CHEM 1101B- Chemistry for Engineers

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HS (Health Sciences) 1301
Mondays & Wednesdays 8:35am - 9:55am

Lecture 11: Liquids

Please feel free to introduce yourself to your neighbors– name, pronouns, a hobby, etc.

and/or

Answer the first wooclap question

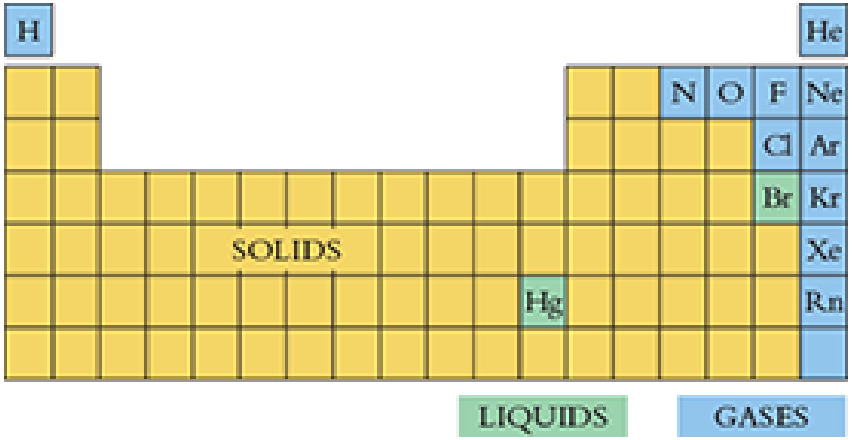
Learning outcome for Topic 10: Phases of Matter – Liquids

Learning Outcomes:

- Predict the relative magnitudes of intermolecular forces and their effects on physical properties of substances
- Describe intermolecular forces in liquids and relate them to heat of vaporization
- Calculate the vapour pressure or boiling point of a liquid

Forces of attraction between molecules are responsible for the existence of liquids and solids

Absence of intermolecular forces, all molecules would be gases!



A comparison of Gases, Liquids, and Solids

The state of a substance depends on the balance between the **kinetic energy** of the individual particles (molecules or atoms) and the **intermolecular forces**

Cool or increase pressure

heat or reduce pressure

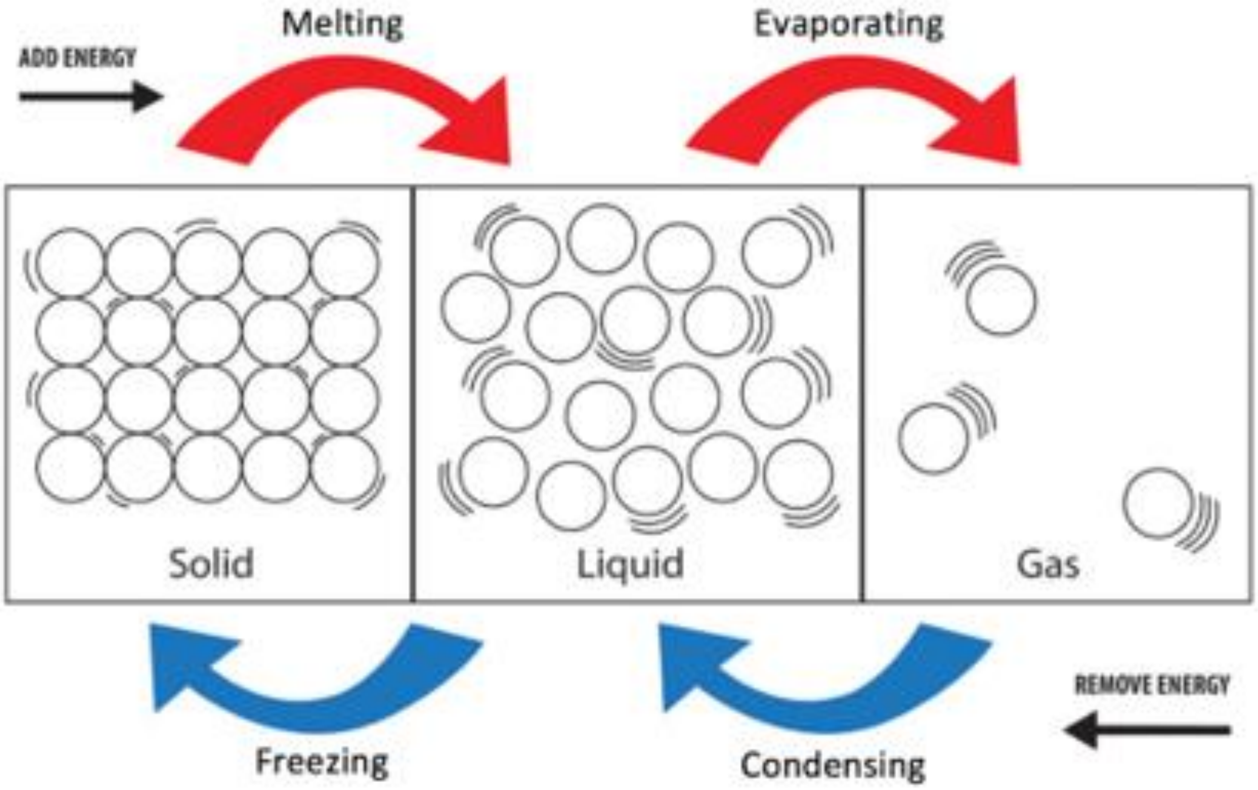
Cool or increase pressure

heat or reduce pressure

- Heating and cooling can change the ***kinetic energy*** of the particles in a substance which **changes the physical state of a substance**
- Increasing the pressure on a substance forces the molecules closer together, which ***increases* the strength of intermolecular forces**

https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/11%3A_Liquids_and_Intermolecular_Forces/11.01%3A_A_Molecular_Comparison_of_Gases_Liquids_and_Solids

What does this look like at the particular level?



https://online-learning-college.com/knowledge-hub/gcses/gcse-physics-help/particle-model/

Properties of Liquids

Why can liquids be poured and assume the shape of their container?

