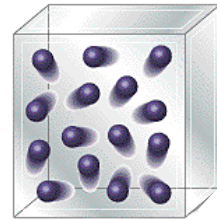


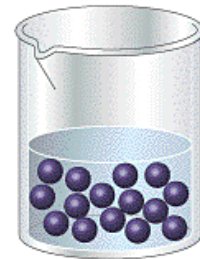
# **LIQUIDS & SOLIDS**

# States

**Gas** → High kinetic energy  
(move fast) → Low attractive forces



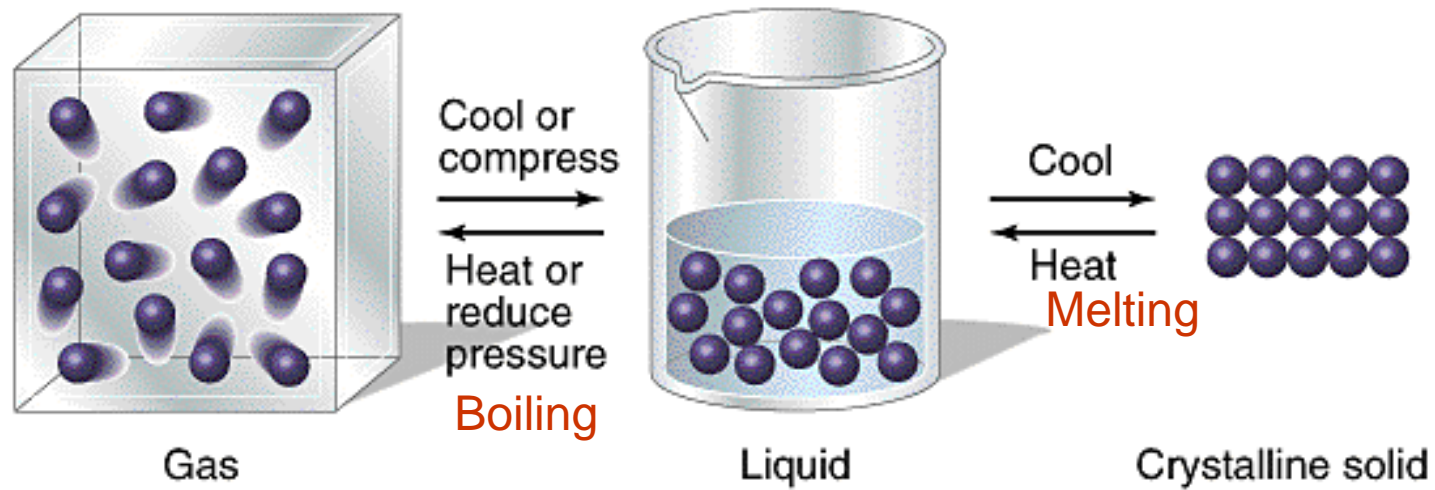
**Liquid** → Medium kinetic energy  
(move slow) → medium attractive forces



**Solid** → Low kinetic energy  
(move slower) → High attractive forces



# Physical Changes



Change of states

Intermolecular  
forces

London dispersion forces

Dipole-dipole interaction

Dipole-induced-dipole interaction <

**ionic bond**  
**covalent bond**

Ion-dipole interaction

Intramolecular  
forces

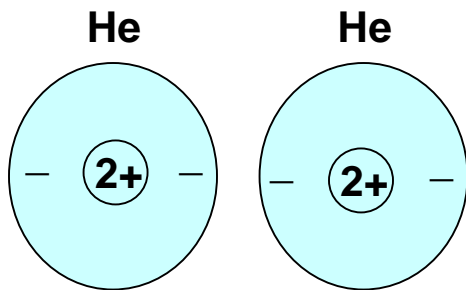
Hydrogen bonding



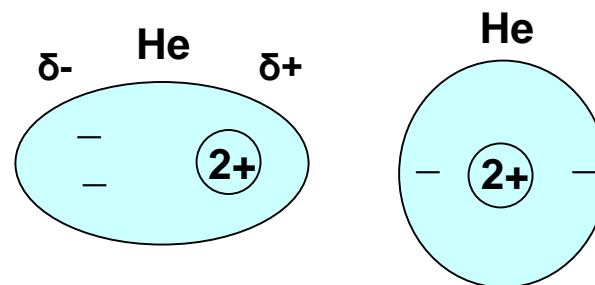
# London dispersion forces

Attractive forces between all molecules

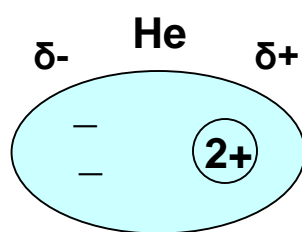
Only forces between nonpolar covalent molecules



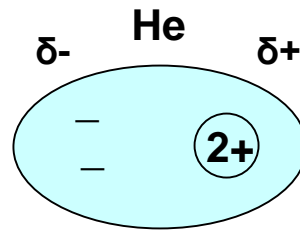
No Polarity



Original Temporary Dipole



Original Temporary Dipole



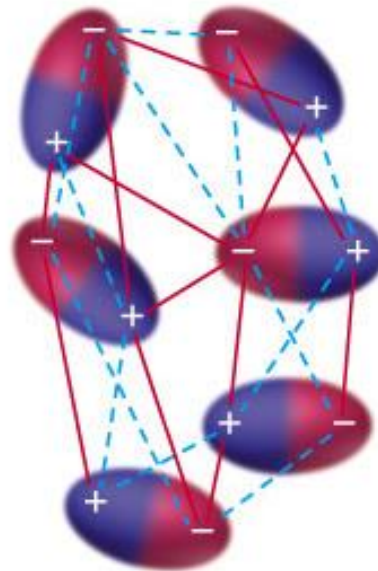
Induced Temporary Dipole

# London dispersion forces

He:

$T = -240^{\circ}\text{C}$  (1 atm)  $\rightarrow$  liquid

$T \downarrow \Rightarrow$  Kinetic energy  $\downarrow$   
Move slower  $\Rightarrow$  Attractive forces become more important  $\Rightarrow$  liquid

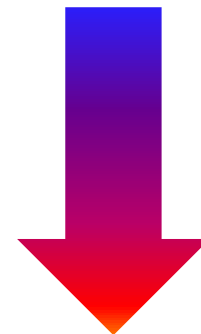


Attraction ———  
Repulsion - - - -

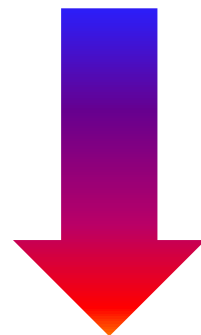
## London Dispersion Forces: Size

|                 | Melting Pt.<br>(°C) | Boiling Pt.<br>(°C) |
|-----------------|---------------------|---------------------|
| He              | -270 (3.5 K)        | -269 (4.2 K)        |
| Ne              | -249                | -246                |
| Ar              | -189                | -186                |
| Kr              | -157                | -153                |
| Xe              | -112                | -108                |
|                 |                     |                     |
| F <sub>2</sub>  | -220                | -188                |
| Cl <sub>2</sub> | -101                | -34                 |
| Br <sub>2</sub> | -7                  | 59                  |
| I <sub>2</sub>  | 114                 | 184                 |

As size increases  
(more shells)



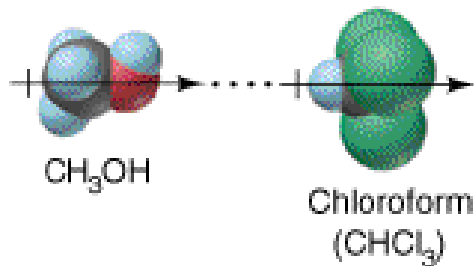
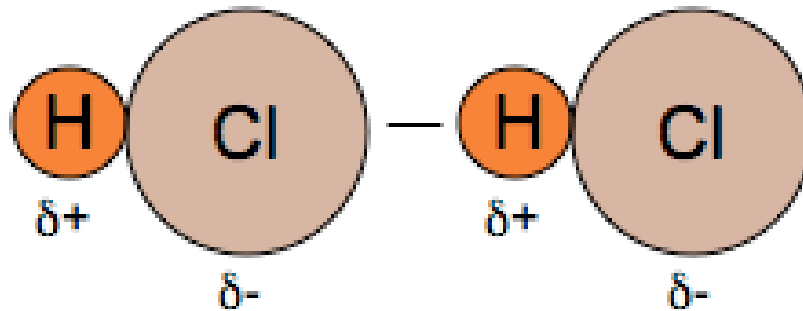
polarizability  
increases



melting and  
boiling points  
increase

# Dipole-Dipole Interactions

Attractive force between **two polar molecules**.



