Table of the Elements

1 H Hydrogen 1.01	2 He Helium 4.00																
3 Li Lithium 6.94	4 Be Beryllium 9.01	5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18										
11 Na Sodium 22.99	12 Mg Magnesium 24.31	13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95										
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.95	43 Tc Technetium 98.91	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium [208.98]	85 At Astatine 209.98	86 Rn Radon 222.02
87 Fr Francium 223.02	88 Ra Radium 226.03	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [277]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [282]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

General Chemistry

202-SN1-RE

with Olivia Bibollet-Bahena

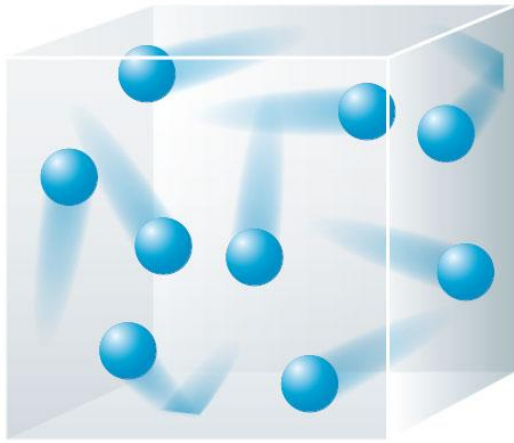
Office: 5th floor

57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.06	71 Lu Lutetium 174.97
89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244.06	95 Am Americium 243.06	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium [254]	100 Fm Fermium 257.10	101 Md Mendelevium 258.10	102 No Nobelium 259.10	103 Lr Lawrencium [262]

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Metalloid
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

Unit 7 – Intermolecular Forces

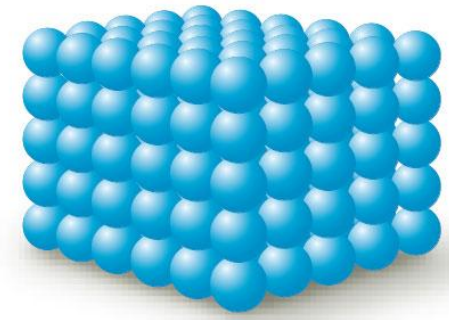
Three States of Matter



Gas



Liquid

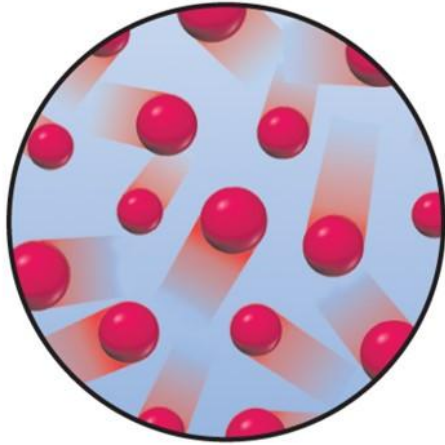


Solid

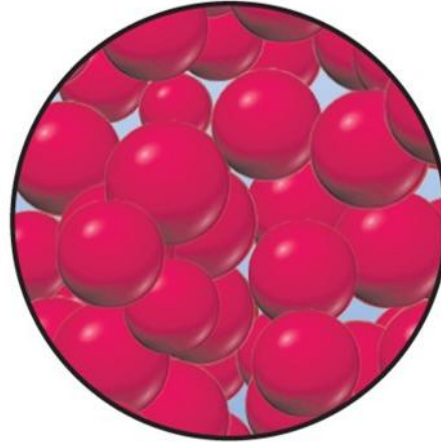
Intramolecular Forces – Interactions that occur *within* a molecule.

Intermolecular Forces – Interactions that occur *between* molecules.

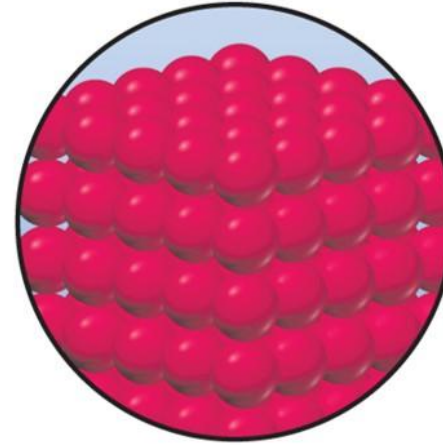
Intermolecular Forces



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

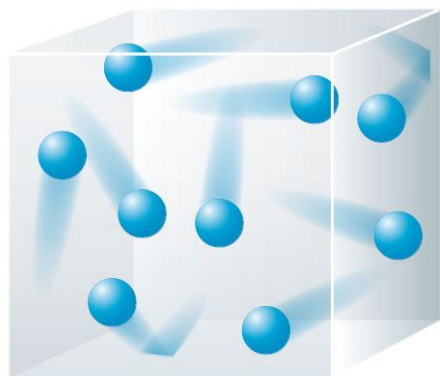


In **liquids**, the particles are held close together by attractive forces but are free to move around one another.