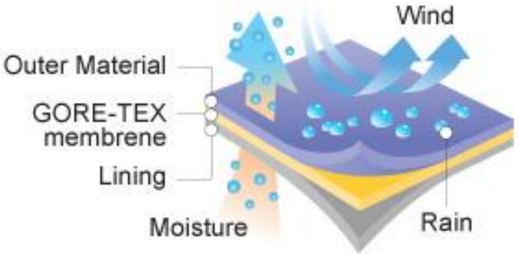
- Intermolecular attractive forces are **strong** enough to hold molecules close together
- Liquids are **more dense and less compressible** than gases
- Liquids have a **definite volume**, independent of the size and shape of the container
- The attractive forces are ***not*** strong enough, to keep neighboring molecules in a fixed position and molecules are free to move past or slide over one another

https://www.scienceabc.com/eyeopeners/why-do-liquids-sometimes-run-down-the-side-of-the-container-when-they-are-poured-out.html

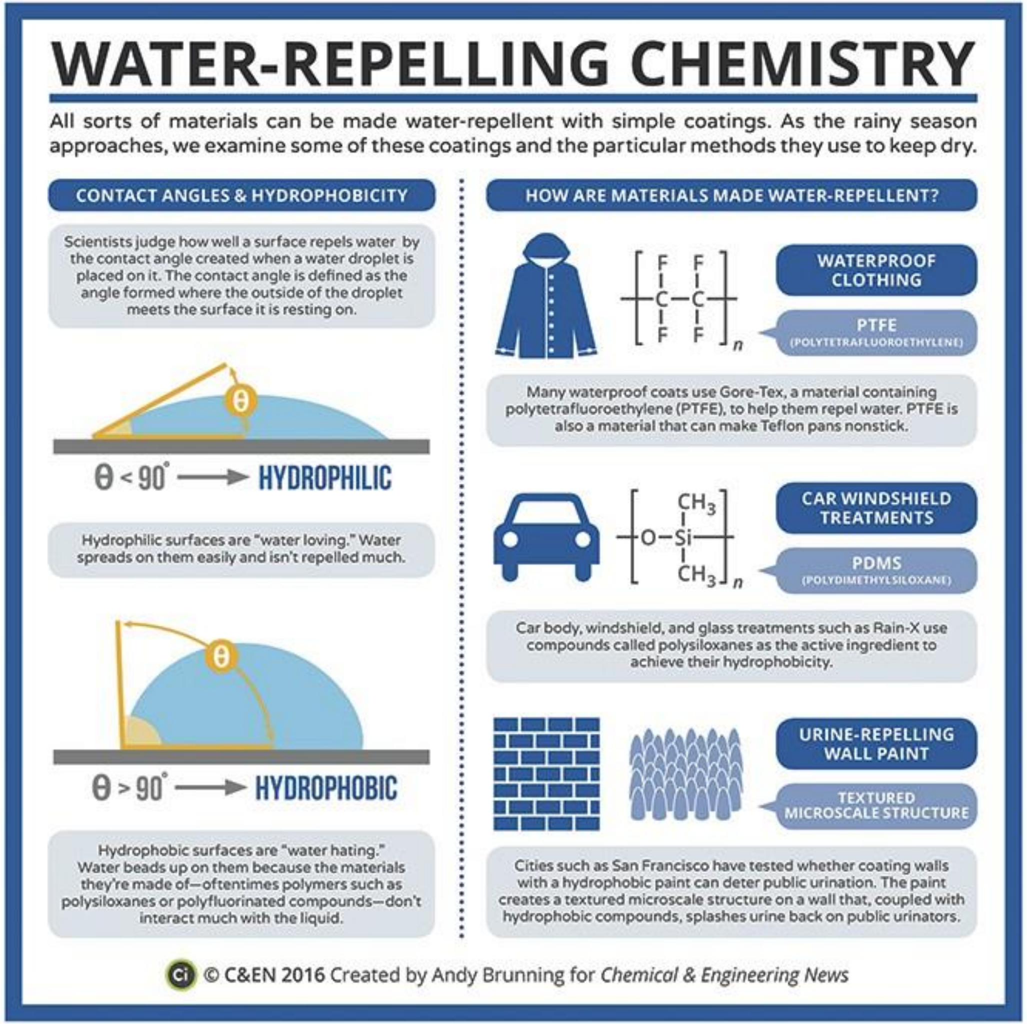
Understanding properties of liquids leads to interesting discoveries

- **Biomimcry**: a practice used by scientists and engineers to model the strategies used by living organisms to solve complex challenges

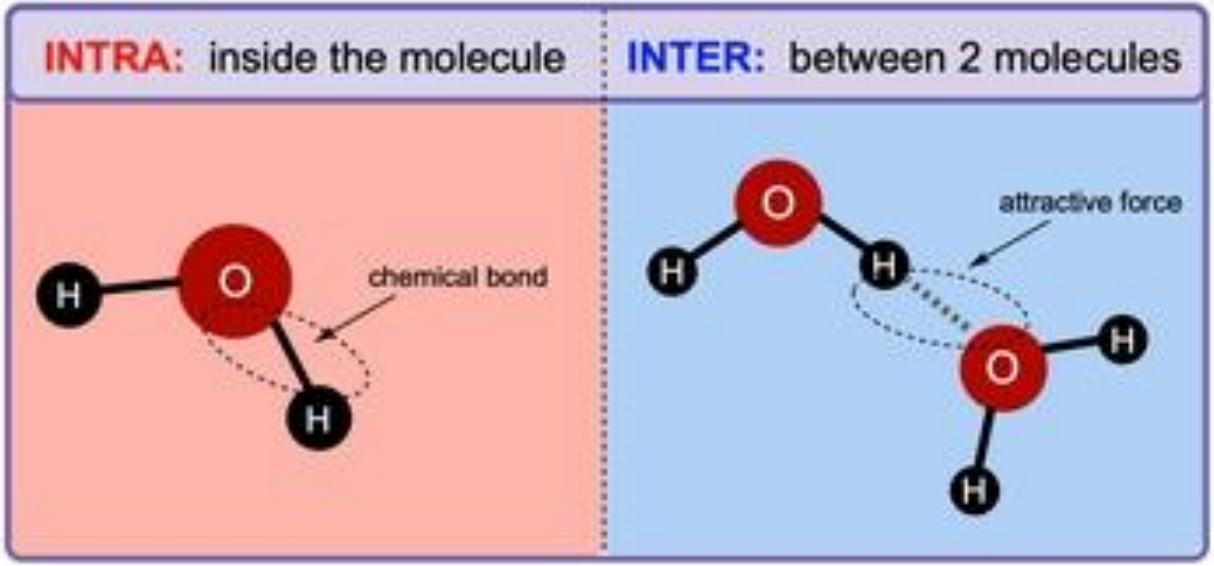
- **Developing water-resistant materials:** Gore-Tex is a breathable, waterproof fabric membrane made using polytetrafluoroethylene



Understanding properties of liquids will help us understand the chemistry behind repelling water surfaces



Intramolecular vs. Intermolecular forces



https://www.pearson.com/channels/general-chemistry/asset/3abecd0e/intermolecular-forces-concept-1

Intramolecular: forces that exist **within** molecules (i.e., ionic and covalent bonds) and influence **chemical properties**

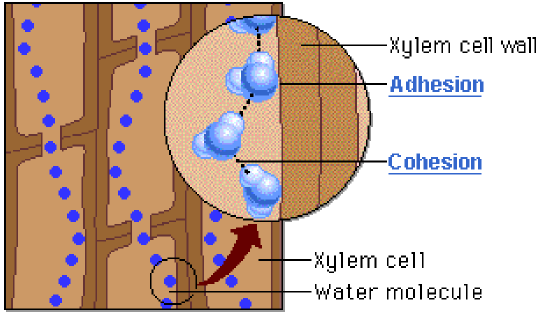
Intermolecular: forces that exist **between** molecules (i.e., hydrogen bonding, dipole-dipole) and influence **physical properties**

