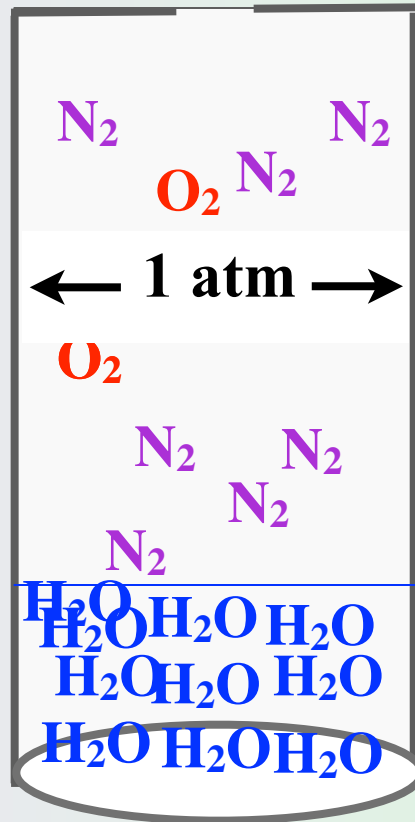


# **The kinetic Molecular Theory of Liquids and solids**

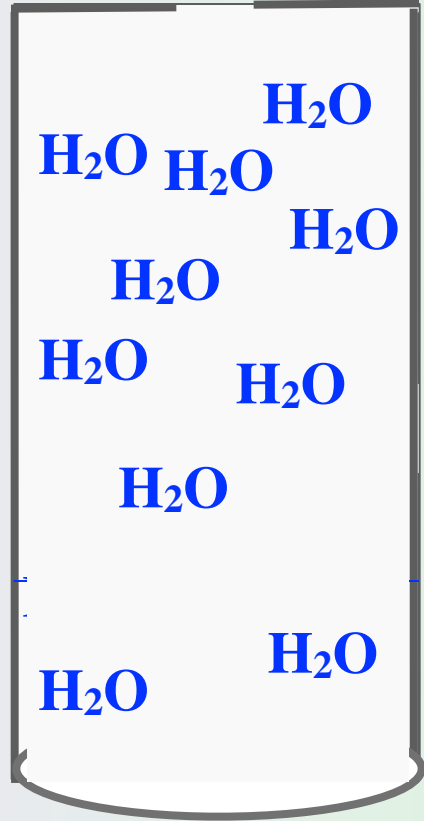
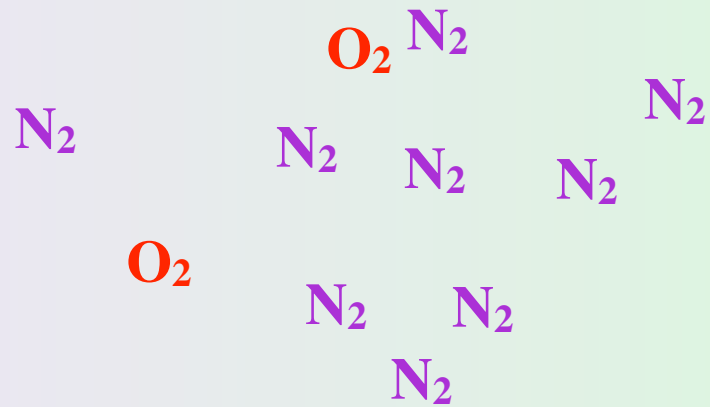
**Particles in motion**

