CHEM 1101B- Chemistry for Engineers

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

Lecture 13: Phase Changes

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

and/or

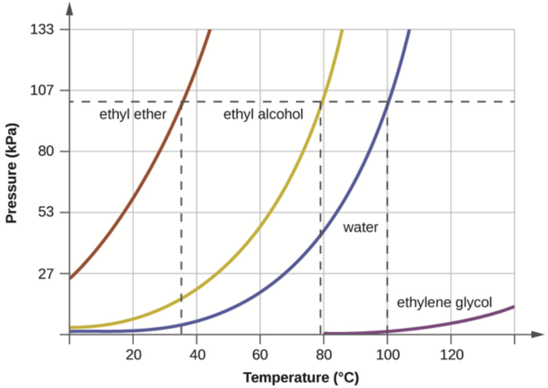
Answer first wooclap question

Learning outcome for Topic 13: Phases of Matter – Phase Changes

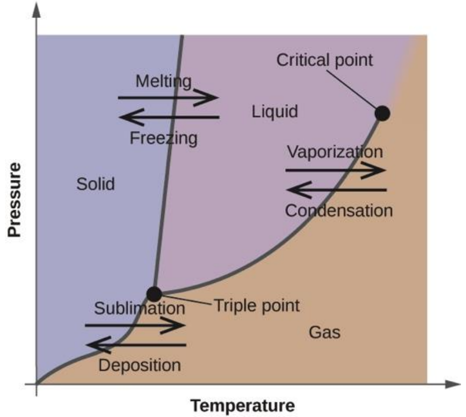
Learning Outcomes:

- Interpret a one-component phase diagram
- Use phase diagrams to identify stable phases at given temperatures and pressures, and to describe phase changes resulting from changes in these properties
- Label and use a one-component phase diagram

Previous topics: Plots of liquid's vapour pressure versus temperature showed us how the boiling point varies with pressure.



This topic: We use phase diagrams to indicate physical states that exist under specific conditions of pressure and temperature .



How are rockets able to shoot up in the air?

- Many rockets use a combination of kerosene and liquid oxygen for their fuel.
- Oxygen can be reduced to the liquid state either by cooling or by using high pressure.
- High pressure can be used to force the oxygen into tanks and cause it to liquefy so it can then mix with the kerosene and provide a powerful ignition to move the rocket.

To understand this phenomena, we need to understand **phase changes** and use **phase diagrams**!

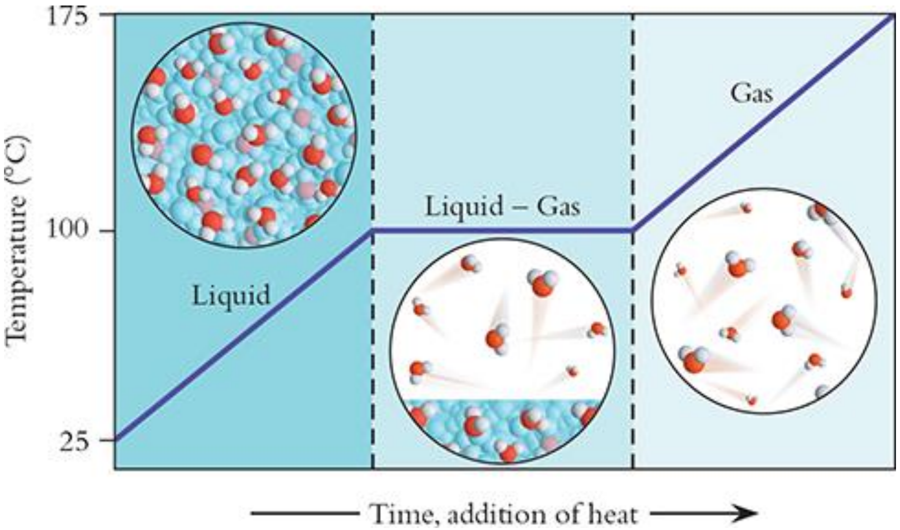
https://courses.lumenlearning.com/umes-cheminter/chapter/general-phase-diagrams/#:~:text=General%20phase%20diagram%2C%20which%20shows,of%20its%20temperature%20and%20pressure.&text=on%20the%20horizontal%20axis%20represents%20the%20normal%20boiling%20point%20of,solid%20to%20liquid%20to%20gas.

What are phase changes

Phase changes: the transformation from one state of matter to another

- Characteristic of all substances
- Phase of substance and separation between molecules are related to the intermolecular forces in a molecule
- **Source of energy needs to be supplied when substance transitions to higher energy state**

Heating/cooling curve of water at constant pressure of 1atm.



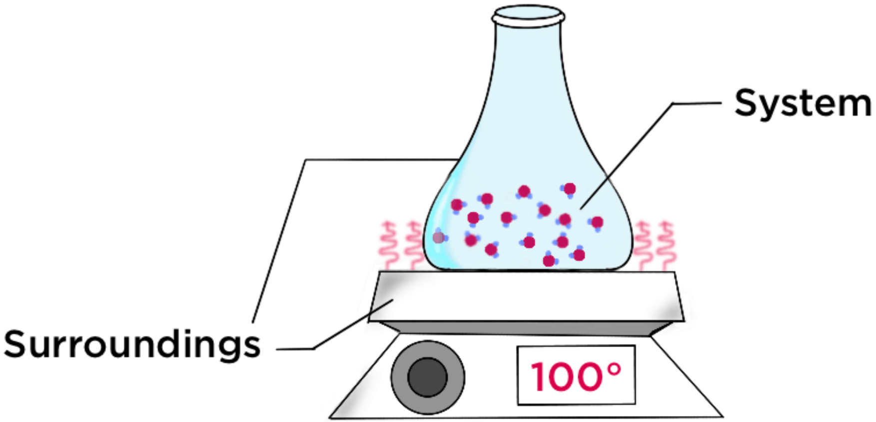
Note: temperature remains constant while the change of state is in progress.

Understanding energy basics

Law of conservation of energy: during a chemical or physical change, energy cannot be created nor destroyed, but can be changed in form

Thermal Energy: the kinetic energy associated with the random motion of atoms and molecules.