Dipole-dipole

stronger than London dispersion forces



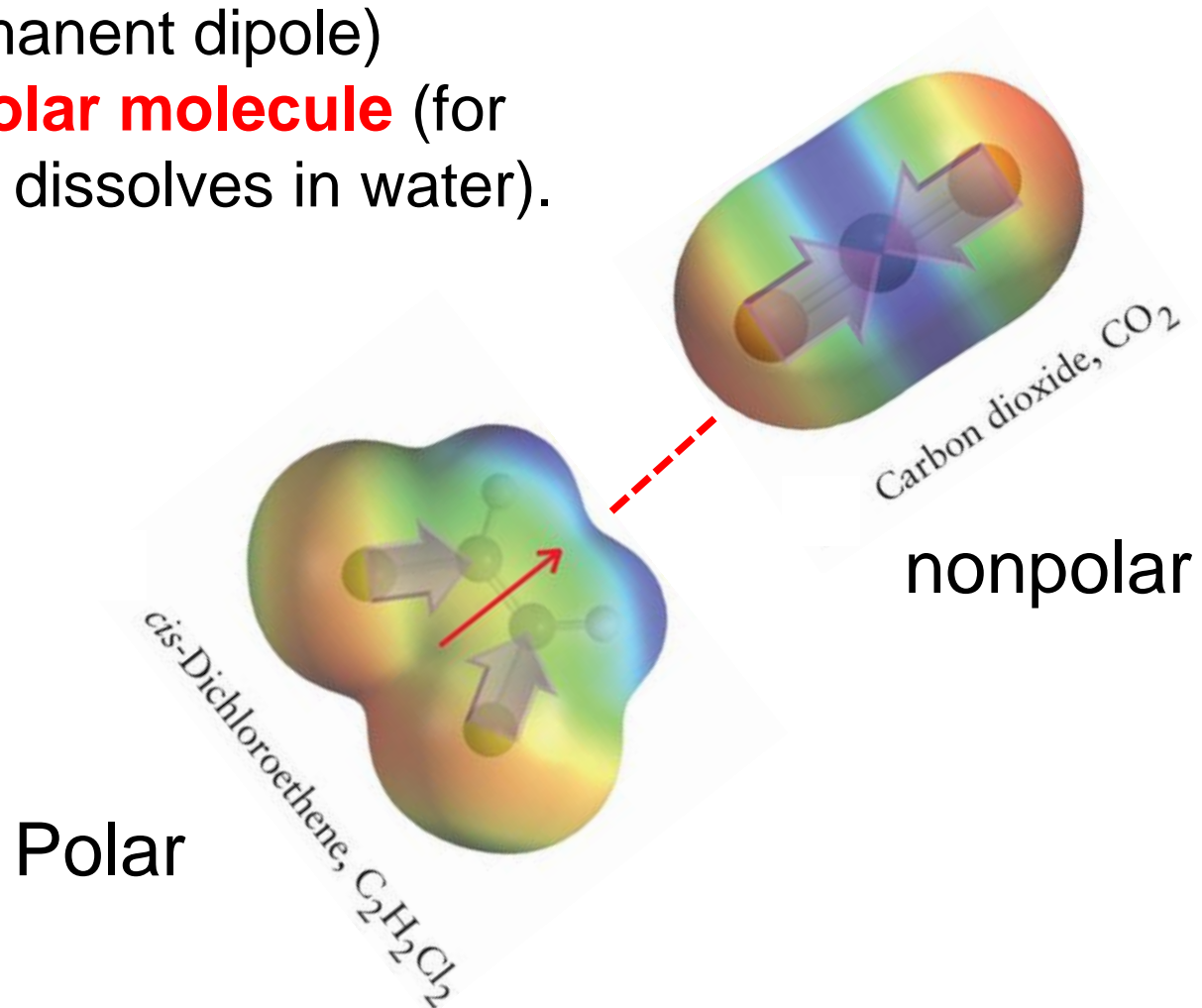
$\uparrow$  intermolecular forces  $\rightarrow$   $\uparrow$  boiling point



# Dipole-induced-dipole Interactions

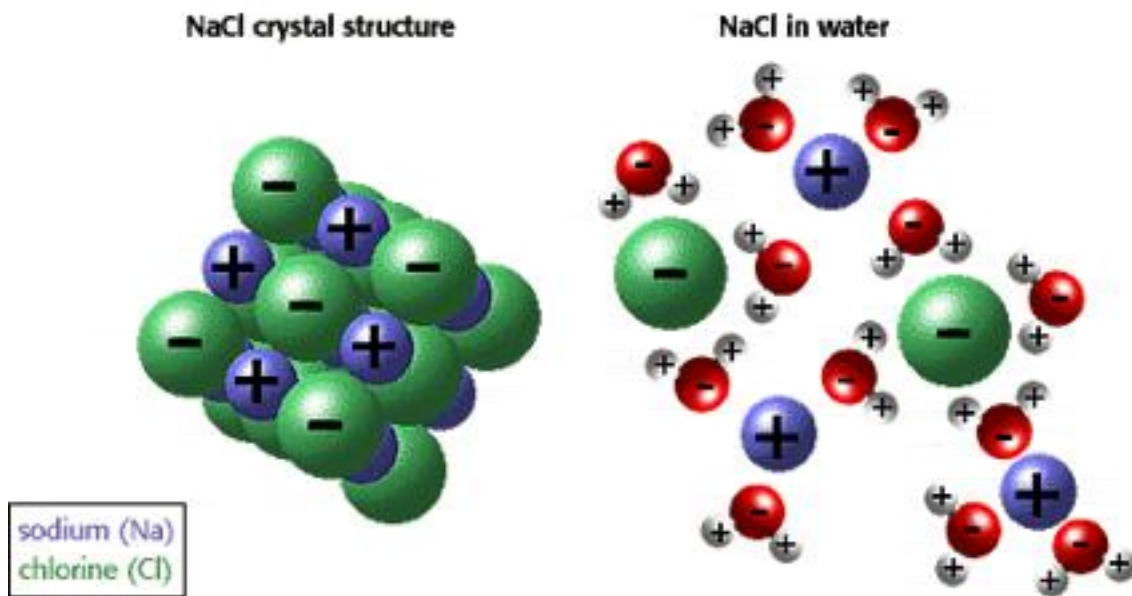
Closely related to the London interaction.

**Polar molecules** (permanent dipole) **interacts** with a **nonpolar molecule** (for example, when oxygen dissolves in water).



# Ion-Dipole Interactions

Attractive force between **ionic compounds** and **polar molecules**.

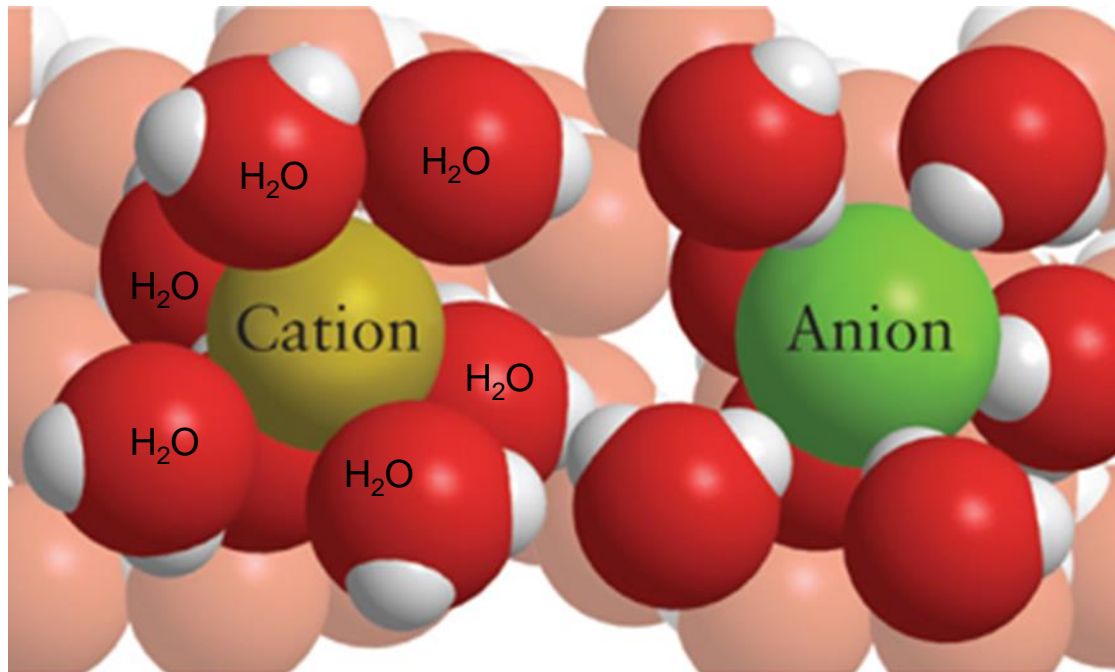


Very strong attraction.

# Ion-Dipole Interactions

The attachment of water to solute particles is called **hydration**. Hydration of ions is due to the polar character of the H<sub>2</sub>O molecule.