**1 atm = one atmosphere  
of pressure**

**1 atm →**



**← 1 atm**



**HEAT**

$N_2$

$N_2$

$O_2$

$N_2$

$N_2$

$N_2$

$O_2$

$H_2O$   $H_2O$

$H_2O$

$H_2O$

$H_2O$

$H_2O$

$H_2O$

$H_2O$

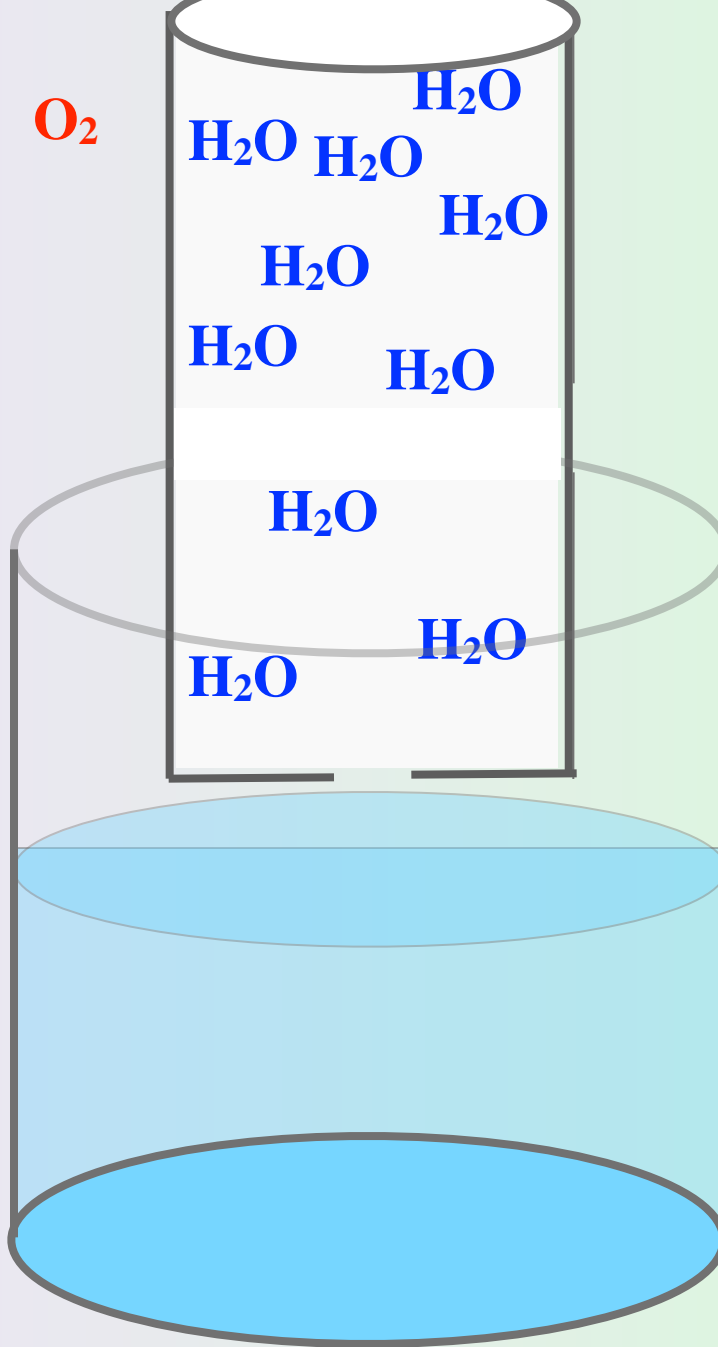
$H_2O$

$H_2O$

$N_2$

$N_2$

$N_2$



N<sub>2</sub>

N<sub>2</sub>

O<sub>2</sub> N<sub>2</sub>

N<sub>2</sub>

N<sub>2</sub>

O<sub>2</sub>

H<sub>2</sub>O

H<sub>2</sub>O

N<sub>2</sub>

H<sub>2</sub>O

N<sub>2</sub>

N<sub>2</sub>

H<sub>2</sub>O

H<sub>2</sub>O

N<sub>2</sub>

H<sub>2</sub>O

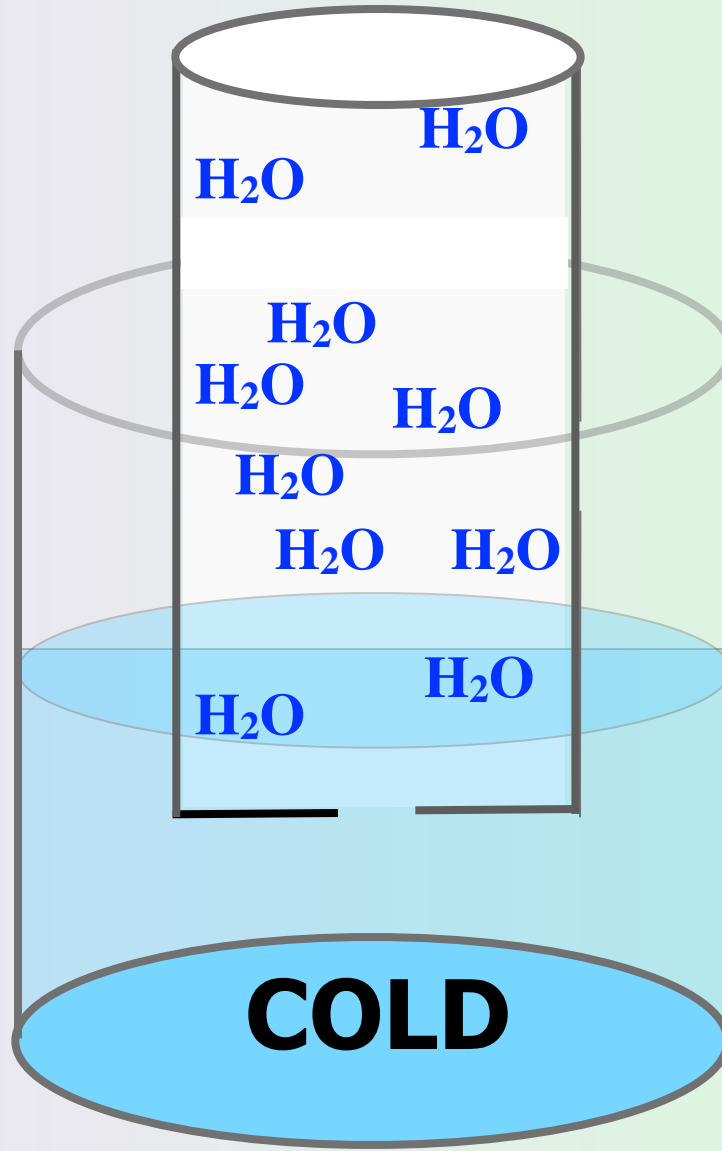
H<sub>2</sub>O

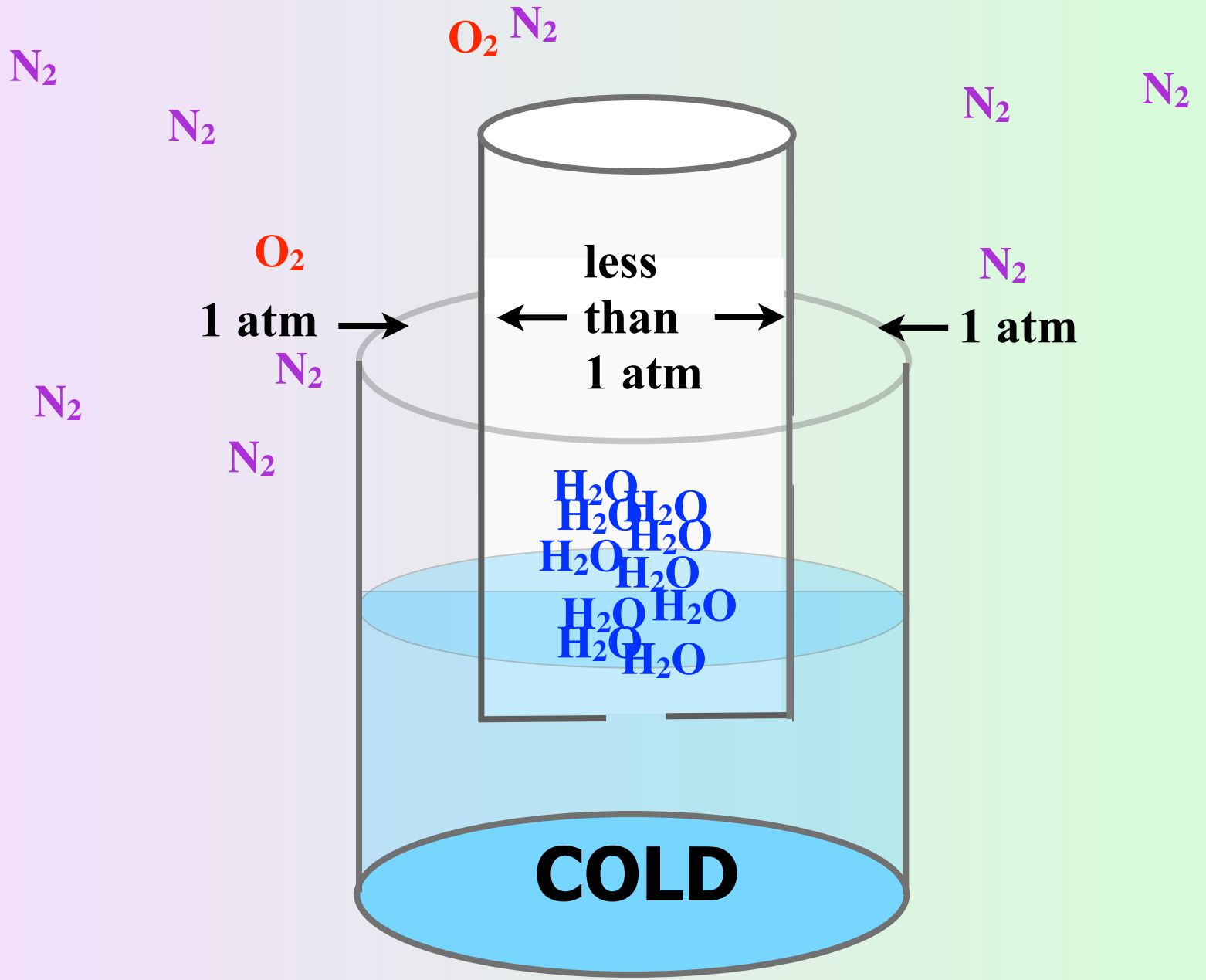
H<sub>2</sub>O

H<sub>2</sub>O

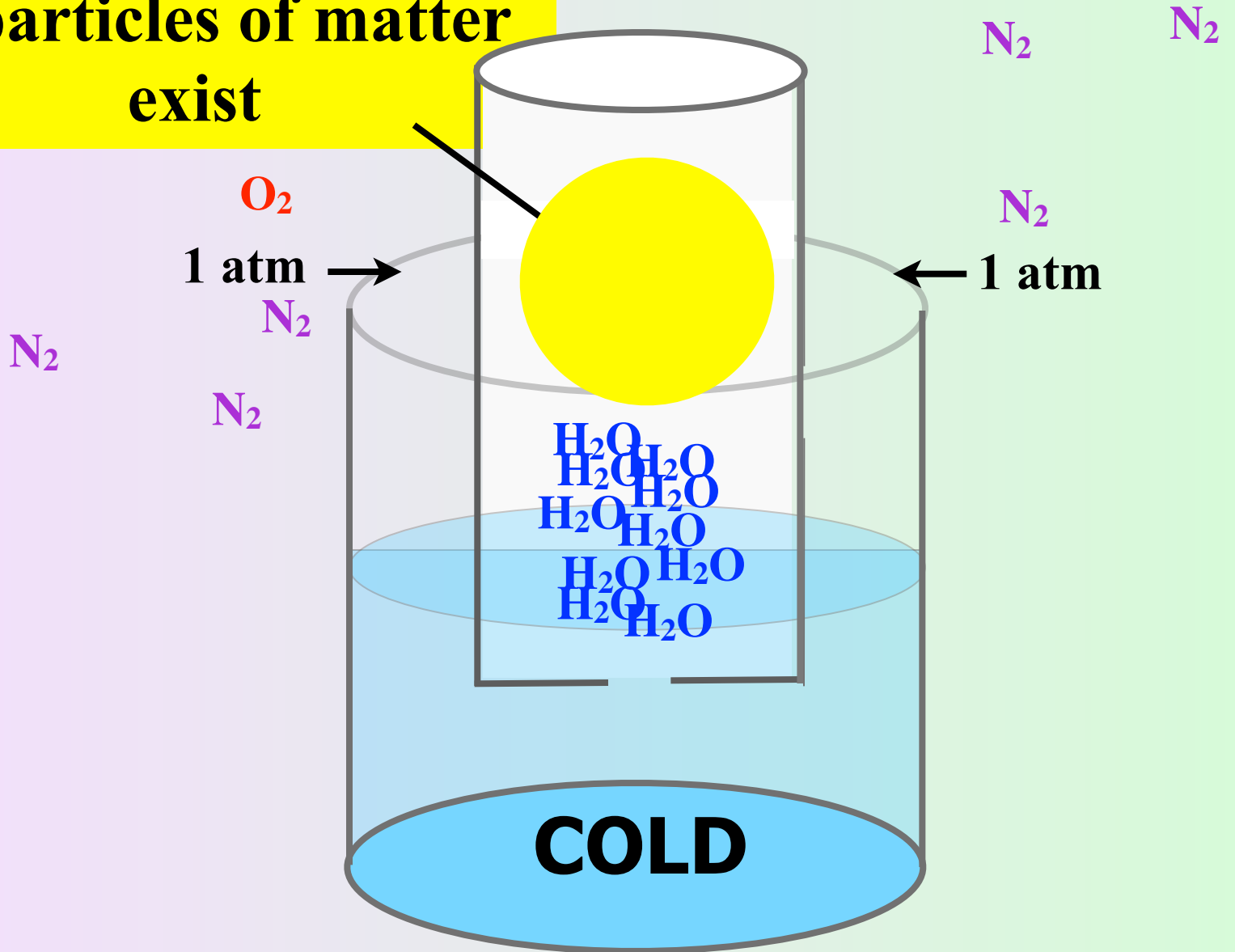
H<sub>2</sub>O

**COLD**





**Vacuum- a space where  
no particles of matter  
exist**



$N_2$

$N_2$

$O_2 N_2$

$N_2$

$N_2$

