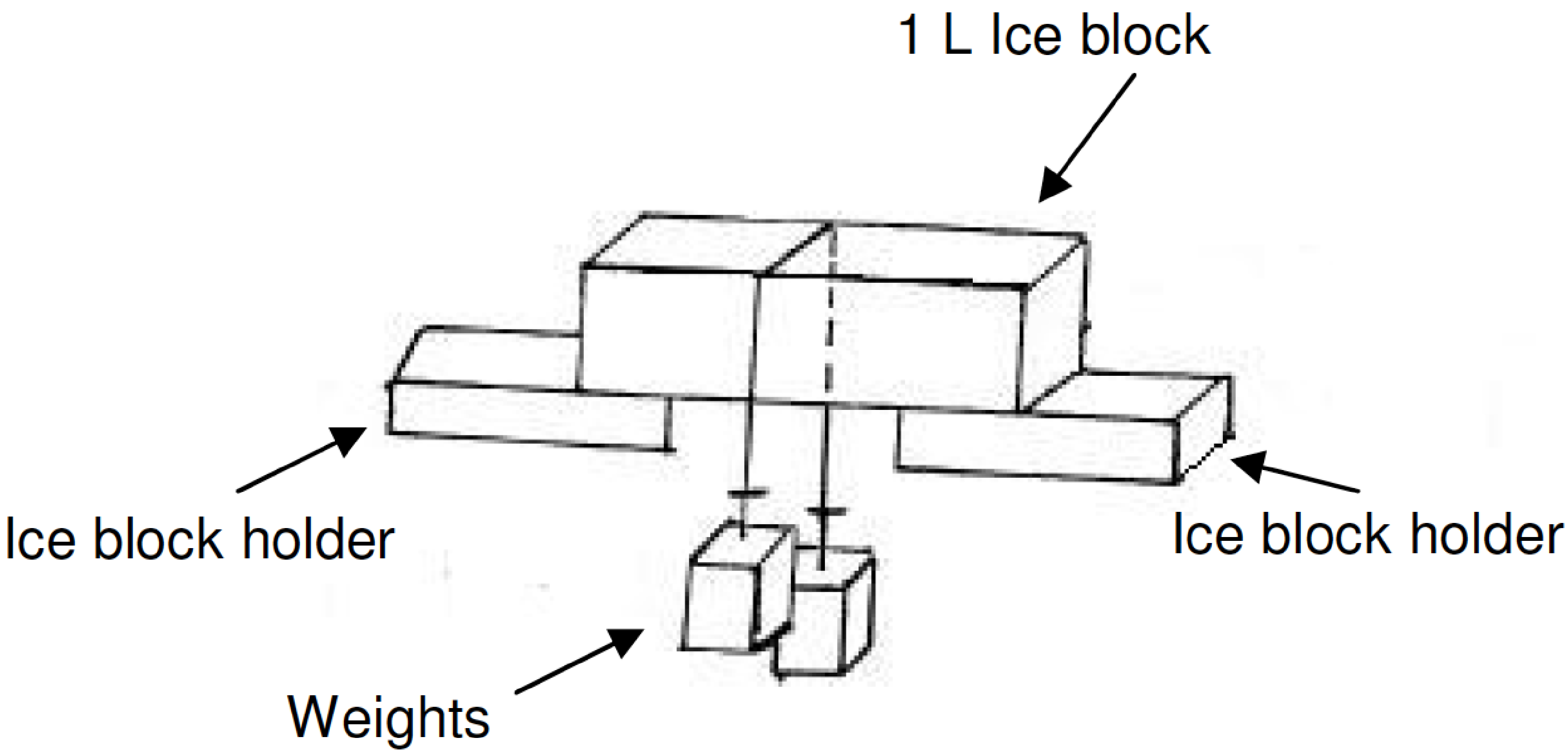
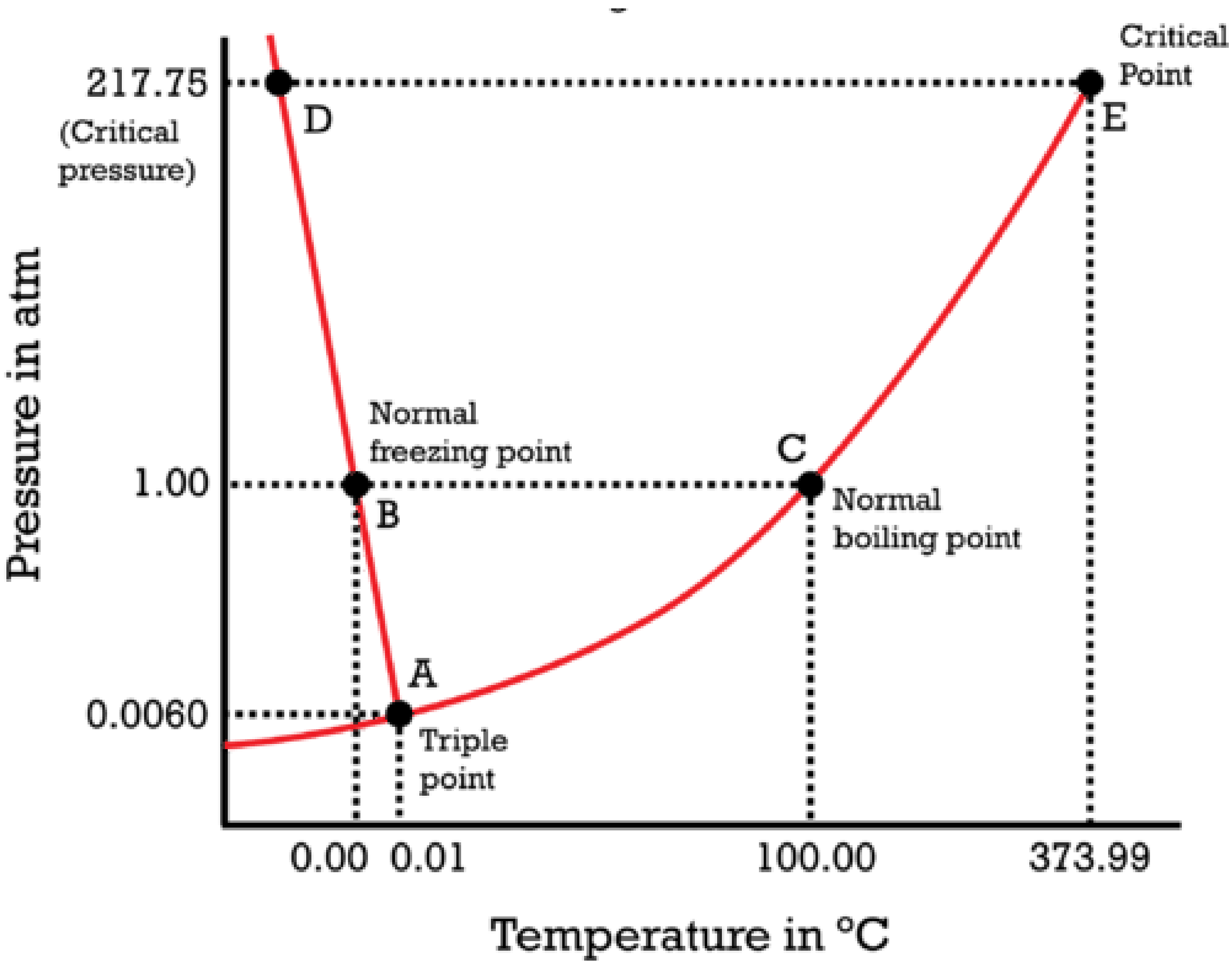
Unit 6 Phases of Matter - Phase Diagrams

Demonstration for Today



Phase Diagram for Water



Learning Objectives

After mastering this unit you will be able to:

- Explain the relationships between intermolecular forces and properties such as melting point, boiling point, and vapor pressure.
- Analyze and interpret phase diagrams to obtain information about states of matter at different pressures and temperatures.
- Describe phase changes using appropriate terminology.
- Predict how changes in pressure and/or temperature will impact phase equilibria, or vice versa.
- Use the ideal gas law to calculate changes in the conditions of pure gases and gas mixtures.

Phases of matter

$$\text{Gas} \quad \underset{\text{Heat or } \textbf{reduce} \text{ pressure}}{\overset{\text{Cool or } \textbf{increase} \text{ pressure}}{\rightleftharpoons}} \quad \text{Liquid} \quad \underset{\text{Heat or } \textbf{reduce} \text{ pressure}}{\overset{\text{Cool or } \textbf{increase} \text{ pressure}}{\rightleftharpoons}} \quad \text{Solid}$$

$\xrightarrow{\text{Increases}}$ Intermolecular Interactions

$\xleftarrow{\text{Increases}}$ Molecular Spacing

$\xleftarrow{\text{Increases}}$ Entropy

Phases - definitions

- A substance is in a distinct phase when all physical properties, such as density or chemical composition, are uniform throughout.

  Examples: solid, liquid, gas, plasma, supercritical fluid.

- A phase change occurs when a substance changes from one phase to another.
- A one-component system is characterized by a single, pure chemical substance. E.g. H_2O: ice, water and steam.

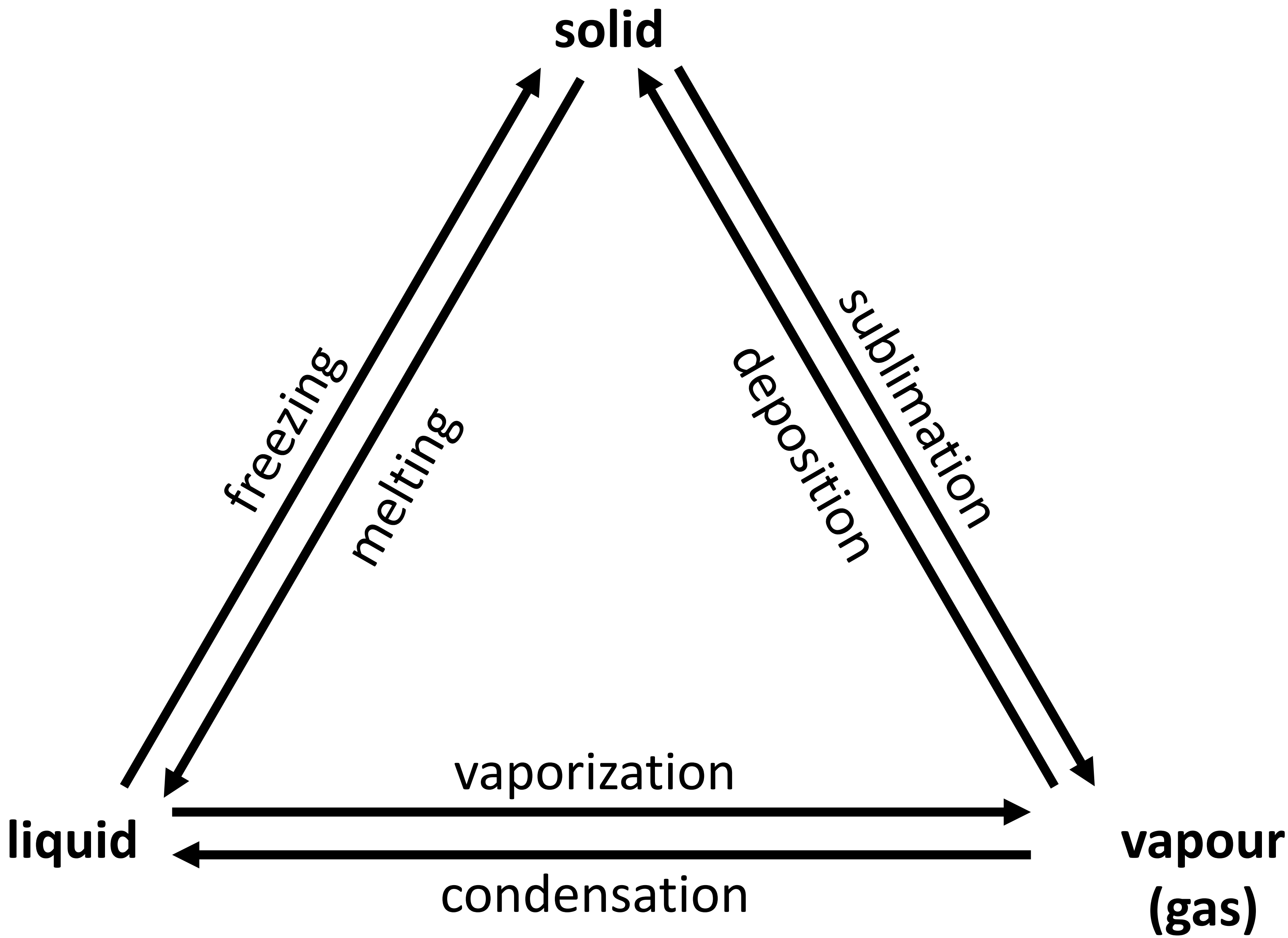
Thermodynamic Equilibrium

- When there are no net macroscopic flows of matter or energy within a system or between the system and surroundings.
- The macroscopic properties of the system remain constant with time **and** the system is robust when subjected to minor perturbations.

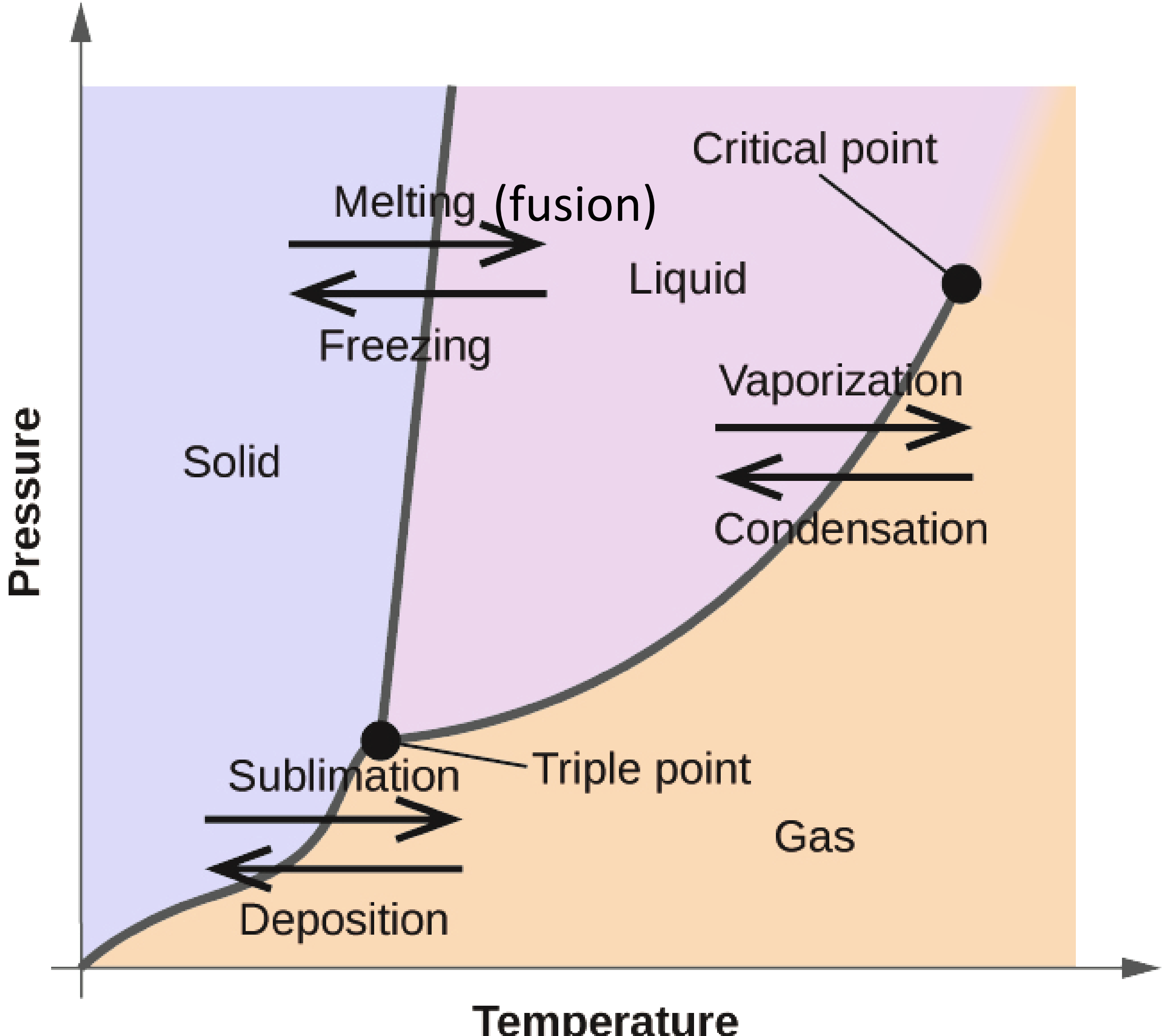
Type of Equilibrium	Thermodynamic Variable
Thermal	Temperature, T
Mechanical	Pressure, P
Chemical or Material	Concentration or Chemical potential, μ

- All these equilibria must be satisfied for a system to be in thermodynamic equilibrium.