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

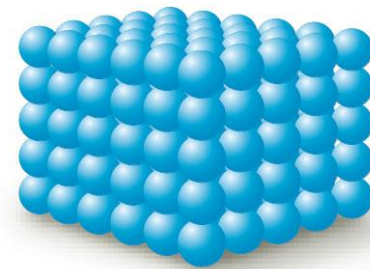
Three States of Matter



Gas



Liquid




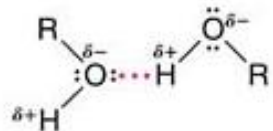
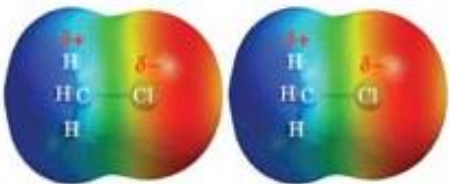
Solid

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

Intermolecular Forces

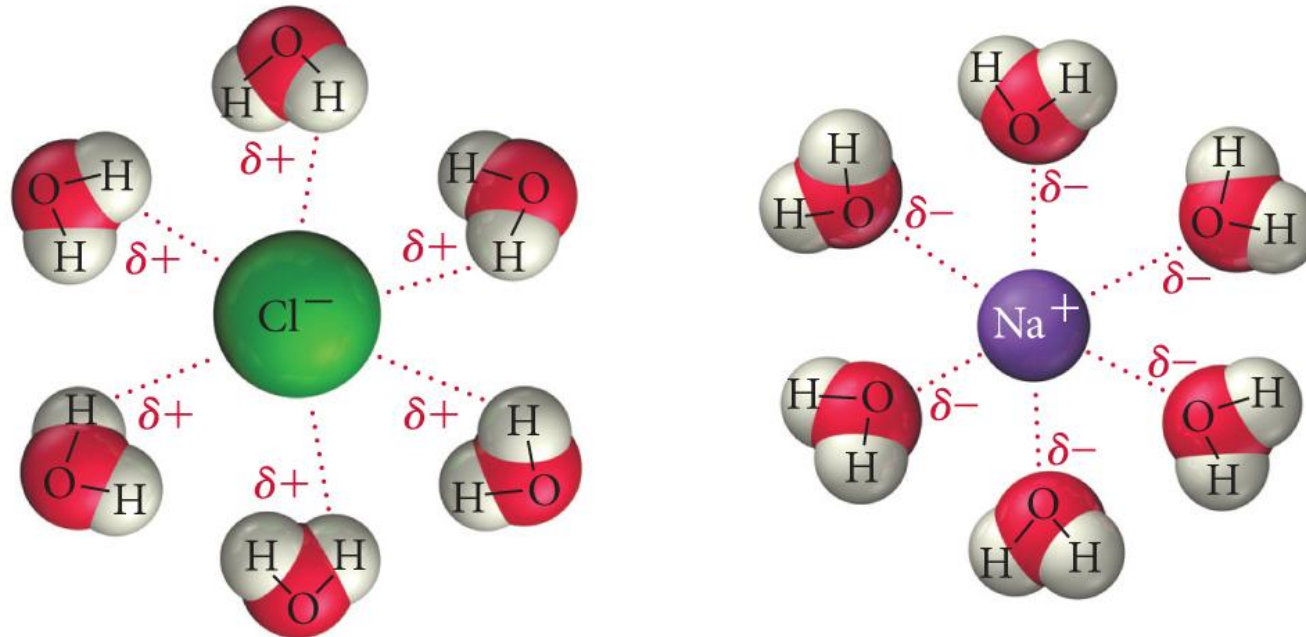
Attractive Electric Forces

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) CH ₃ —CH ₃ (378 kJ mol ⁻¹) I—I (151 kJ mol ⁻¹)

Intermolecular Forces (Van der Waals Forces)			
Hydrogen bonds	Moderate to weak (4–38 kJ mol ⁻¹)	$\delta^- \text{---} \delta^+$ —Z:···H—	
Dipole–dipole (Debye Forces)	Weak	$\delta^+ \cdots \delta^-$	
London Dispersion Forces	Variable	Transient dipole	Interactions between methane molecules

Ion-Dipole Interactions (also important to consider)

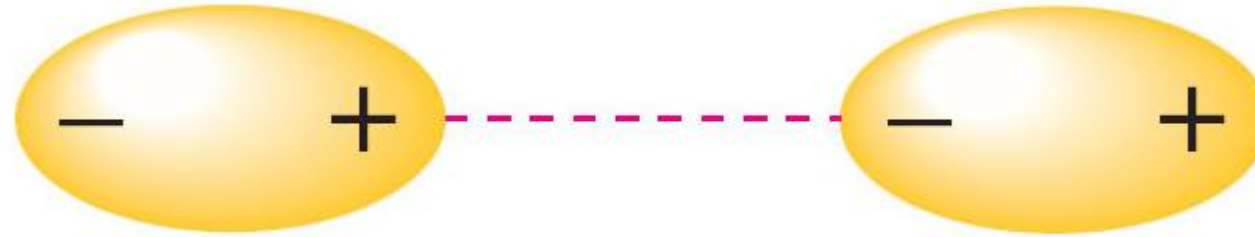
The positively charged end of a polar molecule such as H_2O is attracted to negative ions and the negatively charged end of the molecule is attracted to positive ions.