Practice: identify inter- versus intramolecular forces

wooclap

Identify the type of force involved in the situations below:

1. Condensation of water vapor
2. Formation of NH_3 from N_2 and H_2
3. Sugar dissolves in water
4. Water flowing up the veins of a plant due to capillary action

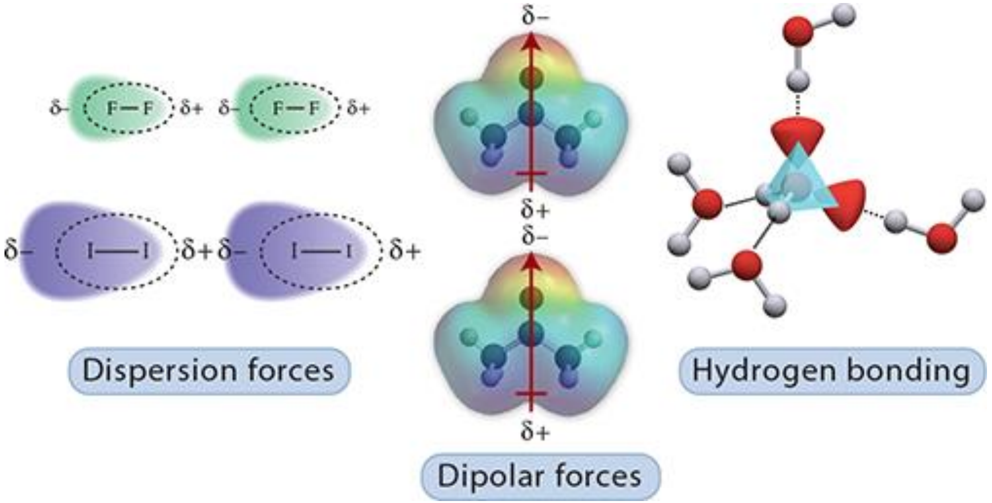


6 types of intermolecular forces attracting molecules together

- Intermolecular forces exist among all ions, dipoles, and uncharged non-polar species
- **Polarity** of compounds play a big role in the type of force present

Types of forces:

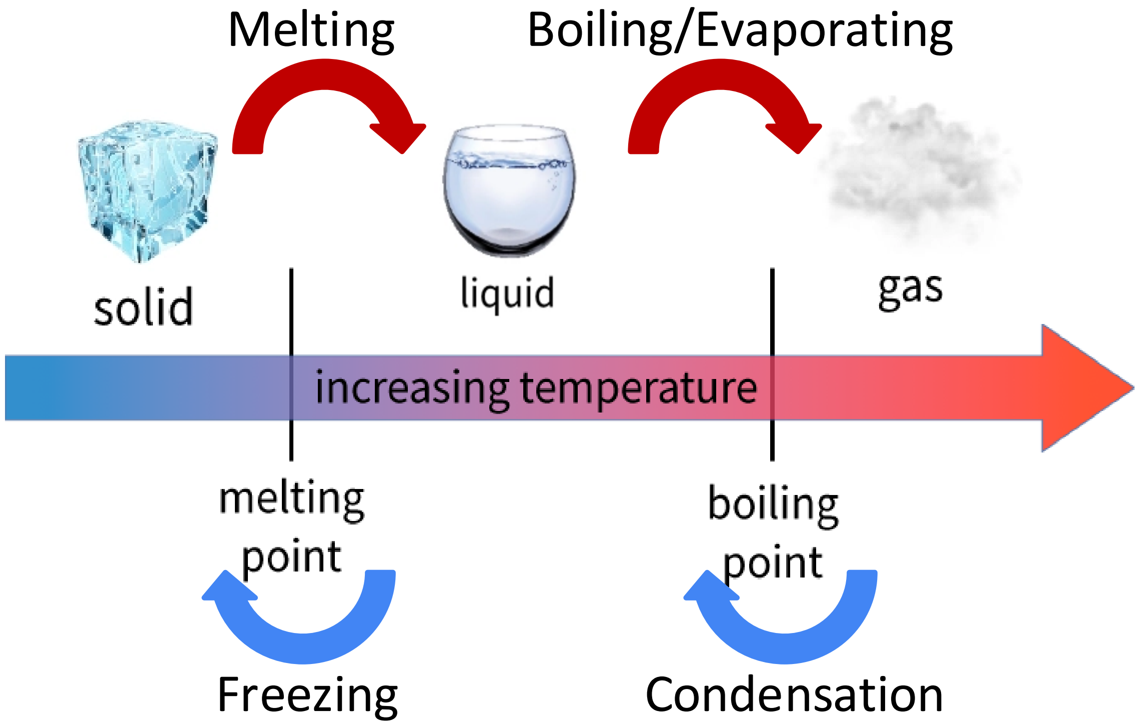
1. Ion – dipole
2. Hydrogen bond
3. Dipole – dipole
4. Ion – induced dipole
5. Dipole – induced dipole
6. Dispersion (London)



Most interested in strongest force existing between 2 molecules – dictates magnitudes of properties of liquids

Intermolecular forces dictates properties: Boiling point

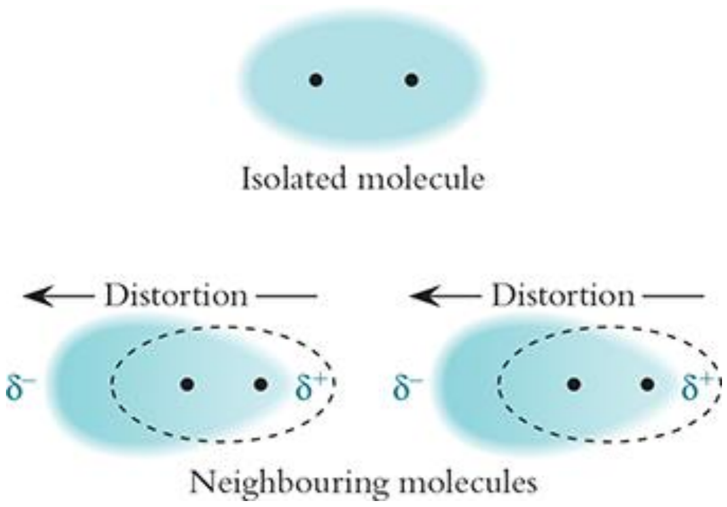
Boiling point: temperature at which the average kinetic energy of molecular motion overcomes energy of intermolecular forces.