Phases of matter, phase changes



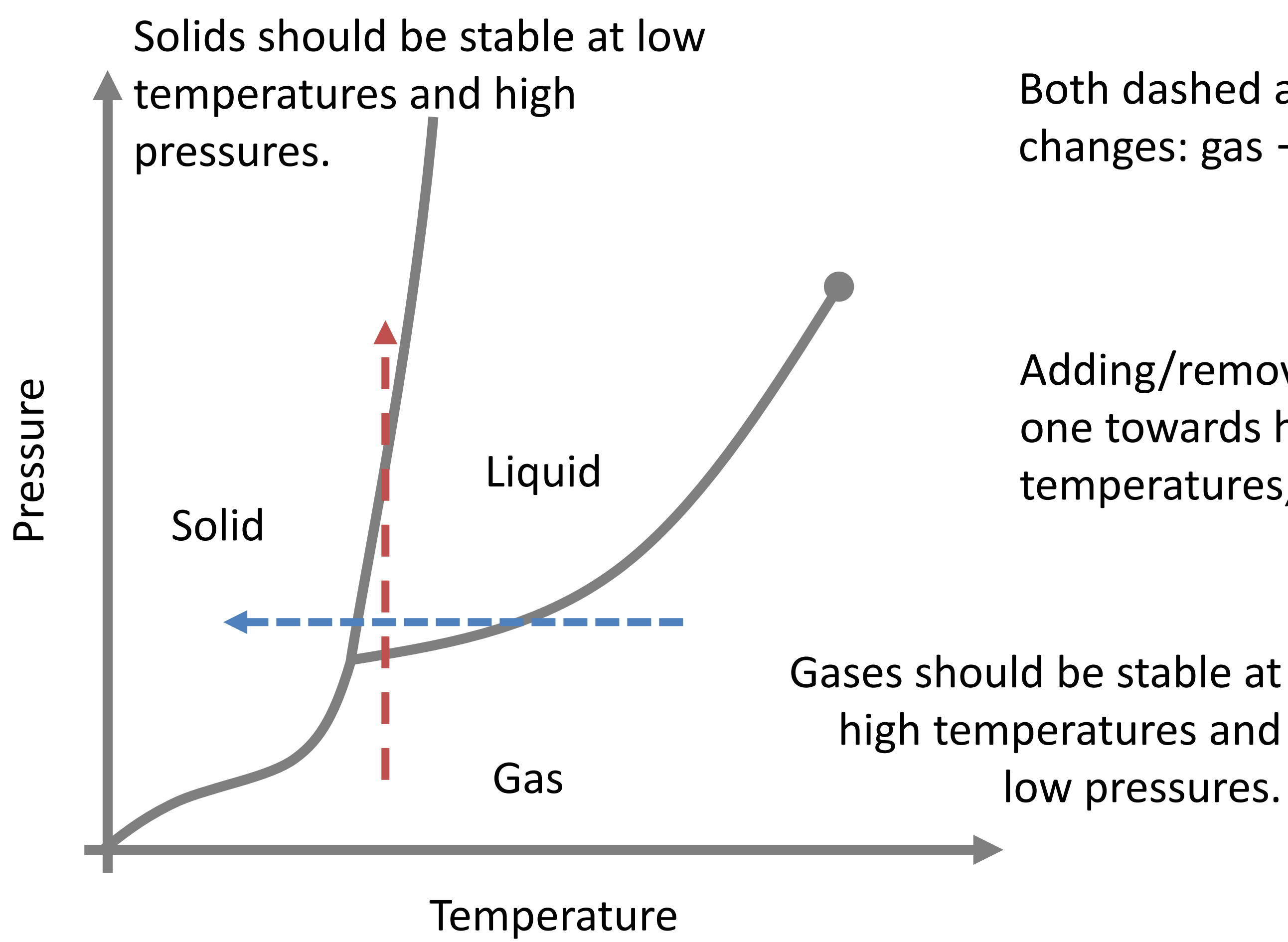
Generic One-Component P-T Phase Diagram



Taken from https://opentextbc.ca/chemistry/chapter/10-4-phase-diagrams/

Density and pressure

Increasing **pressure** or decreasing temperature changes stable phase from a <u>less</u> dense to a <u>more</u> dense form.

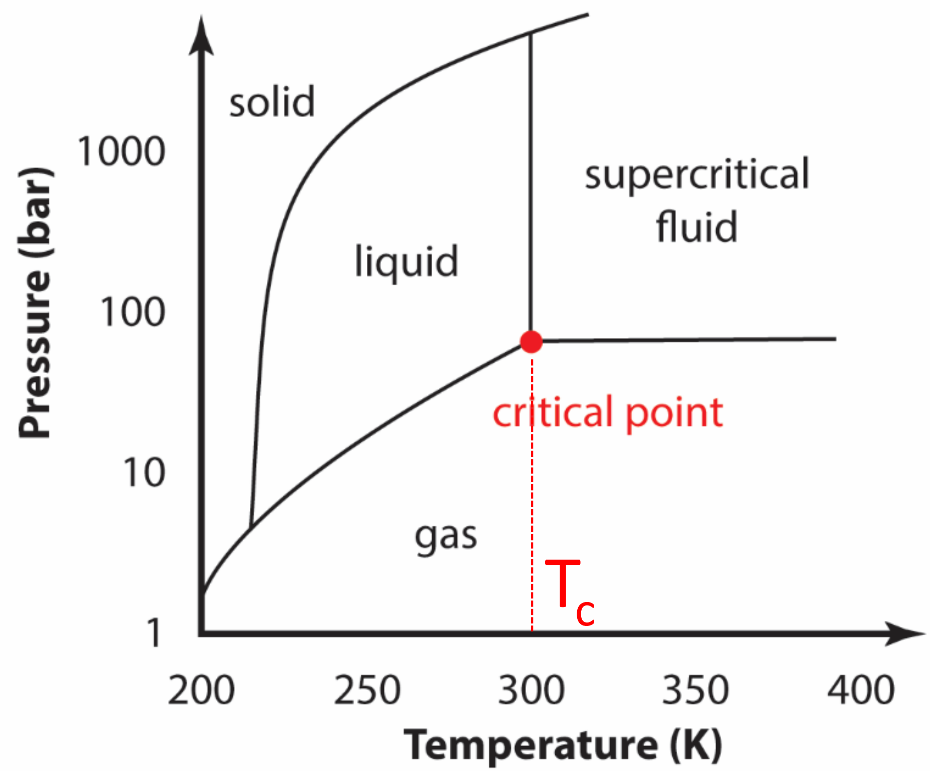


Both dashed arrows show phase changes: gas → liquid → solid

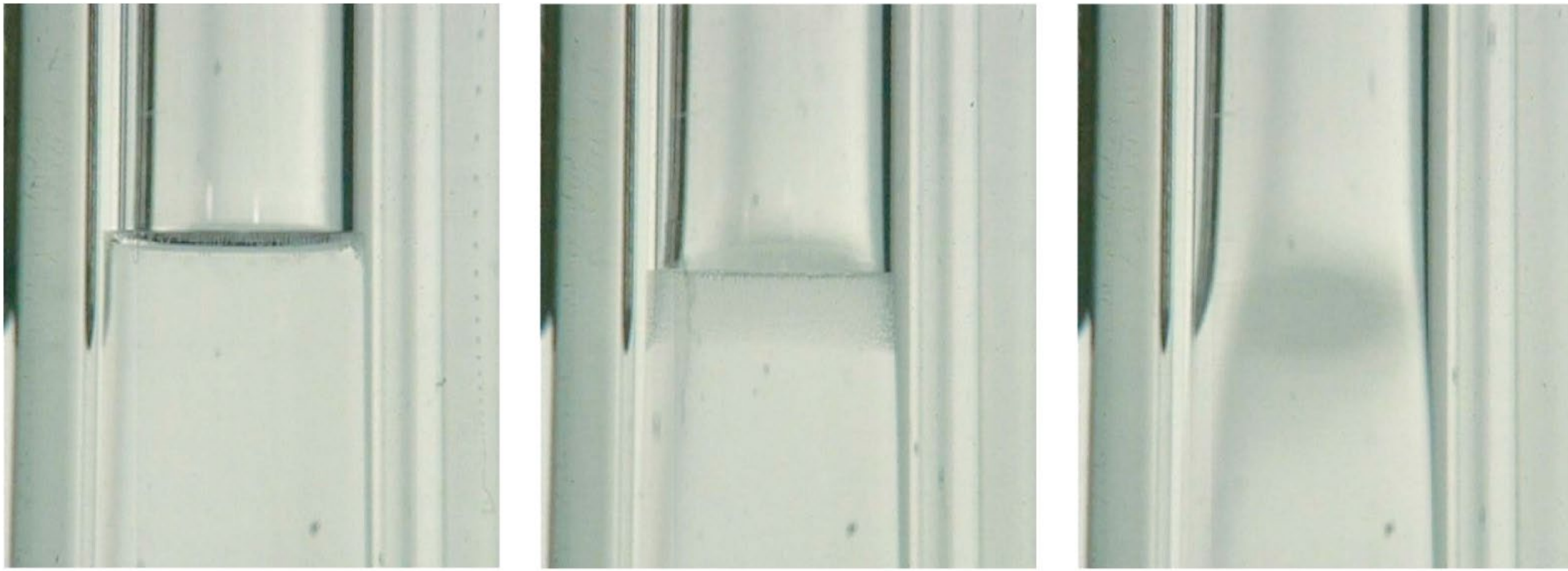
Adding/removing heat moves one towards higher or lower temperatures, respectively.

Supercritical Fluids

- When $T > T_c$, **liquid cannot form** no matter how high P is.
- A substance behaves as a supercritical fluid at temperatures and pressures beyond the critical point.
- A supercritical fluid exhibits properties of a liquid and a gas.



Critical Point



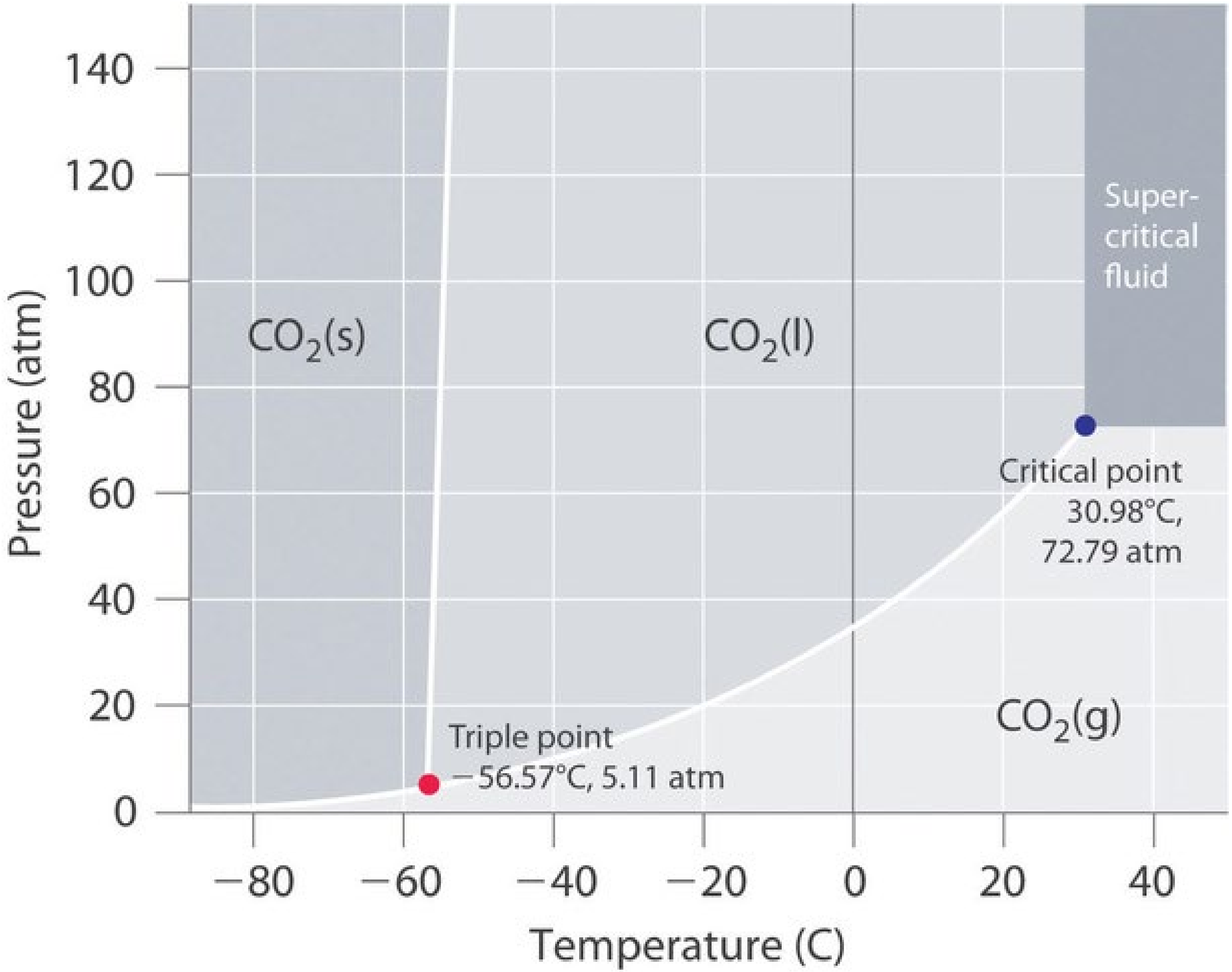
About 10 °C below T_c

About 1 °C below T_c

Critical temp. T_c

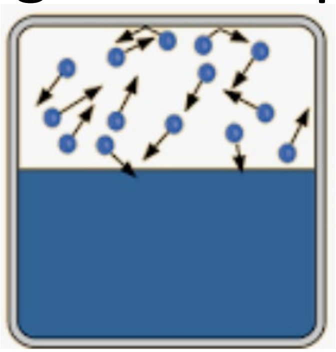
- At Critical Point, Liquid and gas phase become indistinguishable.

Phase Diagram of CO_2

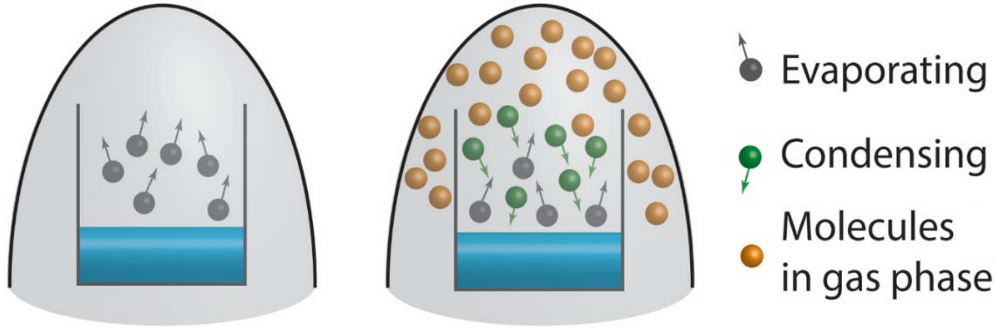


Vapour pressure

- **Vapour pressure** is the pressure exerted by a vapour in thermodynamic equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system.



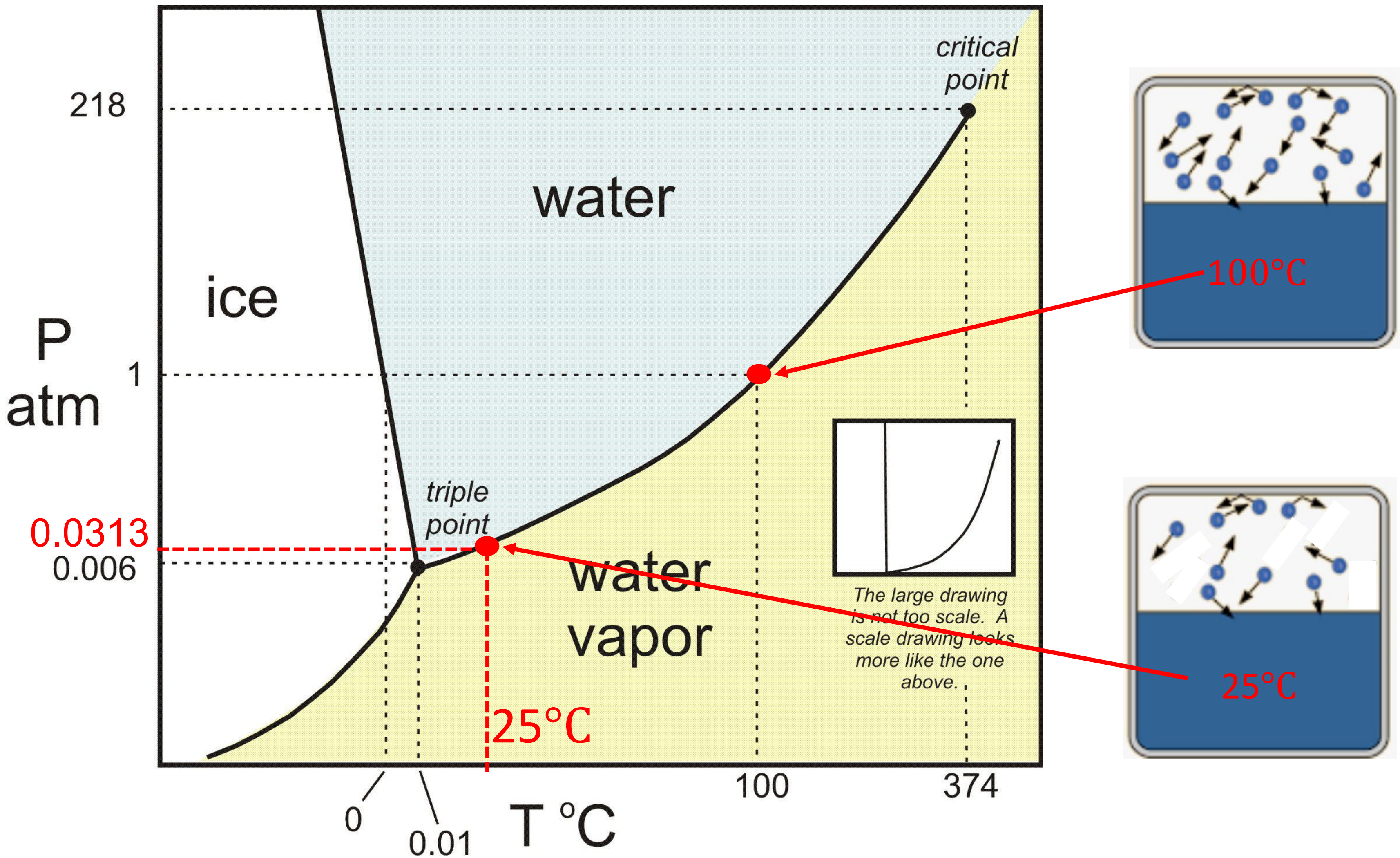
- **Vapourization and condensation** reach dynamic equilibrium