Dipole-Dipole Forces

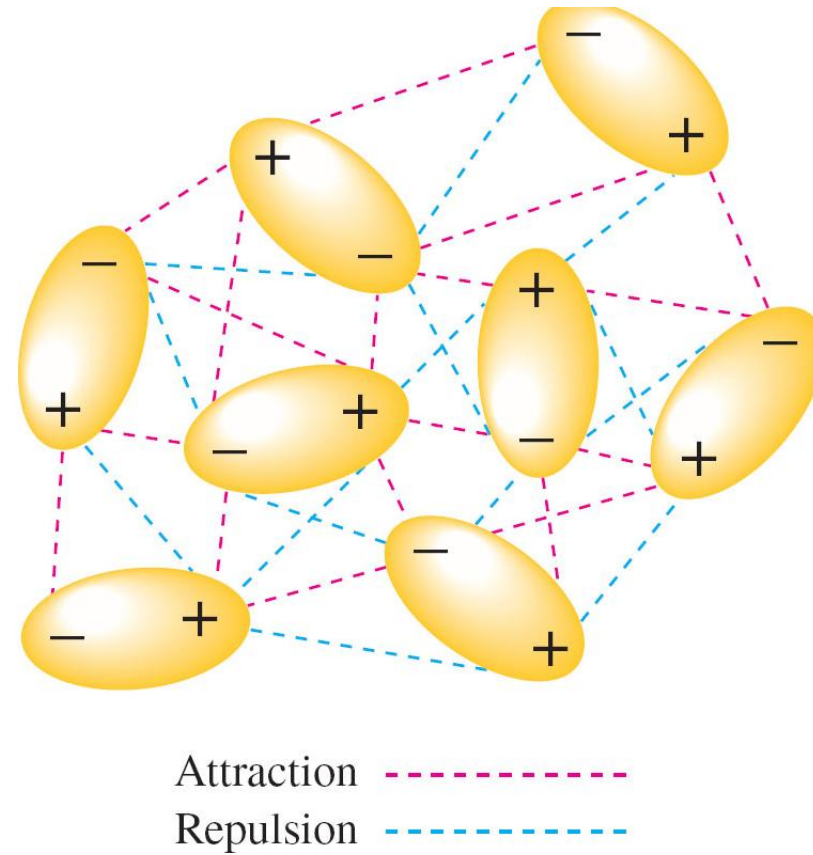
- Dipole moment – molecules with polar bonds often behave in an electric field as if they had a center of positive charge and a center of negative charge.
- Molecules with dipole moments can attract each other electrostatically. They line up so that the positive and negative ends are close to each other.
- Only about 1% as strong as covalent or ionic bonds, and they become weaker as distance between the dipoles increases.

Dipole-Dipole Forces



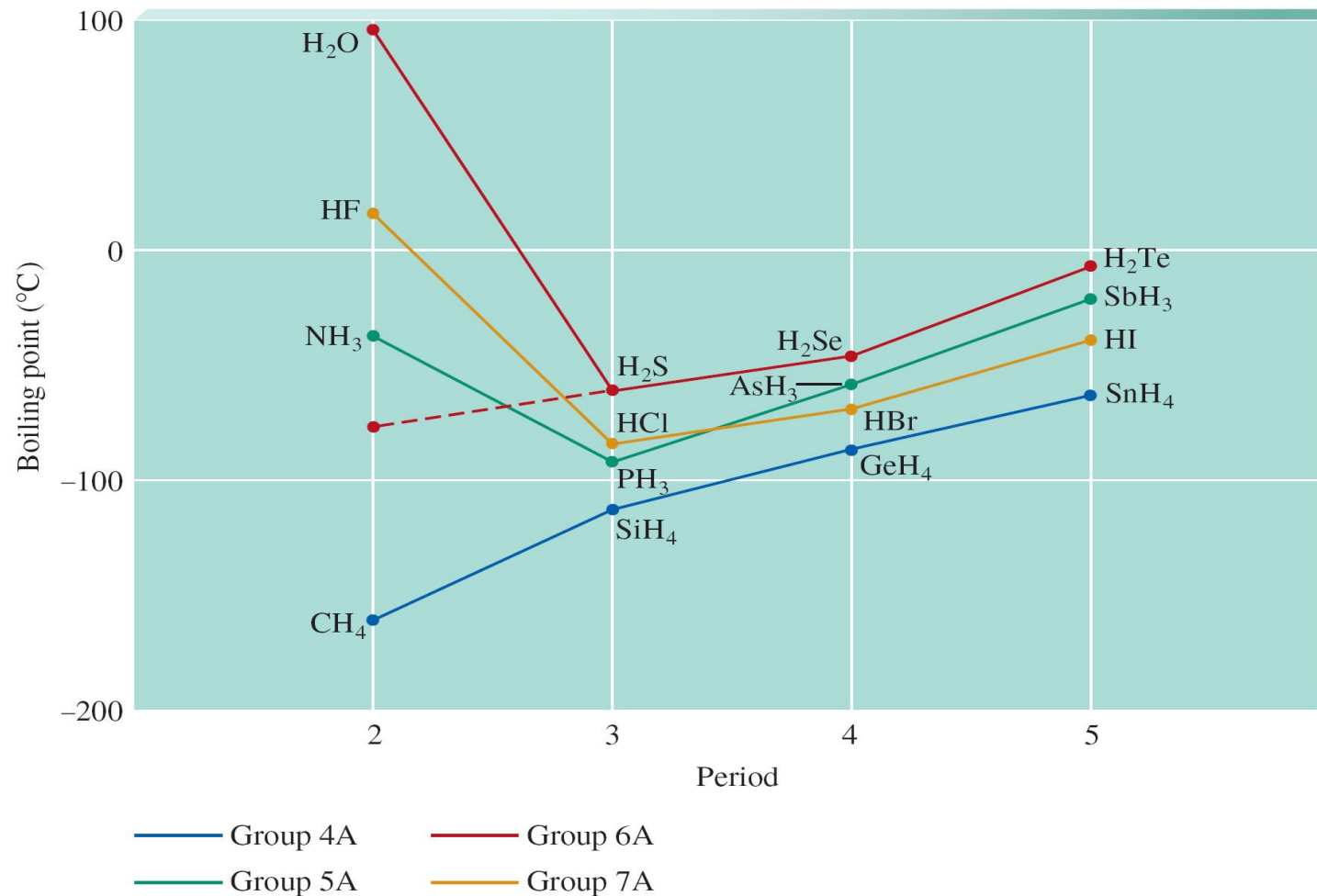
- Polar molecules (molecules with net dipoles) have dipole-dipole forces.
- These forces are very distance dependent, thus in the gas phase are less important.
- In liquids and solids, they can be very important.