Heat (q): the transfer of thermal energy between a system and its surroundings as a result of a difference in temperature



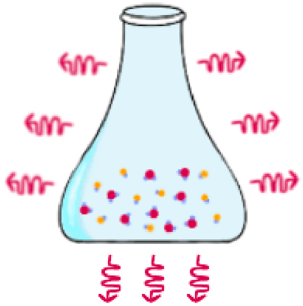
Understanding Enthalpy

Enthalpy: the measurement of energy that describes heat flow at constant pressure

$$\Delta H = q$$

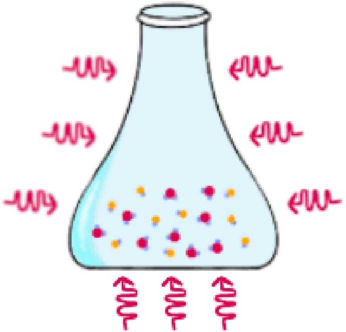
Matter undergoing phase changes can **release or absorb heat**:

Exothermic process: change that **releases heat**
Energy moves from the system to the surroundings
$q < 0$; $\Delta H < 0$



$-q$
$\Delta H =$ -

Endothermic process: change that **absorbs heat**
Energy moves from the surrounding to the system
$q > 0$; $\Delta H > 0$



$+q$
$\Delta H = +$

Exothermic and endothermic phase changes

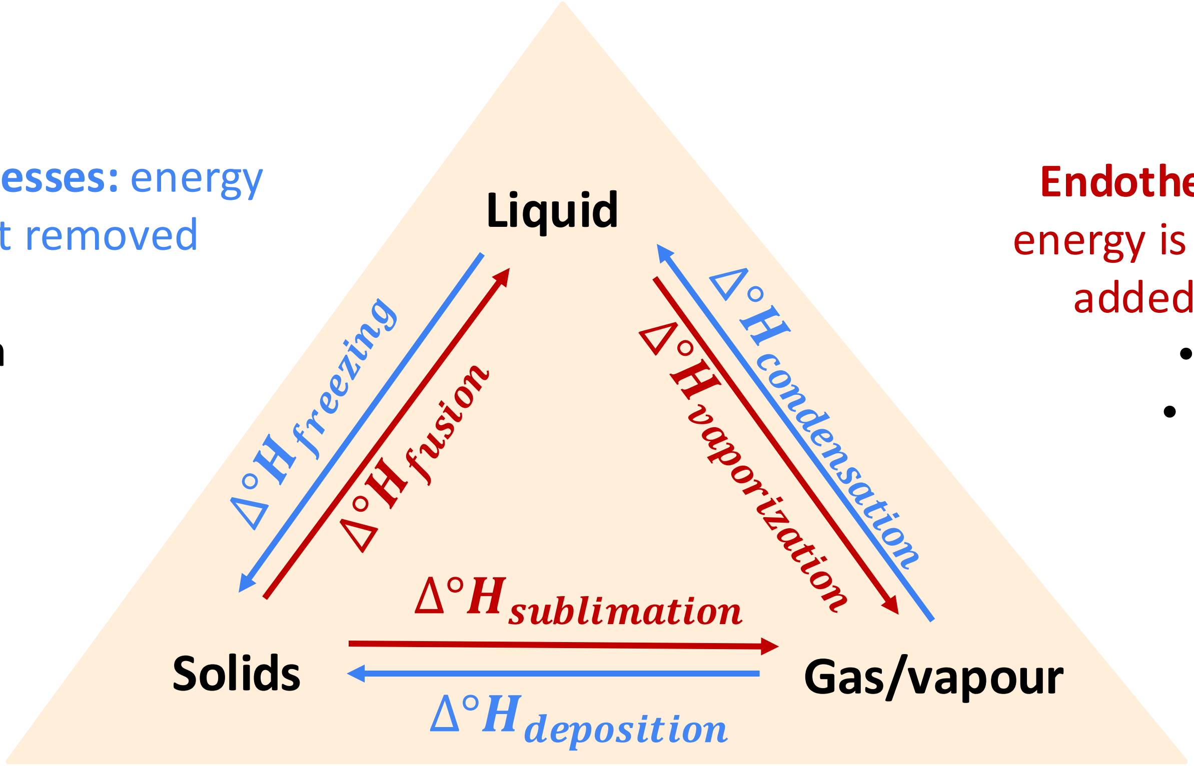
Phase changes involve a change in energy.

Exothermic processes: energy is released / heat removed ($\Delta°H$= **negative**)

- Condensation
- Freezing
- Deposition

Endothermic processes: energy is absorbed / heat added ($\Delta°H$= **positive**)