Note which end of the water is attracted to either a cation or anion. Remember water has **a permanent dipole**.



# Ion-Dipole Interactions

**Ion-Dipole: Smaller radius,  $r$ , means greater hydration**

**Smaller cations** have a stronger ion-dipole interactions verses **Large cations**.

This allows **Small cations to extensively hydrated** while **Large cations** do not hydrate.

$\text{Li}^+$  and  $\text{Na}^+$  commonly form hydrated salts,

Heavier, bigger Group 1 ions ( $\text{K}^+$ ,  $\text{Rb}^+$ , and  $\text{Cs}^+$ ) do not.

Ammonium salts are usually **anhydrous**, or water free, for a similar reason: an  $\text{NH}_4^+$  ion has about the same radius (143 pm) as an  $\text{Rb}^+$  ion (149 pm) .

## Ion-Dipole: Higher charge, $z$ , means greater hydration

**We expect** ions of the **same size** to hydrate the same.

$\text{Ba}^{2+}$  and  $\text{K}^+$  have the same size.

$\text{K}^+$  salts are *not* hydrated versus  $\text{Ba}^{2+}$  salts are hydrated.

Barium chloride is found as  $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ ;

Potassium chloride is anhydrous.

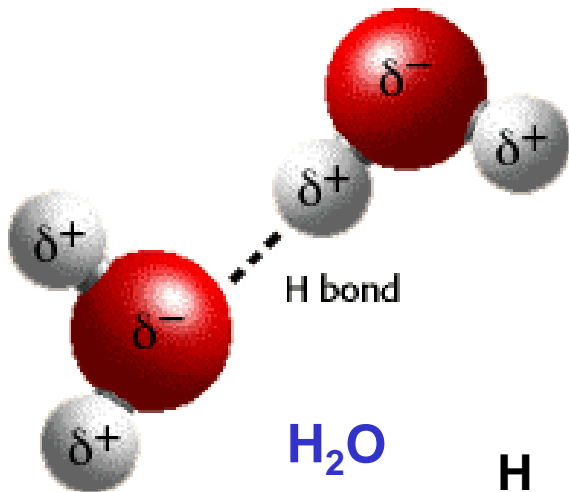
Why: **Barium has a higher ionic charge  $\text{Ba}^{2+}$ .**

Lanthanum is both smaller and highly charged ( $\text{La}^{3+}$ ) and therefore, has a strong ion-dipole interactions. Its salts include  $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$  and  $\text{La}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$ .

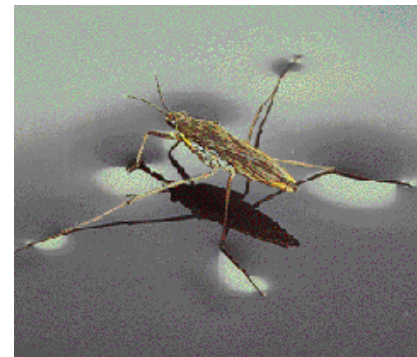
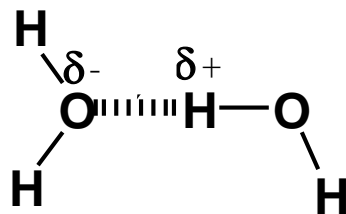
# Hydrogen Bonds

A special case of dipole-dipole

Between **H** bonded to O, N, or F (high electronegativity)  $\rightarrow \delta^+$   
and a nearby **O, N, or F**  $\rightarrow \delta^-$



Stronger than dipole-dipole interactions  
& London dispersion forces



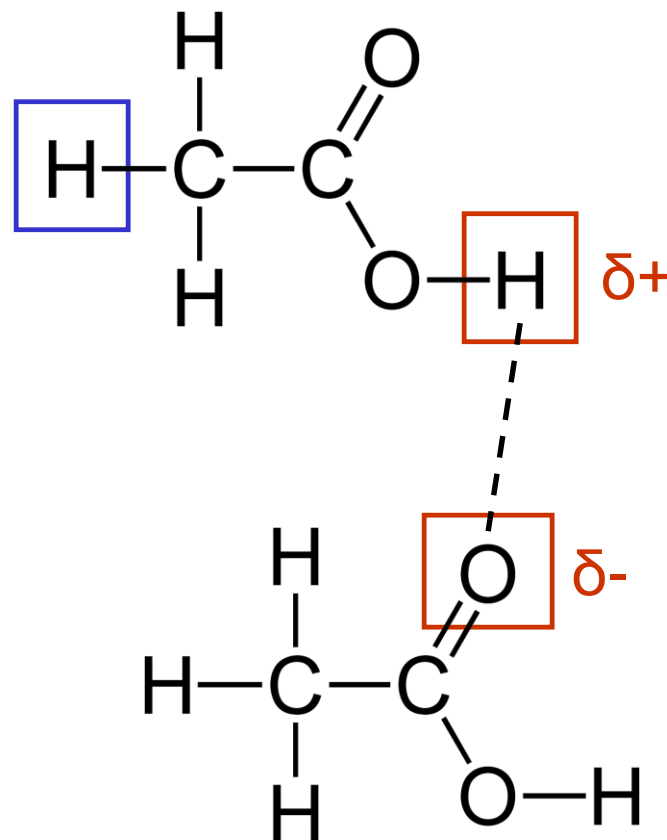
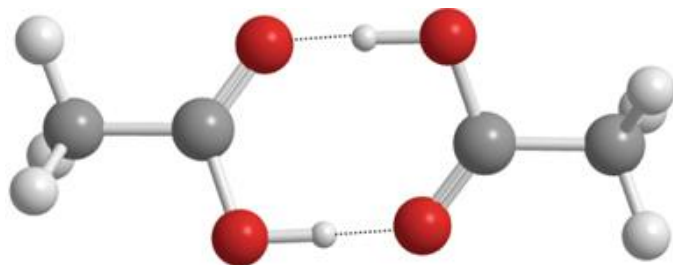
High boiling point

surface tension

# Hydrogen bonding

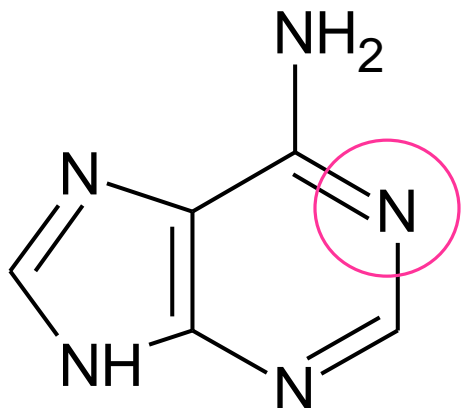


Acetic acid

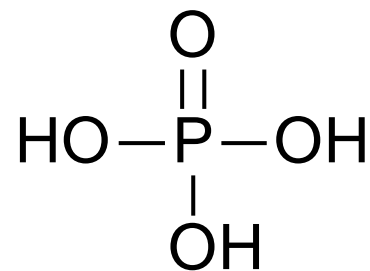


**dimers:** pairs of molecules, linked by two hydrogen bonds.

What possible hydrogen bonds between the “N” on adenine, circled, could occur with phosphoric acid?