Dipole-Dipole Forces

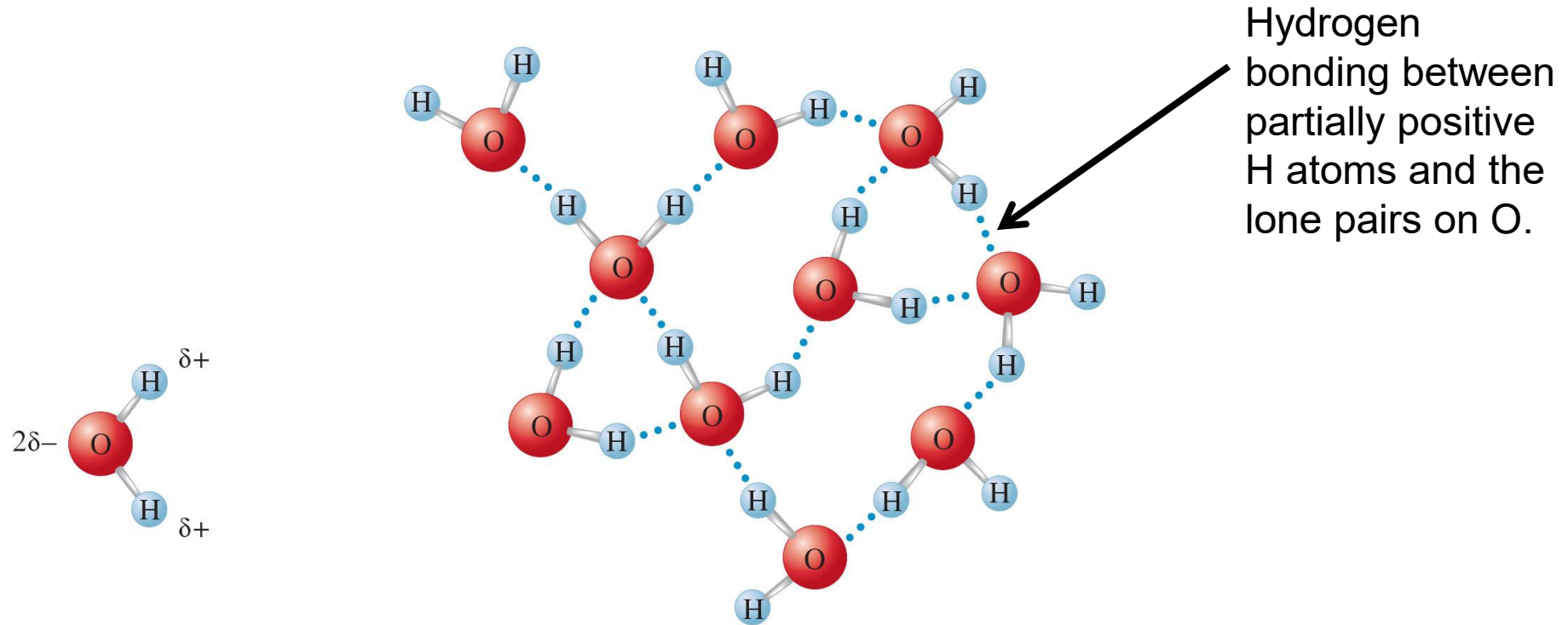


In the liquid phase, dipoles find the best compromise between attraction and repulsion.

