Bromine liquid vapor equilibrium
vapor pressure
temperature
intermolecular forces
Presentation
Closed system vs Open system

In an open system the molecules will continue to evaporate until all have vaporized.
Evaporation: liquid -> gas

An open system
All substances at the same temperature have the same average kinetic energy. However, there is always a distribution of velocities, leading to a distribution of kinetic energies.

A certain fraction of molecules in the liquid phase have enough energy to escape into the gas phase.
Evaporation Big Concept: molecules in a liquid state must have sufficient kinetic energy to overcome the intermolecular forces of attraction operating among the liquid molecules.

Strong IMFs between molecules => Force of attraction is Strong
But, we also know that at the same temperature, different substances evaporate at different rates.

Why is that?
What is different about these 2 curves?

Same average kinetic energy.

“Minimum escape energy” is different.
What are the IMFs in water and gasoline ($C_8H_{18}$)?

- Hydrogen bonding
- London dispersion forces
Evaporation, Vapor Pressure & IMFs

Vaporization (evaporation) will occur if molecules in the liquid phase possess enough kinetic energy to overcome the intermolecular forces of attraction holding the molecules together.

Since the strength of total IMFs vary with different molecules:

1. the rate of vaporization will be different for different substances at the same temperature.

2. the vapor pressure of the gases of different substances, at the same temperature, will vary.
A closed system

**Vapor pressure**

Gas pressure builds up (increases) inside the closed container due to an increase in gas particles striking the walls of the container.

Initial: place liquid in a flask and put a stopper in the top.

Time = 0.0 second

Time = 240.0 seconds
**The vapor pressure** is the pressure exerted by the vapor on the liquid. The pressure increases until equilibrium is reached; **at equilibrium the pressure is constant.**
Animation of the Dynamic Equilibrium of a hypothetical substance “R”. What two processes are occurring? Write the equilibrium equation.

R(l) ⇌ R(g)

Particulate representation of equilibrium between gas and liquid. Note that the rate of evaporation of the molecules in the liquid is equal to the rate of condensation of the gas.
All substances at the same temperature have the same average kinetic energy. However, there is a distribution of velocities, leading to a distribution of kinetic energies.

A certain fraction of molecules in the liquid phase have enough energy to escape into the gas phase.
In an open system, the \( \text{Br}_2 \) molecules in the liquid phase have a fast rate of evaporation. Why?
Consider bromine, $\text{Br}_2$, at room temperature.

A significant number of $\text{Br}_2$ molecules in the liquid phase have enough kinetic energy to overcome the intermolecular forces (potential energy) and enter the gas phase.

A certain fraction has enough energy to escape into the gas phase.
Boiling Point and Vapor Pressure

- The **boiling point** of a liquid is the temperature at which its vapor pressure equals atmospheric pressure.
- The **normal boiling point** is the temperature at which its vapor pressure is 760 torr.
Dynamic Equilibrium, Br₂

Count the molecules in the gas phase

Count the molecules in the liquid phase

Write the equilibrium equation

Br₂(l) ⇌ Br₂(g)
$\text{Br}_2(\text{liquid}) \rightleftharpoons \text{Br}_2(\text{gas})$

A particulate model of the dynamic equilibrium of bromine

https://youtu.be/092HBcCq5P8
A computer animation

University of Oregon
\[ \text{Br}_2(\text{liquid}) \rightleftharpoons \text{Br}_2(\text{gas}) \]

The rate of the forward process equals the rate of the reverse process. The processes continue, they do not stop.

https://youtu.be/092HBcCq5P8

A computer animation

University of Oregon
Liquid-gas equilibrium and vapor pressure

In a closed flask, the system reaches a state of dynamic equilibrium, where molecules are leaving and entering the liquid at the same rate.

\[ \text{Br}_2(l) \rightleftharpoons \text{Br}_2(g) \]

Once equilibrium is reached, no changes will be observed, though the process is still occurring on a molecular level.
The liquid and vapor reach a state of dynamic equilibrium: liquid phase molecules evaporate and vapor phase molecules condense at the same rate.