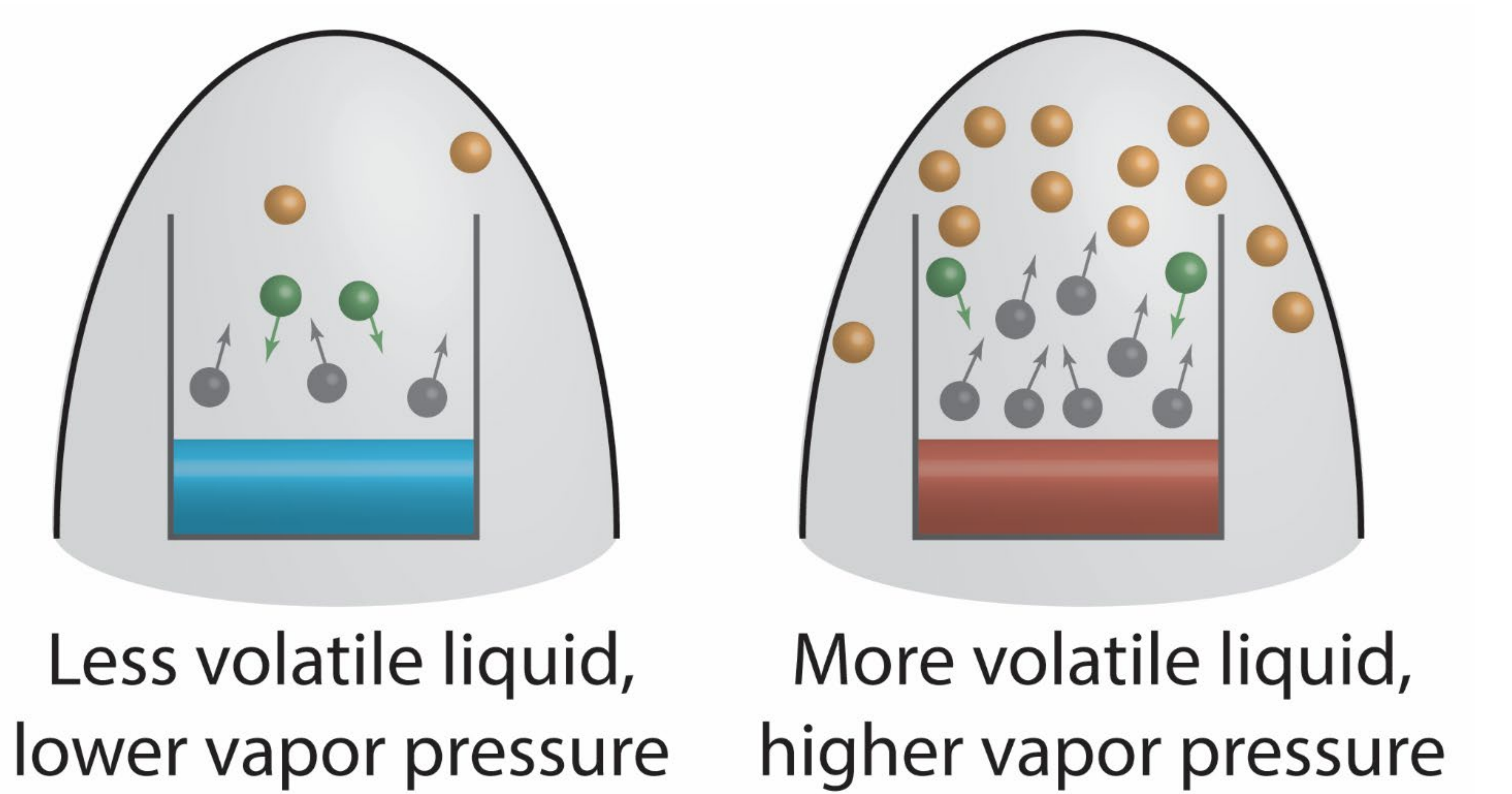
Two processes occurring: Vapourization and condensation

$$\text{Liquid} \rightleftharpoons \text{Gas}$$

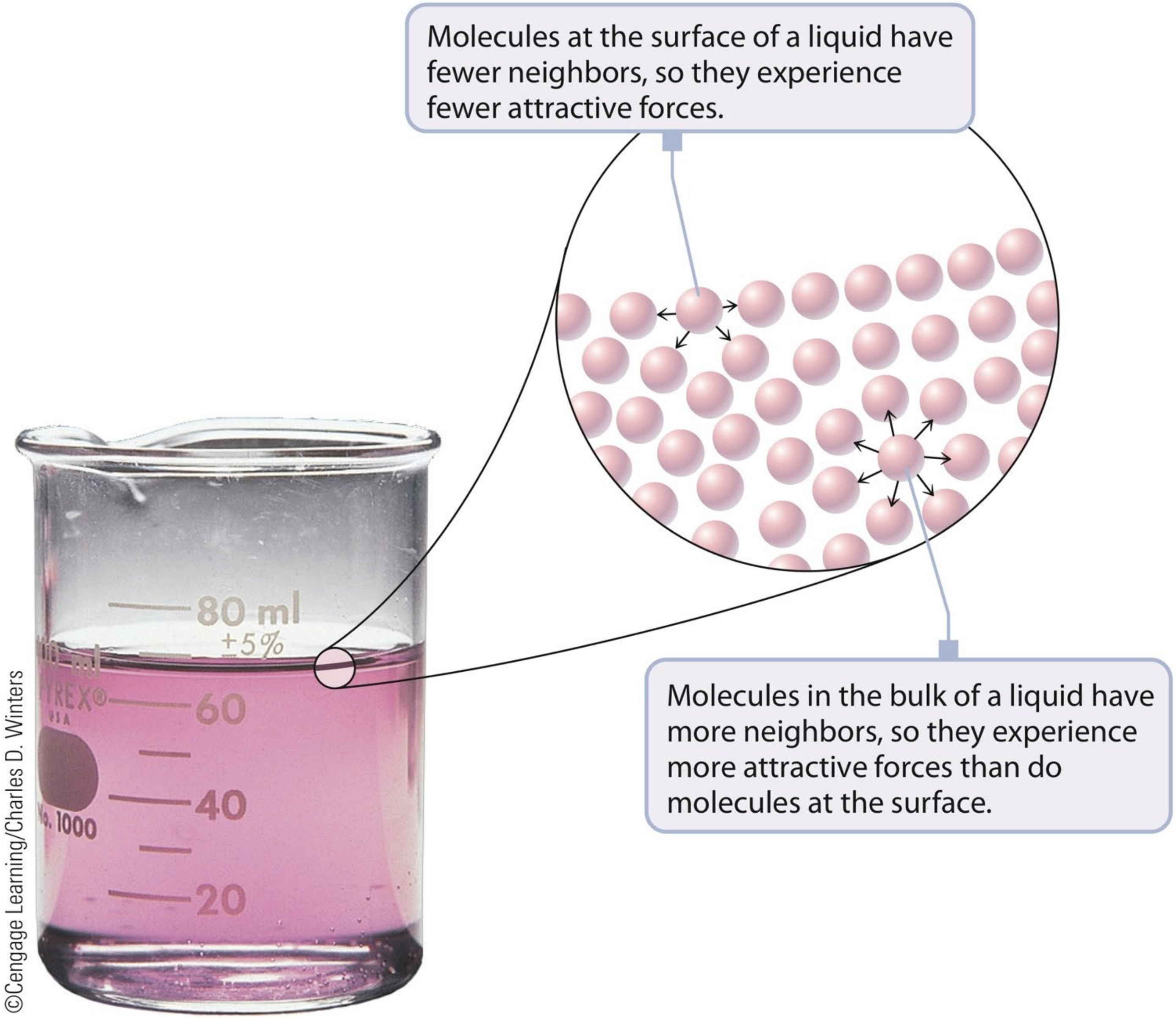
Vapour Pressure of Water



Volatility and **Vapour Pressure**

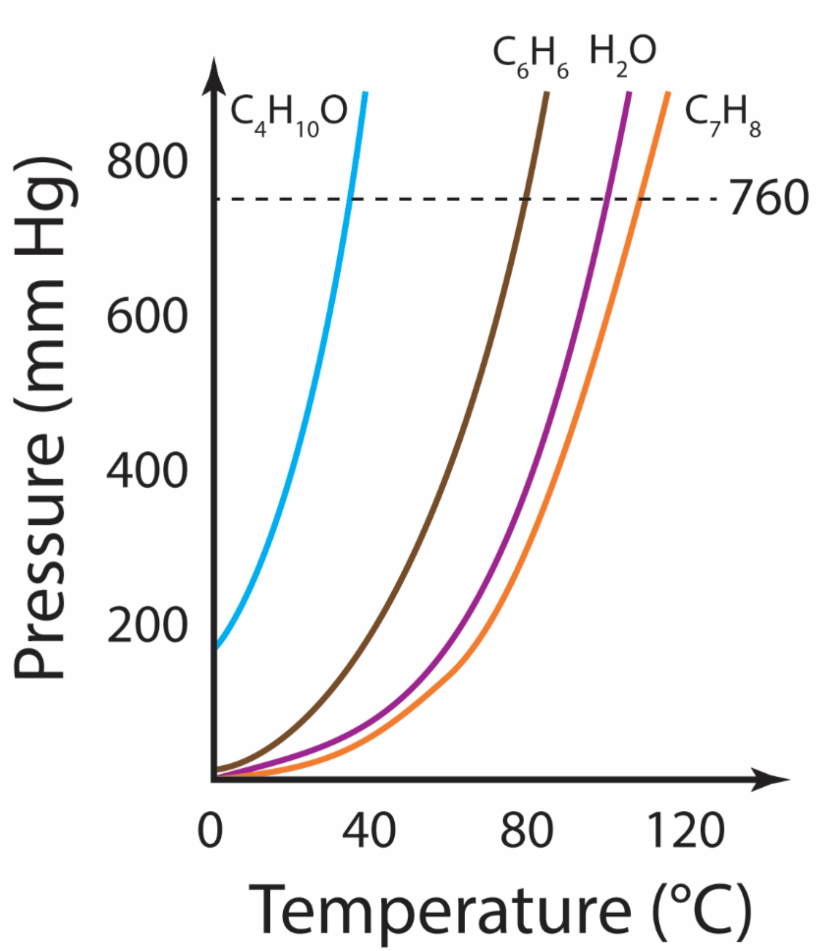


Why does a liquid evaporate?



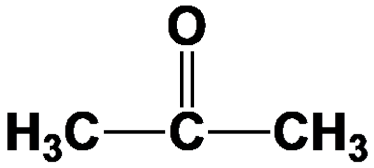
Vapor pressure (VP)

1. VP increases with increasing T
2. More molecules escaping to gas phase
3. **Liquids boil when VP = atmospheric pressure**

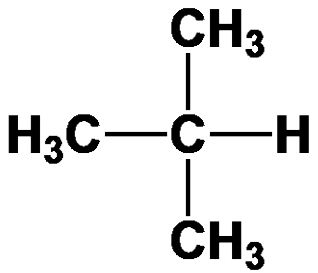


Clicker Question

Acetone boils at a significantly higher temperature than 2-methylpropane (isobutane) because…



Acetone



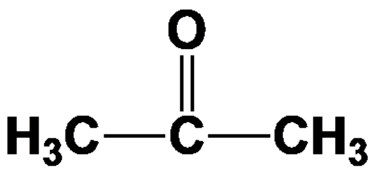
2-Methylpropane

a) The London dispersion forces in 2-methylpropane are weaker than the dipole-dipole forces in acetone
b) Dipole-dipole forces are always greater than dispersion forces
c) The molecular mass of acetone is slightly less than that of 2-methylpropane
d) The hydrogen bonding interactions in acetone are stronger than the London dispersion forces in isobutane.
e) The London dispersion forces in 2-methylpropane are weaker than those in acetone

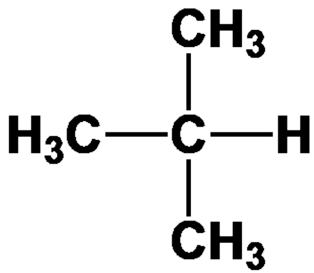
Clicker Question

Acetone boils at a significantly higher temperature than 2-methylpropane (isobutane) because…

Polar



Acetone



Nonpolar or weakly polar

2-Methylpropane

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b) Dipole-dipole forces are always greater than dispersion forces

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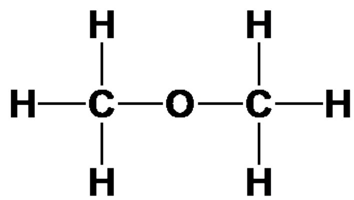
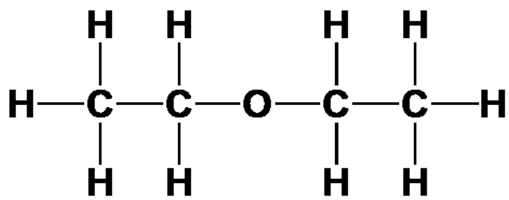
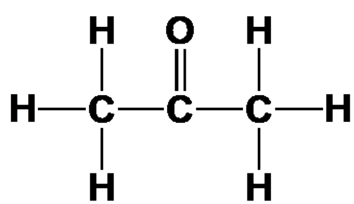
Arrange the following molecules in order of increasing vapour pressure at room temperature.



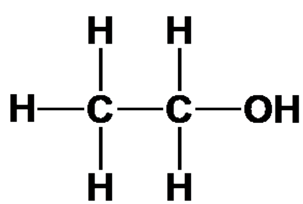
1



2



3



4

a) 2 < 3 < 1 < 4

b) 1 < 4 < 3 < 2

c) 4 < 3 < 2 < 1

d) 3 < 4 < 1 < 2

e) 4 < 1 < 2 < 3

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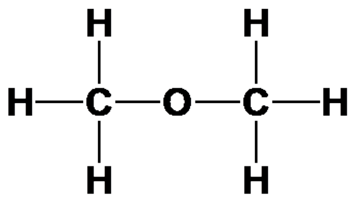
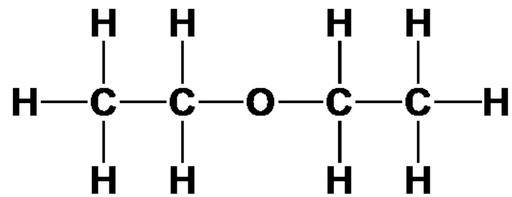