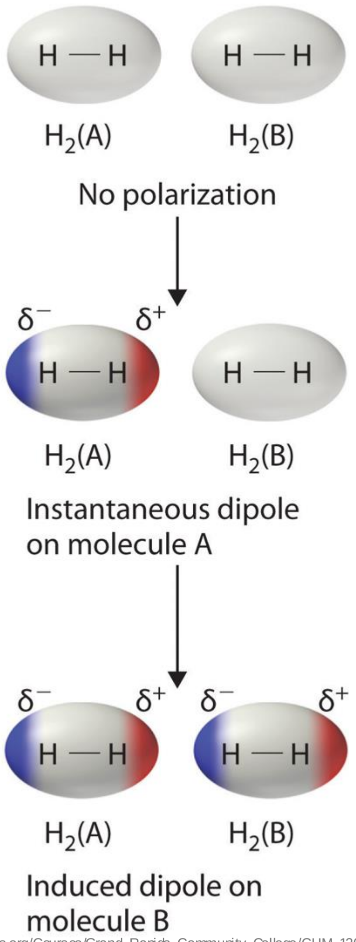


Dispersion Forces

Weakest force: exist in all molecules

- Net attractive forces among molecules generated by induced charge imbalances
- Increases in strength with increasing mass (more electrons)





Approx potential energy range: 0.1 - 5 kJ/mol

Examples: F – F, all halogen gases

https://chem.libretexts.org/Courses/Grand_Rapids_Community_College/CHM_120_-_Survey_of_General_Chemistry%28Neils%29/4%3A_Intermolecular_Forces_Phases_and_Solutions/4.02_Intermolecular_Forces

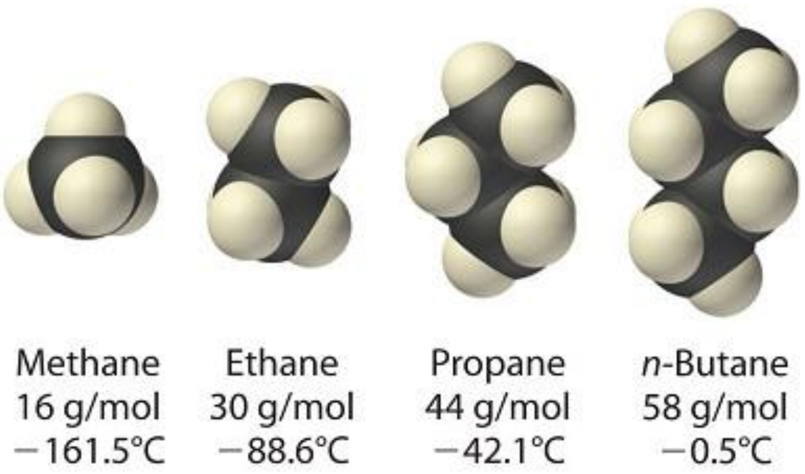
Factors affecting Dispersion Forces

Factor 1: MASS

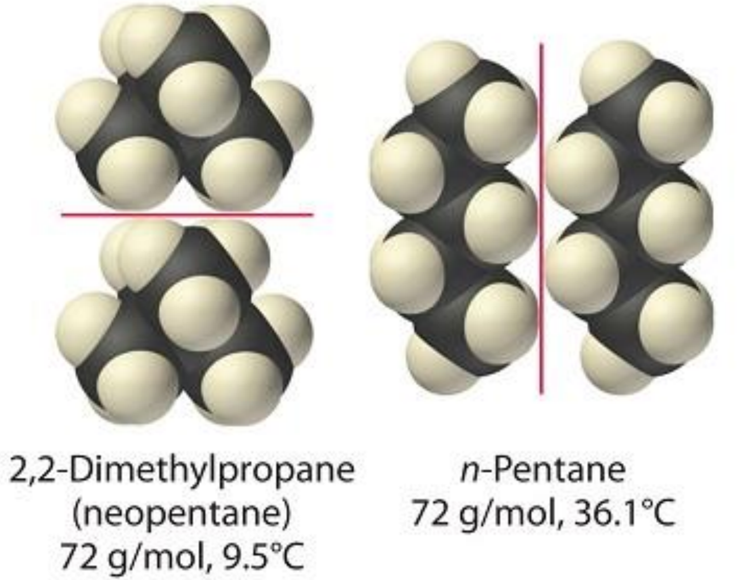
Increased molecular weight = higher boiling point

Factor 2: SHAPE

Longer, compact molecules = higher boiling point



(a) Increasing mass and boiling point



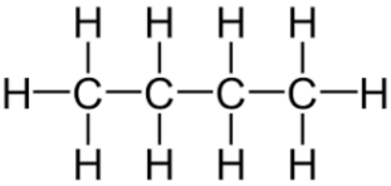
(b) Increasing surface area and boiling point

https://chem.libretexts.org/Courses/Grand_Rapids_Community_College/CHM_120_-_Survey_of_General_Chemistry%28Neils%29/4%3A_Intermolecular_Forces_Phases_and_Solutions/4.02_Intermolecular_Forces

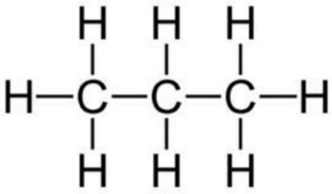
Practice: Order of boiling points

Arrange butane, propane, 2-methylpropane, and pentane in order of increasing boiling points.