Hydrogen Bonding: A Special Type of Dipole-Dipole

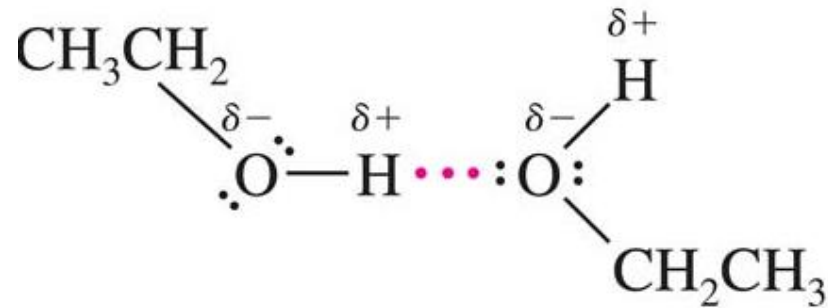


Hydrogen Bonding: A Special Type of Dipole-Dipole



Hydrogen bonding 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

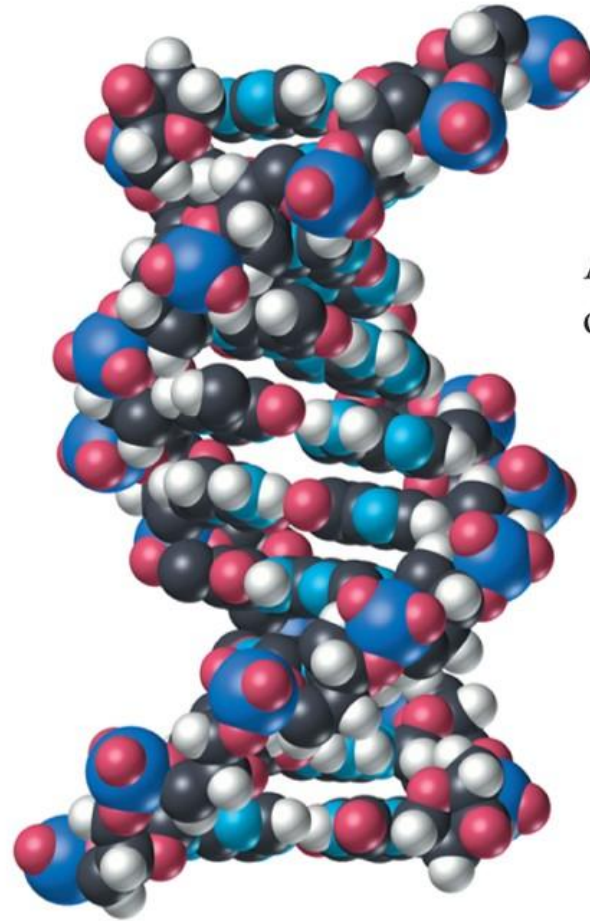
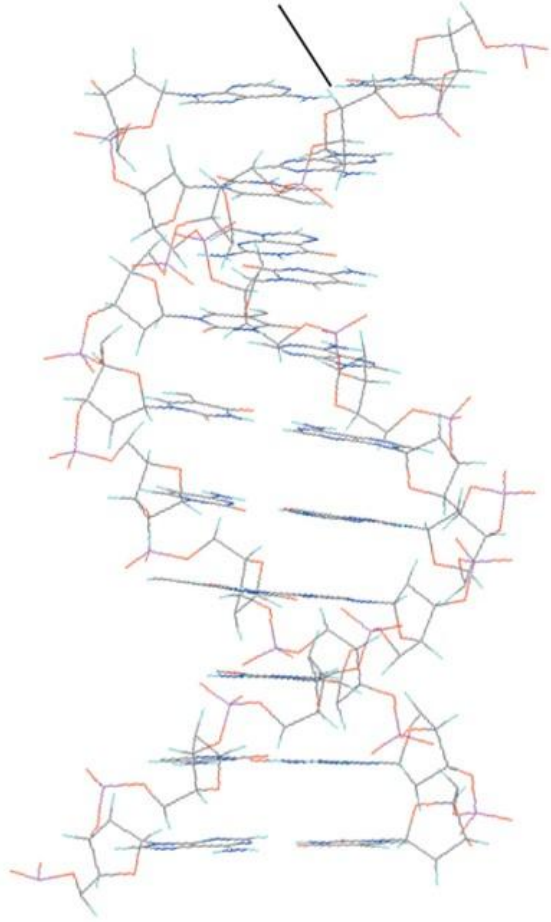


Factors Involved in Hydrogen Bonding:

- 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.