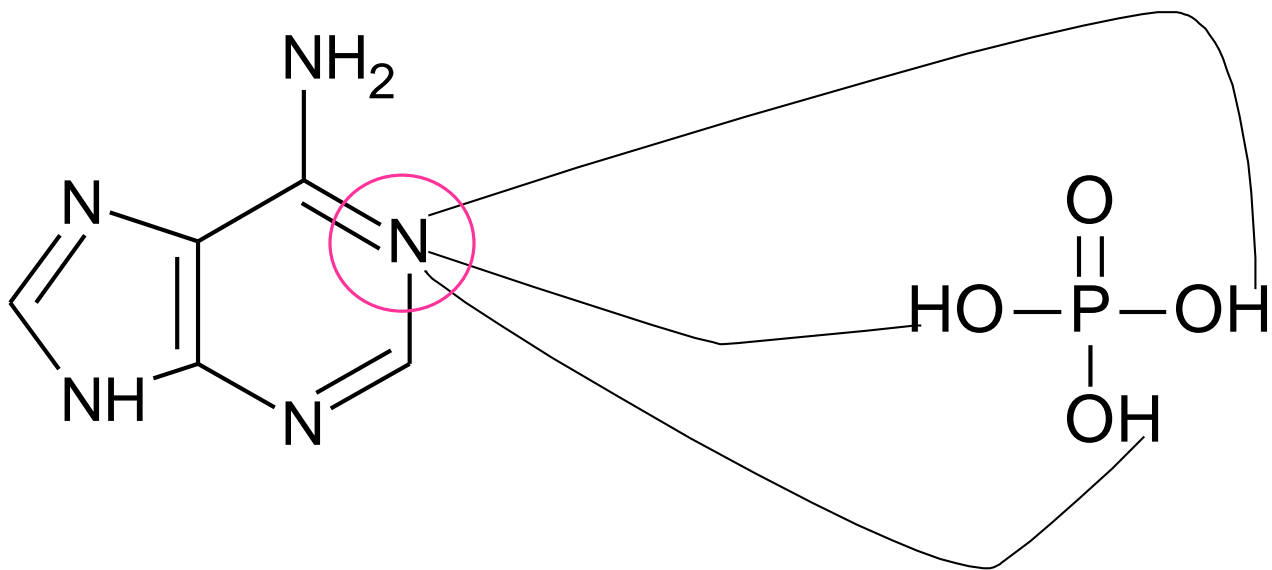
Adenine



Phosphate



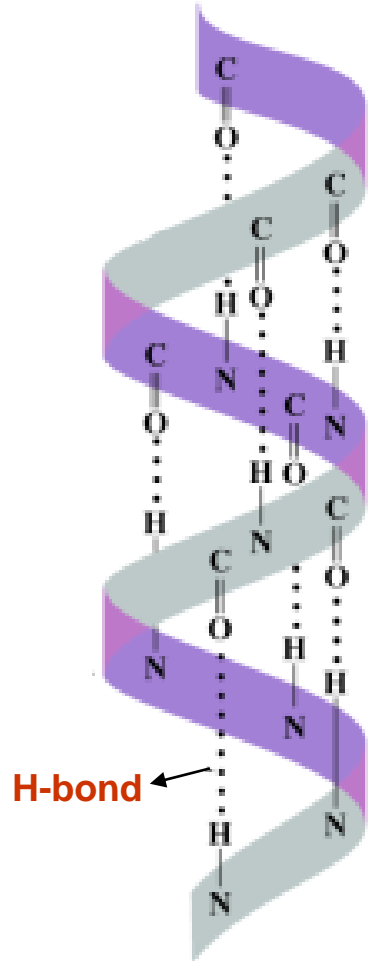
What possible hydrogen bonds between the “N” on adenine, circled, could occur with phosphoric acid?



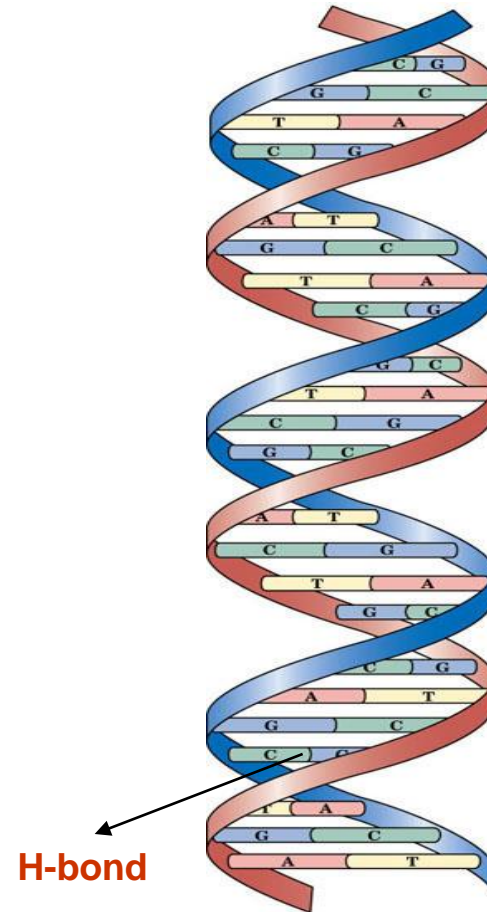
Adenine

Phosphate

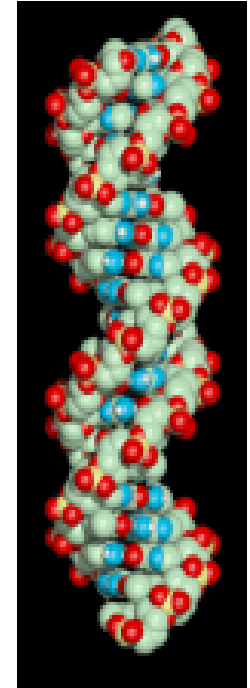
# H-bonding in our body



Protein ( $\alpha$ -helix)



DNA



# Viscosity & Surface Tension

Viscosity is liquids resistance to flow: the higher the viscosity of the liquid, the more sluggish the flow.

Compared to water, honey has high viscosities at room temperature, so it is "viscous ."

Water is easy to pour, it has low viscosity.

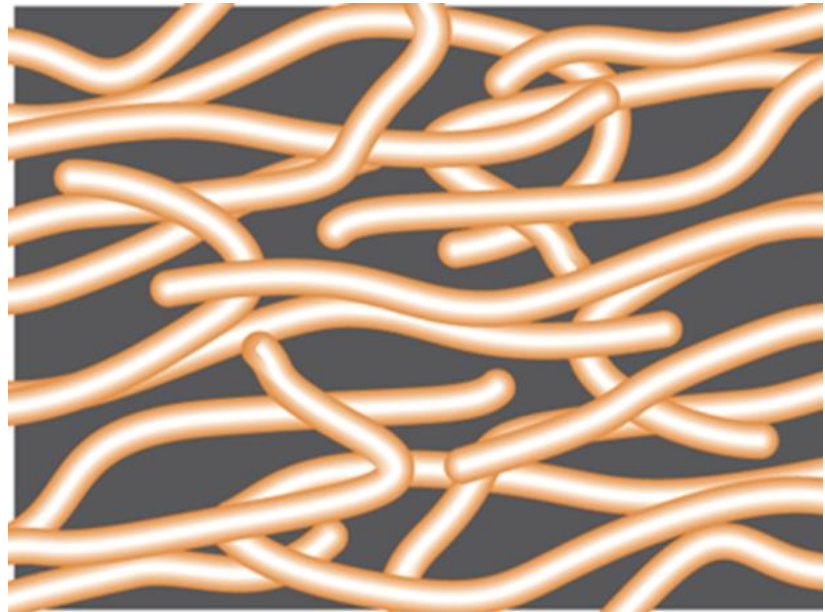
Phosphoric acid,  $\text{H}_3\text{PO}_4$ , and glycerol,  $\text{HOCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$ , are very viscous because of the *numerous hydrogen bonds* between the molecules.

↑ Viscosity indicates ↑ intermolecular strength.

# Viscosity & Surface Tension

**London forces** dominate **Nonpolar hydrocarbons**.

Instead viscosity is due to hydrocarbon chains with 19 or more carbons, that form spaghetti-like structures.

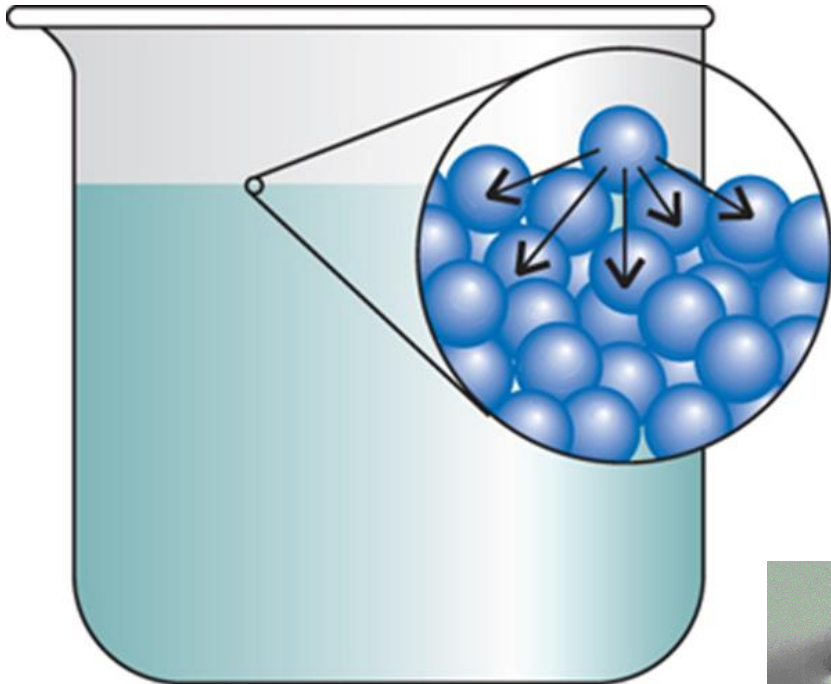


# Viscosity & Surface Tension

**Surface tension** is why the surface of a liquid is smooth.

Strong forces pull the molecules together, with a **net inward pull**.

Water has a surface tension about 3 times greater than most other liquids.



| Liquid                  | Surface tension,<br>$\gamma$ ( $\text{mN}\cdot\text{m}^{-1}$ ) |
|-------------------------|--|
| benzene                 | 28.88  |
| carbon<br>tetrachloride | 27.0   |
| ethanol                 | 22.8   |
| hexane                  | 18.4   |
| mercury                 | 472  |
| methanol                | 22.6   |
| water                   | 72.75<br>58.0 at 100°C   |



## Viscosity & Surface Tension

Surface tension **pulls** the molecules into the most compact shape, a sphere.