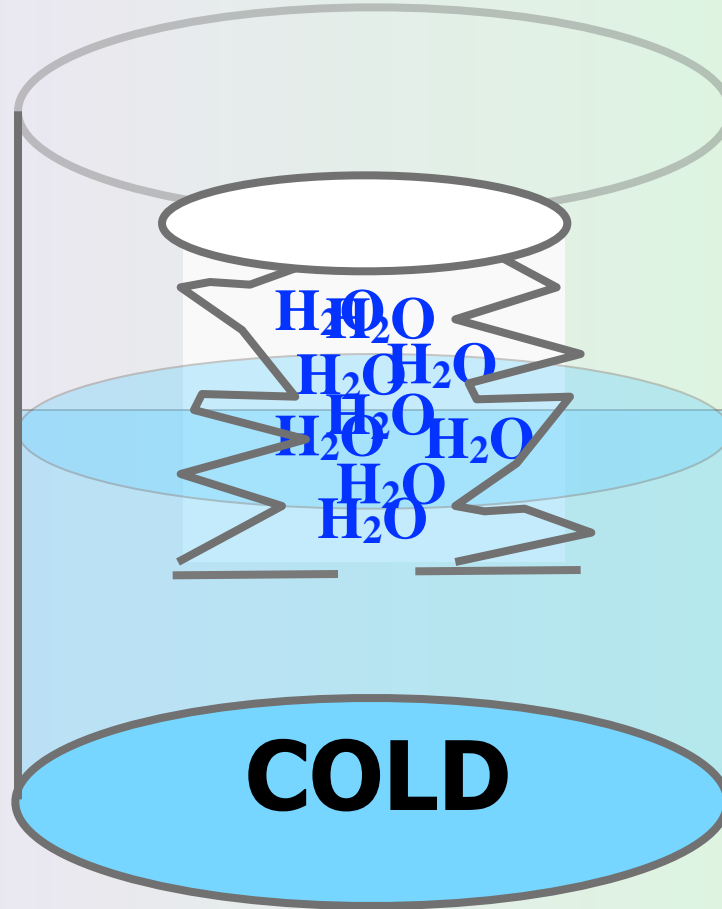
$O_2$

$N_2$

$N_2$

$N_2$

$N_2$



**COLD**

$H_2O$

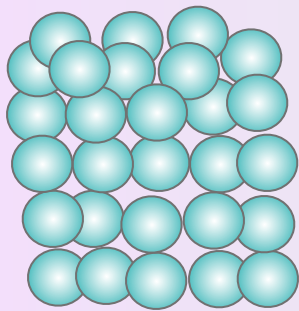
$H_2O H_2O$

$H_2O H_2O$

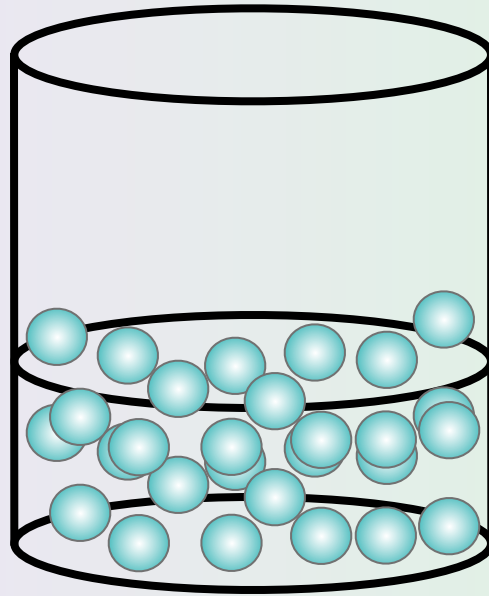
$H_2O$

$H_2O$

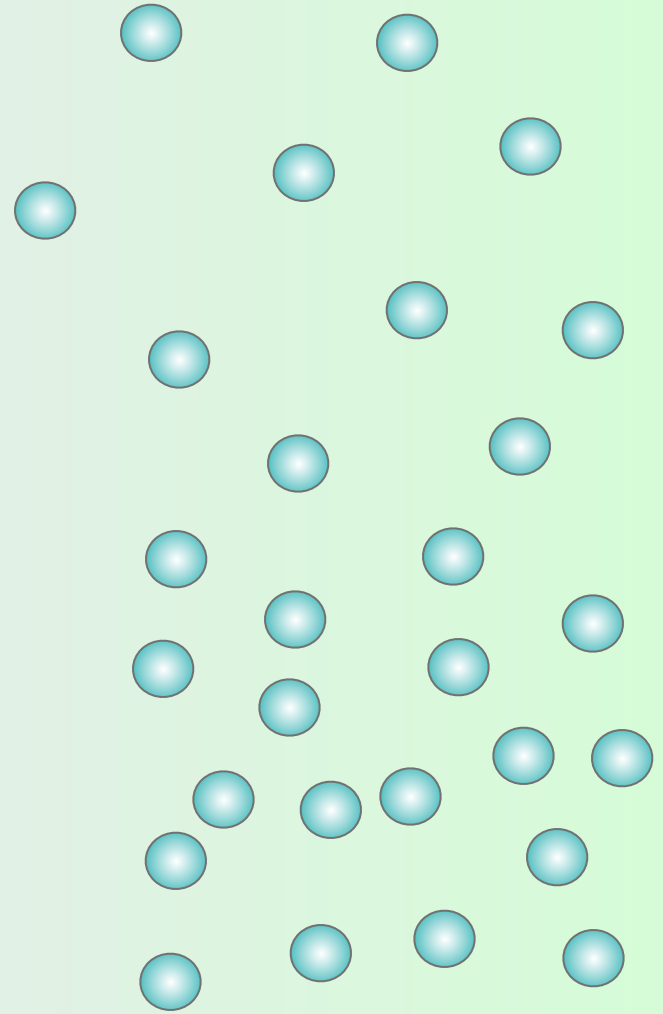




solid

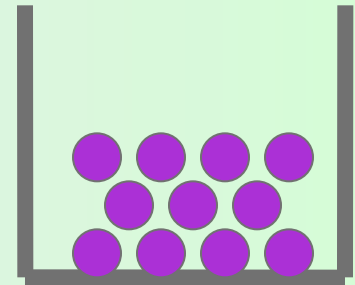
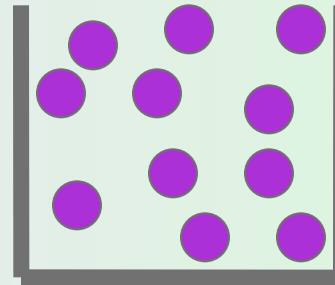
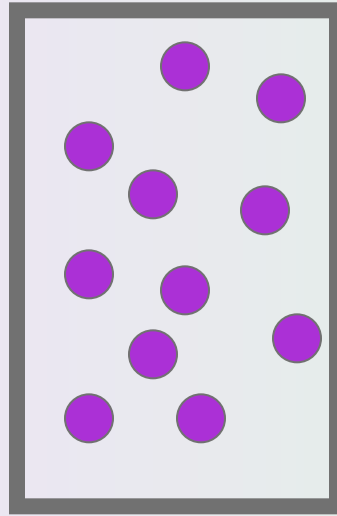


liquid



gas

# Characteristics properties of gases, liquids, and solids



**gas**

**liquid**

**solid**

**Definite volume**

**no**

**yes**

**yes**

**Definite shape**

**no**

**no**

**yes**

**density**

**low**

**high**

**high**

**compressibility**

**high**

**slight**

**no**

**Molecular motion**

**free**

**slide**

**vibrate**

## **. States of matter**

**solid**

**Liquid**

**Gas**

- the various states of matter can be understood by examining attractive forces between molecules**