- Vapourization
- Melting/fusion
- Sublimation



Phase change enthalpy relationships

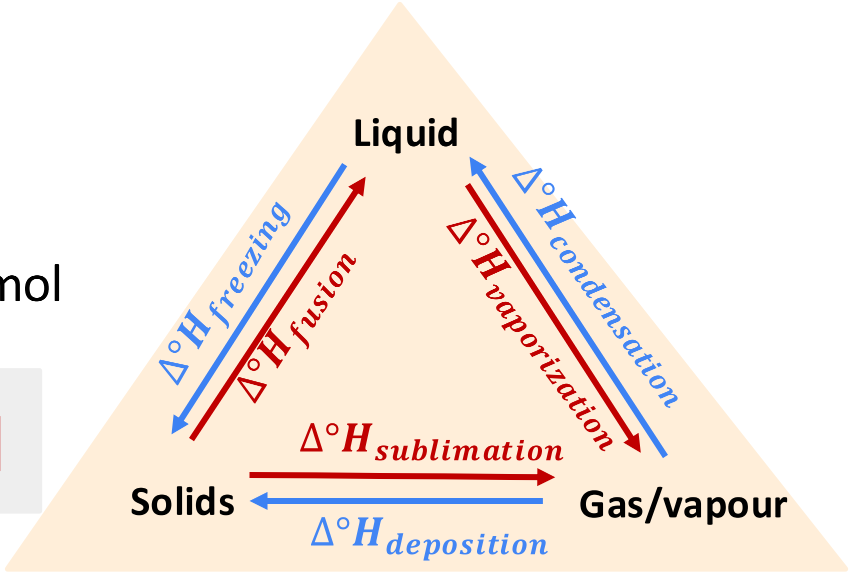
$$H_2O(s) \longrightarrow H_2O(l)$$

$$\Delta°H_{fus} = 6.01 kJ/mol$$

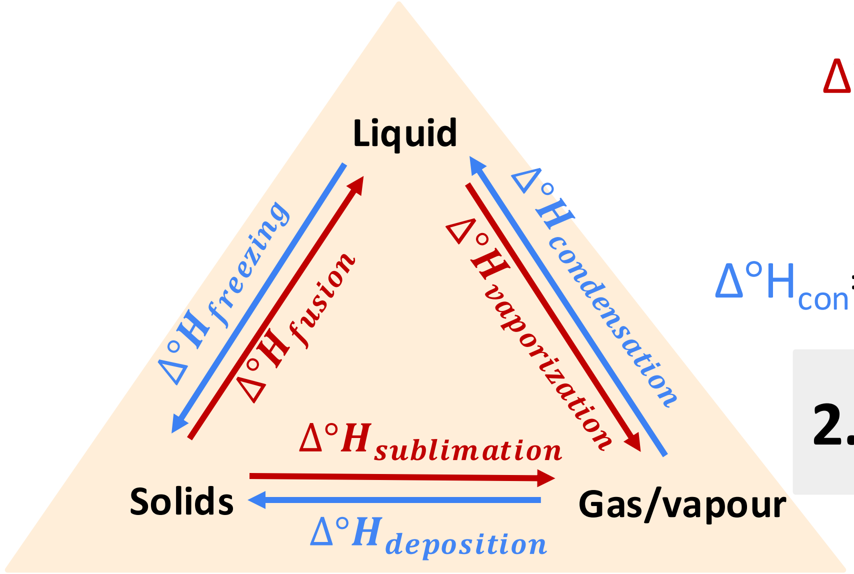
$$H_2O(l) \longrightarrow H_2O(s)$$

$$\Delta°H_{frz} = -\Delta°H_{fus} = -6.01 kJ/mol$$

1. $|\Delta°H_{frz}| = |\Delta°H_{fus}|$



Phase change enthalpy relationships



$H_2O(l) \longrightarrow H_2O(g)$

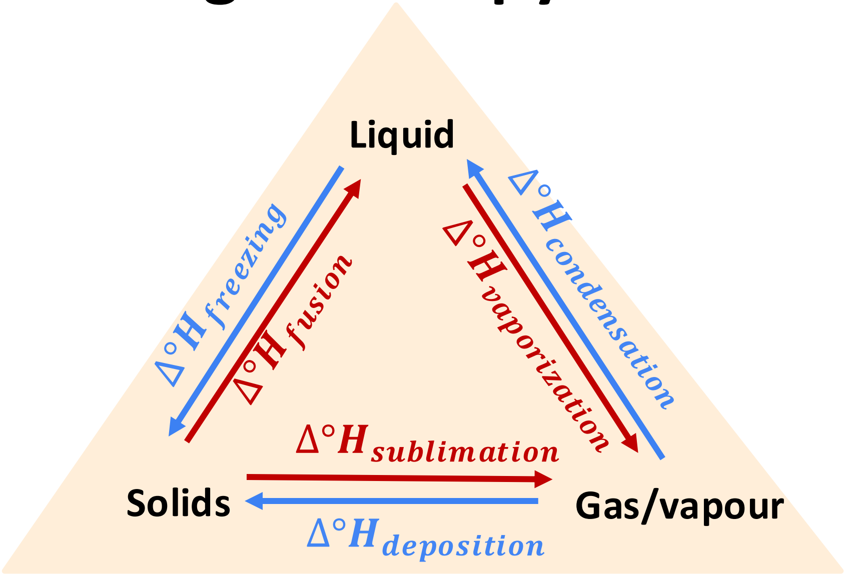
$\Delta^{\circ}H_{vap} = 45.07 kJ/mol$

$H_2O(g) \longrightarrow H_2O(l)$

$\Delta^{\circ}H_{con} = -\Delta^{\circ}H_{vap} = -45.07 kJ/mol$

2. $|\Delta^{\circ}H_{con}| = |\Delta^{\circ}H_{vap}|$

Phase change enthalpy relationships



$CO_2(s) \longrightarrow CO_2(g)$

$\Delta°H_{sub} = 26.1 kJ/mol$

$CO_2(g) \longrightarrow CO_2(s)$

$\Delta°H_{dep} = -\Delta°H_{sub} = -26.1 kJ/mol$

3. $|\Delta°H_{dep}| = |\Delta°H_{sub}|$

Phase change enthalpy relationships

$$\text{Solids} \underset{\Delta H_{deposition}}{\overset{\Delta H_{sublimation}}{\rightleftarrows}} \text{Gas/vapour}$$

$H_2O(s) \longrightarrow H_2O(l)$ $\Delta°H_{fus}$=6.01kJ/mol
$H_2O(l) \longrightarrow H_2O(g)$ $\Delta°H_{vap}$= 45.07 kJ/mol

$H_2O(s) \longrightarrow H_2O(g)$ $\Delta°H_{sub} = \Delta°H_{fus} + \Delta°H_{vap}$
=51.08 kJ/mol

$H_2O(l) \longrightarrow H_2O(s)$ $\Delta°H_{frz}$=−6.01kJ/mol
$H_2O(g) \longrightarrow H_2O(l)$ $\Delta°H_{con}$=−45.07kJ/mol

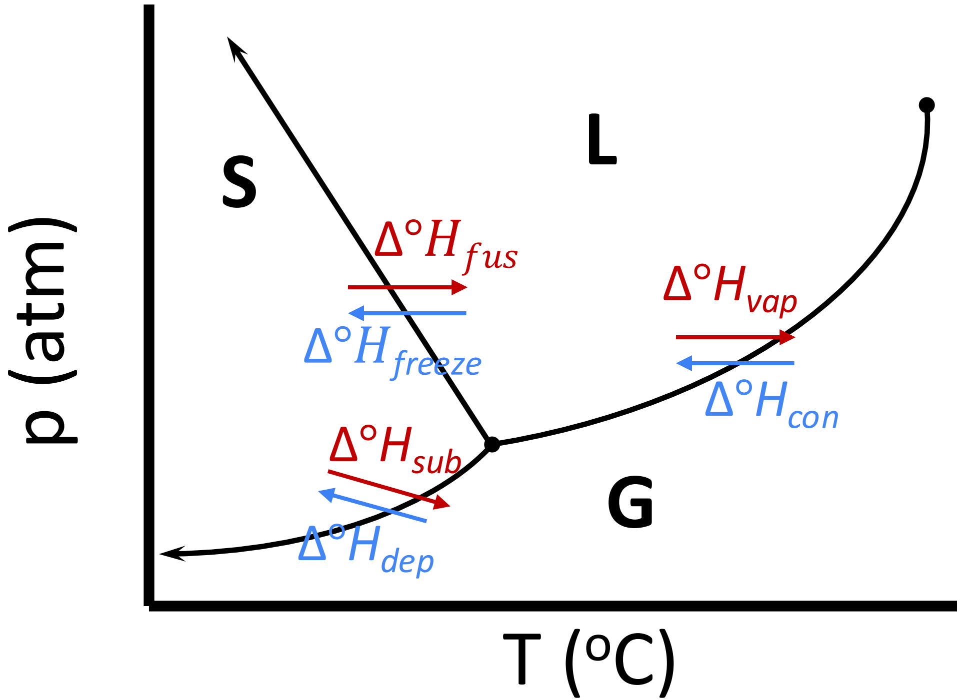
$H_2O(s) \longrightarrow H_2O(g)$ $\Delta°H_{dep} = \Delta°H_{frz} + \Delta°H_{con}$
= -51.08 kJ/mol