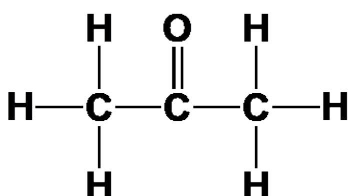
Small dipole

1



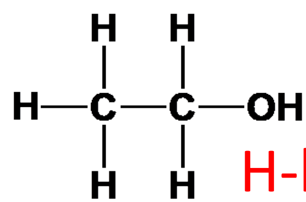
Small dipole

2



C=O has a larger dipole

3



H-bonds

4

a) 2 < 3 < 1 < 4

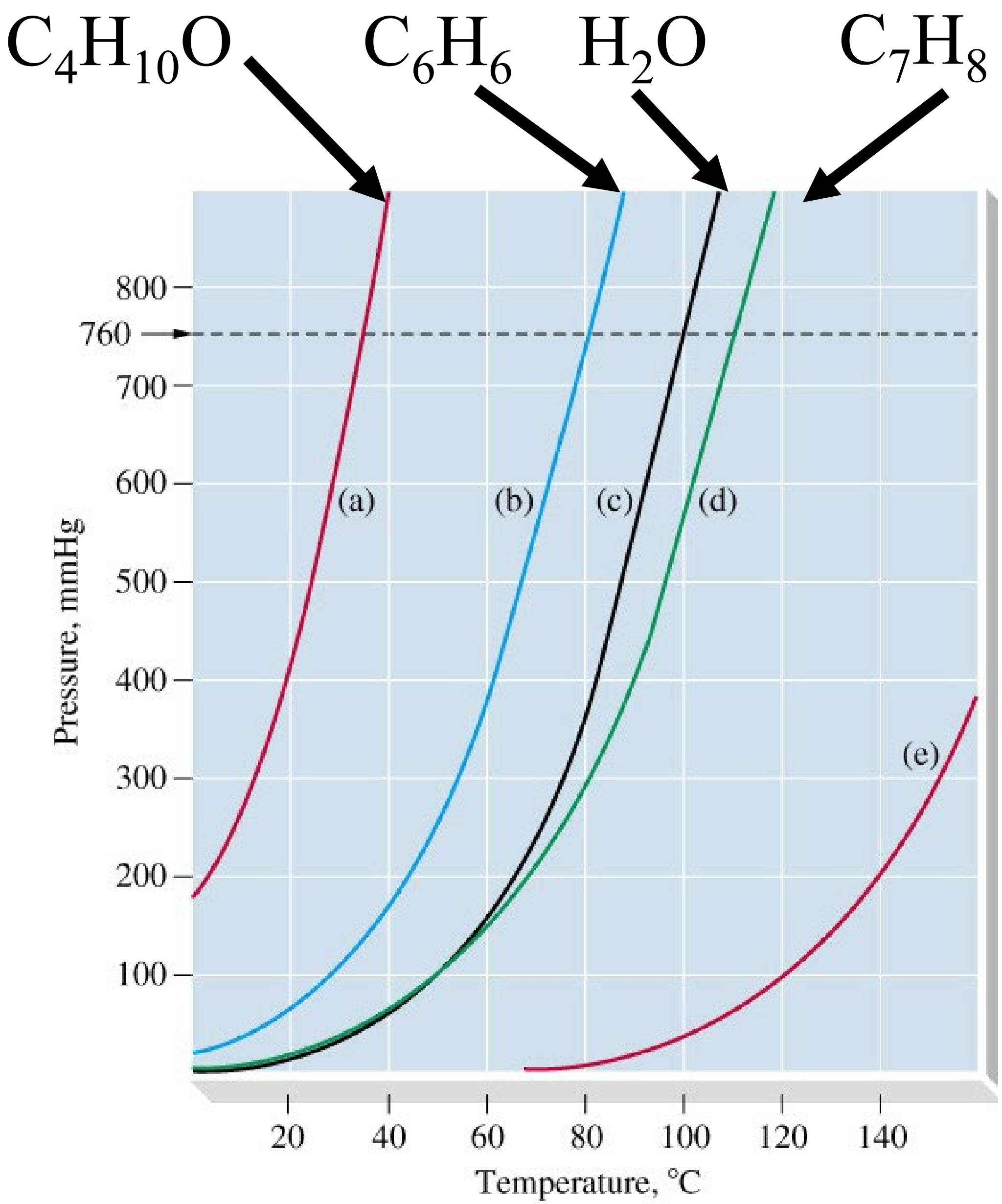
b) 1 < 4 < 3 < 2

✓ c) 4 < 3 < 2 < 1

d) 3 < 4 < 1 < 2

e) 4 < 1 < 2 < 3

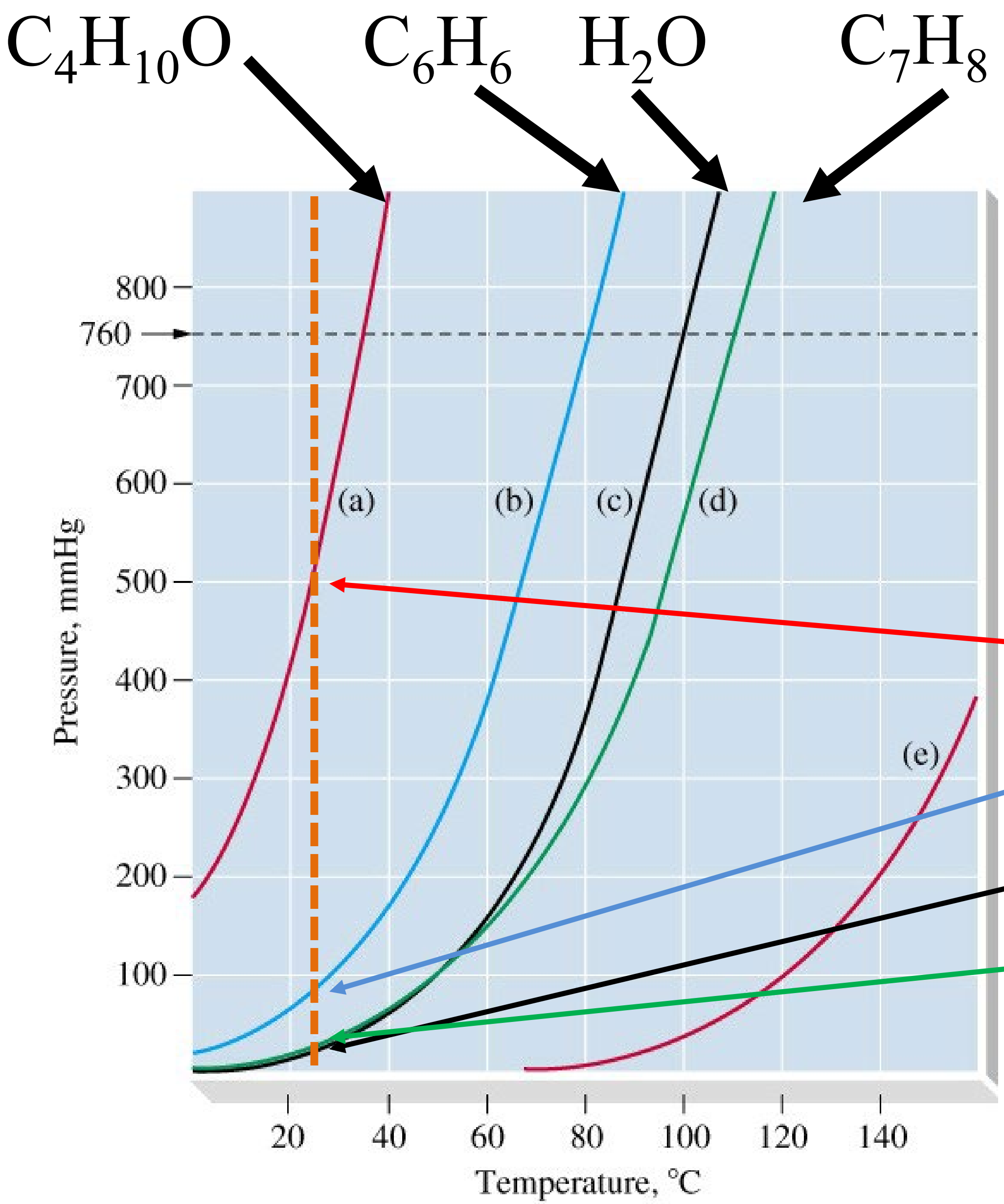
Clicker Question



Based on the figure, which molecule will have the <u>highest</u> <u>vapor pressure</u> at <u>room temperature</u>?

a) $C_4H_{10}O$
b) C_6H_6
c) H_2O
d) C_7H_8

Clicker Question



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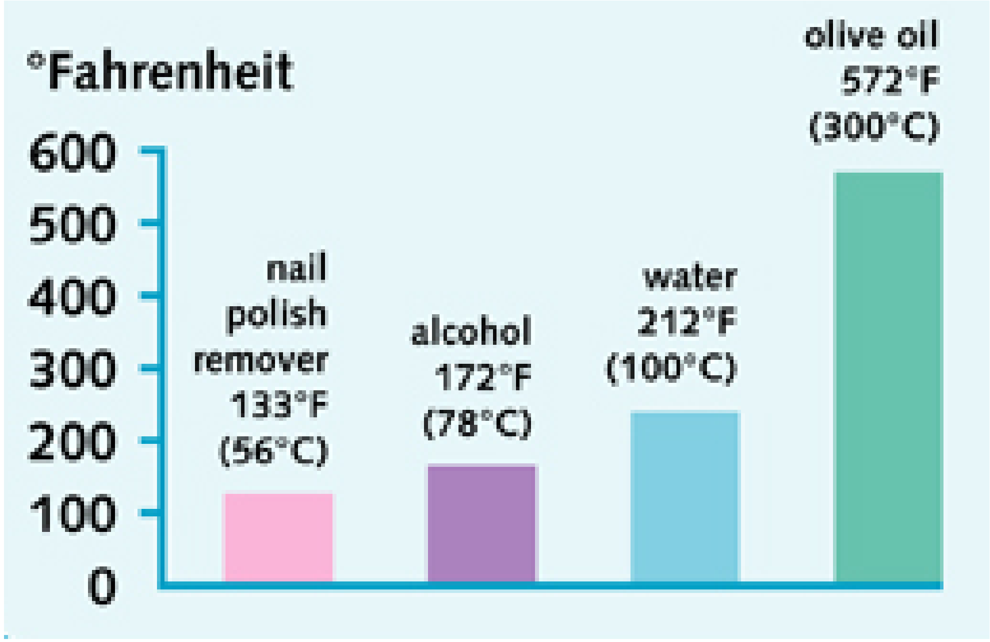
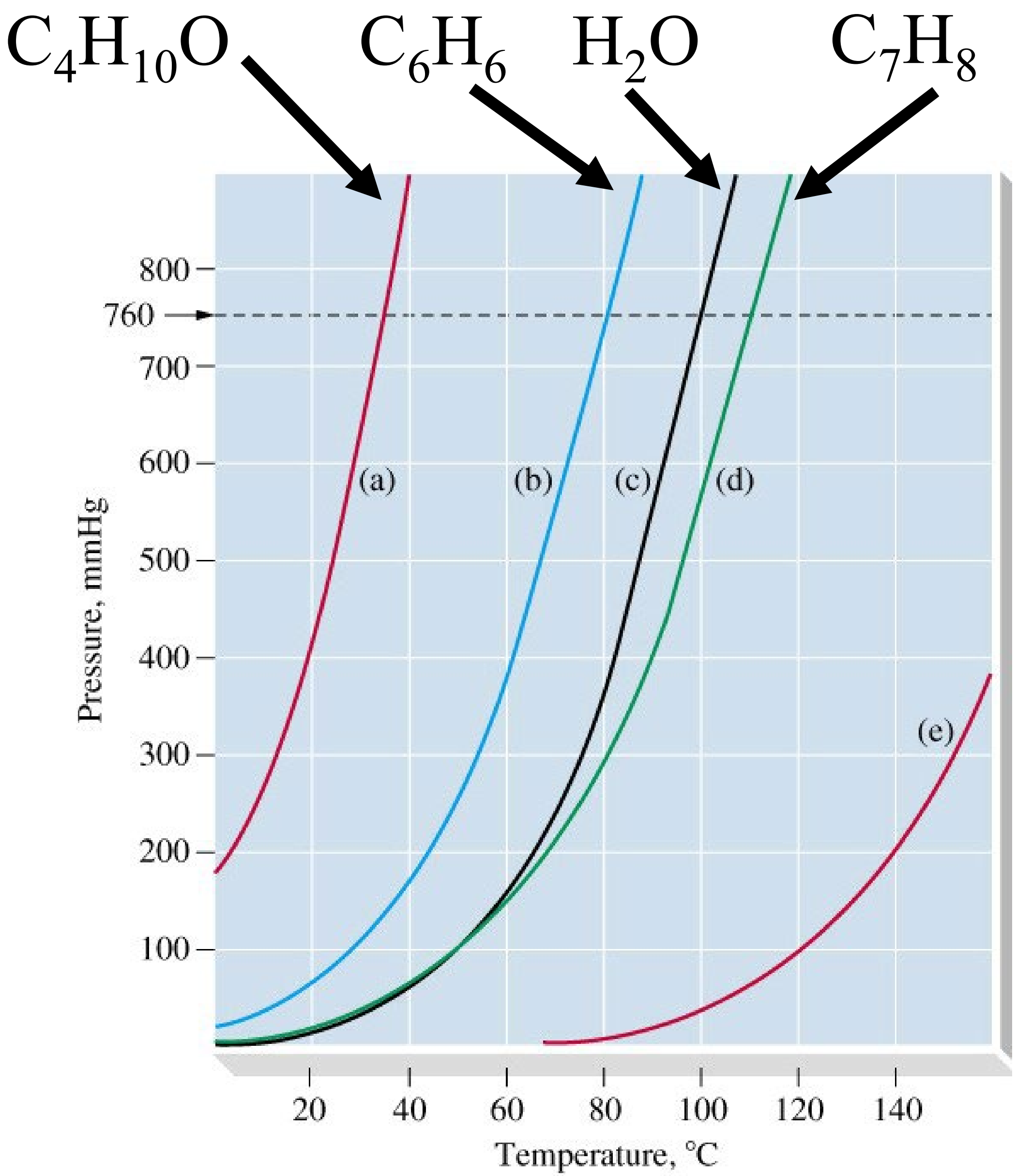
Boiling Point

- **Boiling point** is the temperature at which a <u>liquid's vapor pressure equals the surrounding environmental pressure</u>, causing the liquid to rapidly change into a vapor throughout its bulk.
- The boiling point is dependent on the pressure.
- Boiling points at 1 atm:



Clicker Question



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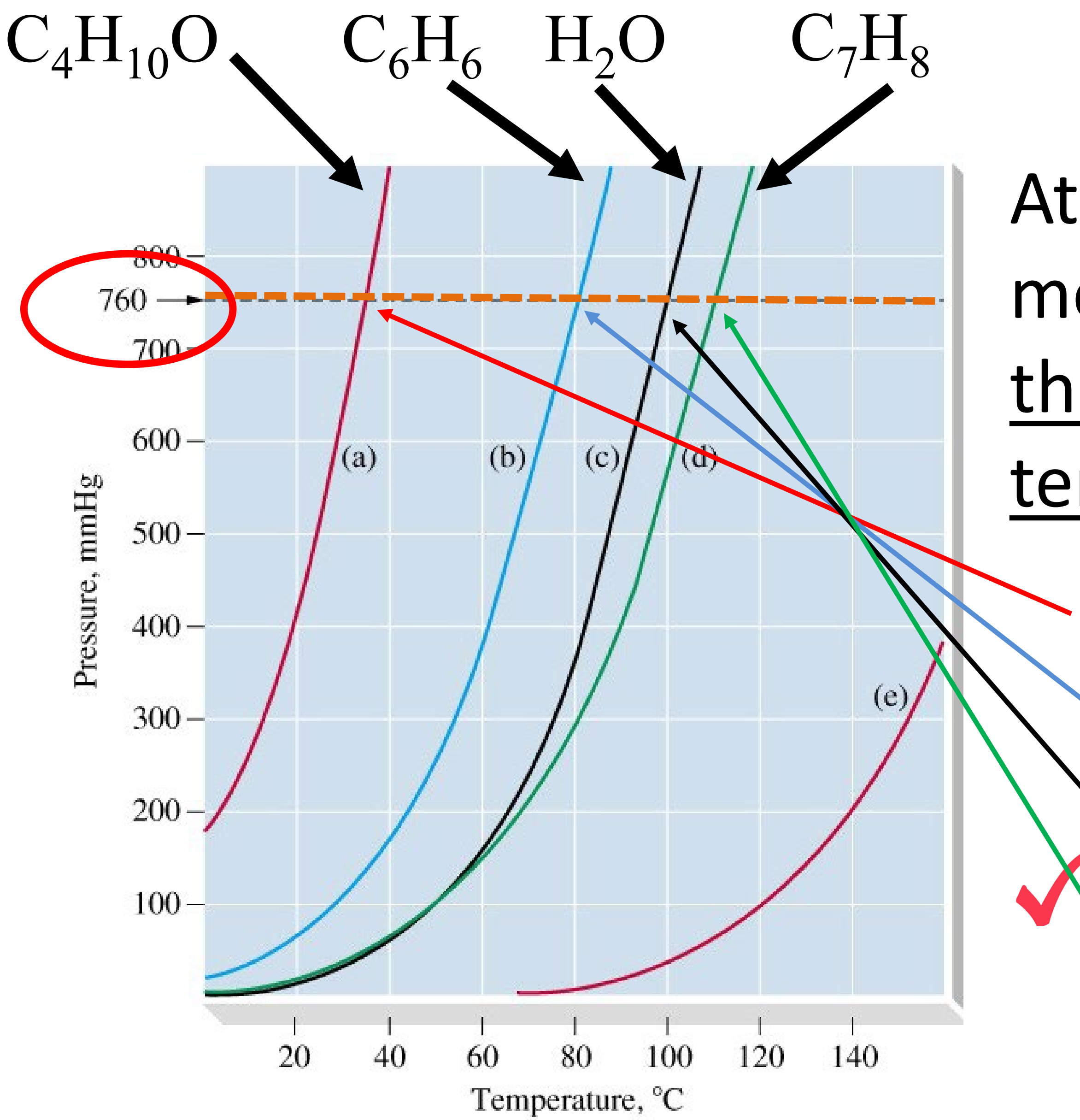

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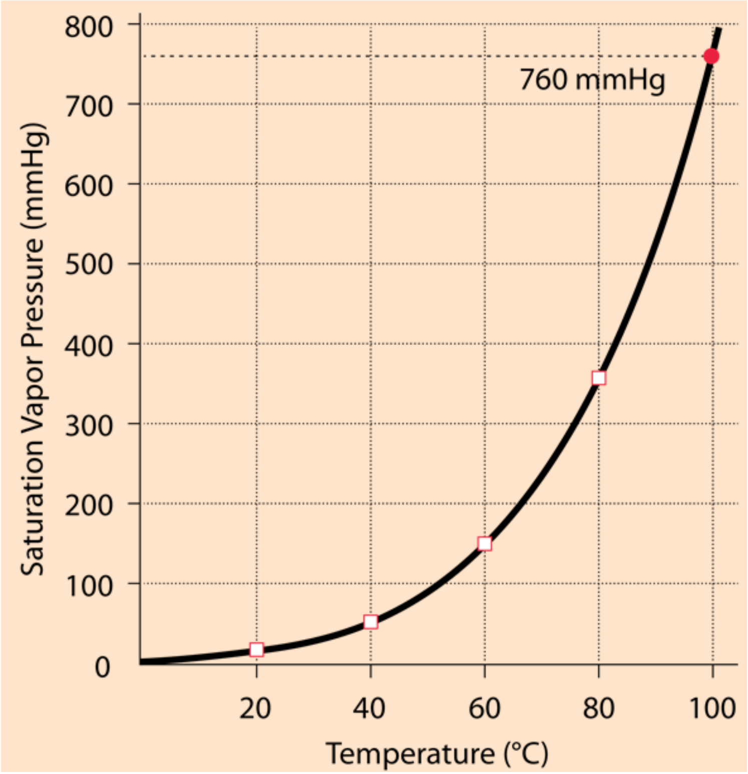
Clicker Question

A 2 L flask contains 500 mL of <u>liquid water at 70 °C</u>. The flask is stoppered and connected to a vacuum pump. The vacuum pump is turned on, reducing the pressure inside the flask. The water starts to boil. What is the temperature of the water as soon as boiling begins?

a) Greater than 100 °C
b) 100 °C
c) 70 °C
d) Less than 70 °C
e) Cannot be determined.



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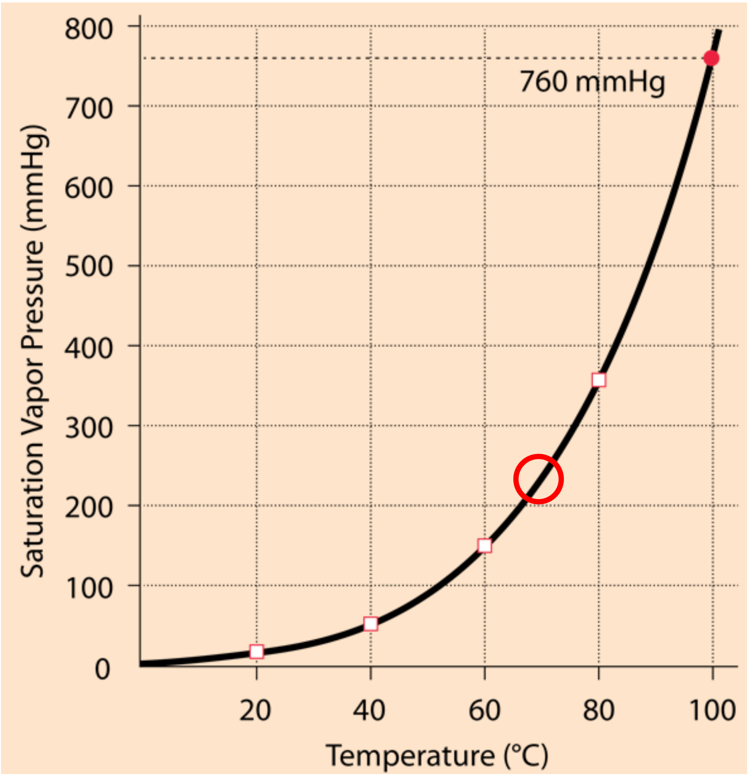
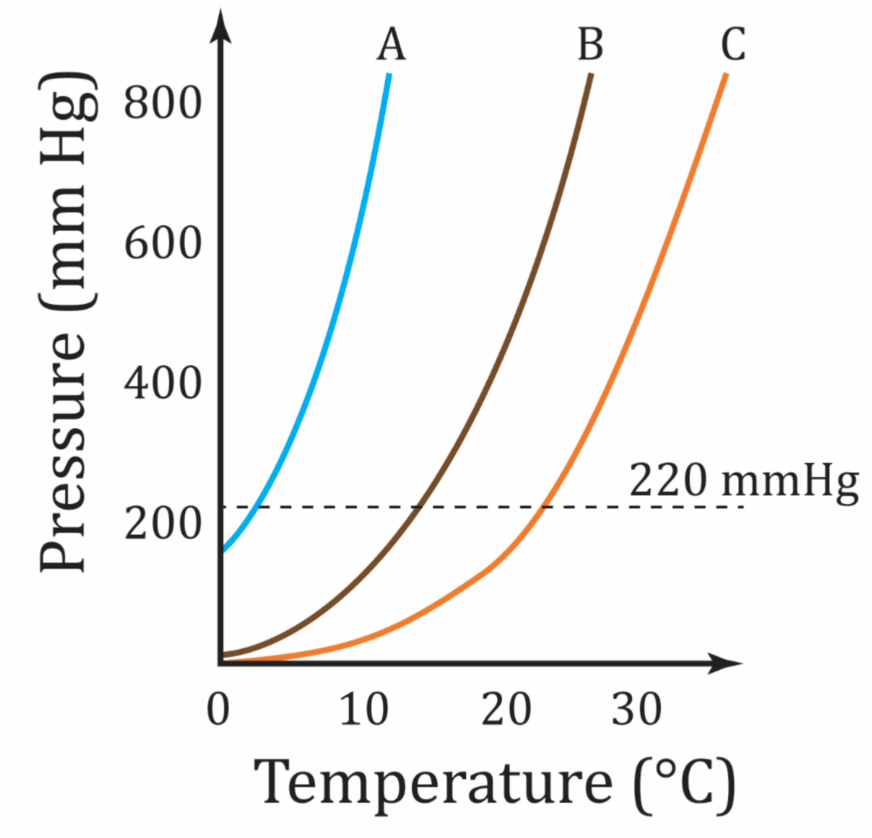


Worksheet Question #1

The vapour pressure of three substances as a function of temperature is shown below. Which substance(s) (A, B, or C) is/are most likely to boil at 20 °C at the top of Mount Everest (atm P ~220mmHg shown as a dashed line on the plot)? Briefly explain.