**Intermolecular Forces**

# **Intermolecular Forces**

**Attractive forces between molecules**

# Intermolecular Forces

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**ion-ion**

**ion-dipole**

**ion-induced dipole**

**dipole-dipole**

**dipole-induced dipole**

**induced dipole-induced dipole**

# Intermolecular Forces

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## Van der Waals forces

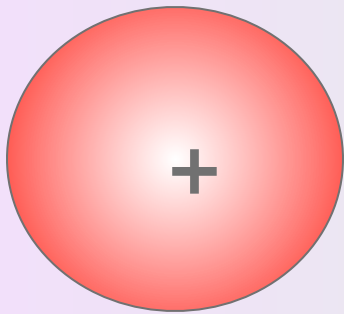
**dipole-dipole**

**dipole-induced dipole**

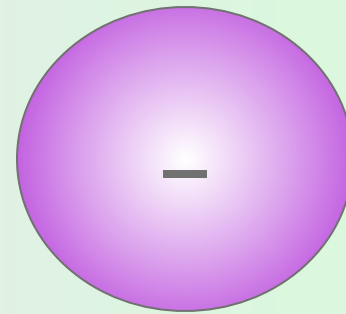
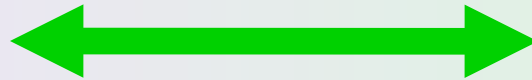
**induced dipole-induced dipole**

# Ion-ion attractive force

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cation



anion

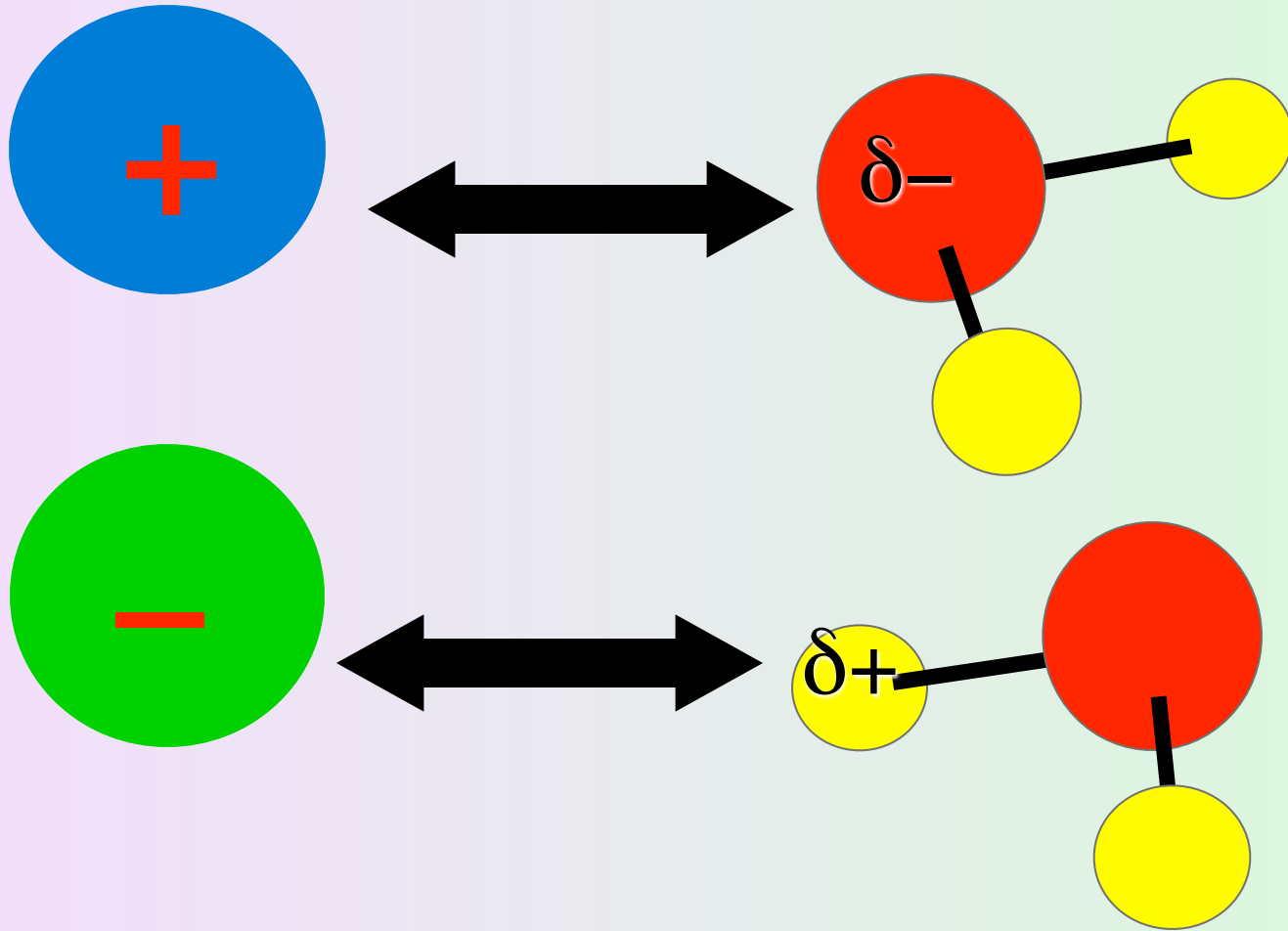
- **is an ionic bond**
- **very strong**