Standard enthalpies calculated at constant temp and pressure: **0°C and 1atm**

Phase Diagrams

Phase diagrams: combines plots of **pressure versus temperature** for a liquid-gas, solid-liquid, and solid-gas phase change of a substance.

- Shows which **phases are the most stable** at any condition of temperature and pressure
- Allows us to organize phase change data **at more than one pressure and temperature.**

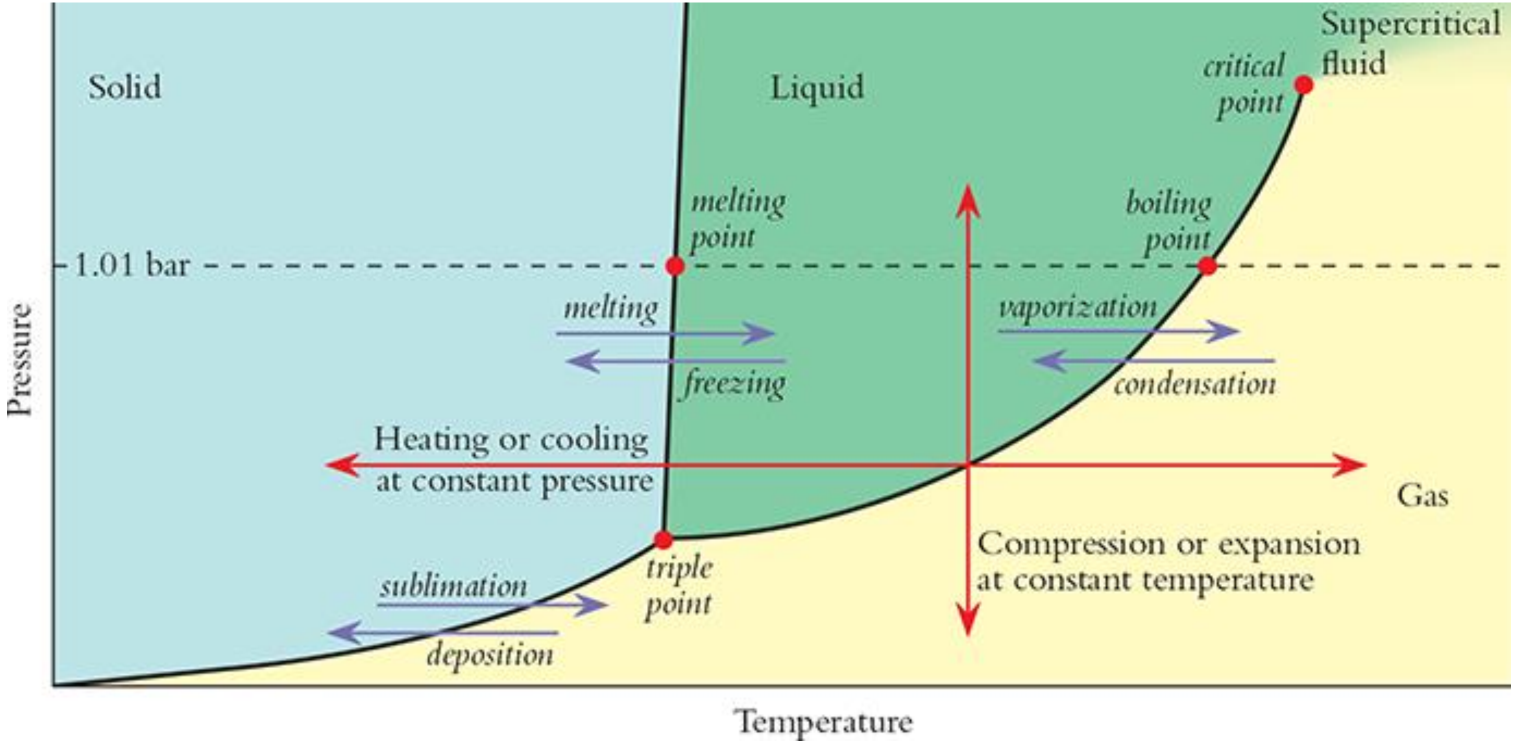


Phase Diagrams: Key features

Normal melting and **boiling points:** defined at **p = 1 atm**, 1.01325 bar.

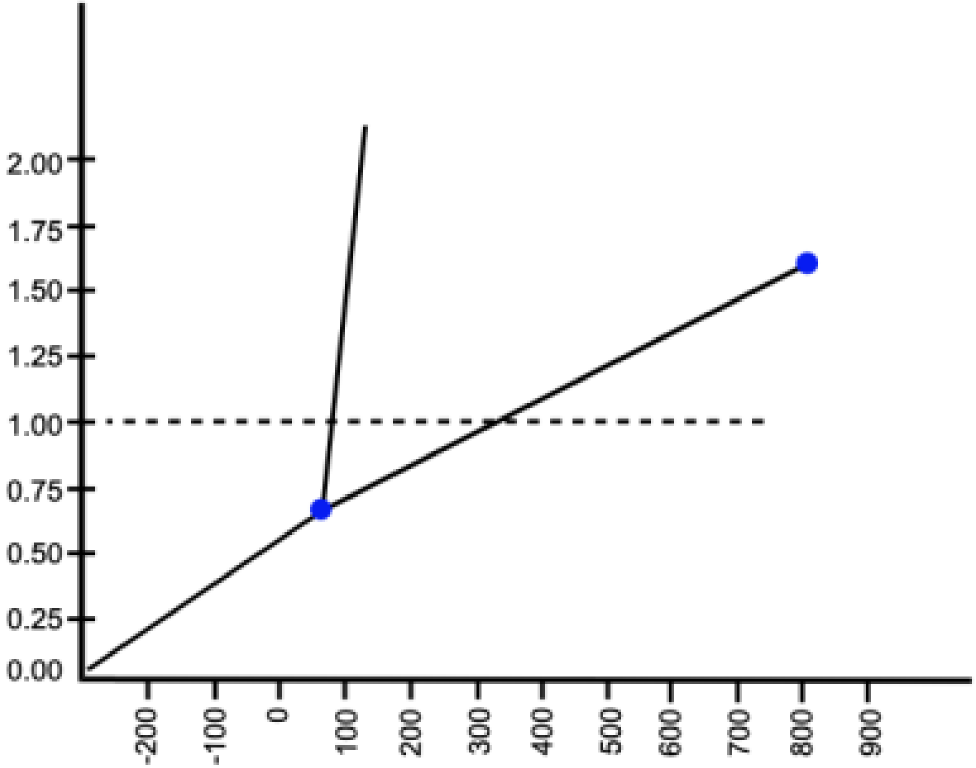
Triple point: temp and pressure where **all 3 phases** simultaneously **stable/coexist.**