Rate of the forward process equals the rate of the reverse process.

The number of particles in the liquid and gas state do not change.

\[ \text{Br}_2(\text{l}) \rightleftharpoons \text{Br}_2(\text{g}) \]
**Intermolecular Forces:** Your job is to be able to predict the forces and understand how they relate to physical properties such as boiling and freezing points.

The **stronger** the attractions between the atoms or molecules, the more energy is required to separate the molecules the **larger** the **heat of vaporization** and the **higher** the **boiling point**.
# Physical Properties of Bromine ($\text{Br}_2$)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>melting point</td>
<td>-7.2°C (19°F)</td>
</tr>
<tr>
<td>boiling point</td>
<td>58.8°C (137.8°F)</td>
</tr>
<tr>
<td>vapor pressure at 25°C</td>
<td>0.30 atm (228 mm Hg)</td>
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<tr>
<td>$\Delta H_{\text{vaporization}}$</td>
<td>29.96 kJ/mole</td>
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Intermolecular Forces: Your job is to be able to predict the forces and understand how they relate to physical properties such as vapor pressure.

The **stronger** the attractions between the atoms or molecules, the more energy is required to separate the molecules, the **lower** the vapor pressure.

Molecules in the liquid phase having strong IMFs hold unto their neighboring molecules strongly thus only a few get into the vapor phase.
London Dispersion IMF

Unequal distribution of electrons

Attractive force

Temporary dipoles
Comparison of Vapor Pressures and IMFs of Other Substances to Bromine (Br$_2$)

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<tr>
<th>Substance</th>
<th>Vapor Pressure at 25°C</th>
<th>Primary Intermolecular Force Between Molecules</th>
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<tr>
<td>Propane (CH$_3$CH$_2$CH$_3$)</td>
<td>8.45 atm</td>
<td>London Dispersion</td>
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<tr>
<td>Ethanol (CH$_3$CH$_2$OH)</td>
<td>0.08 atm</td>
<td>Hydrogen-Bonding</td>
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<tr>
<td>Water (H$_2$O)</td>
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Intermolecular Forces are forces of attraction between a molecules, each molecule has a net dipole moment.

The IMFs between water molecules are stronger compared to the IMFs between Br₂ molecules.
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Two liquids, same temperature, in closed containers. Which container has the higher vapor pressure?

Temperature = 25°C

Liquid A

Liquid B
Concept: In a closed container
More gas phase molecules = More pressure

Temperature = 25°C

The vapor pressure above liquid B is higher compared to the vapor pressure above liquid A.
Evaporation (or vaporization)

Evaporation of a liquid will occur if molecules possess enough kinetic energy to overcome intermolecular forces.

1. KE increases with temperature, so rate of evaporation increases with temperature.

2. IMFs vary with molecule structure so the rate of vaporization will be different for different substances at the same temperature.
Vapor Pressure of a gas over its liquid

- At a low temperature some molecules in a liquid have enough energy to break free and enter the gas phase.
- As the temperature rises, the fraction of molecules that have enough kinetic energy to break free increases.
Bromine (Br$_2$) Vapor Pressure vs Temperature

Pressure (mm Hg) vs Temperature (°C)
Vapor Pressure

- At any temperature some molecules in a liquid have enough energy to break free and enter the gas phase.
- As the temperature rises, the fraction of molecules that have enough energy to break free increases.
As temperature increases, the rate of vaporization increases.
Same substance at different two different temperatures
More gas phase molecules = More pressure

Temperature = 25°C

Temperature = 85°C

The vapor pressure above liquid in container B is higher compared to the vapor pressure above the liquid in container A.
To Summarize

Vaporization (evaporation) will occur if molecules in the liquid phase possess enough KE to overcome intermolecular forces.

1. KE increases with temperature, more molecules have enough energy to escape the liquid, the vapor pressure increases with temperature.

2. IMFs vary with molecules, vapor pressure will be different for different substances at the same temperature.

3. The stronger the IMF, the lower the vapor pressure.