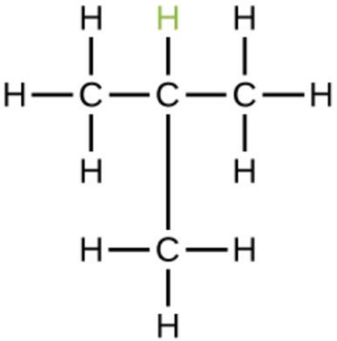
butane



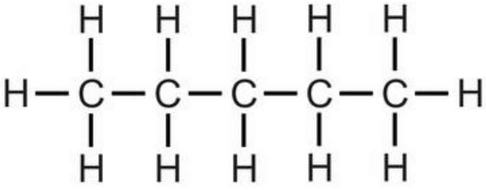
propane



2-methylpropane

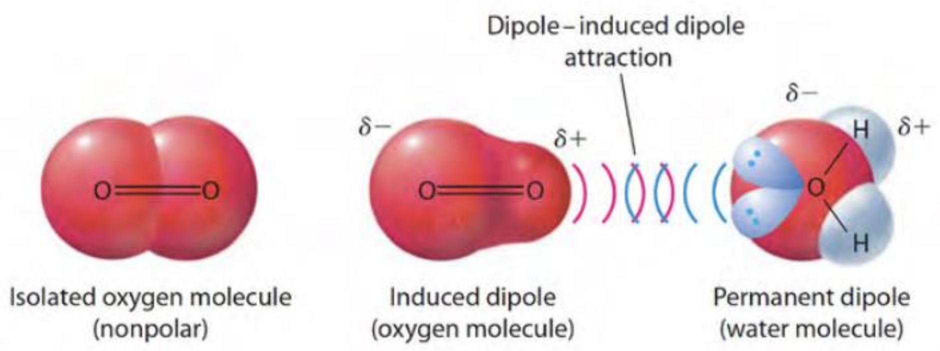


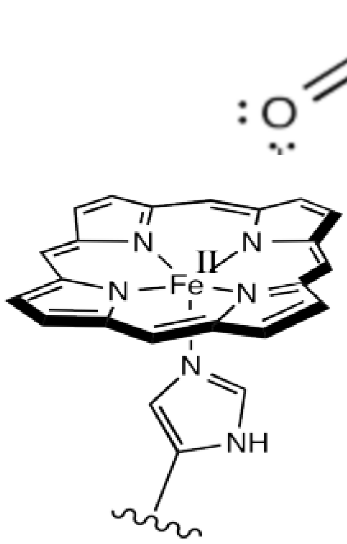
pentane



Ion-/Dipole- Induced Dipole interactions

4th strongest force: interactions between polar molecules (or ions) and non polar molecules





Simplified structure of hemoglobin

Approx potential energy range: 2 – 10 kJ/mol

Examples: HCl – Cl_2

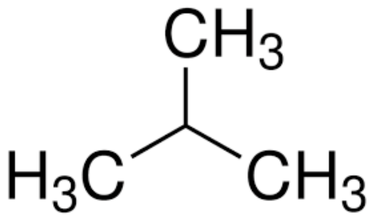
Approx potential energy range: 3 – 15 kJ/mol

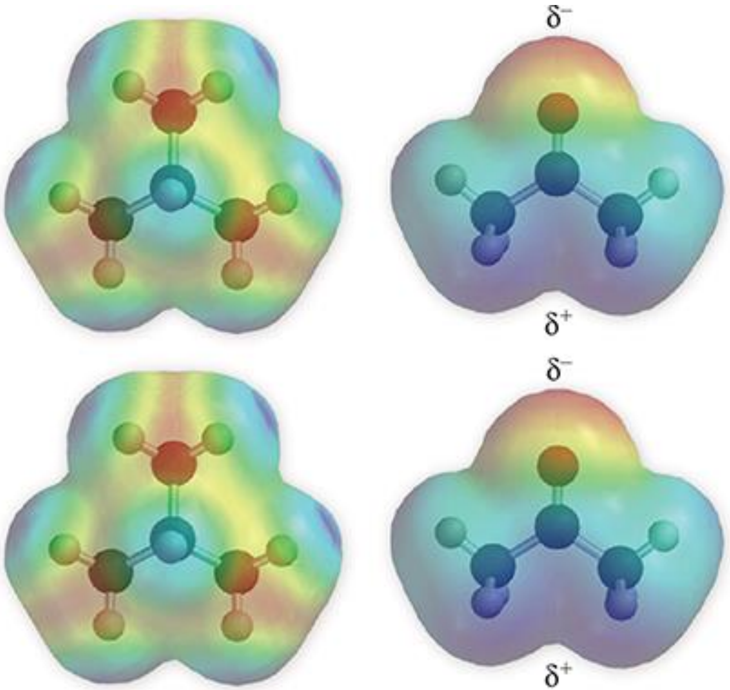
Examples: Ca^{+2} – O_2

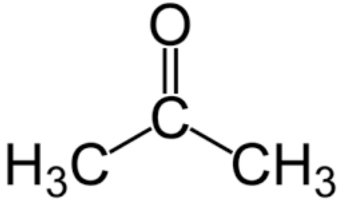
Dipole-Dipole interactions

3rd strongest force: between two polar molecules

2-methyl propane (gas) Acetone (liquid)







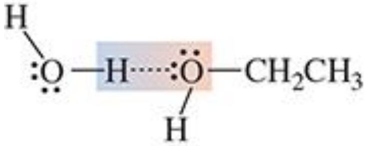
Based on these images, why is 2-methyl propane a gas and acetone a liquid at room temp?

Approx potential energy range: 5-25 kJ/mol **Examples:** HCl – HCl

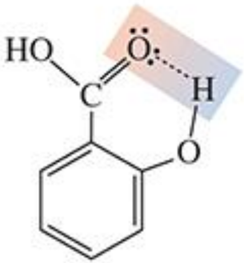
Hydrogen Bond

2nd strongest force: when hydrogen is directly bonded to F, O, or N (type of dipole-dipole interaction)

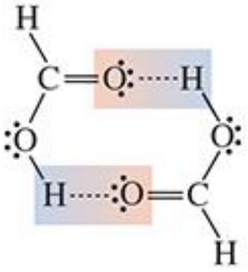
Hydrogen fluoride



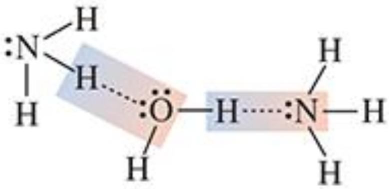
Water–ethanol



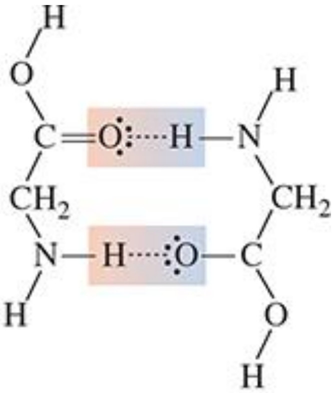
Salicylic acid



Formic acid



Ammonia–water



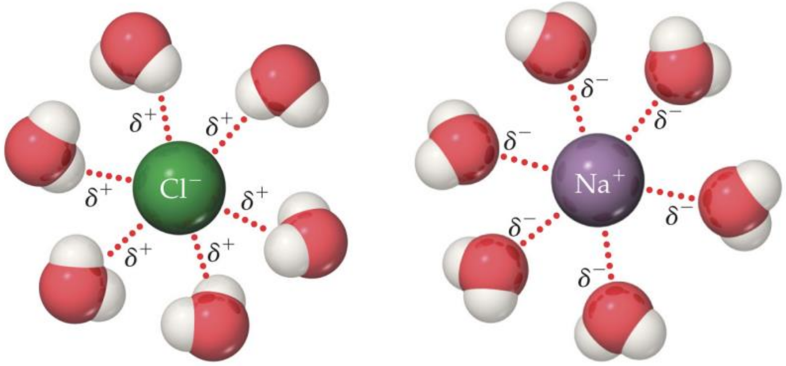
Glycine
(an amino acid)