Critical point: temp and pressure above which the distinction between gas and liquid disappears.



Practice: Identifying features on phase diagram

At what temperature can we no longer tell the difference between the liquid and gas phases?



A) 90 °C
B) 200 °C
C) 400 °C
D) 820 °C

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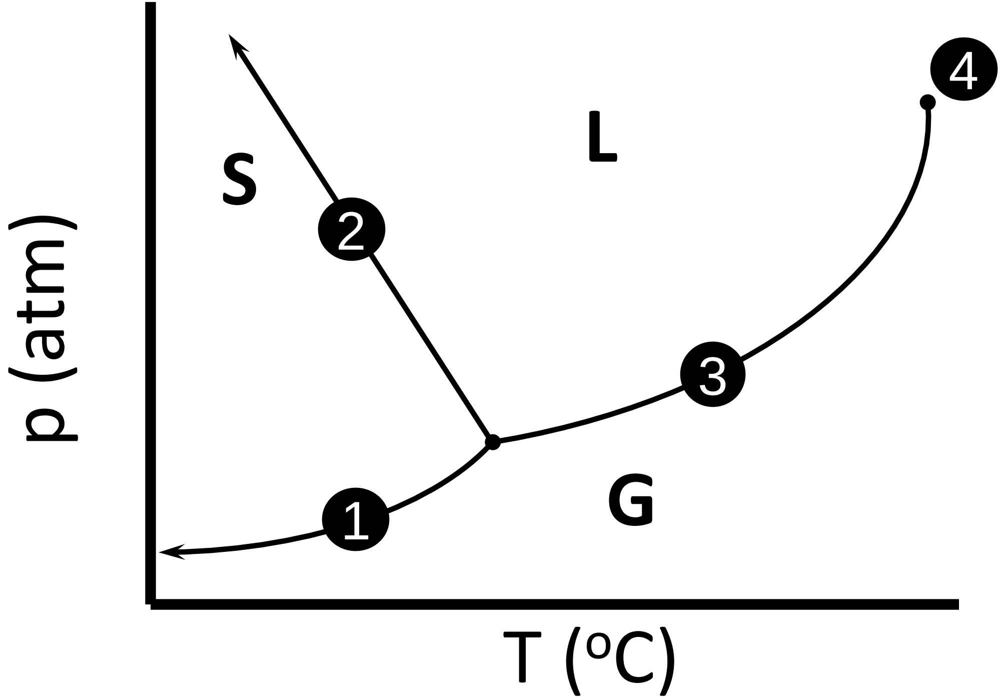
Practice: Identifying features on phase diagram

What point on the phase diagram describes the phase change that explains how freeze-dried foods, like ice cream can be dehydrated by sublimation at pressures below the triple point for water?



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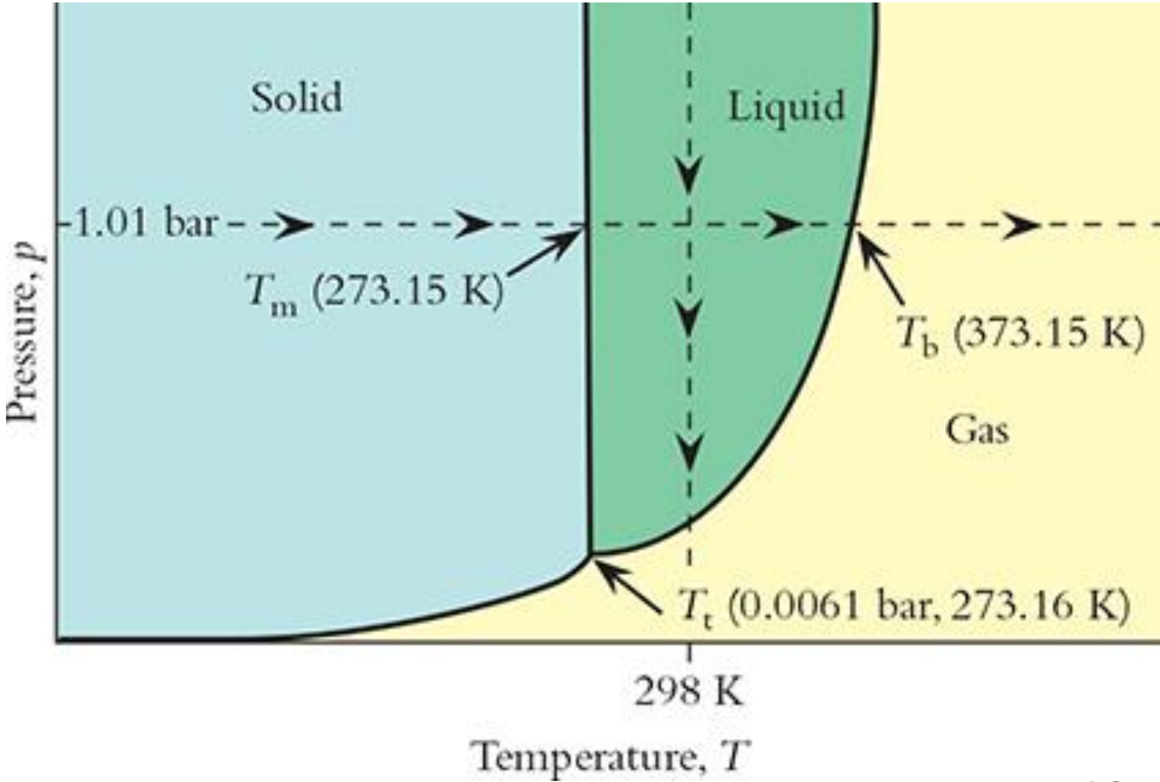
Phase Diagram for water