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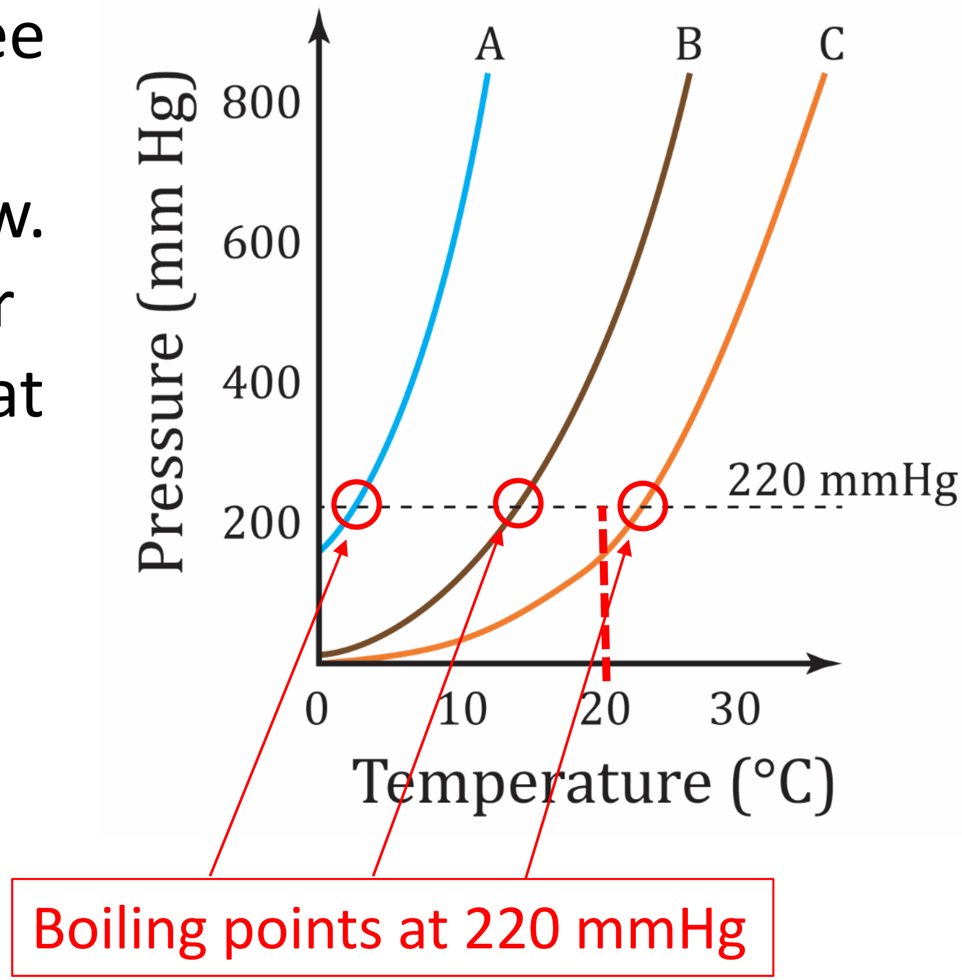
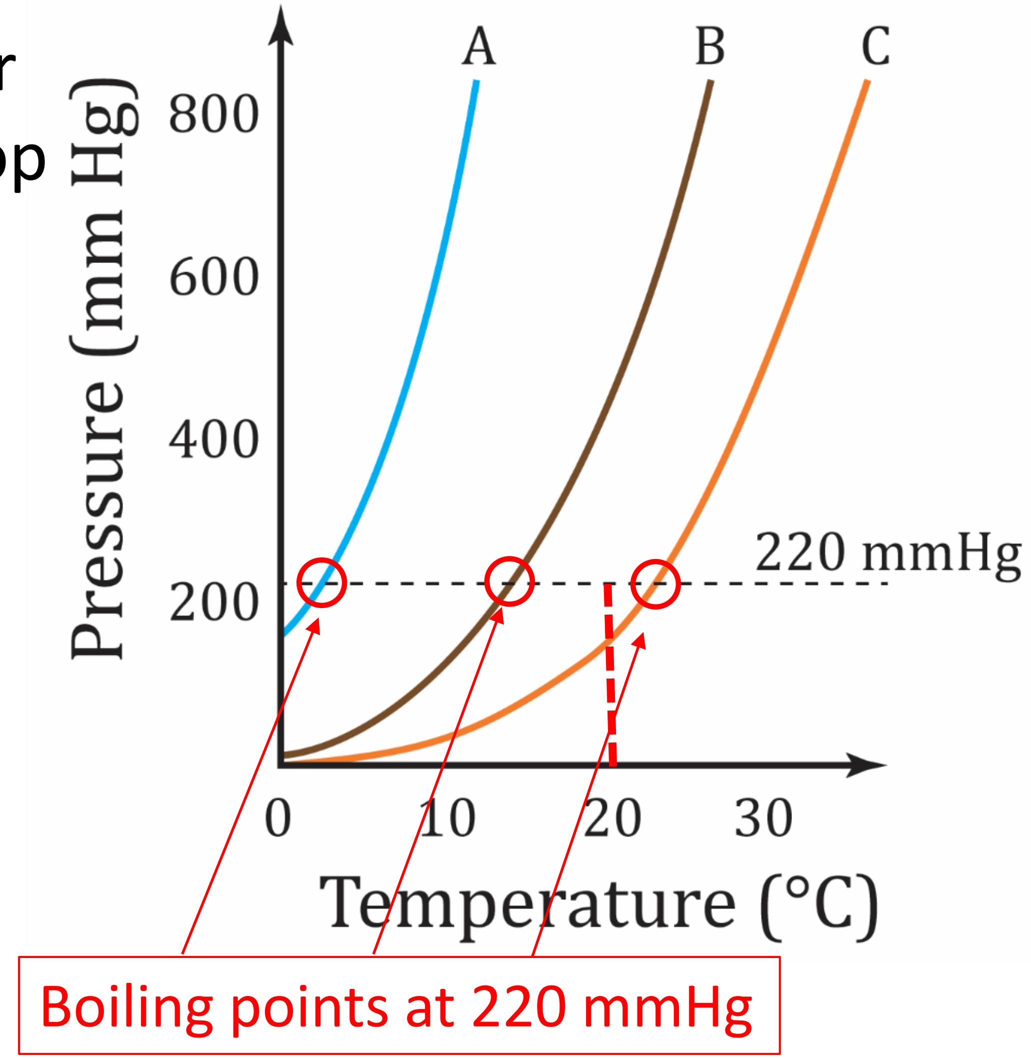


Worksheet Question #1 (Clicker)

Which substance(s) (A, B, or C) will boil at 20 °C at the top of Mount Everest (atm P ~220mmHg shown as a dashed line on the plot)?

a) Substance A
b) Substance B
c) Substance C
d) Substance A and B



Clicker Question

Deep within the Chemistry building lies an underground cellar from the Cold War era. This cellar is 150 meters below sea level (Pressure = 1.02 atm = 1.03 bar = 775 mmHg).

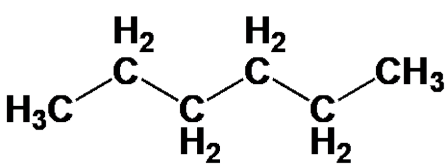
In the cellar a CHEM 154 student is performing an experiment with a beaker containing hexane and another beaker containing 1-hexanol. Both beakers are heated and brought to a boil. What can be said about the vapour pressures of boiling hexane and boiling 1-hexanol?

a) Vapour pressure of 1-hexanol is higher

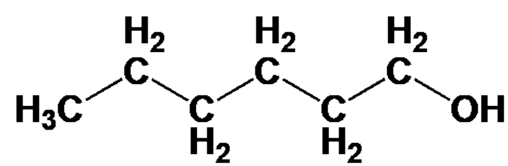
b) Vapour pressure of hexane is higher

c) The vapour pressure is the same for hexane and 1-hexanol

d) Cannot be determined based on the information given



Hexane



1-Hexanol

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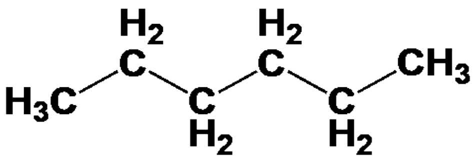

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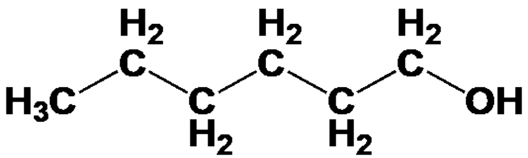

1-Hexanol

Both are at their <u>boiling points</u>, so vapor pressures must equal <u>atmospheric pressure</u>.

Clicker Question

A CHEM 154 student is asked to measure the boiling point temperatures for beakers containing hexane and 1-hexanol, as described in the previous question. The student places a thermometer into each beaker to <u>measure the boiling point</u> temperature. What is the correct relationship between the boiling point temperatures for hexane and 1-hexanol?

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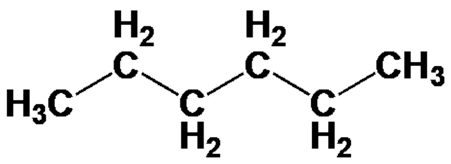
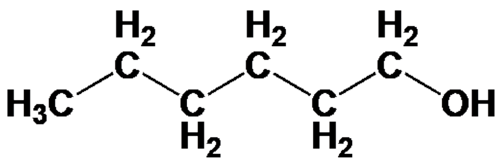


Hexane



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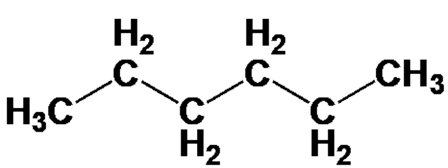
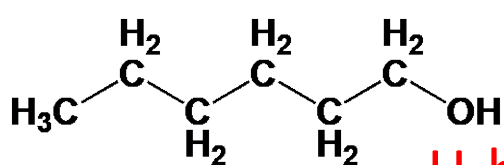


Hexane

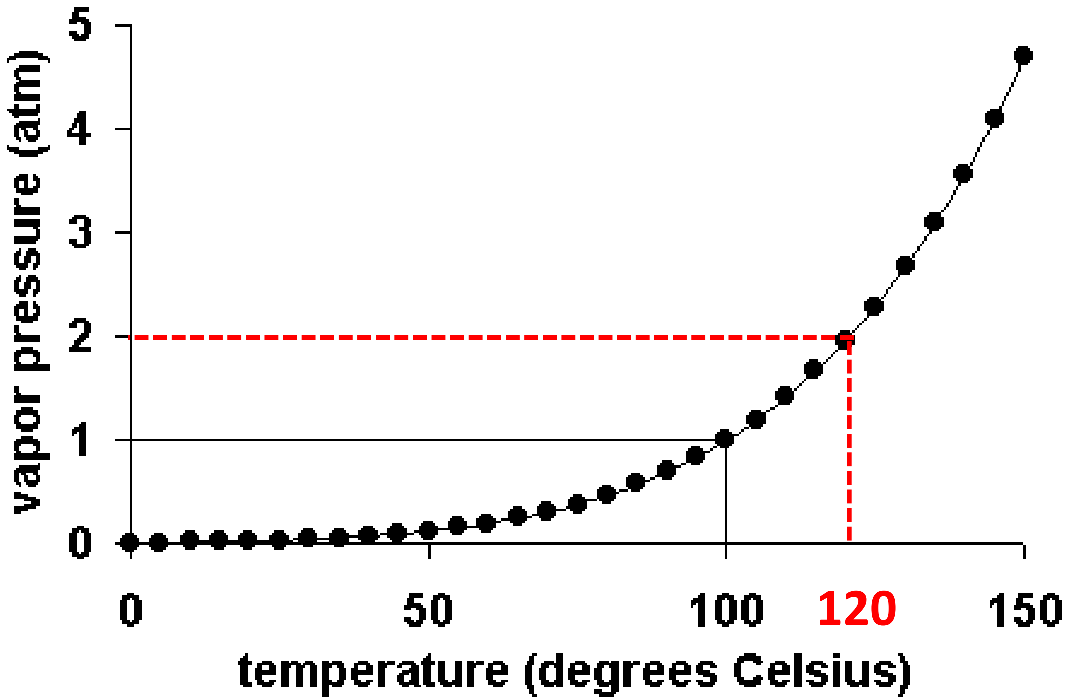


H-bonds

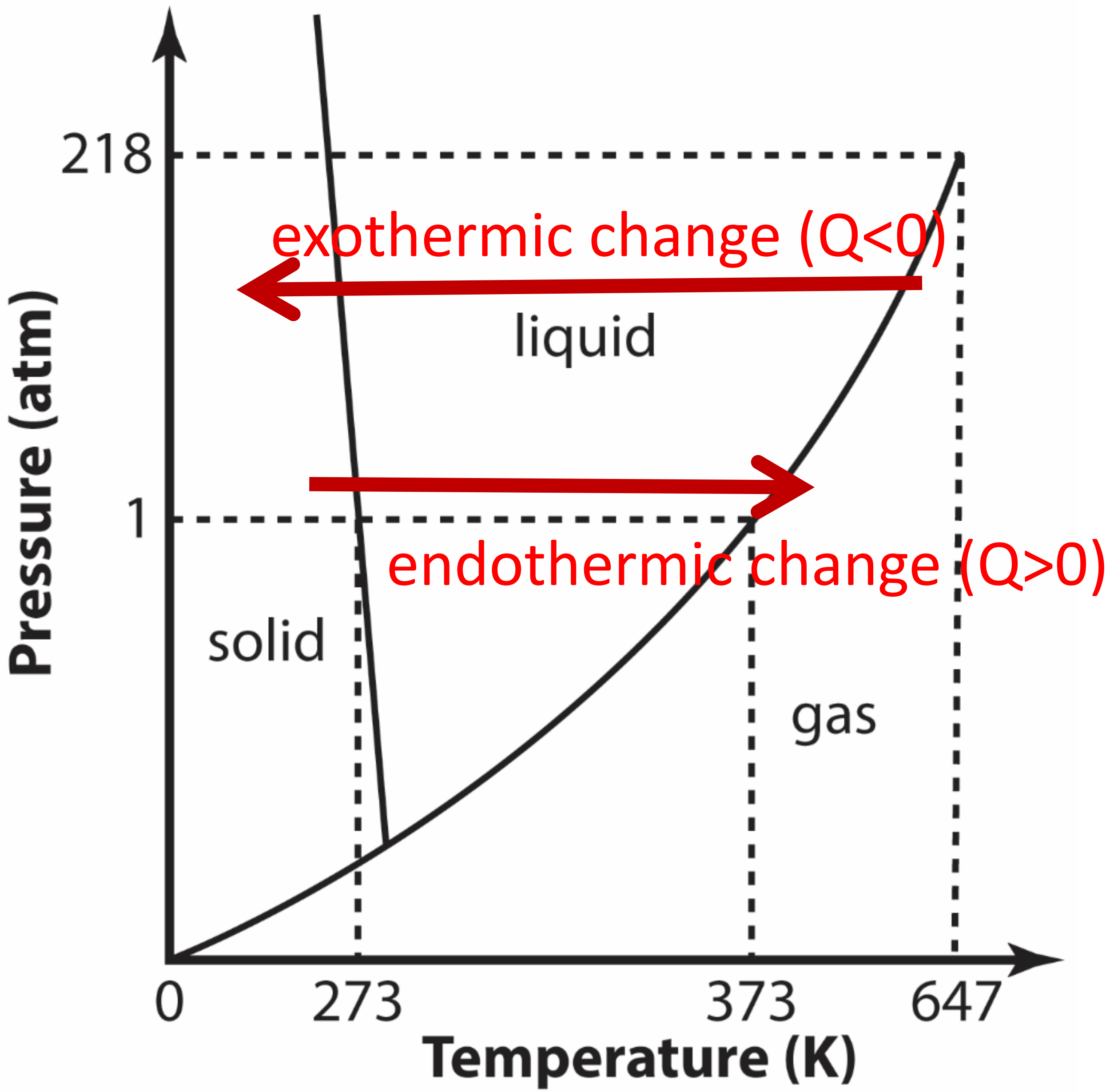
1-Hexanol

Cooking food, faster (Pressure cooker)

- Pressure cookers operate at 2 bar (~2 atm)
- Water boils at 120 °C at 2 bar pressure.
- Higher boiling point = faster cooking!



Temperature and phase diagrams



Clicker Question

Which of the following processes is endothermic?

a) Vaporization
b) Condensation
c) Deposition
d) Freezing

Clicker Question

Which of the following processes is endothermic?