Approx potential energy range: 5 – 50 kJ/mol

Examples: H – NH_3 , H – H_2O, H -- HF

Ion-dipole forces

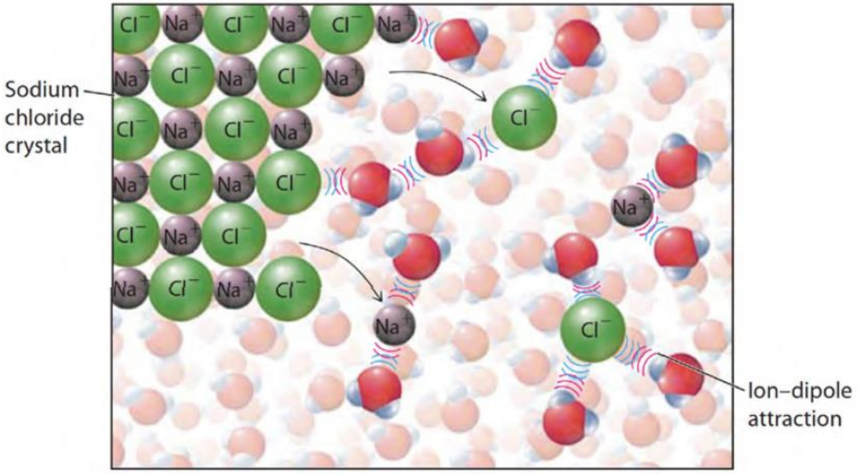
Strongest force: **between an ion and a permanent dipole (polar compounds)**



Positive ends of polar molecules are oriented toward negatively charged anion

Negative ends of polar molecules are oriented toward positively charged cation

Reality



Aqueous solution of sodium chloride

Approx potential energy range: 40 – 600 kJ/mol

Examples: Cl^- – H_2O and Na^+ – H_2O

Practice: Identifying intermolecular forces

What intermolecular forces will be primarily responsible for overcoming the kinetic energy of the following molecules when they are in the liquid phase?

1) ClF_3

2) H_2O

3) CO_2

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Summary of intermolecular forces in mixtures

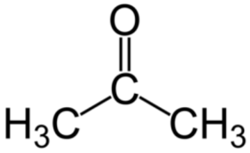
List of all the types of intermolecular forces in the following mixtures:

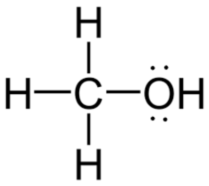
Type of molecules in mixture	Intermolecular forces involved
Only non-polar molecules	Only dispersion forces
Only polar molecules	Dispersion forces, dipole-dipole forces, and possibly hydrogen bonding
Mixture of polar and nonpolar molecules	Dispersion forces and dipole-induced dipole forces
Mixture of ions and nonpolar molecules	Dispersion forces and ion-induced dipole forces
Mixture of ions and polar molecules	Dispersion and ion-dipole forces

Practice: Intermolecular forces in mixtures

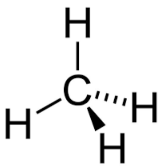
List all the types of intermolecular forces in the following mixtures:

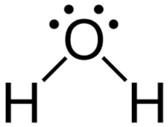
1) Acetone and methanol



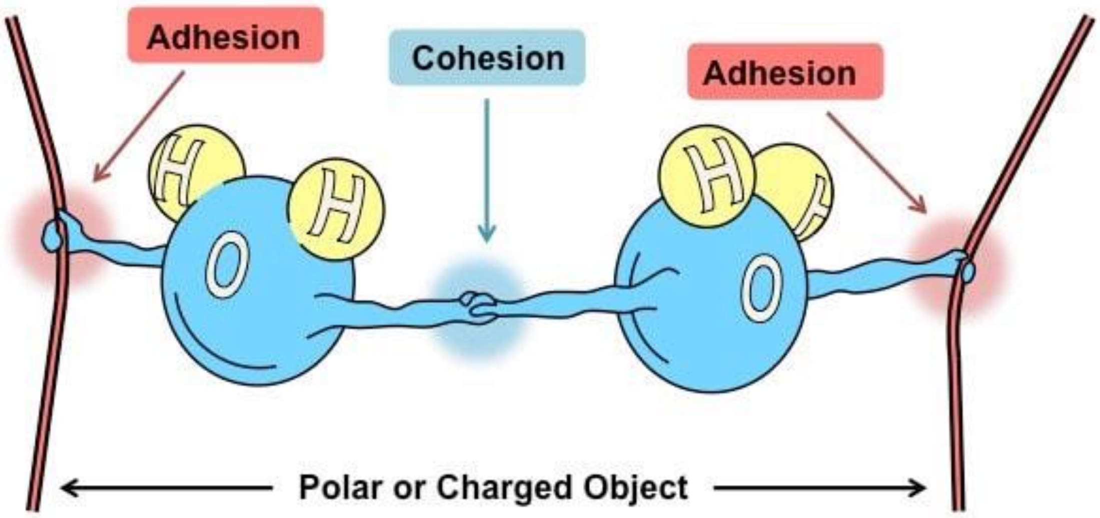


2) Methane and water





Intermolecular forces affects other physical properties: cohesion and adhesion



Adhesion: attract molecules in the liquid to molecules of the container

"attraction between **unlike** molecules"

Cohesion: attract molecules in a liquid to one another

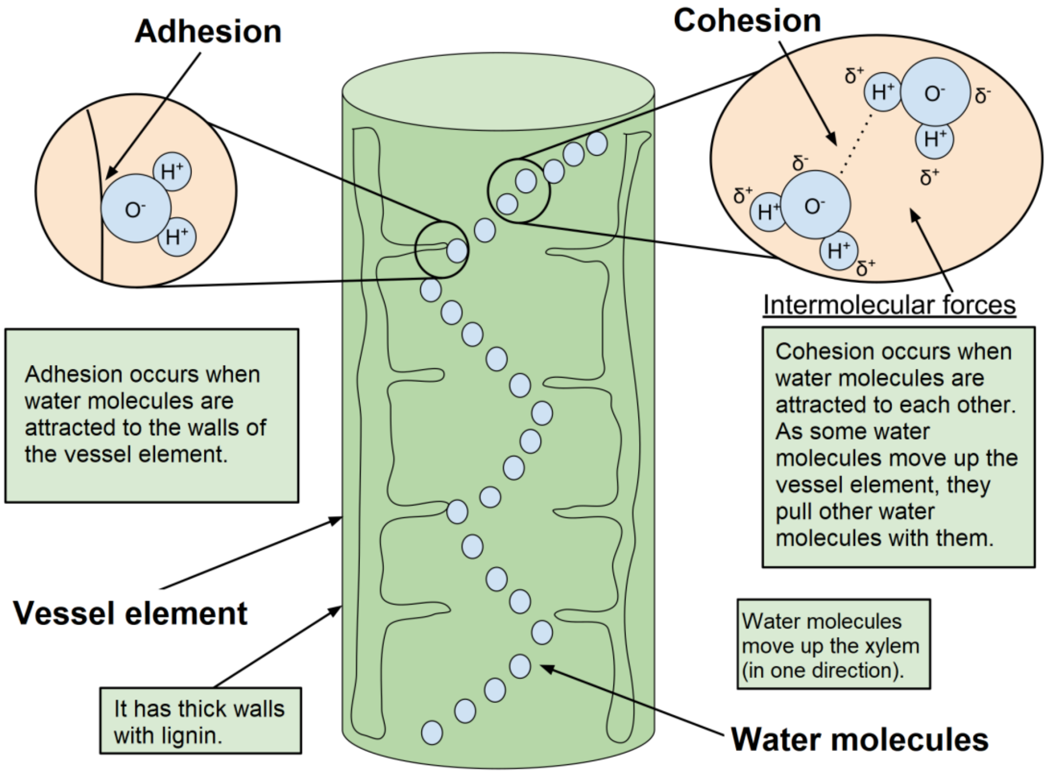
"attraction between **like** molecules"

https://biology4me.weebly.com/sc912l1812-properties-of-water.html

Intermolecular forces affects physical properties:

capillary action: the upward movement of a liquid in a narrow tube against the force of gravity