Attractive forces between water are greater than between water and the waxy hydrocarbon leaf surface (London) cause droplets.

Surface tension **decreases** with rising temperatures.



# Viscosity & Surface Tension

**Adhesion** two surfaces or materials sticking together.

Water spreads out over a paper towel due to adhesion between  $\text{-OH}$  groups in paper and water.



**Cohesion** two surfaces or materials not attracted to each other.

Water beads-up on a waxy surface due to lack of cohesion.



# Viscosity & Surface Tension

**Capillary action** is how liquids flow up narrow tubes.

The **upward** curved meniscus of water forms because both water and glass have comparable forces:

**Adhesion  $\approx$  Cohesion**

The **downward** meniscus of mercury forms because the cohesive forces in mercury is strong than between mercury atoms and the glass:

**Cohesion  $\neq$  Adhesion**





# Boiling & Melting points

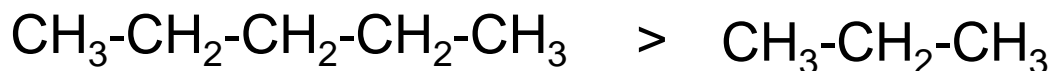
Factors that affect boiling point:

## 1. Intermolecular forces:

London dispersion forces < Dipole-Dipole interactions < Hydrogen bonds

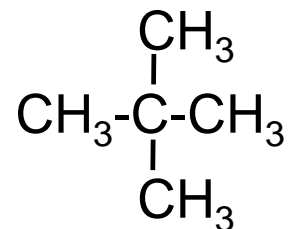
## 2. Number of sites for intermolecular interactions (surface area):

Larger surface (more electrons) → more sites for London → ↑ b.p.

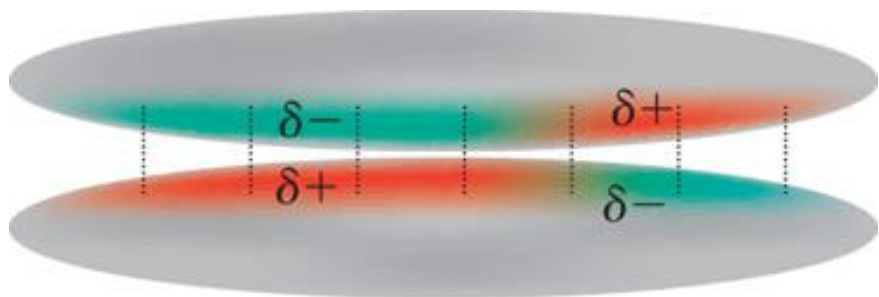


## 3. Molecular shape: With the same molecular weight.

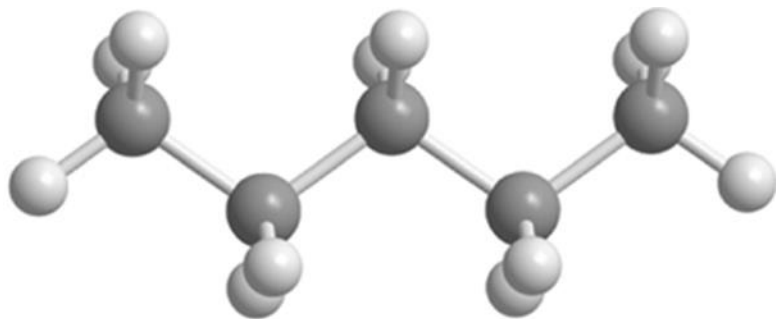
linear  $\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_3 >$  spherical



## London Forces: Shape

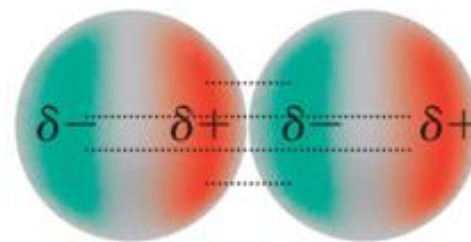


Rod-like molecules have a **greater surface area**, **more contact points** for molecules to join together.

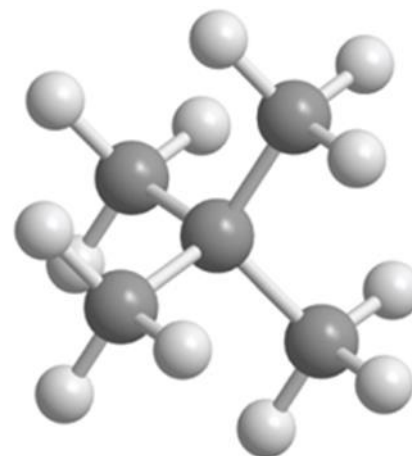


Pentane,  $C_5H_{12}$

Boiling Points:  $36^\circ C$



Ball or spherical shaped molecules have **fewer contact points** for molecules to join together.



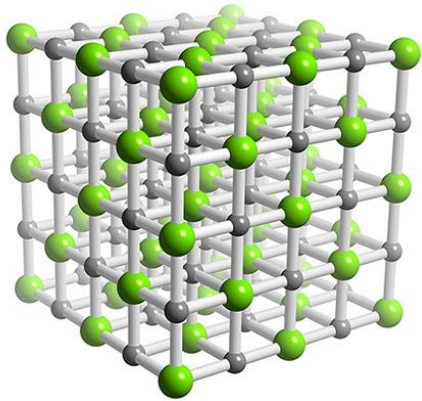
2,2-Dimethylpropane,  $C(CH_3)_4$

(isomers)  $10^\circ C$

# Solid

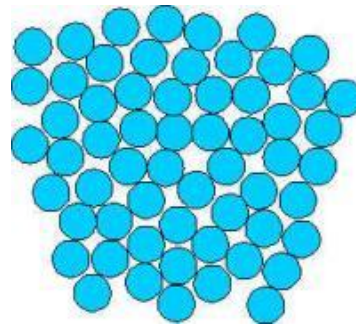
**Crystalline solid (Network solids)**

**long-range order**



**Amorphous solid**

**short-range order**

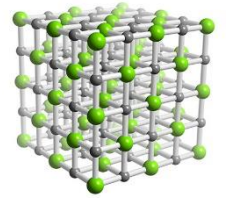


# Crystalline solids (Network solids)

Ionic solids: **Consist of ions (metal-nonmetal)**

NaCl

Stable - High melting points



Molecular solids: **Consist of molecules.** Sugar, Ice

Lower melting points

Hold together by intermolecular forces:  
London dispersion forces, Dipole-Dipole interaction, H-Bond



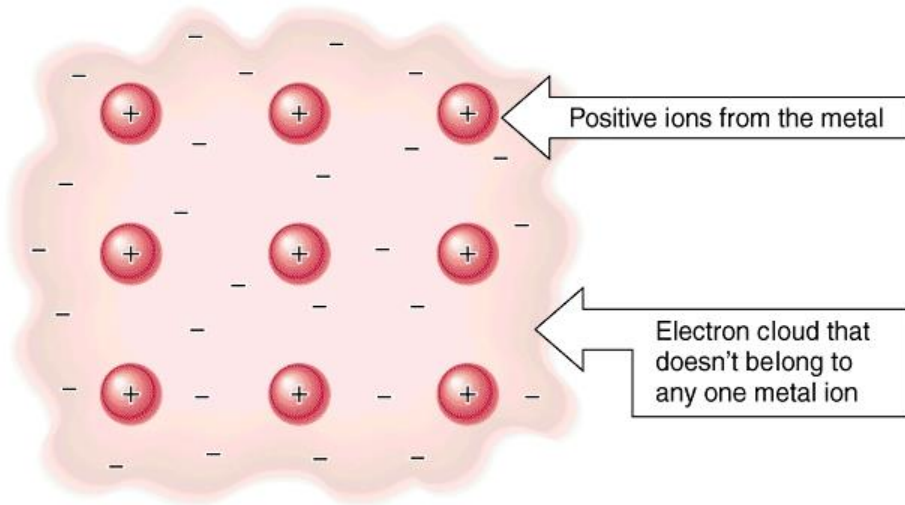
Atomic solids: **Consist of atoms.** Diamond, Graphite, Metals

Different melting points (because of forces between atoms).

Crystalline solid

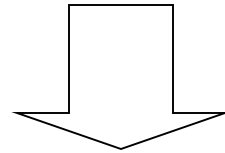


# Metallic solids



## Electron Sea Model

**Valance electrons are shared among the atoms in a nondirectional way.**



Metals conduct heat and electricity.

They are malleable and ductile.

We can make alloys.

## Metallic solids

Metals are thought of as spheres adopting a **close-packed structure**, in which the hard spheres stack, **wasting as little space as possible**, like this fruit on display.