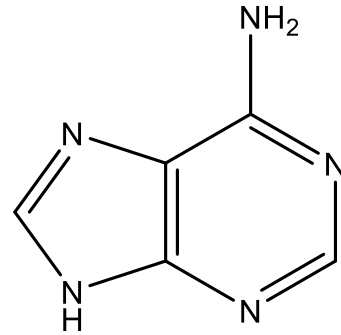
Intermolecular Forces

Hydrogen bond
between chains

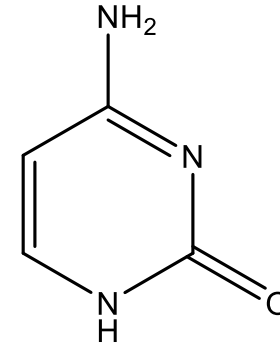


A short segment
of DNA

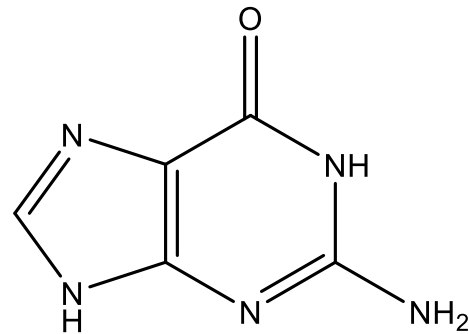
DNA and IMFs



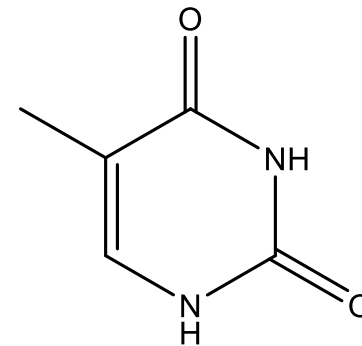
Adenine



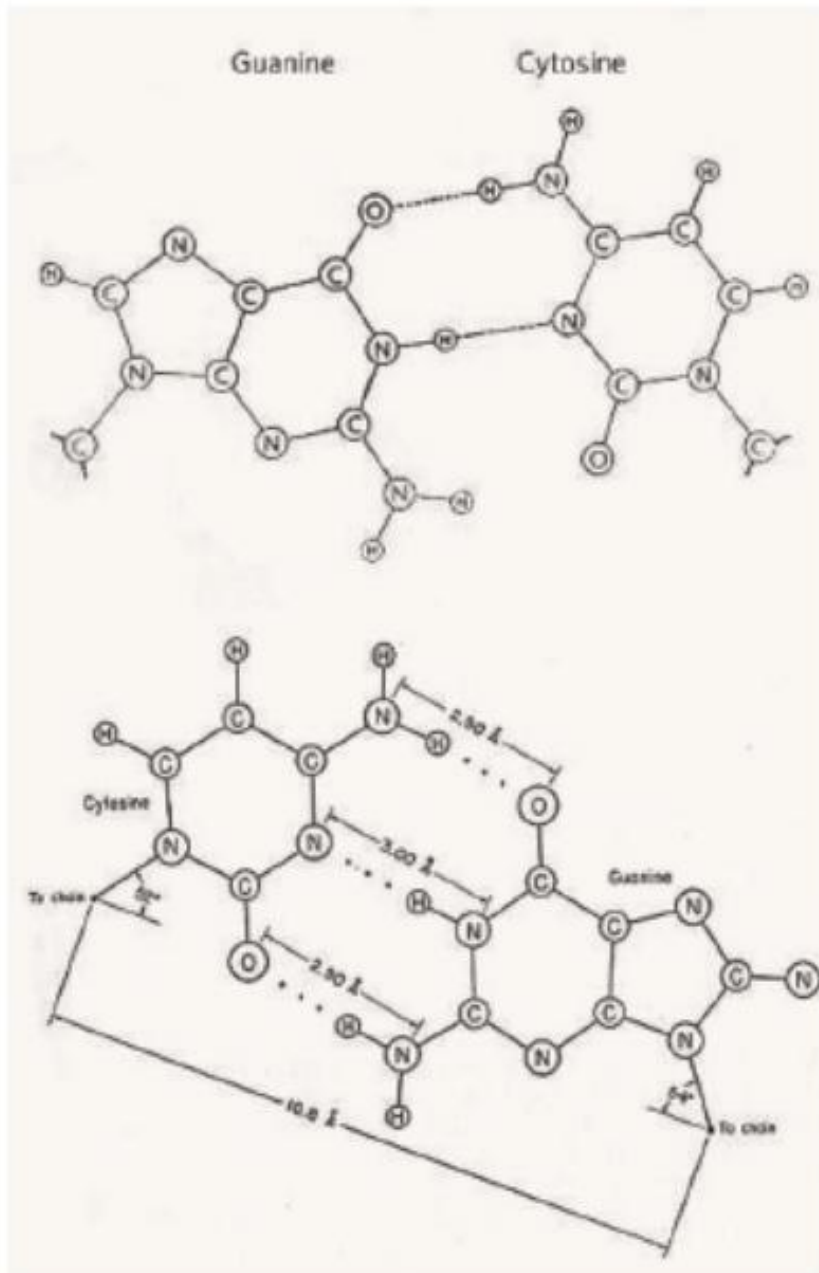
Cytosine



Guanine



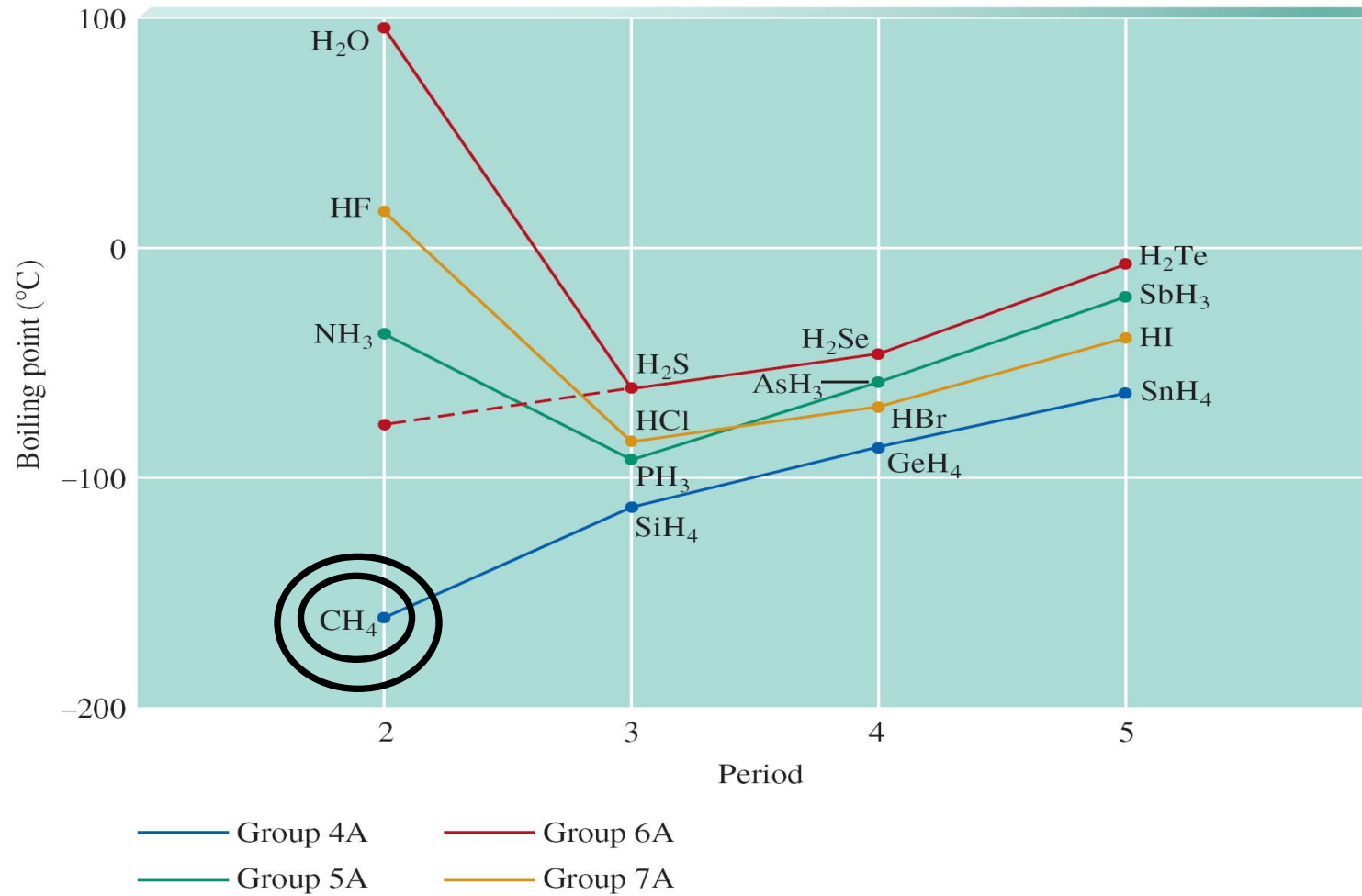
Thymine



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...



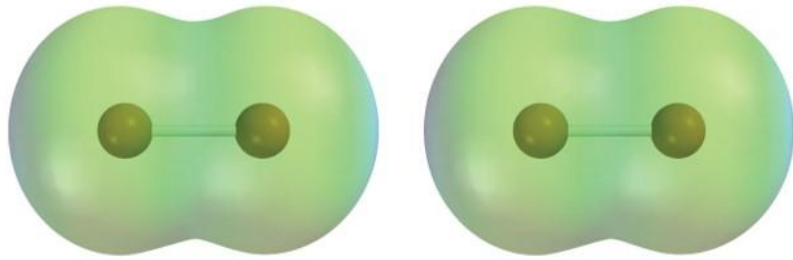
bp = -162 °C

Why does methane ever become a solid or a liquid?