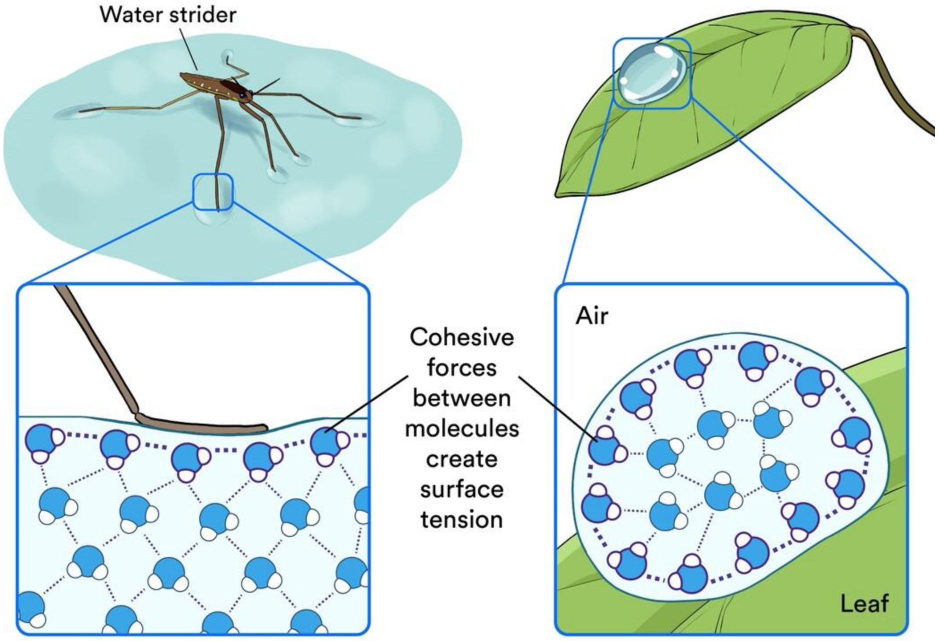
Example:
capillary action causing water to flow up the stem of a plant



https://bio.libretexts.org/Bookshelves/Botany/Botany_%28Ha_Morrow_and_Algiers%29/04%3A_Plant_Physiology_and_Regulation/4.05%3A_Transport/4.5.01%3A_Water_Transport/4.5.1.03%3A_Cohesion-Tension_Theory

Intermolecular forces affects physical properties: surface tension

Surface tension: measures the resistance of a liquid due to the cohesive forces between molecules → minimizing the liquid's surface area

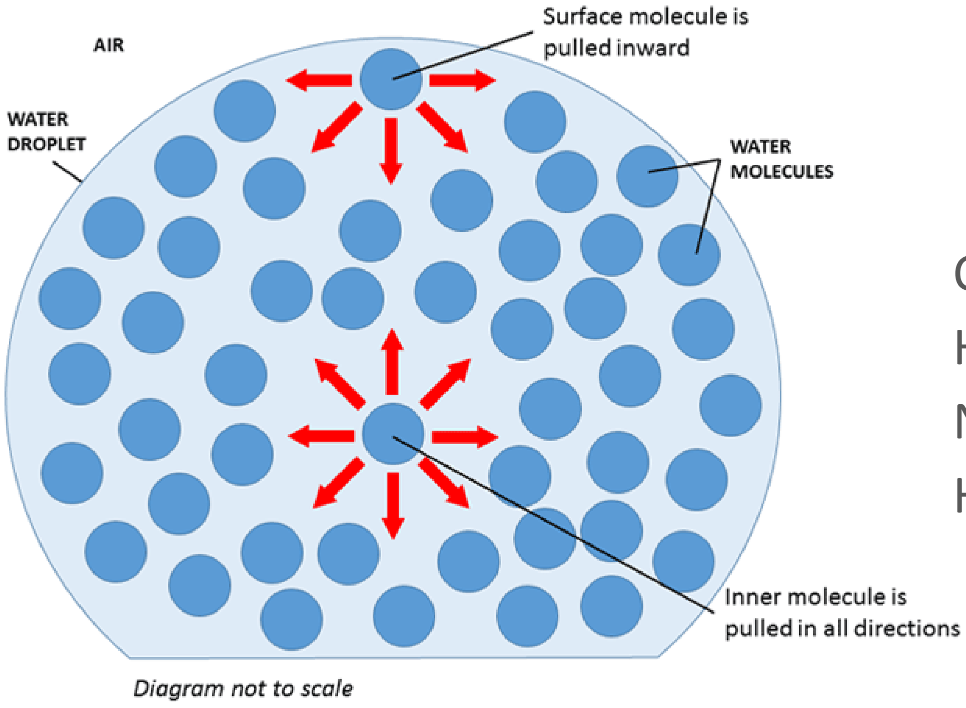


Surface tension results from the net inward force experienced by the molecules on the surface of a liquid

https://biology4me.weebly.com/sc912l1812-properties-of-water.html

Intermolecular forces affects physical properties: surface tension

Molecular level illustrating why liquids exhibit surface tension



Substances with higher intermolecular forces have higher surface tensions

	Surface Tension, J/m^2	
$CH_3(CH_2)_2CH_{3(l)}$	0.0184	(dispersion)
$H_2O_{(l)}$	0.0728	(H-bonds)
$NaCl_{(l)}$	0.100	(ionic bonds)
$Hg_{(l)}$	0.472	(metallic bonds)

Practice: surface tension

The mercury inside the glass column of a barometer displays a convex meniscus rather than the concave meniscus shown by water inside a glass column. **Explain in terms of intermolecular forces.**