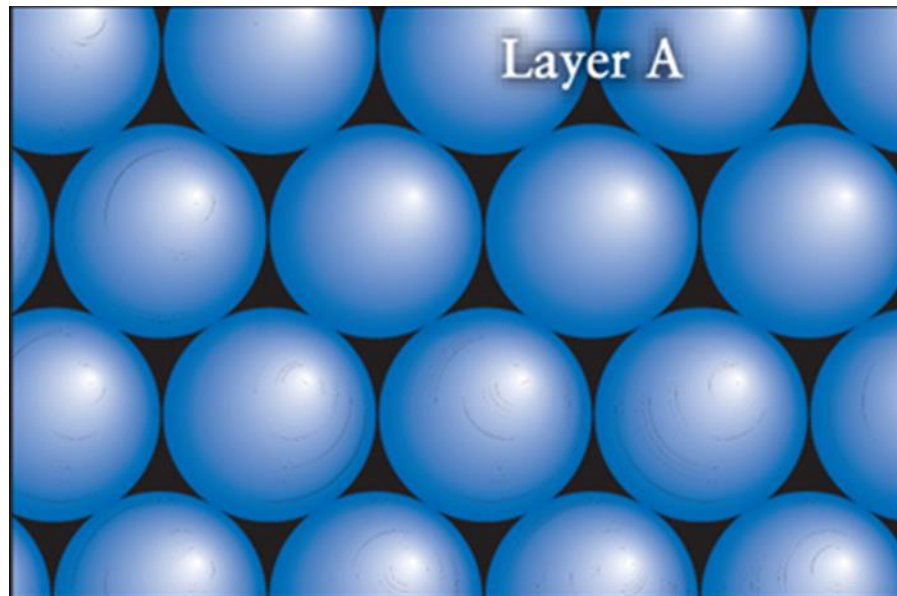


## Metallic solids

**Closed-packed** stacking starts by laying layer upon layer, in a highly efficient manor, of atoms on top of each other.

The **first layer** is a hexagon with spheres (atoms) packed as tightly as possible.

This is often referred to as **Layer A**.

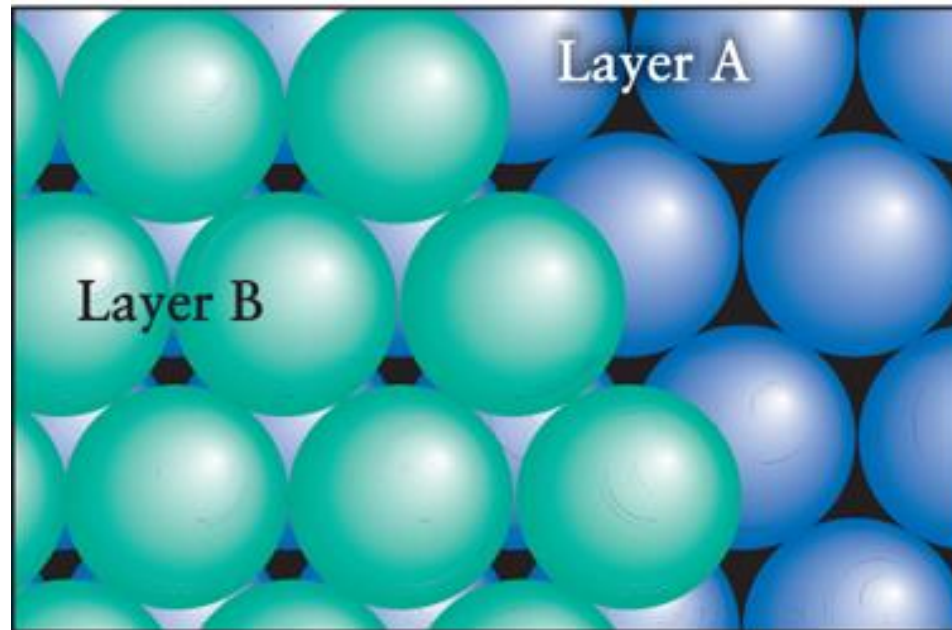


## Metallic solids

Next a **second layer** is added on top of the Layer A.

This is called **Layer B**.

Notice how the spheres rest in the small cavity created between each sphere in Layer A.





# Metallic solids

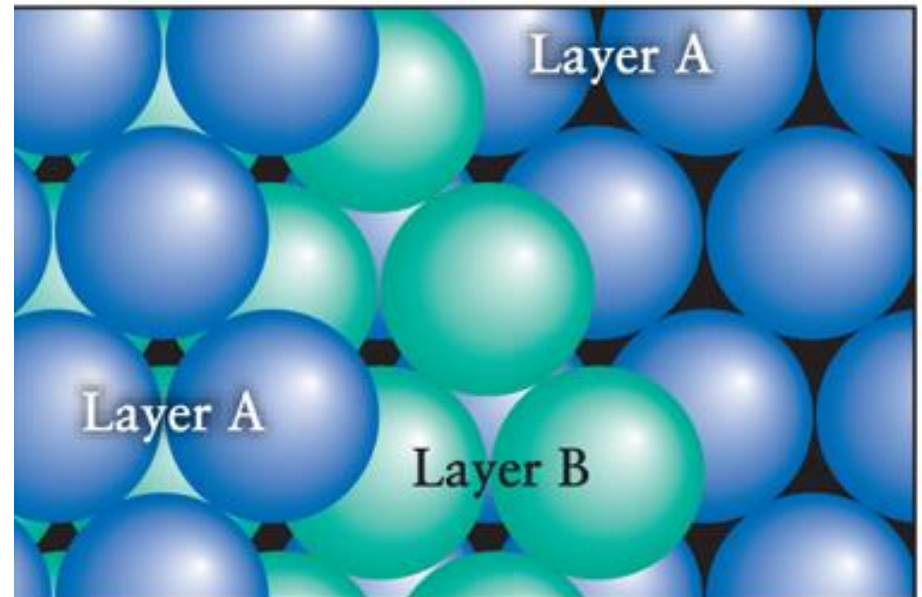
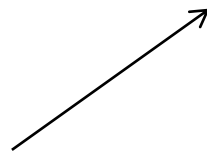
For the **third layer**, there are two options:

Option 1:

Shown is a third layer identical to Layer A, referred to as a ABABAB pattern. Each atoms is over the atom in Layer A.

A more common name for this is Hexagonal Closed-Pack (hcp).

Notice the hole visible all the way to the first layer.



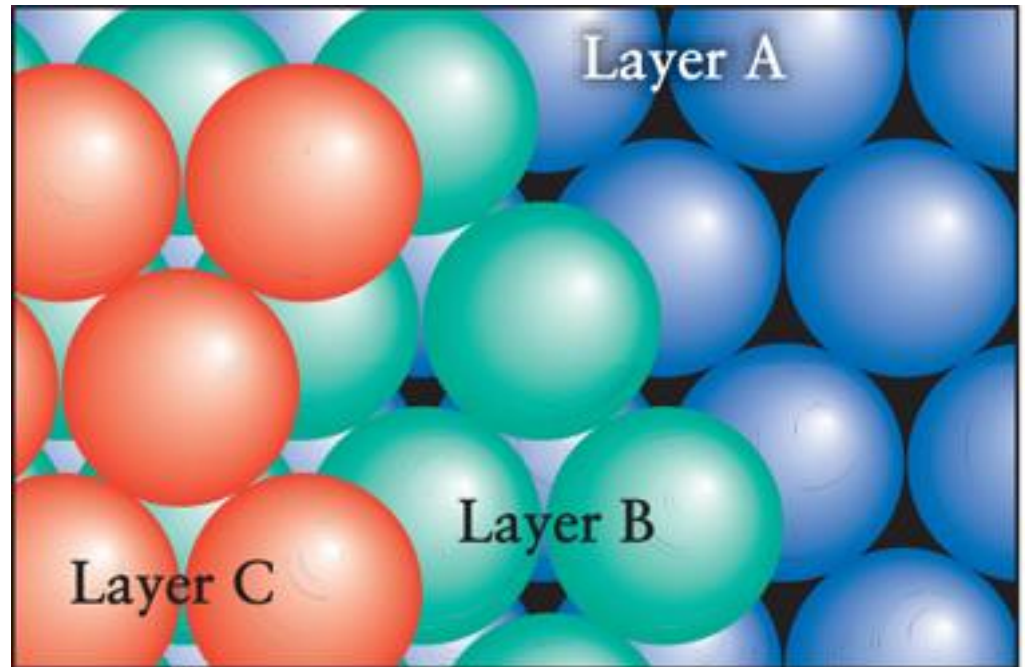
# Metallic solids

## Option 2:

The second options differs slightly by placing a layer offset to Layer A, and is called **Layer C** or an ABCABC pattern.