$Q > 0$

a) Vaporization

b) Condensation

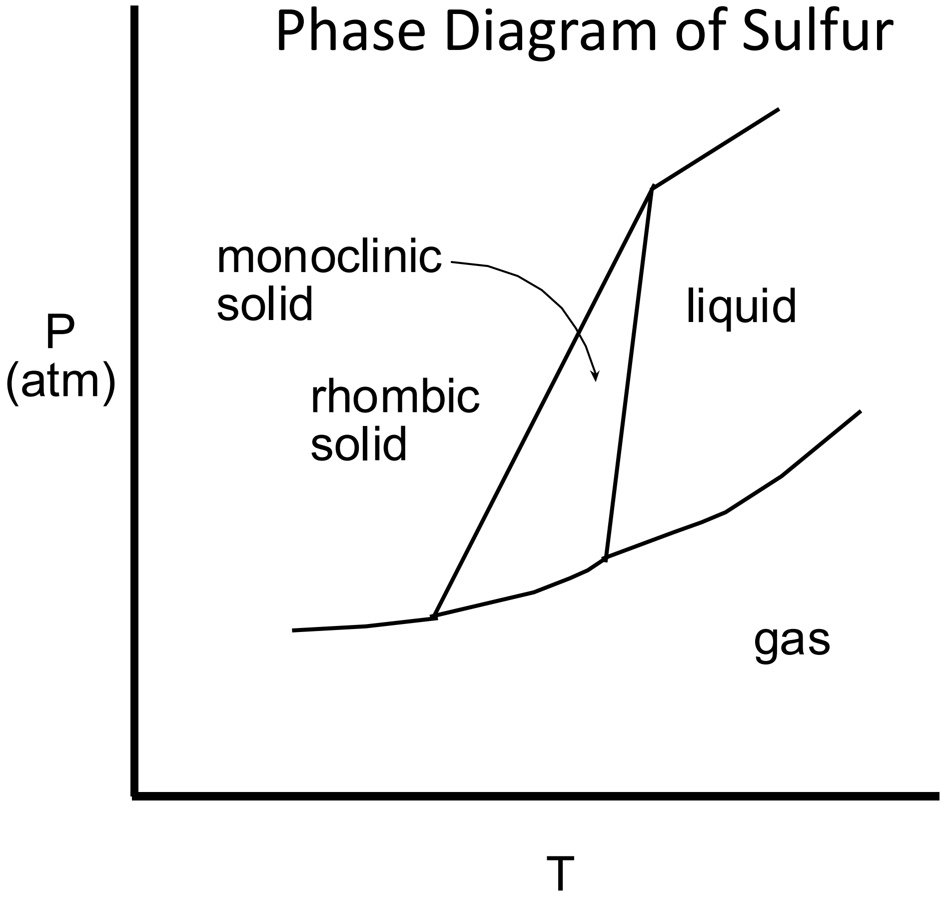
c) Deposition

d) Freezing

Clicker Question

Which phase is more dense - Rhombic solid or Monoclinic solid?

a) Rhombic solid
b) Monoclinic solid

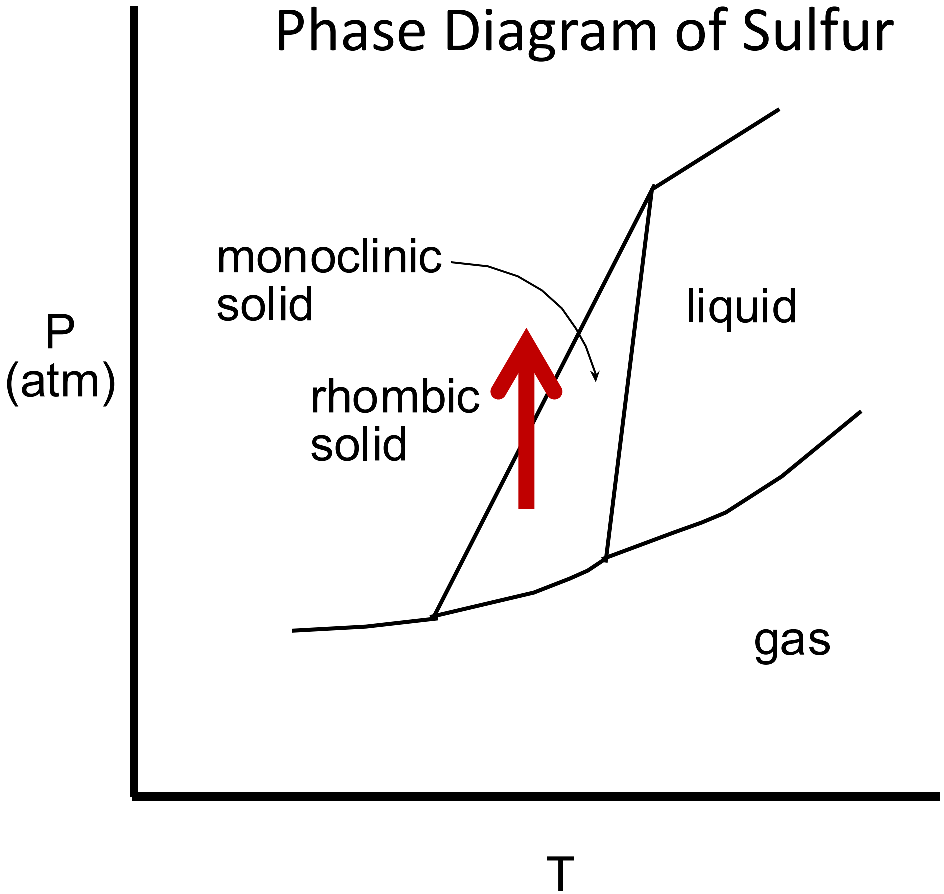


Clicker Question

Which phase is more dense - Rhombic solid or Monoclinic solid?

a) Rhombic solid

b) Monoclinic solid

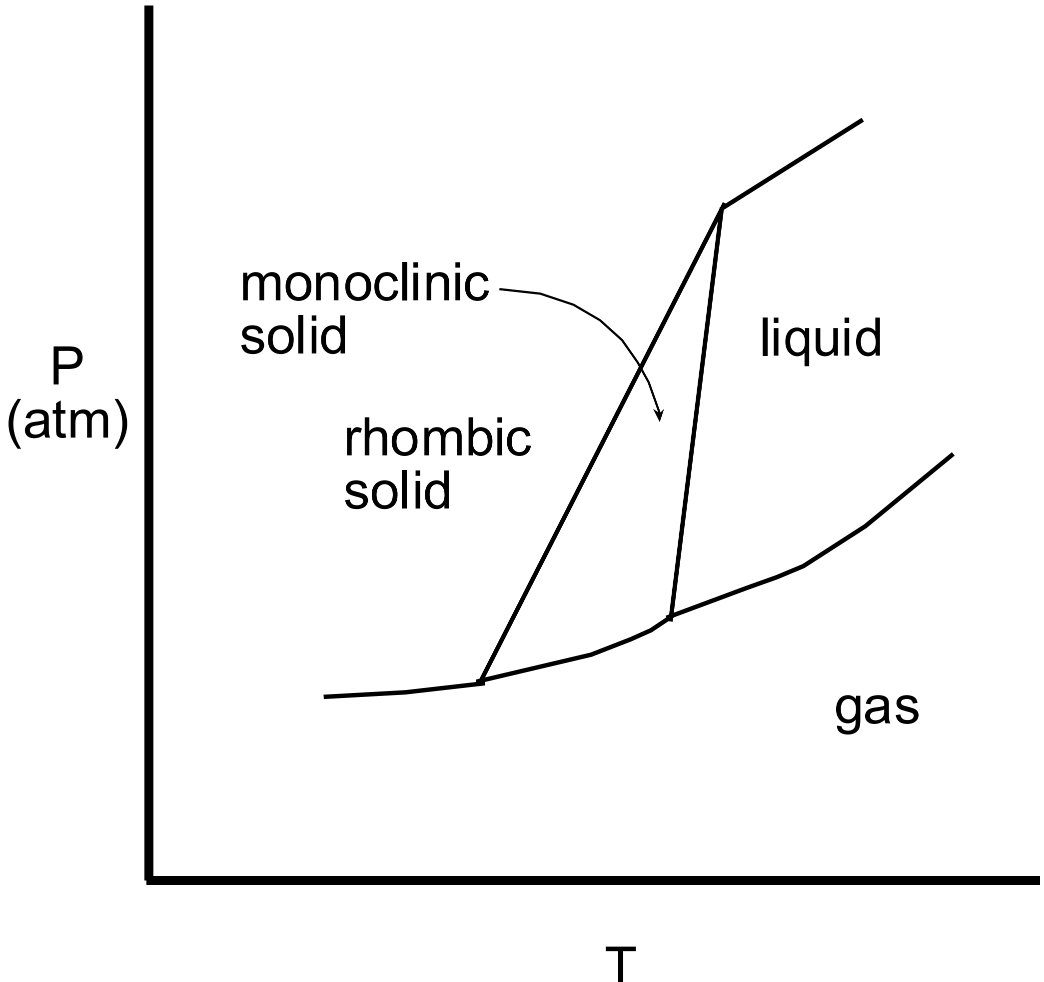


Rhombic is stable at higher P (higher density).

Clicker Question

Which best describes the monoclinic solid -> rhombic solid transition?

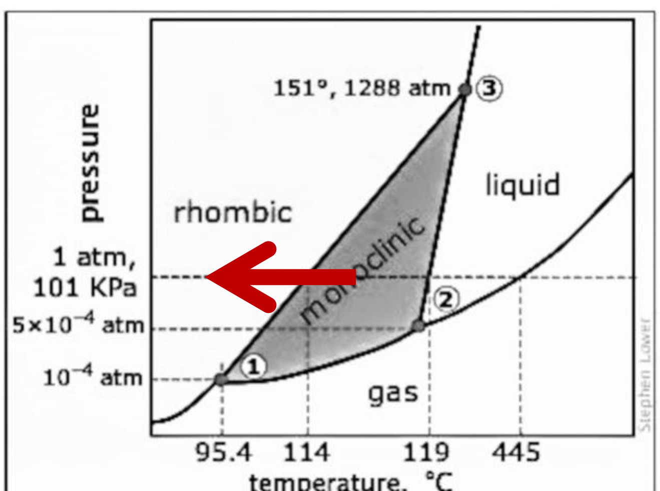
a) Fusion
b) Endothermic
c) Exothermic
d) Crystallization
e) None of the above



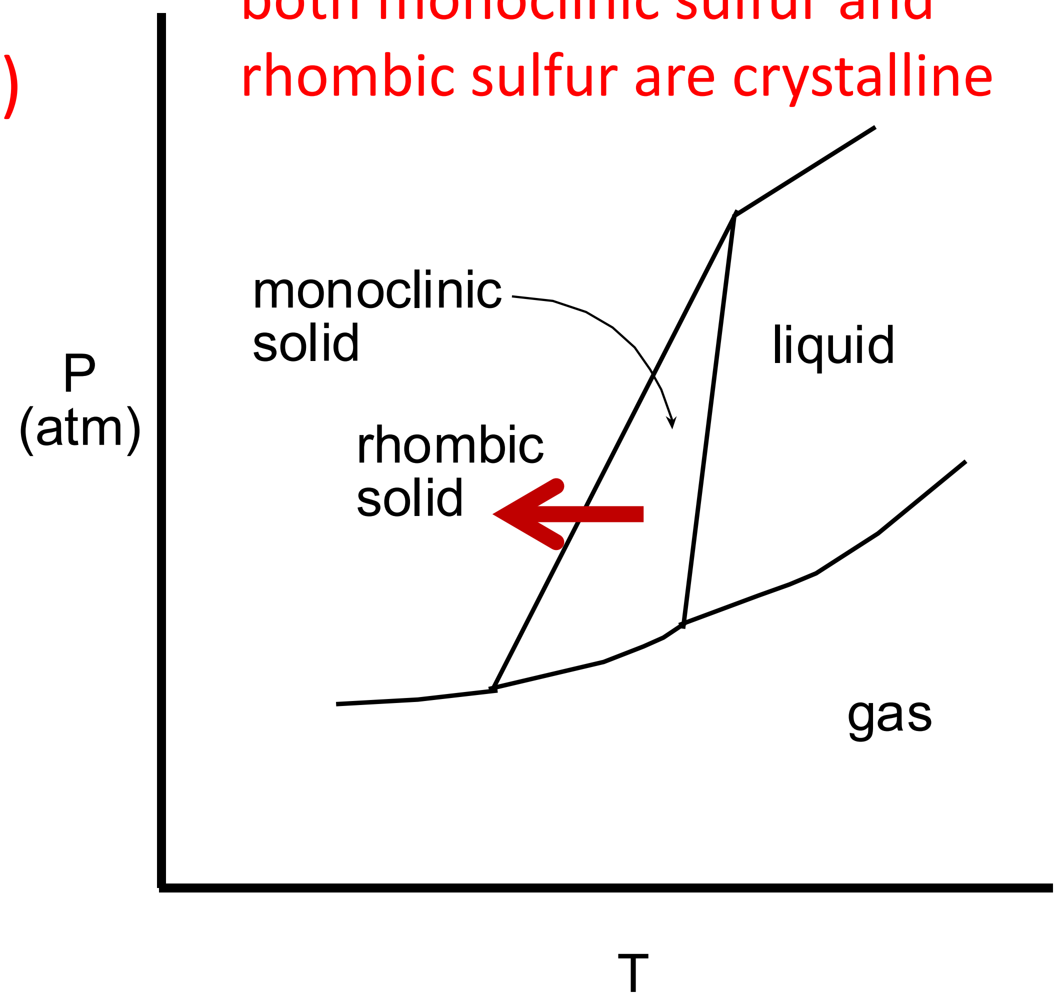
Clicker Question

Which best describes the monoclinic solid -> rhombic solid transition?

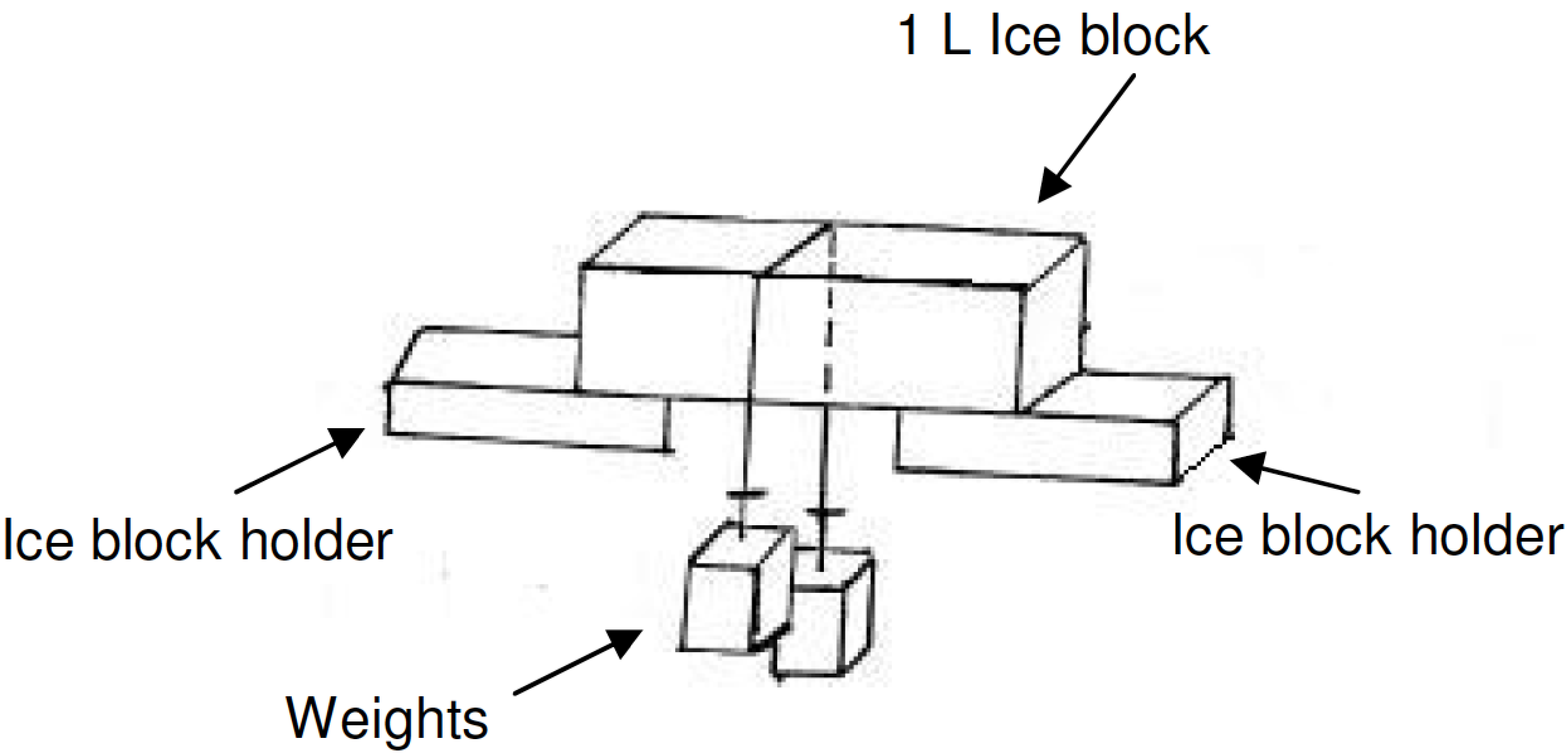
a) Fusion (solid to liquid)
b) Endothermic (Q>0)
c) Exothermic (Q<0)
d) Crystallization
e) None of the above



both monoclinic sulfur and rhombic sulfur are crystalline

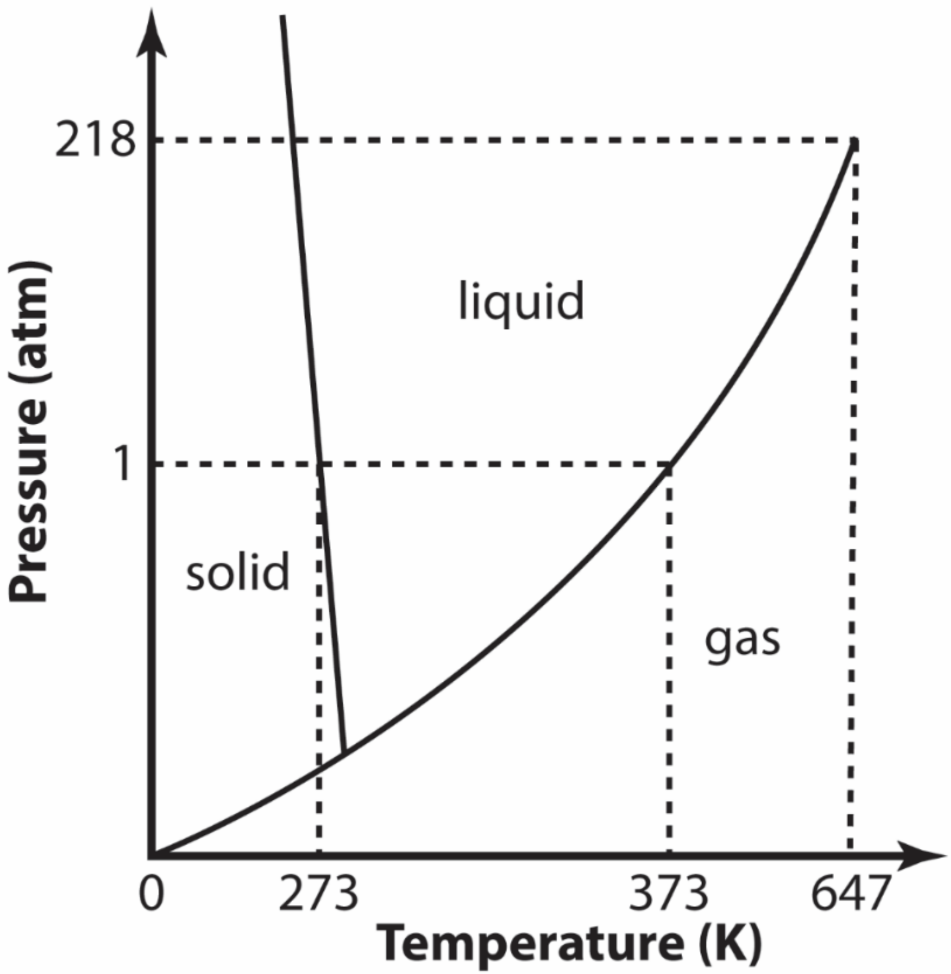


Demonstration for Today



Worksheet Question #3

…Use the phase diagram for water to explain the results of the demo experiment.