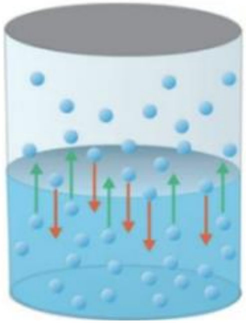
Practice: surface tension

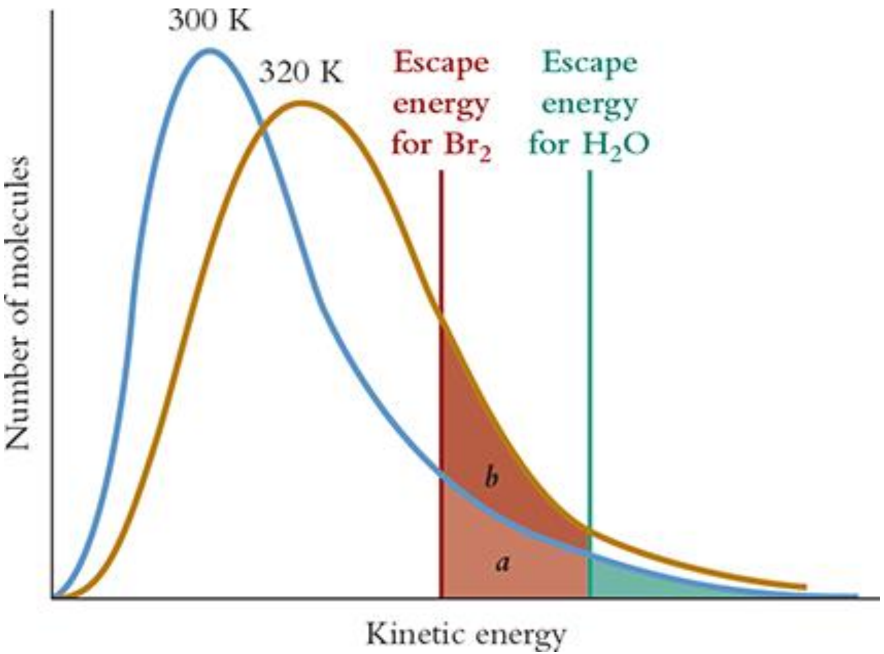
Aluminium tubing has a thin surface layer of aluminium oxide. What shape meniscus would you expect to find for water and for mercury inside aluminium tubing? **Explain your answers in terms of intermolecular forces**.

Intermolecular forces affect physical properties

vapour pressure

Vapour pressure: pressure exerted above the liquid by its vapour in a closed system.





# of molecules of liquid that have enough energy to escape into gas phase depends on:

- Temperature
- Strength of intermolecular forces

Practice: Vapour pressure

For each of the following pairs of liquids, choose which has the lower vapour pressure at room temperature and state the reason why:

1. benzene (C_6H_6) or chlorobenzene (C_6H_5Cl)

2. hexane (C_6H_{14}) or 1-hexanol ($C_6H_{13}OH$)

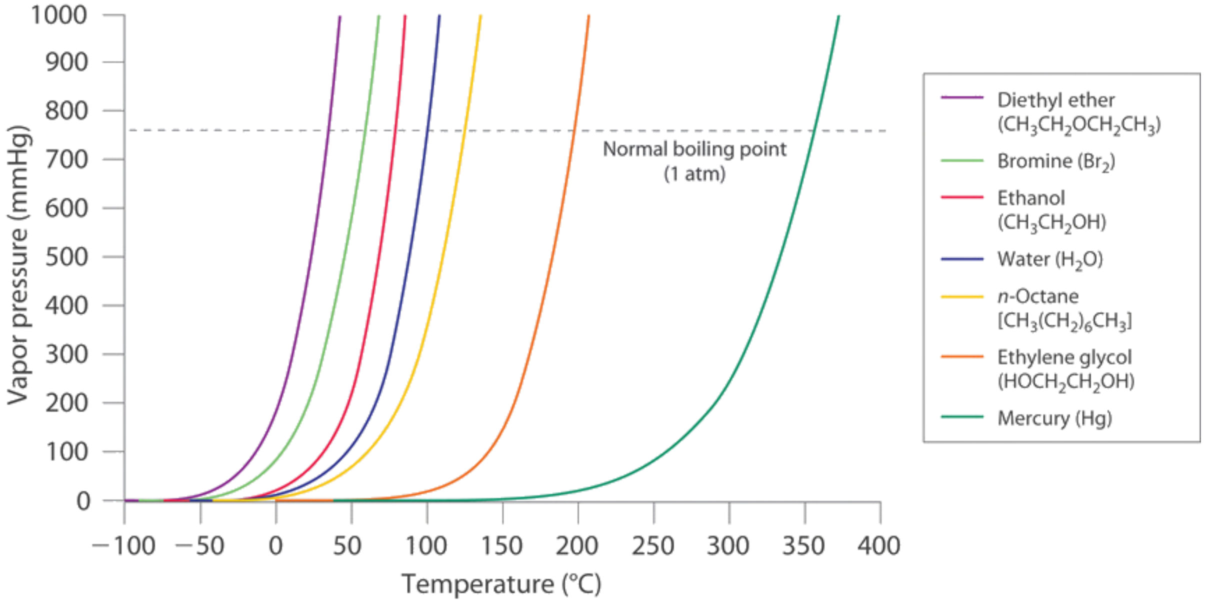
wooclap

Intermolecular forces affect physical properties

vapour pressure

Vapour pressure steadily increases as temperature increases.

Point where the vapour pressure crosses **P = 1atm** is the **normal boiling point (NBP)** of the liquid.



https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Physical_Properties_of_Matter/States_of_Matter/Phase_Transitions/Clausius-Clapeyron_Equation

Intermolecular forces correlate with physical properties

solving for vapour pressure at any temperature

CLAUSIUS-CLAPEYRON EQUATION:

$$\ln\left(\frac{P_1}{P_2}\right) = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

P_1 ,T_1 : The vapour pressure P_1 at some Temp T_1(K).

P_2 ,T_2 : The vapour pressure P_2 at some other Temp T_2(K).

ΔH^o_{vap} : The standard state heat of vaporization(J/mol)- The energy required to vaporize one mole of the substance at 25^{o}C

R : The gas constant (8.314 J/K mol)

Practice: Example 1 Vapour pressure

What is the vapour pressure of acetic acid at 23℃, given that its NBP is 117.9℃ and ΔH^{o}_{vap} = 39.1 kJ/mol

R = 8.314 J/K mol
= 0.08206 L atm/K mol

Practice: Example 2 Vapour pressure

At what temperature does water boil at the summit of Mount Everest, where the atmospheric pressure is 0.35 atm? ΔH^{o}_{vap} (water) = 43.4 kJ/mol

R = 8.314 J/K mol
= 0.08206 L atm/K mol

Practice: Vapour pressure

You go climbing in the Andes, and stop to make tea. You find that the water boils at a temperature of 92.5 °C. What is the atmospheric pressure where you are? (Given: $\Delta H^\circ_{vap}(H_2O) = 43.4$ kJ/mol)

R = 8.314 J/K mol
= 0.08206 L atm/K mol