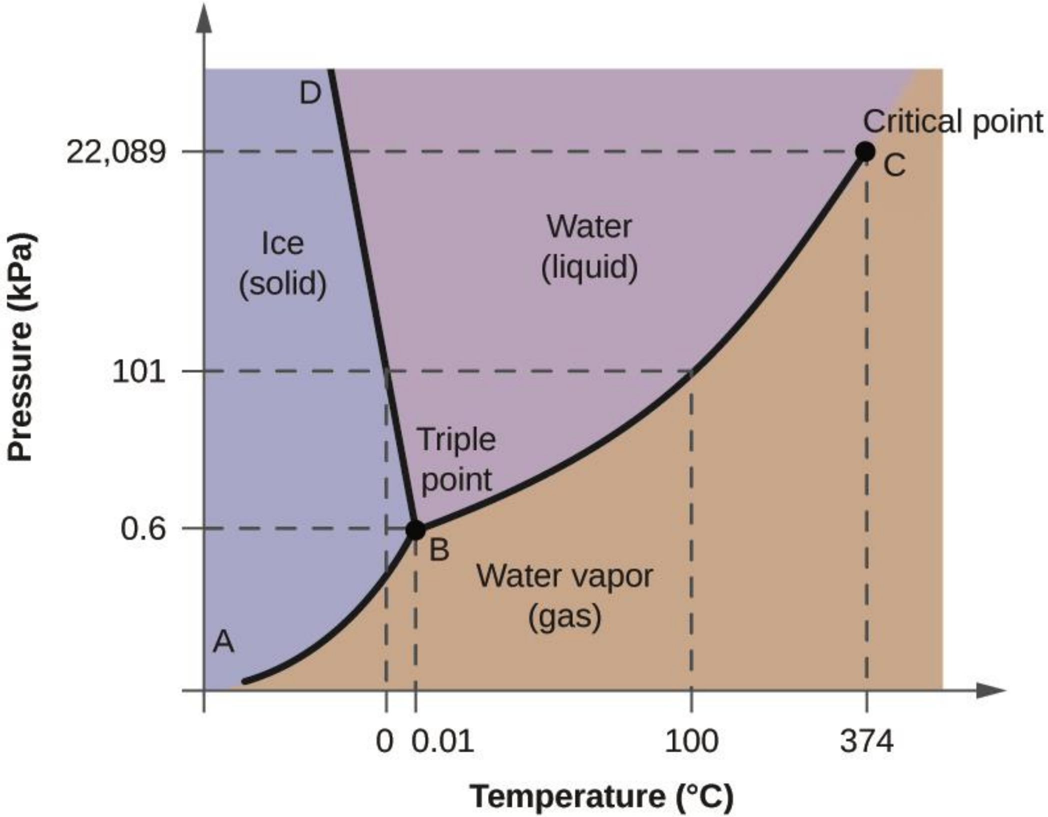
Horizontal dashed line: phase changes that occur as the **temperature increases** at **constant pressure, p = 1.01 bar.**

Vertical dashed line: phase changes that occur when **pressure is reduced** at **constant temperature of 298K.**



Practice: Interpreting phase diagrams

Using the phase diagram for water, determine the state of water at the following temperatures and pressures



A) -10°C and 50 kPa

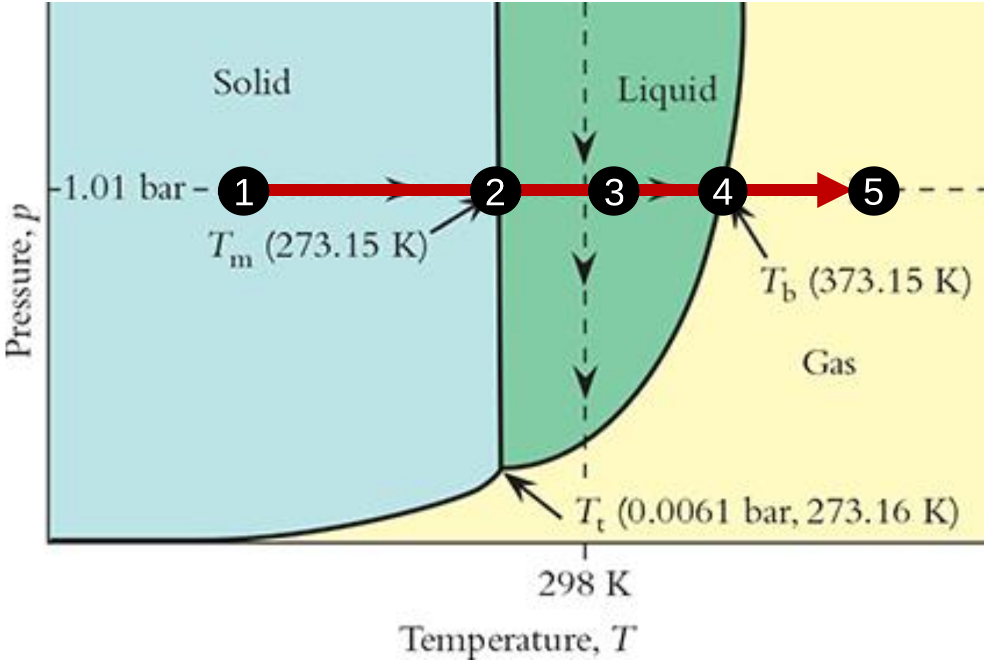
B) 50°C and 40 kPa

C) 80°C and 5 kPa

Describing phase diagrams at constant pressure

Describe what happens when you heat water from –50 ^oC to 300 ^oC at a constant pressure of 1 atm:

Make reasonable estimates based on plot



1. From -50 ^oC to 0 ^oC:

2. @ 0 ^oC:

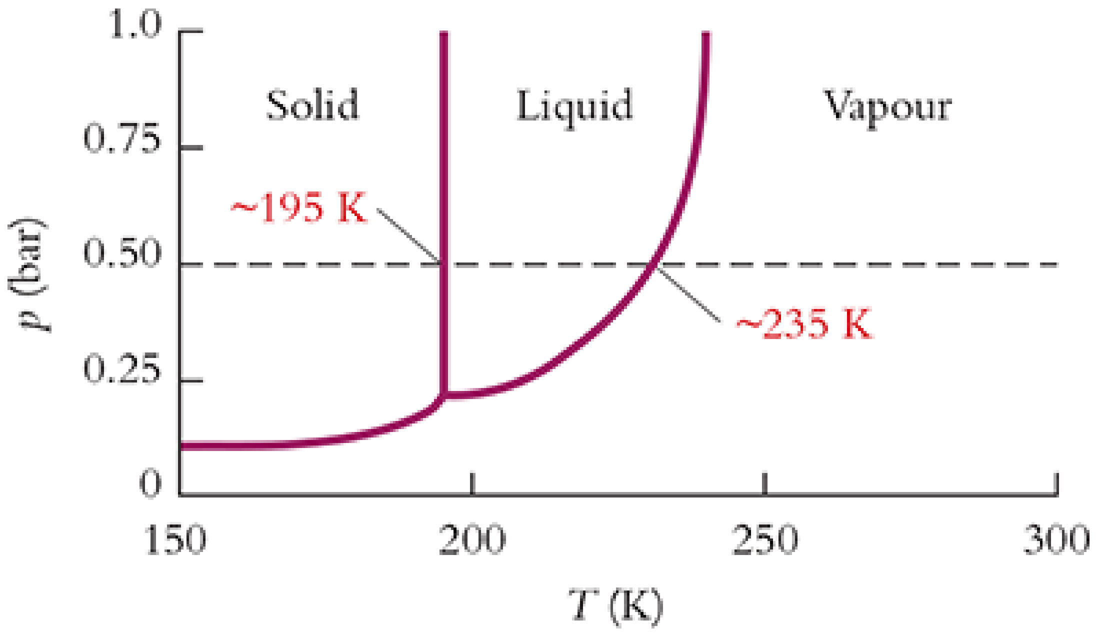
3. From 0 ^oC to 100 ^oC:

4. @ 100 ^oC:

5. From 100 ^oC to 300 ^oC:

Practice: Interpreting phase diagrams

A chemist wants to perform a synthesis in a vessel at p = 0.50 bar using liquid NH_3 as the solvent. **What temperature range would be suitable?** When the synthesis is complete, the chemist wants to boil off the solvent without raising T above 220 K. **Is this possible?**



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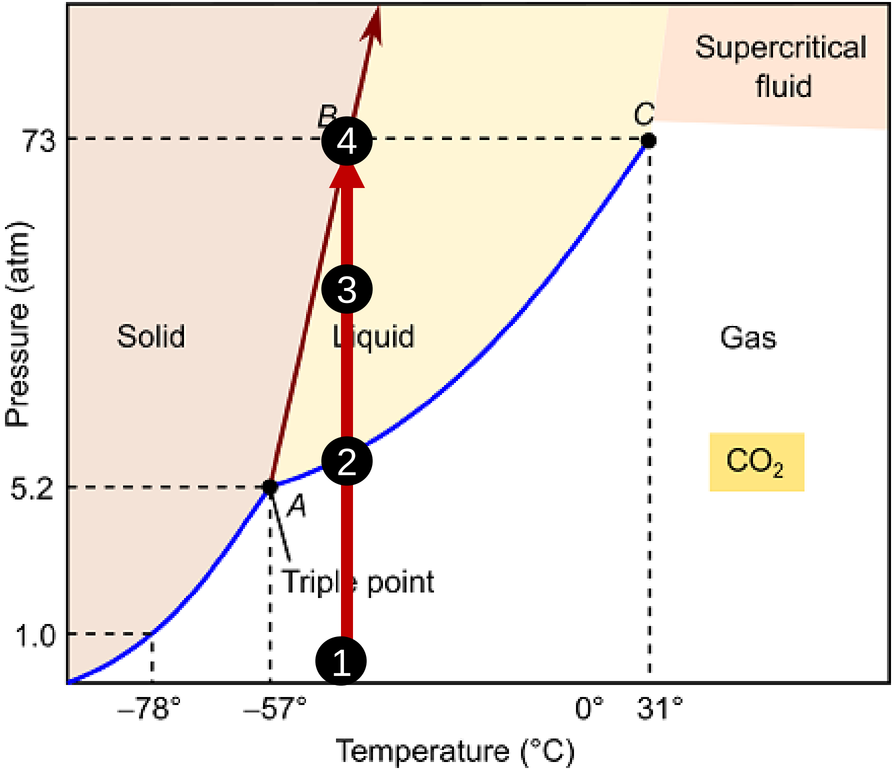
Describing phase diagrams at constant temp

Describe what happens when you raise the pressure of CO_2 from 0.1 atm to 73 atm at a constant temperature of –40 ºC:



Make reasonable estimates based on plot

1. From 0.1 atm to 7 atm:

2. @ 7 atm:

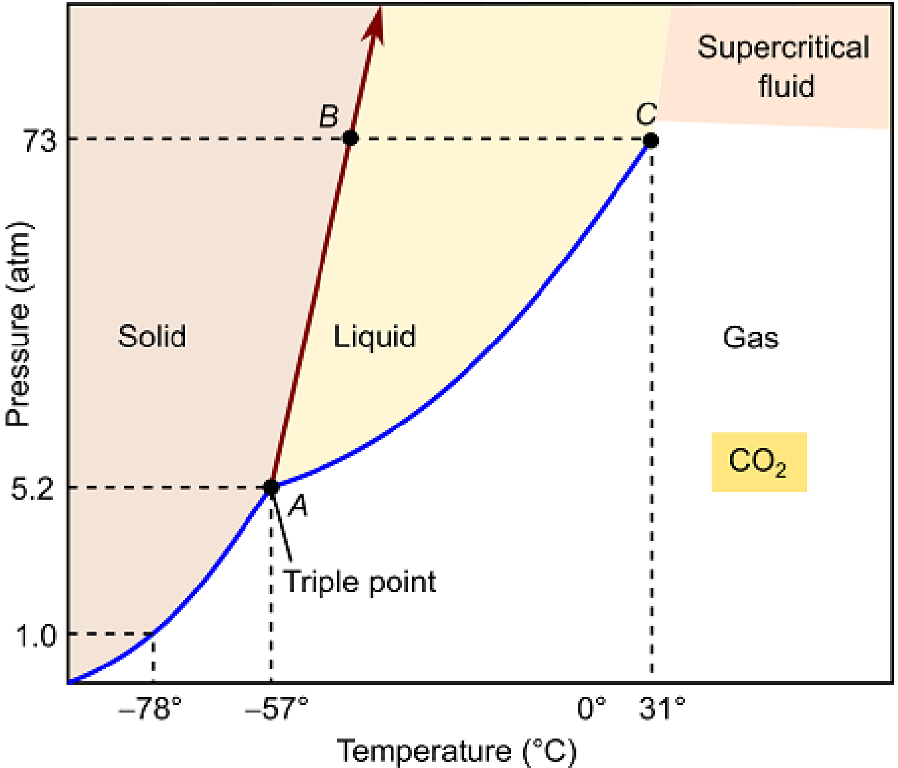
3. From 7 atm to 73 atm:

4. @ 73 atm:

Practice: Interpreting phase diagrams

Determine the phase changes carbon dioxide undergoes when its temperature is varied, thus holding its pressure constant at 15 atm?