# **ion-dipole attractive forces**

**attractive forces between an ion and a polar molecule**



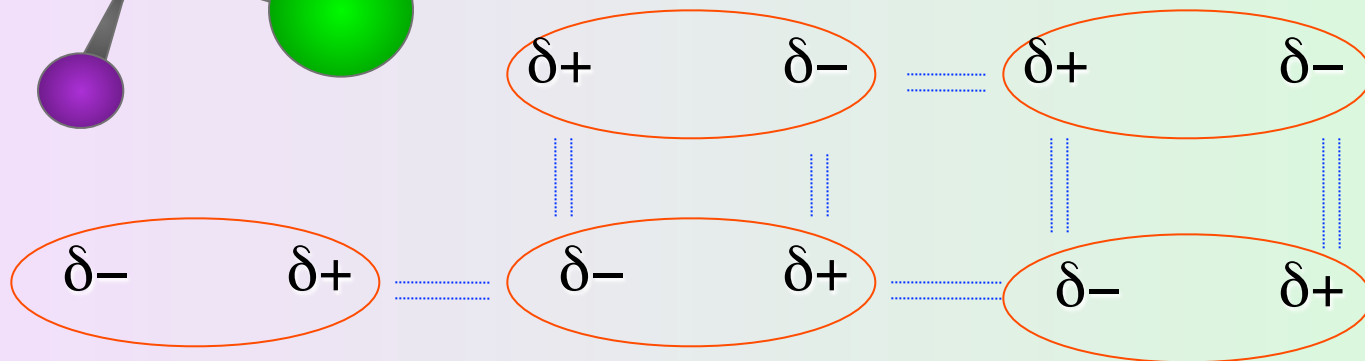
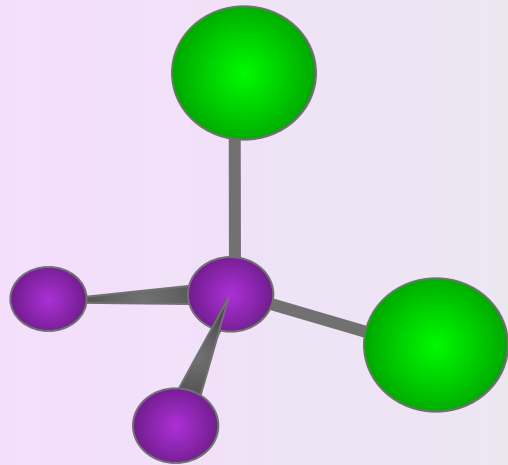
# ion-dipole attractive force



# **dipole -dipole attractive forces**

**attractive forces between polar molecules**

# dipole-dipole attractive force

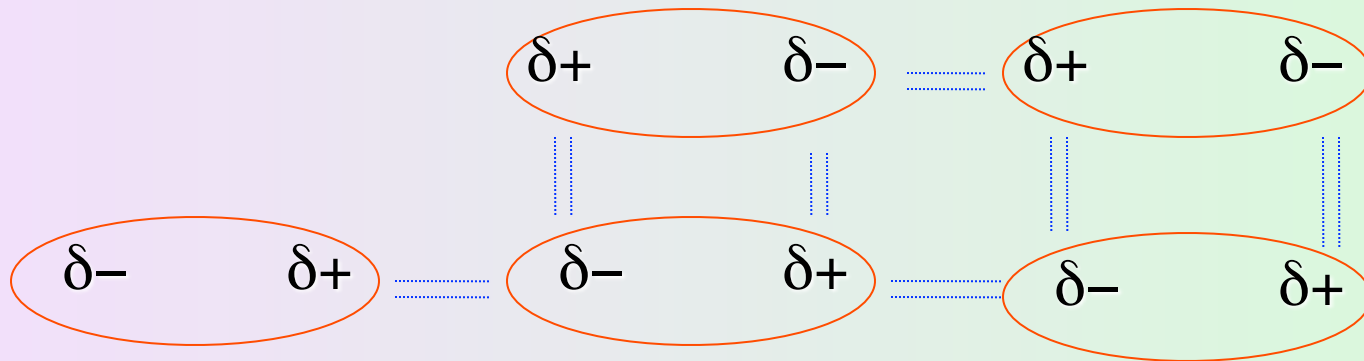
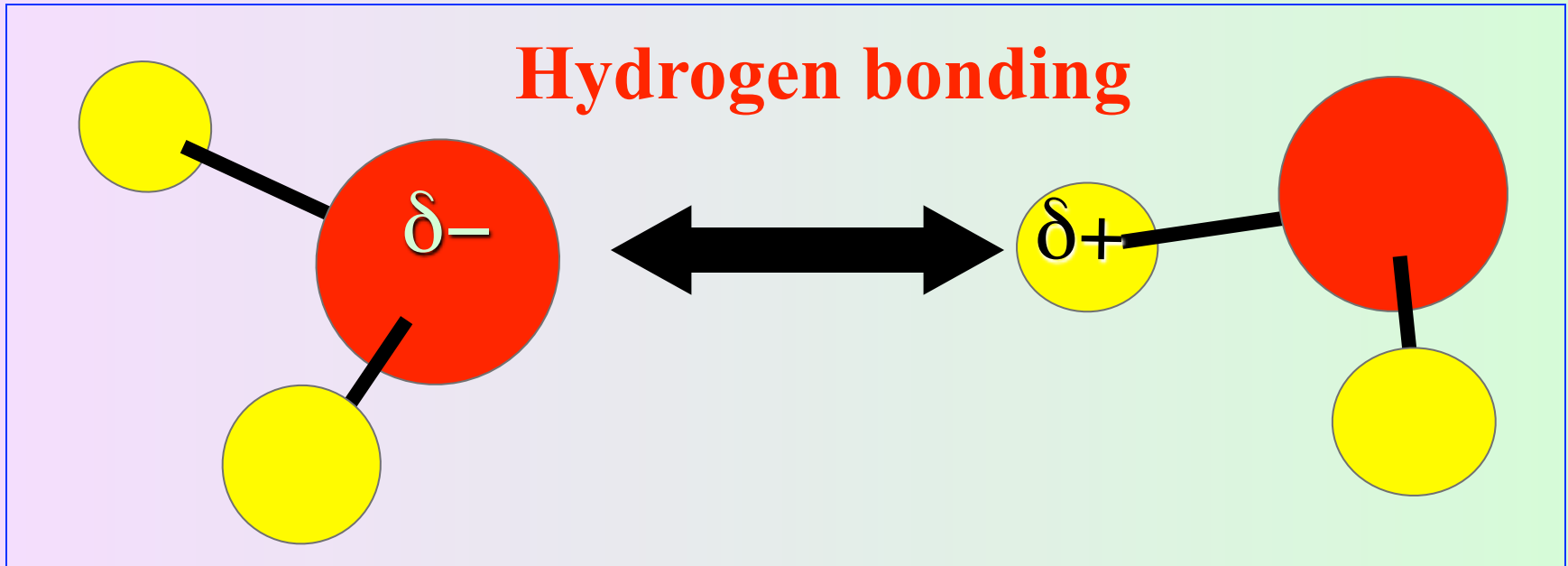