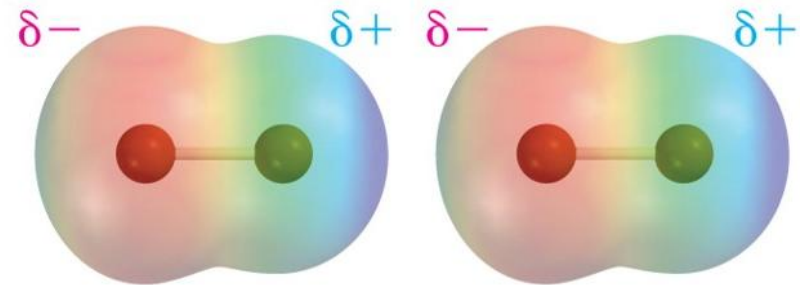
CH₄ is nonpolar, the main form of attraction between the molecules is through London dispersion forces.

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.



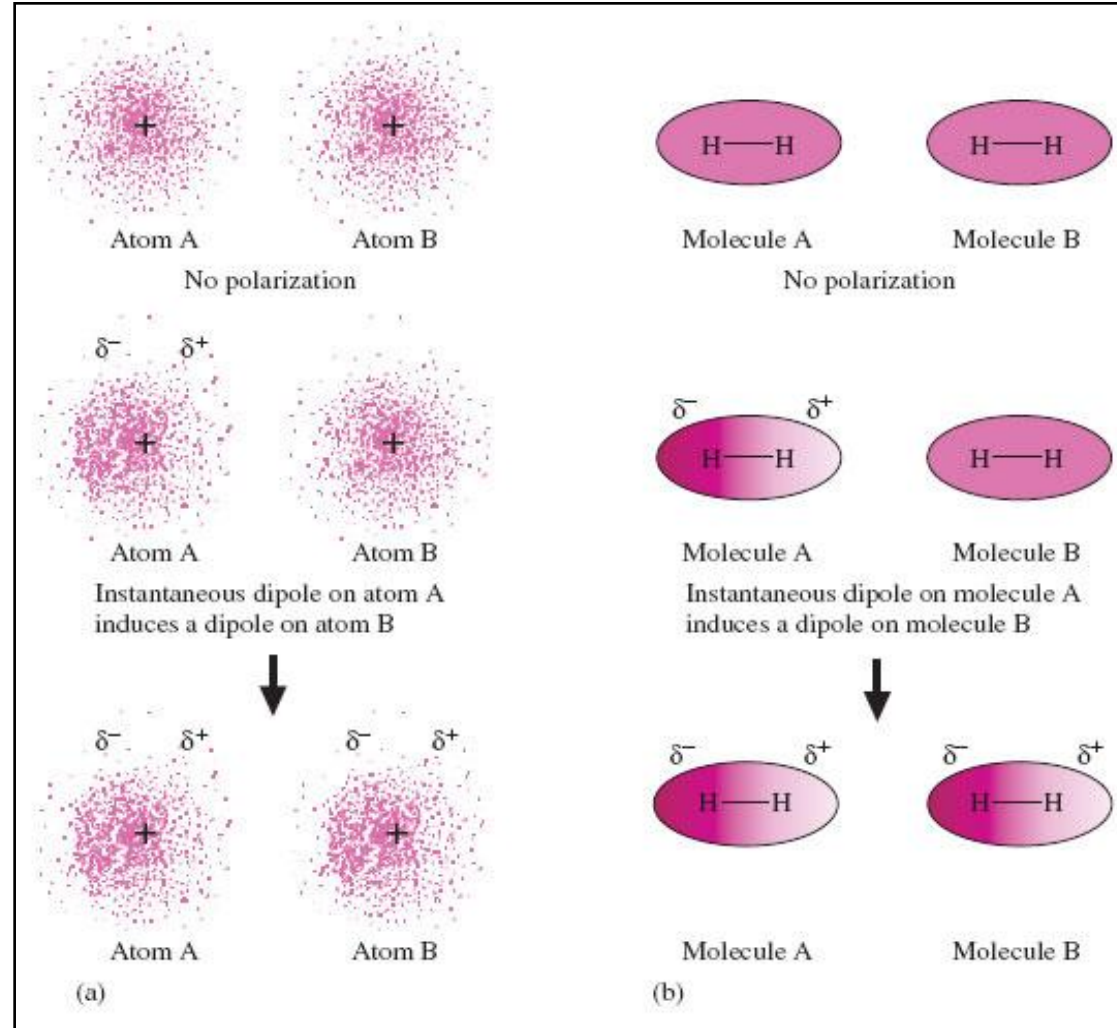
Averaged over time, the electron distribution in a Br₂ molecule is **symmetrical**.



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



Boiling point = 184 °C



Boiling point = - 188 °C

At room temperature, I₂ is a solid and F₂ is a gas.