At what approximate temperatures do these phase changes occur?

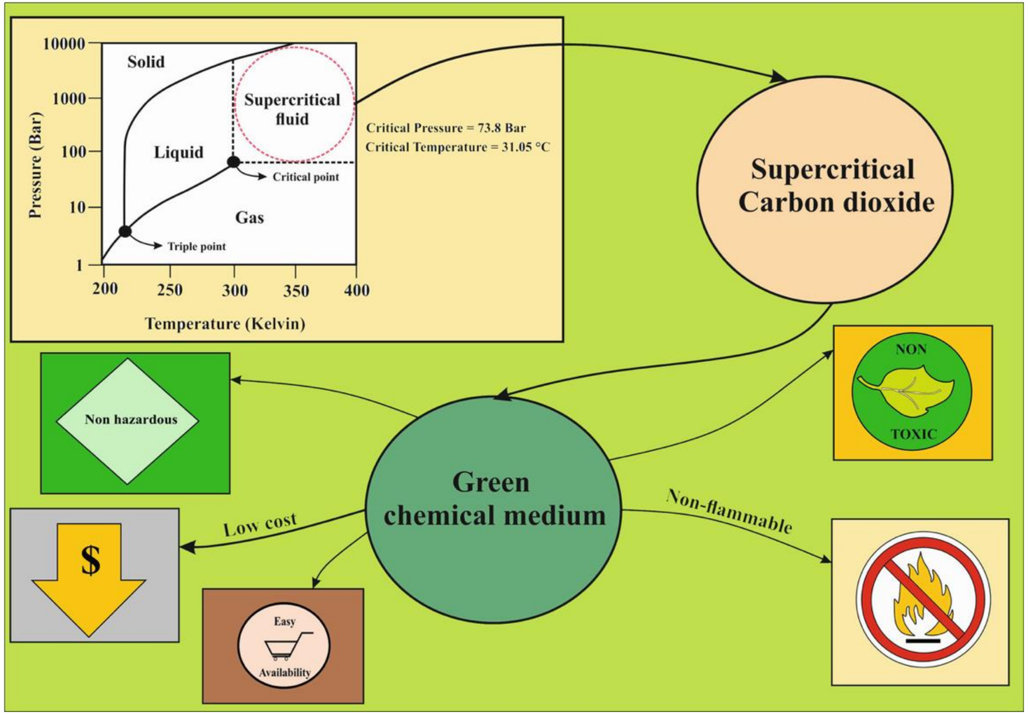


Supercritical fluids CO_2 as a greener alternative

Most important application is the use of supercritical CO_2

- CO_2 is a natural product of biological processes, therefore it is non-toxic → well suited for **Green Chemistry applications**

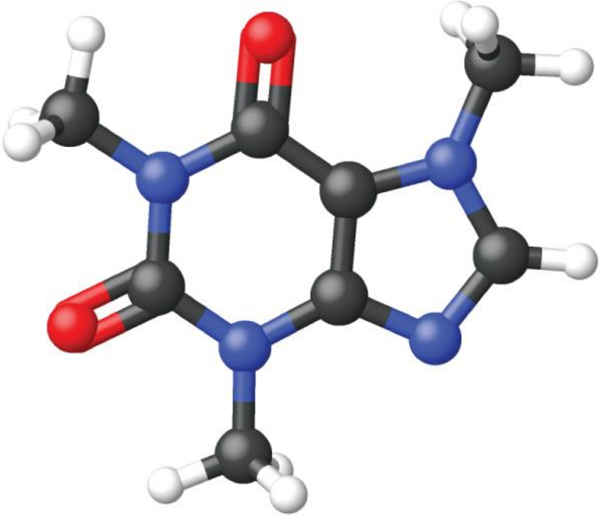
- Supercritical CO_2 used as a solvent for dry cleaning, petroleum extraction, decaffeination and polymer synthesis



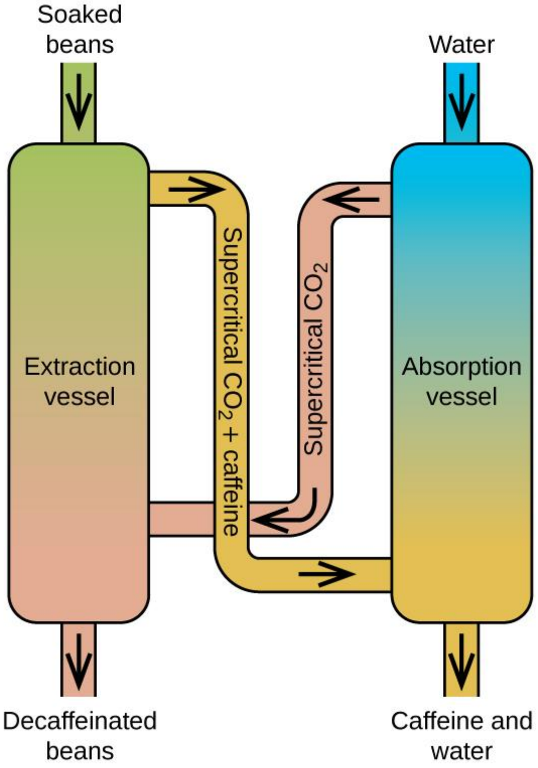
https://link.springer.com/chapter/10.1007/978-3-030-44984-1_5/figures/1

Green Chemistry Application: Decaffeinating coffee using Supercritical CO_2

Supercritical fluid extraction using carbon dioxide is now being a widely use and **more effect** and **environmentally friendly** decaffeination method.



(a)



(b)

https://boisestate.pressbooks.pub/chemistry/chapter/10-4-phase-diagrams/