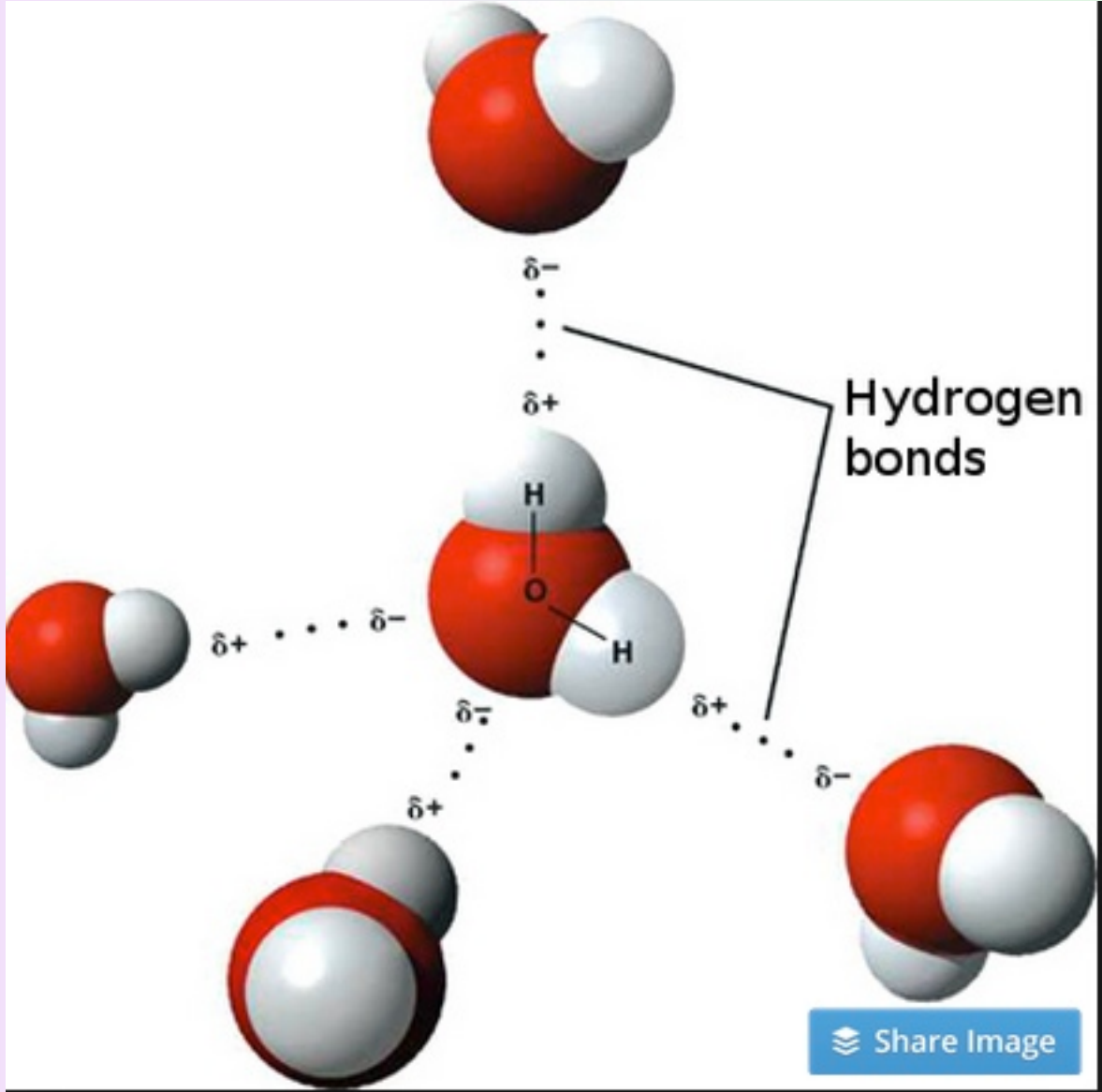
# Hydrogen bonding

**A special type of dipole- dipole interaction**

*A very strong dipole interaction*

# dipole-dipole attractive force

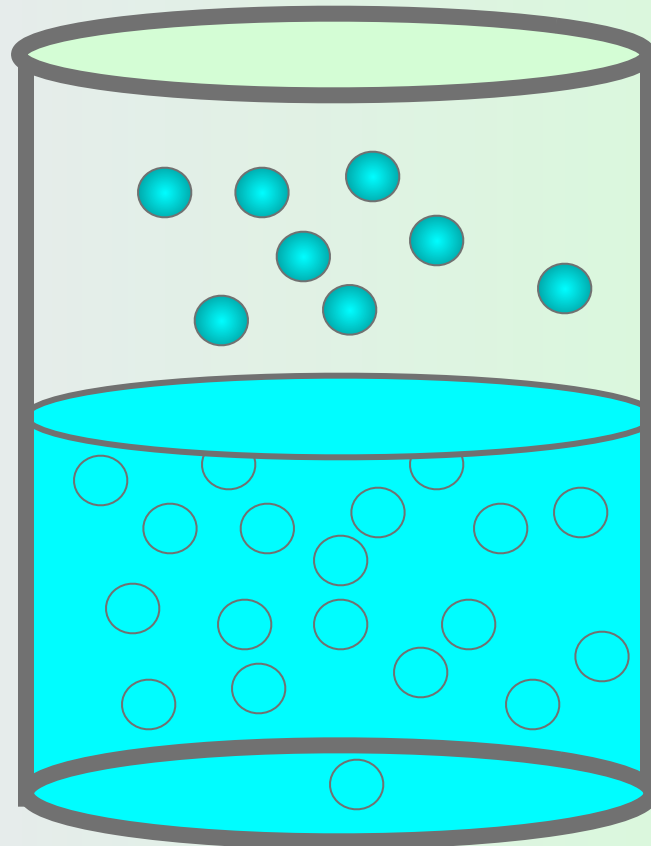




# Boiling point

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**The temperature at which a liquid's vapor pressure is equal to atmospheric pressure.**