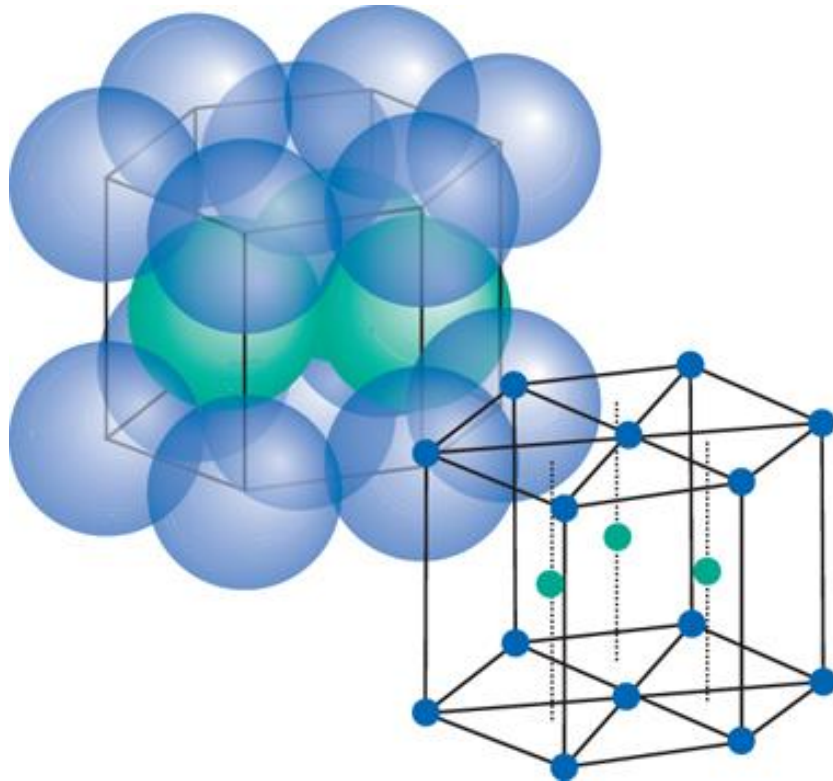
A more common name is **Cubic Closed-Pack (ccp)**.

Notice the hole disappears.

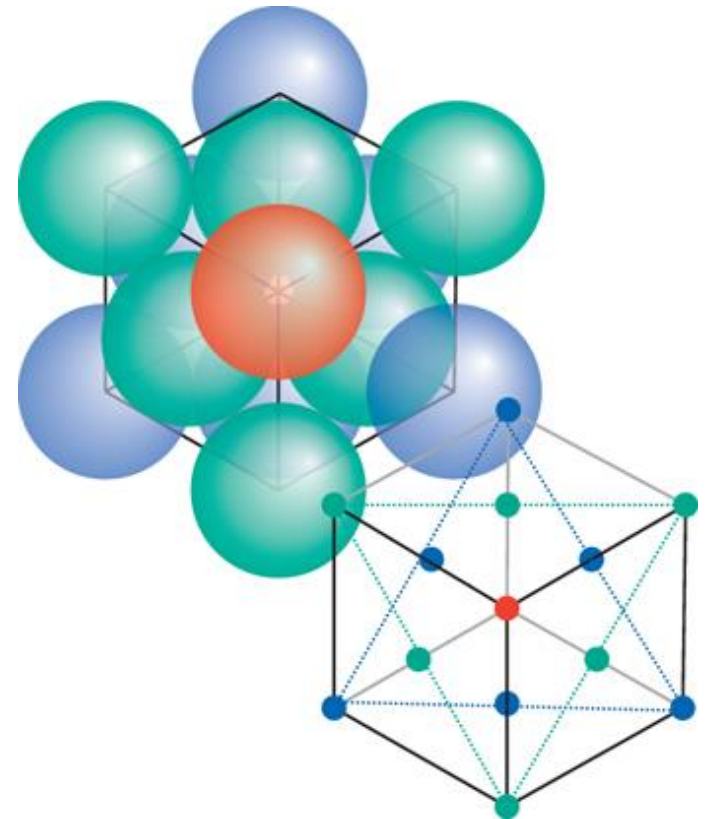


# Metallic solids

hcp



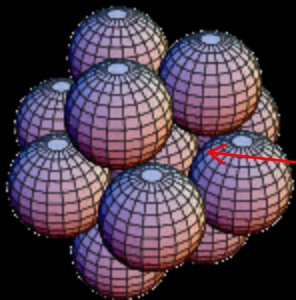
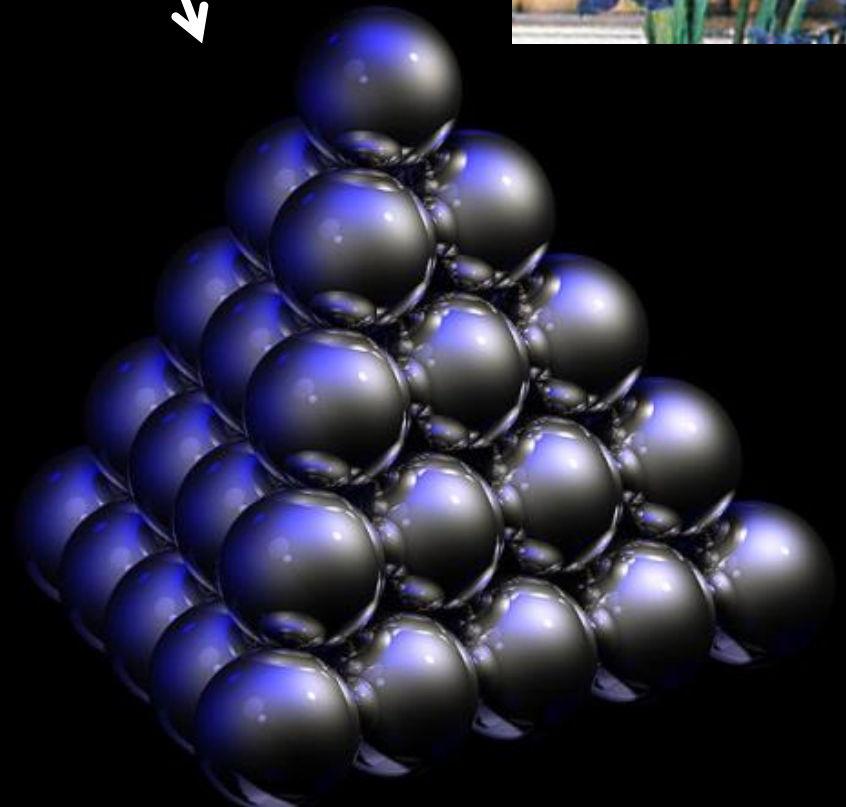
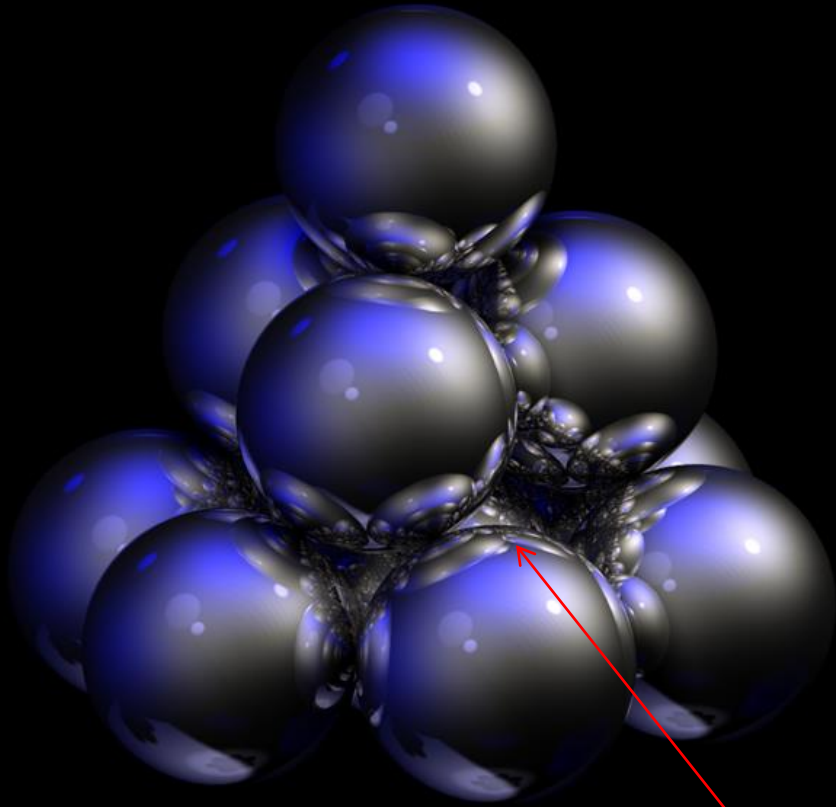
ccp



In each structure each atom has a coordination number of 12, which is the **maximum number** of atoms another atom can be bound to a any one time.

hcp

ccp (sometimes called face centered cubic, fcc).