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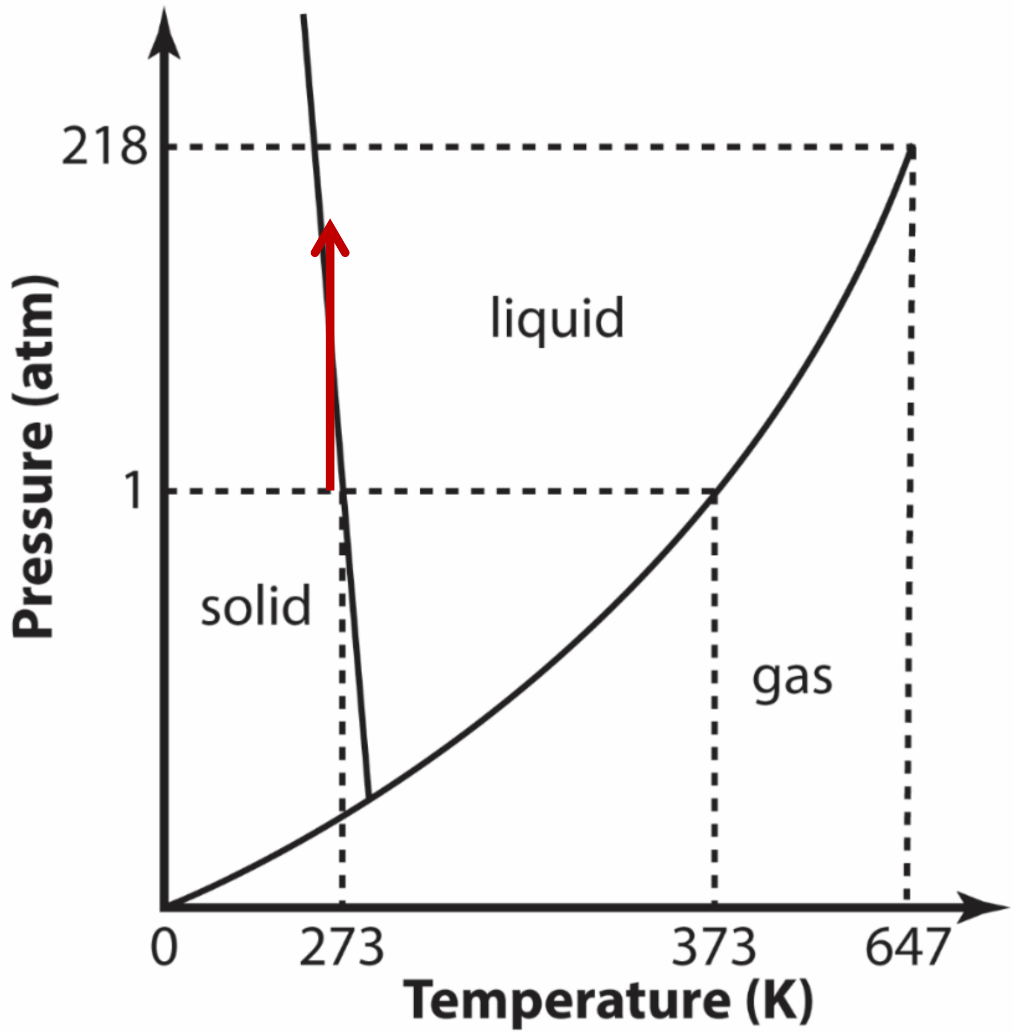


Demonstration for Today

“ice creep” can be an issue in ice climbing.

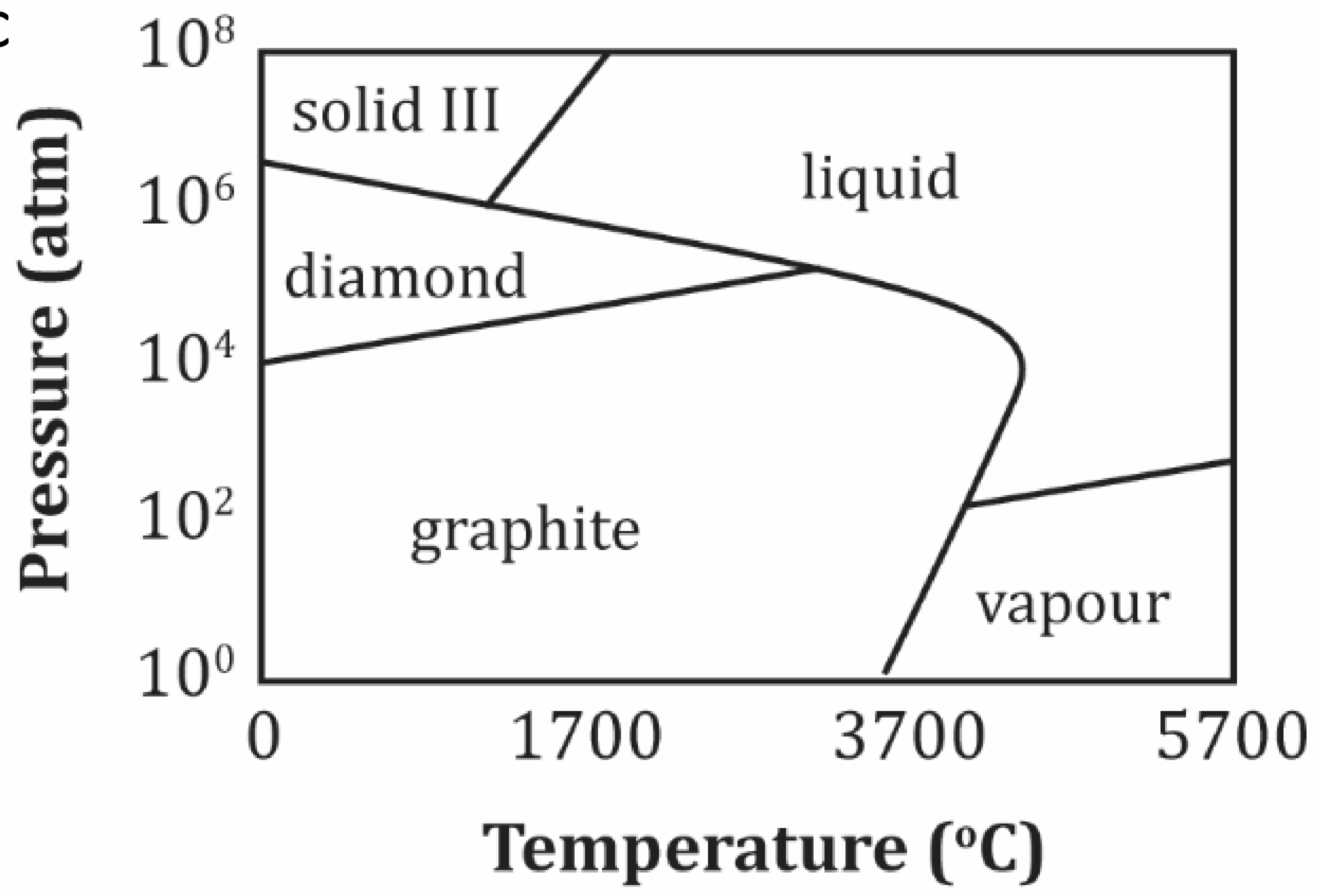
The pressure exerted by climbers can slowly cause ice melting – meaning safety gear could fall out of the ice!

Worksheet Question #4a

The phase transition from diamond to graphtie can be best described as:

a) Endothermic

b) Exothermic

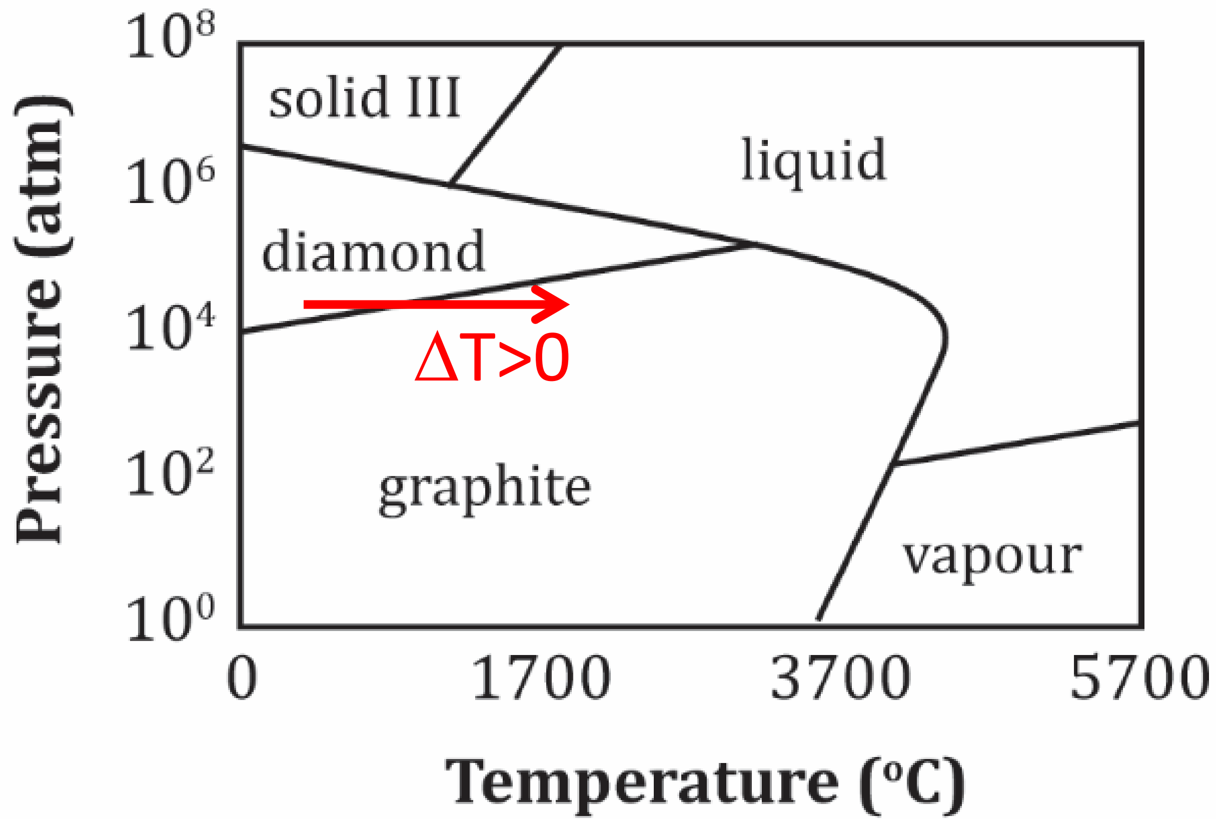


Worksheet Question #4a

The phase transition from diamond to graphtie can be best described as:

✓ a) Endothermic (Q>0)

b) Exothermic (Q<0)



Worksheet Question #4b

Based on the phase diagram, how many triple points exist for carbon:

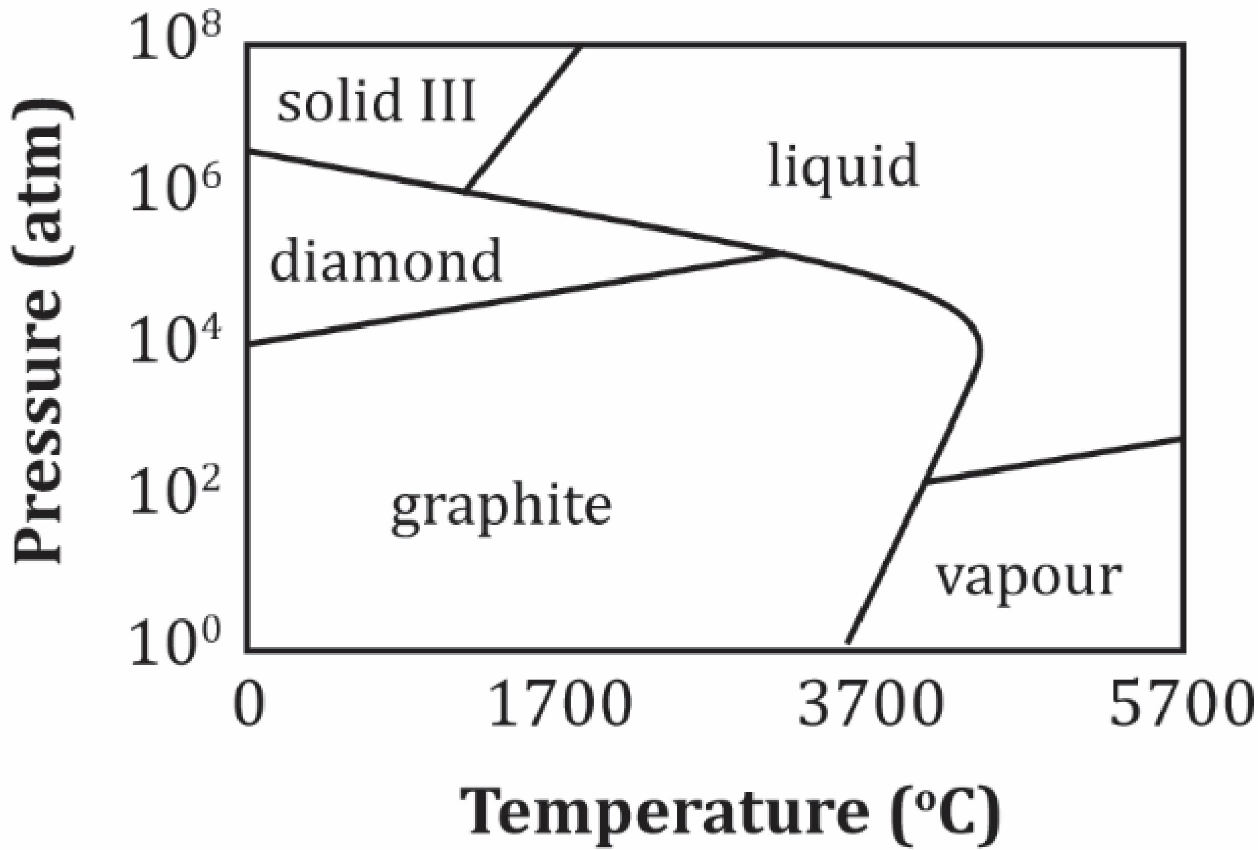
a) 0

b) 1

c) 2

d) 3

e) 4



Worksheet Question #4b

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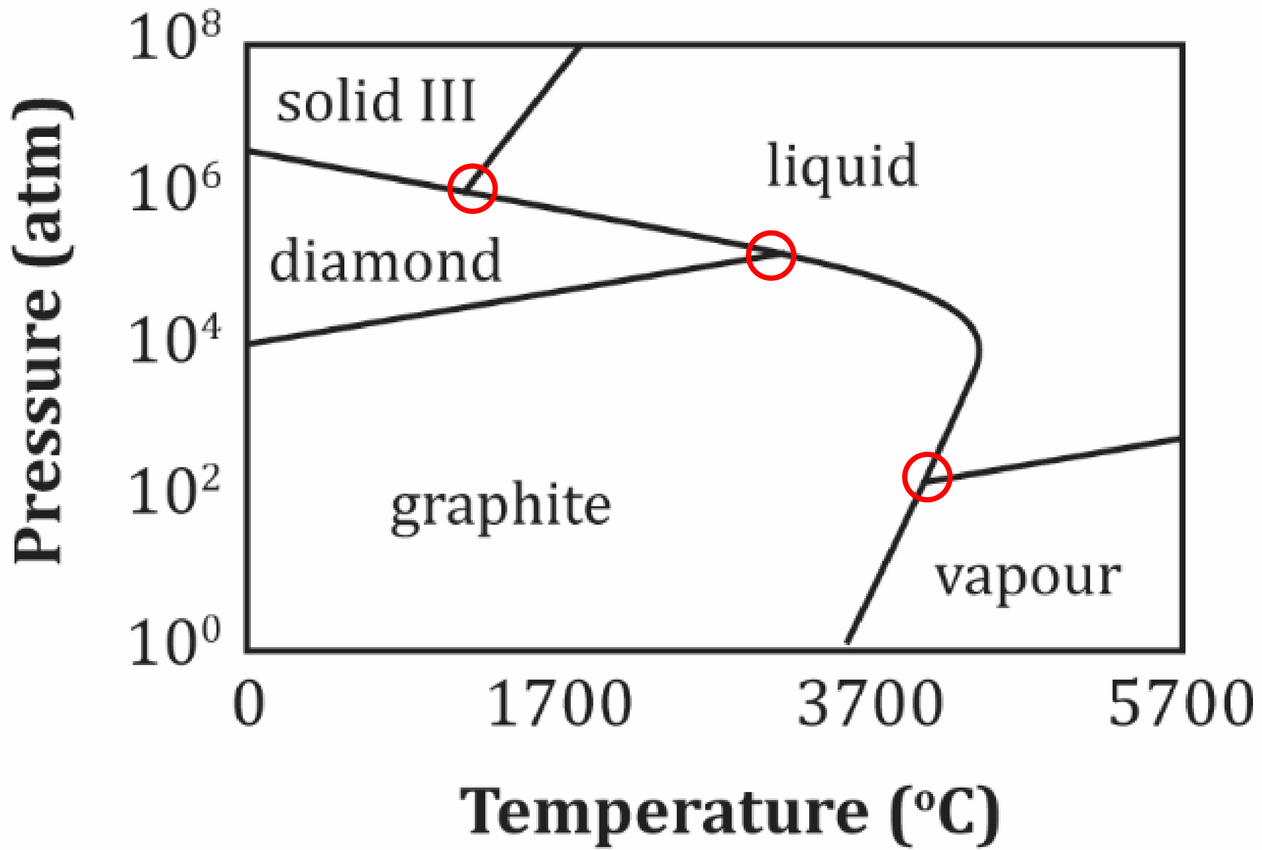
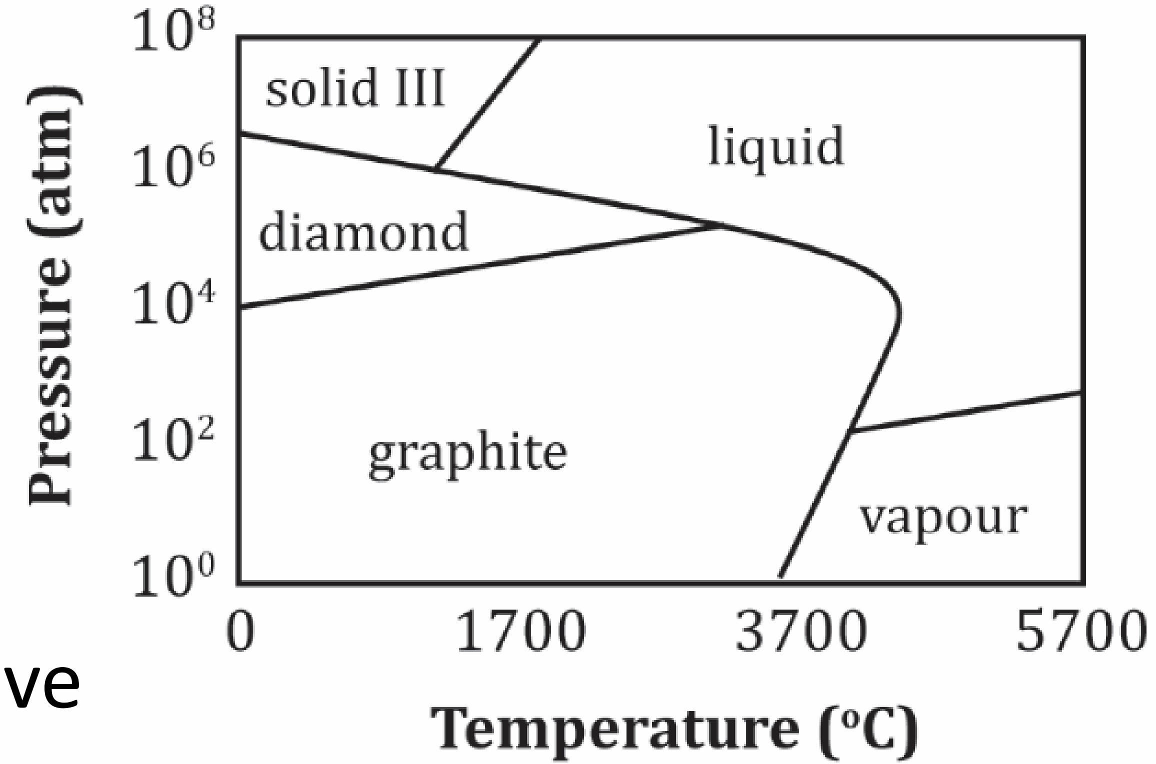


Worksheet Question #4c

What phase change occurs by going from 4700 °C to 2700 °C at 10 atm pressure?

a) Freezing
b) Sublimation
c) Deposition
d) Vaporization
e) None of the above



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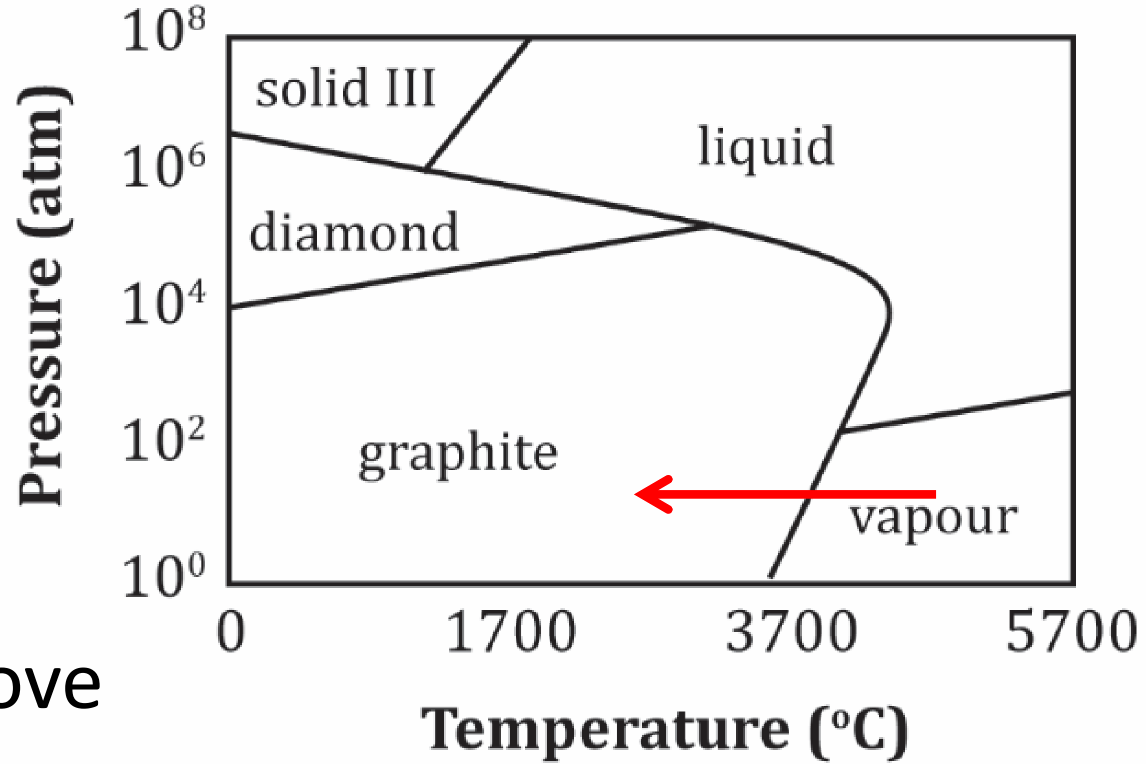
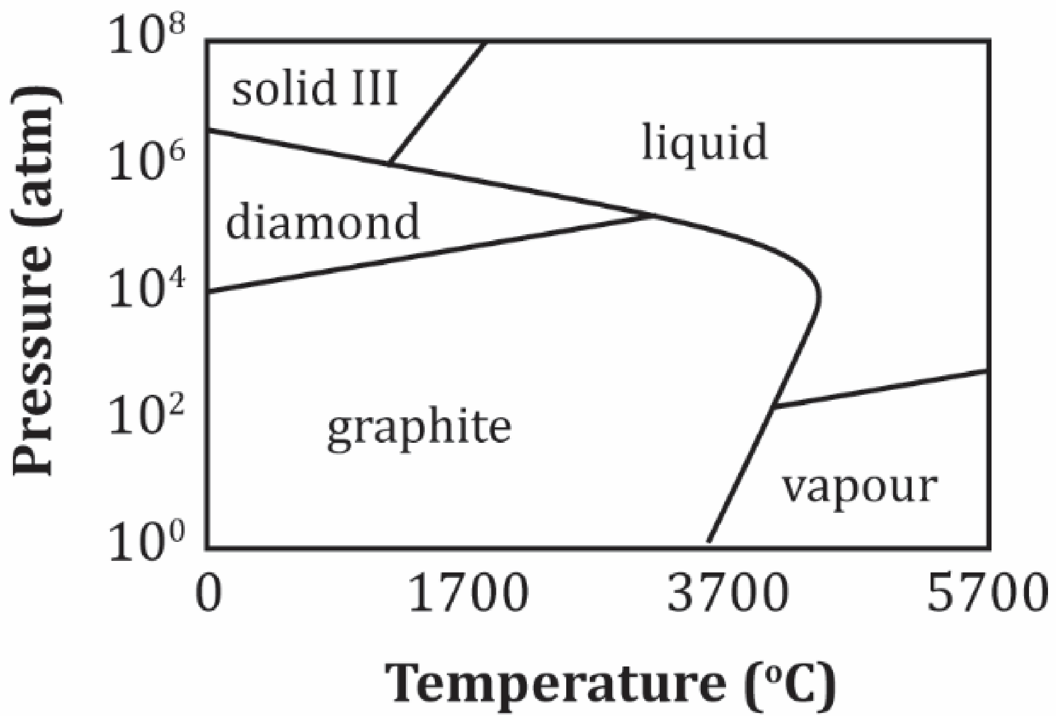


Worksheet Question #5 – GOOD QUESTION

One of the engineers at Diamonds-R-Us proposes that the diamonds could be separated from graphite by placing them in a pool of liquid carbon at 1700 °C. They say that the diamonds will float in the liquid carbon while the graphite will sink to the bottom. Is the engineer correct?



a) Yes

b) No

Worksheet Question #5 – GOOD QUESTION

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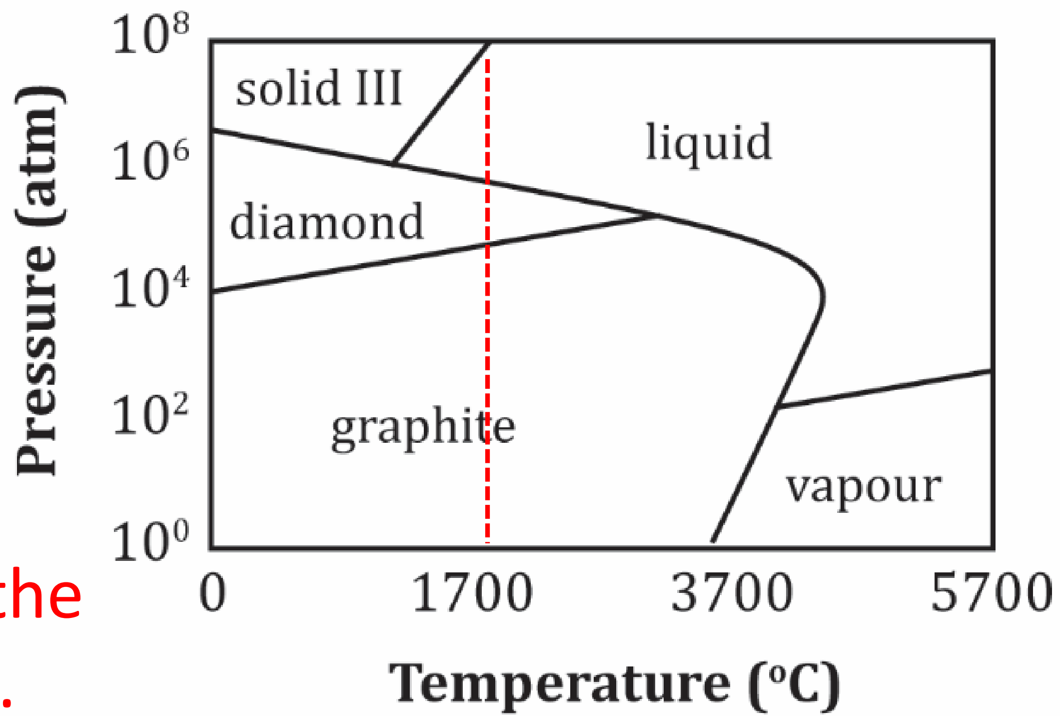


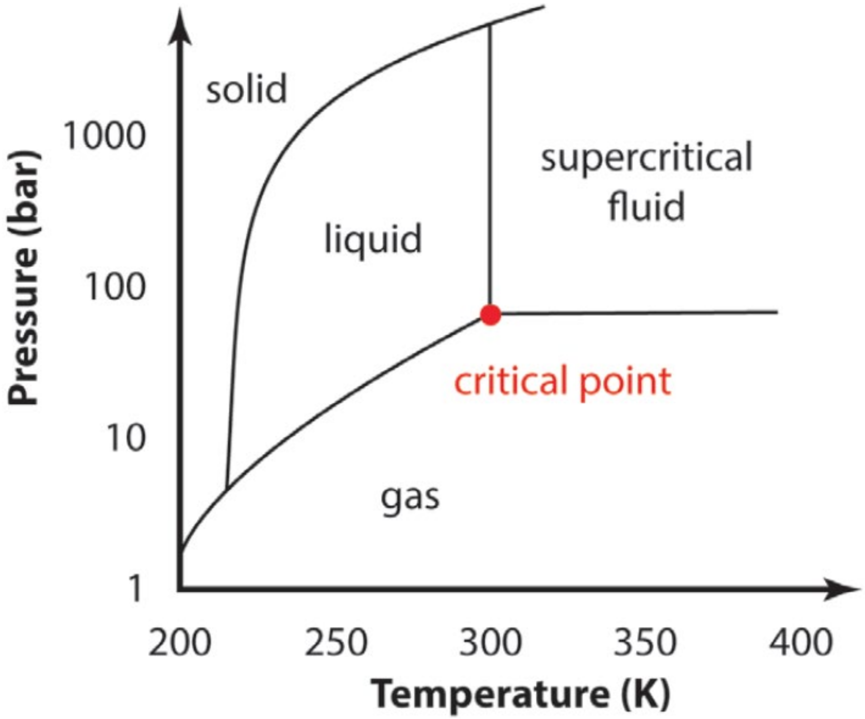
a) Yes

✓ b) No

Both are less dense than the liquid so both would float.

Worksheet Question #6 – GOOD QUESTION

The hanging ice-drop experiment is repeated, but the block of liquid H_2O (ice) is replaced with a solid block of dry ice (CO_2). The phase diagram for CO_2 is shown at right. Will the result of the experiment be the same? Explain.



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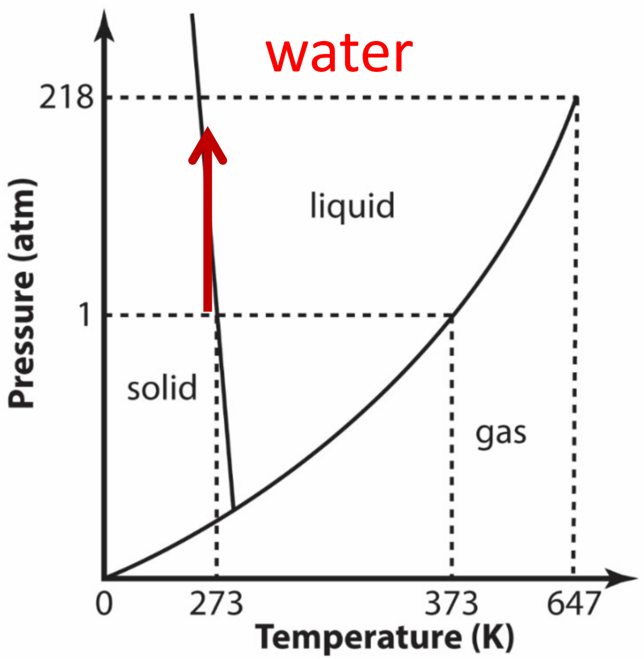

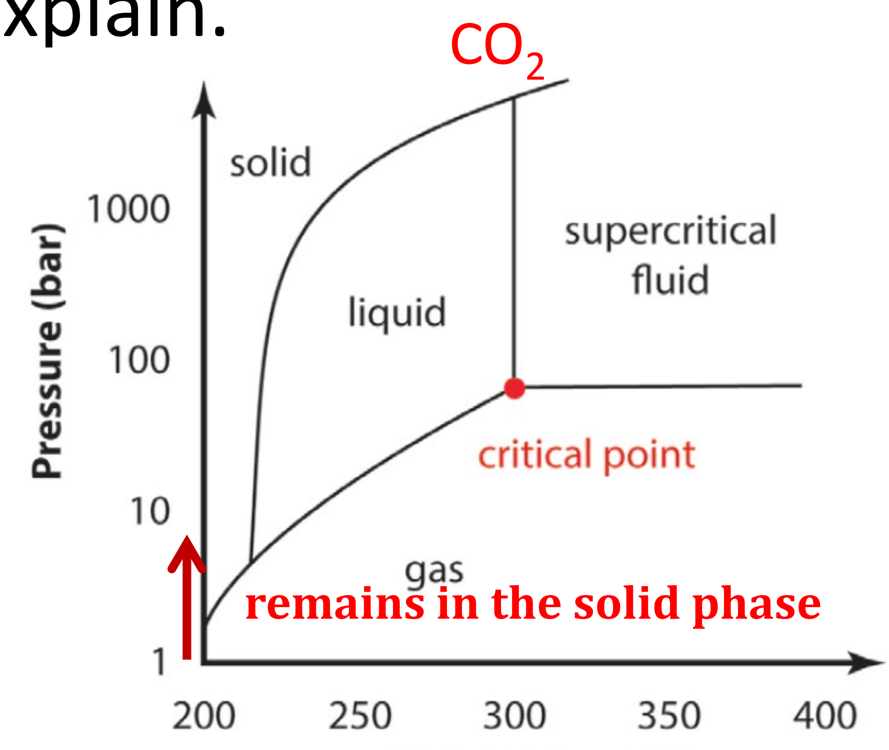

The temperature of dry ice = 194.7 K