# Boiling point depends on:

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**The temperature at which a liquid's vapor pressure is equal to atmospheric pressure.**

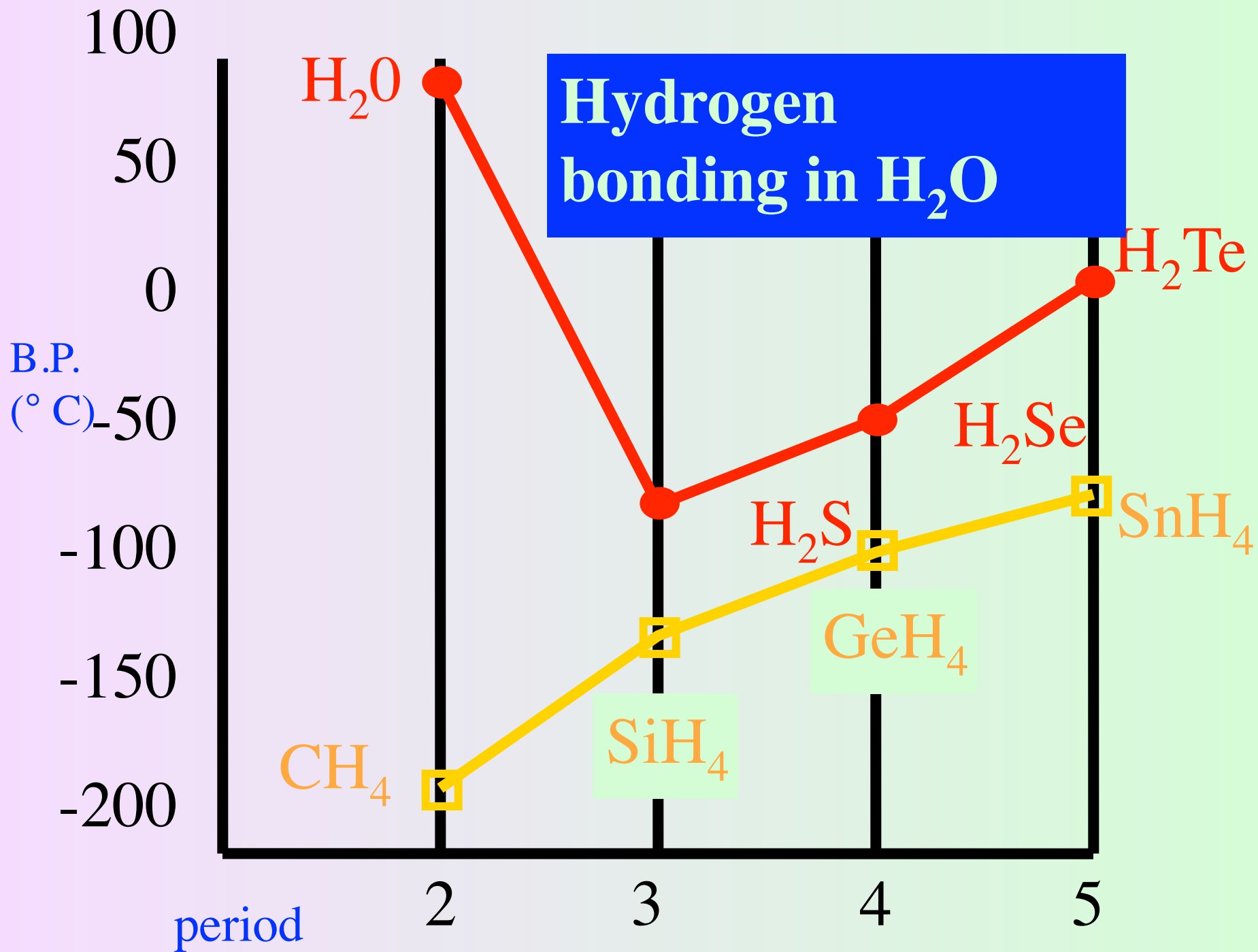
- **molar mass**
- **intermolecular forces**



# Importance of Hydrogen Bonding

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compound	MW	$\mu$	Bp, °C
$\text{CH}_3\text{CH}_2\text{CH}_3$	44	0	-42
$\text{CH}_3\text{CH}_2\text{OH}$	46	1.7	+78

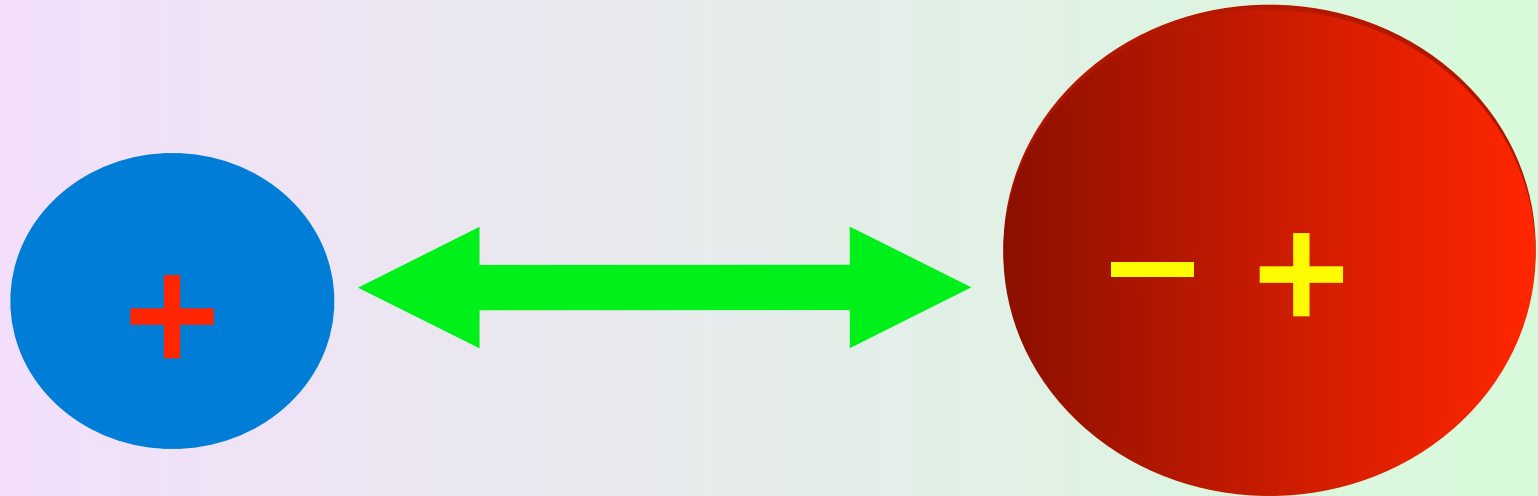


## Dispersion forces

attractive forces that result from temporary dipoles induced in an atom or molecule

# ion-induced dipole attractive force

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**Polarizability:** the ease with which the electron distribution surrounding an atom is distorted by an external electric field