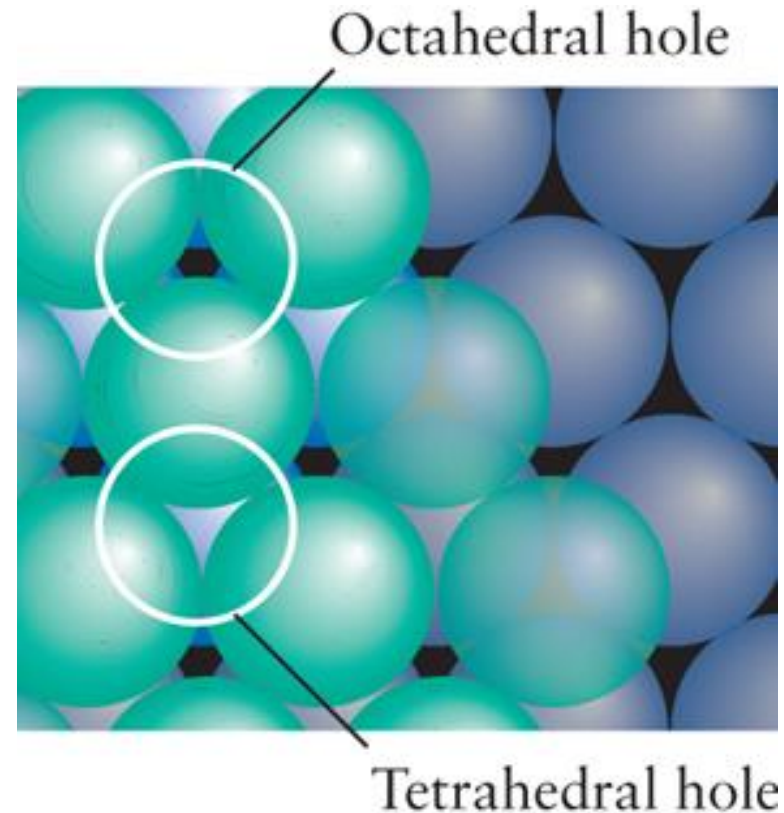
You can see another sphere

# Alloys

Holes in a close-packed structure can be filled with smaller atoms to form alloys.

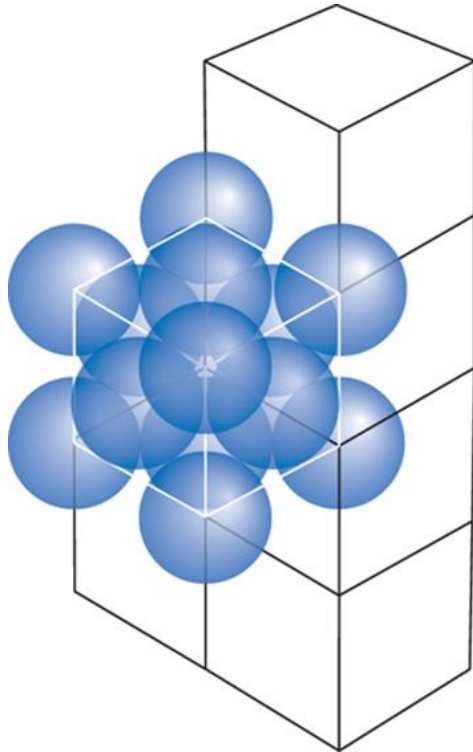
If a dip **between three atoms** is directly covered by another atom, we obtain a tetrahedral hole, or hcp.

When a dip in a layer coincides with a dip in the **next layer**, we obtain an octahedral hole, or fcc.



# Unit Cells

The smallest region of the crystal lattice that repeats itself, this is referred to as the **unit cell**.

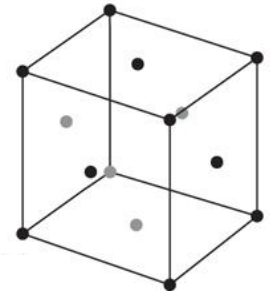


From the cubic arrangement exist three types of cubic structures:

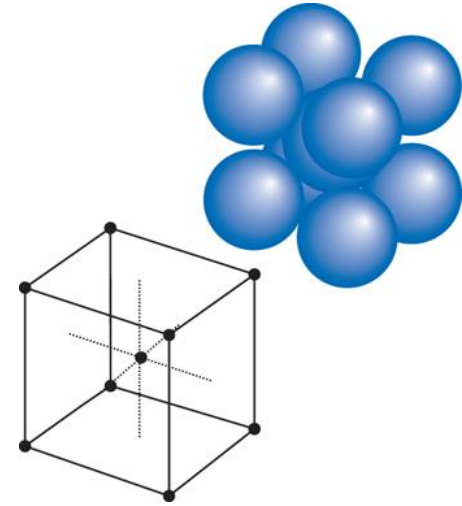
1. Primitive cubic
2. Body centered cubic
3. Cubic closed-packed

# Unit Cells

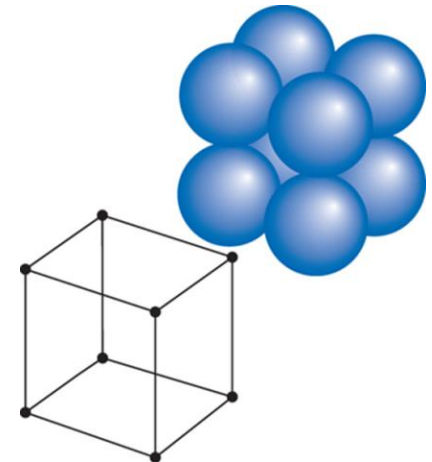
A **cubic close-packed** unit cell has an atom at the center of each face of the unit cell; for this reason, it is also called a face-centered cubic structure (ccp either fcp or hcp).



A **body-centered cubic** structure (bcc), single atom lies at the center of a cube formed by eight other atoms. This structure is **not close packed**.



A **primitive cubic** structure has an atom at each corner of a cube. The atoms touch along the edges. This structure is known for only one element, polonium.



# Liquid Crystals

**Liquid crystals** are neither a solid nor a liquid, but intermediate called a **mesophase**. Here molecules have fluidity of a liquid and some order of a molecular solid.

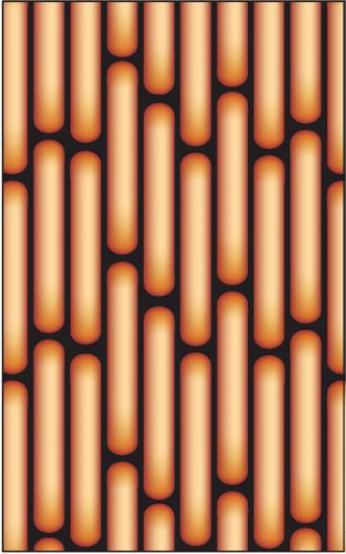
They are **responsive** to changes in temperature and electric fields.





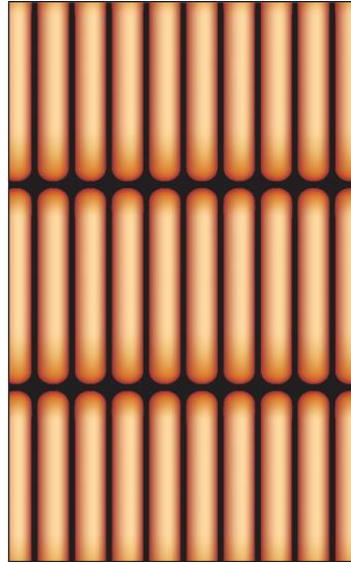
# Liquid Crystals

**Anisotropic** materials depend on the direction of measurement. **Isotropic** materials do not depend on orientation, water's viscosity is the same in all directions.



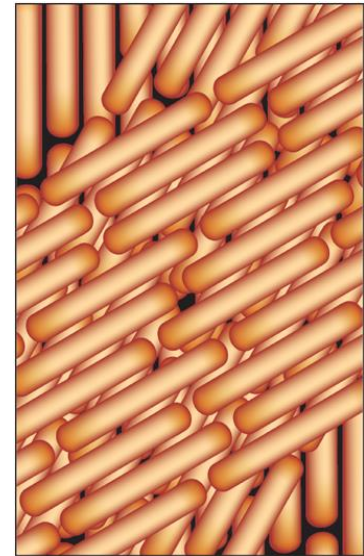
## Nematic phase

parallel molecules, and staggered along their long axes.



## Smectic phase

molecules are parallel and they line up next to form sheets.



## Cholesteric phase

sheets of parallel molecules are rotated relative to their neighbors and form a helical structure.

# Liquid Crystals

**Thermotropic liquid crystals** are made by melting the solid phase, usually have a short temperature range between the solid and the liquid states.

Thermotropic liquid crystals become isotropic liquids when heated above a characteristic temperature.

These are used in applications such as watches, computer screens, and thermometers.