Dispersion Forces



Boiling point = 184 °C



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

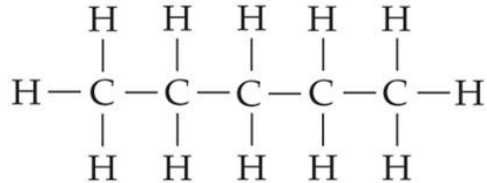
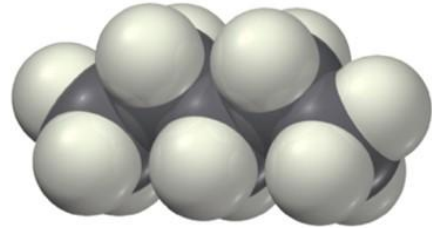
- **London Dispersion Forces**

Table 8.4 Melting Points and Boiling Points of the Halogens

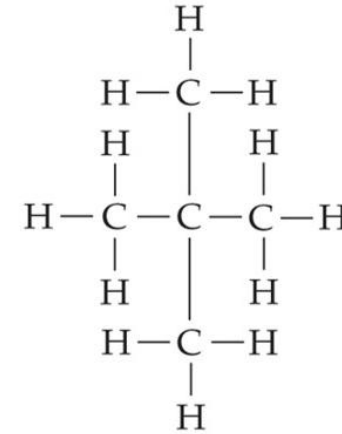
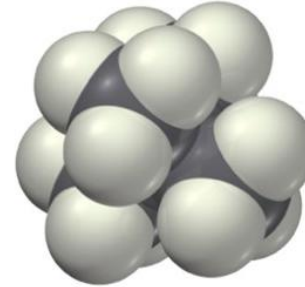
Halogen	mp (K)	bp (K)
F ₂	53.5	85.0
Cl ₂	171.6	239.1
Br ₂	265.9	331.9
I ₂	386.8	457.5

- 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)

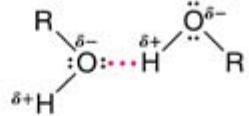
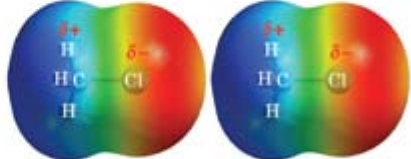


2,2-Dimethylpropane (bp = 282.6 K)

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)	$\overset{\delta-}{\text{Z}} \cdots \overset{\delta+}{\text{H}}$	
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).

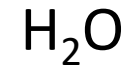
Intermolecular Forces

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

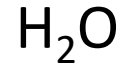
Which molecule is capable of forming **stronger** intermolecular forces?



Explain.

Exercise

Which molecule is capable of forming **stronger** intermolecular forces?

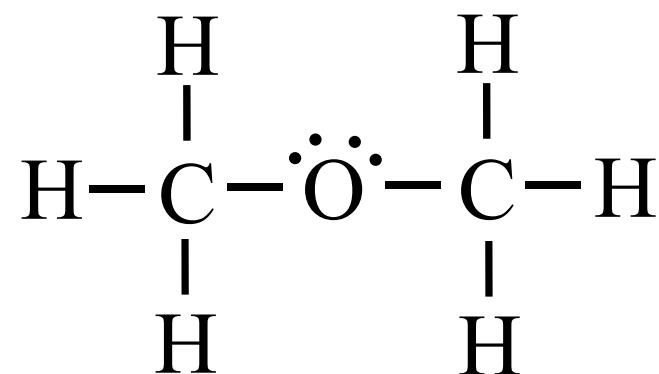
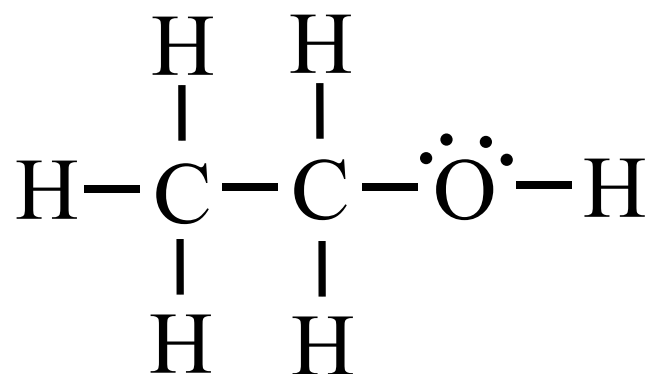


Explain.

H₂O has the stronger intermolecular forces because it exhibits hydrogen bonding, whereas N₂ only exhibits London dispersion forces.

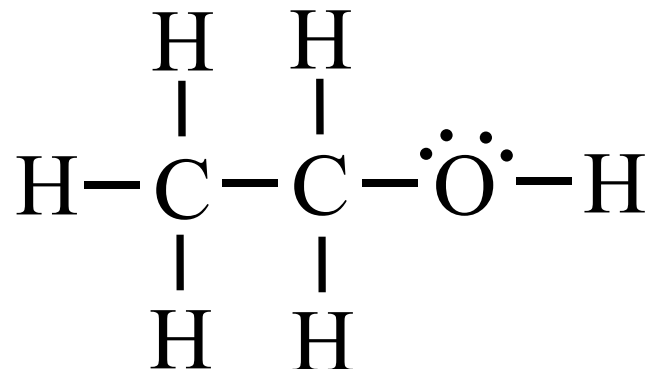
Exercise

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

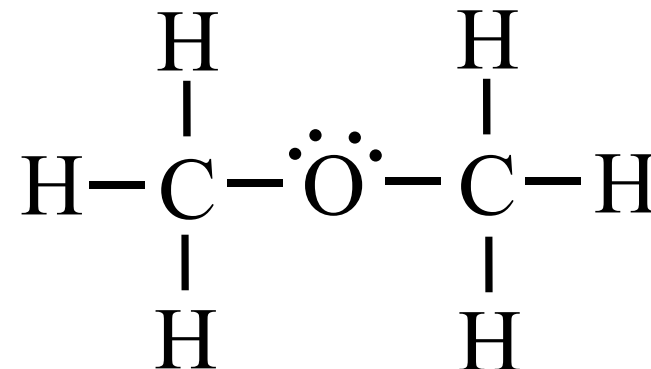


Exercise

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



Ethanol

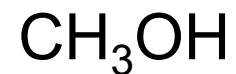


Dimethyl ether

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?



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

$\text{CH}_3\text{OH} > \text{HBr} > \text{CBr}_4$