# Polarizability

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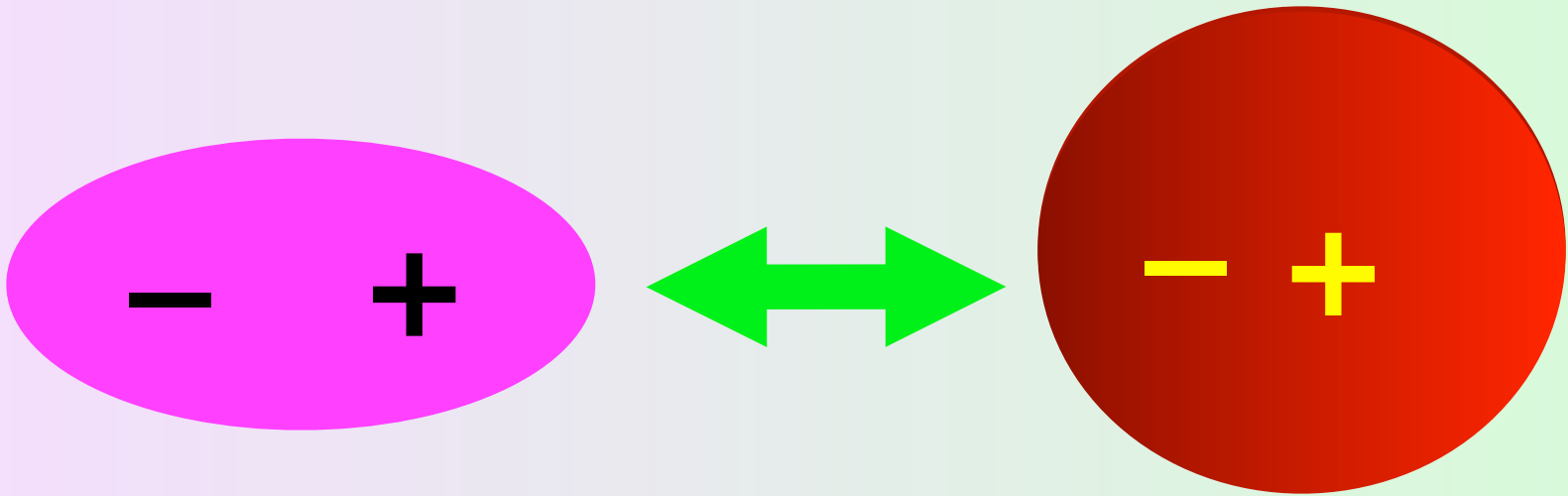
- increases with size of atom

**fluorine very nonpolarizable (“hard”)**

**iodine very polarizable (“soft”)**

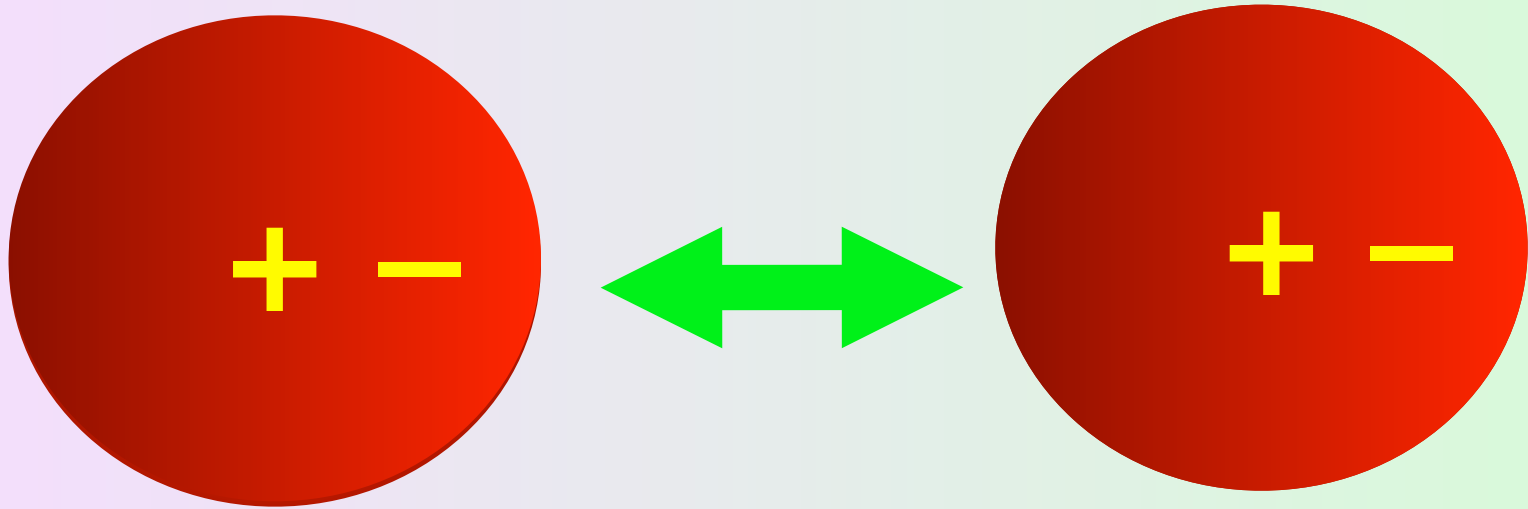
# Dipole-induced dipole attractive forces

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# Induced dipole-induced dipole attractive forces (*London Forces*)

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# Boiling Points

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**depend on intermolecular attractive forces in liquid state**

**Example:**

$\text{F}_2$

$\text{Cl}_2$

$\text{Br}_2$

$\text{I}_2$





$$\Delta H^\circ = 62 \text{ kJ/mol}$$

**This is a direct measure of the induced dipole-induced dipole attractions between I<sub>2</sub> molecules in the solid state**

# Melting points of similar nonpolar molecules

compound	Melting Point, °C
$\text{CF}_4$	-150
$\text{CCl}_4$	-23
$\text{CBr}_4$	90
$\text{CI}_4$	171

**More electrons, more polarizable, stronger dispersion forces**

**Fluorine is very nonpolarizable, and dispersion forces involving fluorine are weak**

<b>compound</b>	<b>bp, ° C</b>
<b>CH<sub>3</sub>CH<sub>3</sub></b>	<b>-89</b>
<b>CH<sub>3</sub>CH<sub>2</sub>F</b>	<b>-32</b>
<b>CH<sub>3</sub>CHF<sub>2</sub></b>	<b>-25</b>
<b>CH<sub>3</sub>CF<sub>3</sub></b>	<b>-47</b>
<b>CF<sub>3</sub>CF<sub>3</sub></b>	<b>-78</b>



# Hydrogen bonding important in compounds with

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OH bonds

water, alcohols, acids, carbohydrates

NH bonds

ammonia, amines, peptides, proteins,  
nucleic acids

FH bonds

# Approximate magnitudes of intermolecular forces

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<b>Force</b>	<b>Energy, kJ/mol</b>
<b>ion-ion</b>	<b>500–1000</b>
<b>ion-dipole</b>	<b>40–600</b>
<b>ion-induced dipole</b>	
<b>dipole-dipole</b>	<b>5–25</b>
<b>dipole-induced dipole</b>	<b>2–10</b>
<b>induced dipole– induced dipole</b>	<b>0.05–40</b>