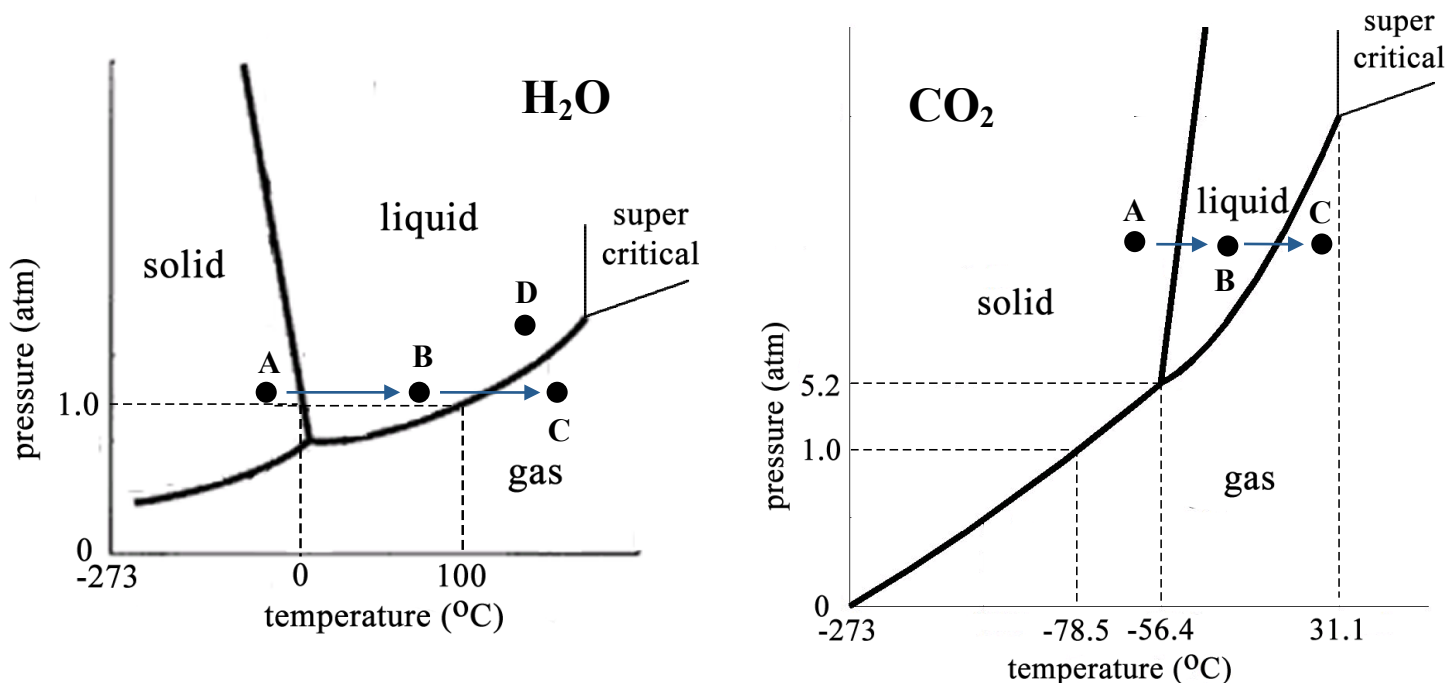


CHEM1102 Worksheet 10: Making a Perfect Snowball

Model 1: Phase Diagrams for Water and Carbon Dioxide

The *phase diagrams* for H_2O and CO_2 are shown below. A phase diagram summarizes the behaviour of a substance and different temperatures (x axis) and pressures (y axis). The different areas of the diagram represent conditions under which the material is a gas, liquid or solid. The thick, solid lines represent the transitions between these phases.



For example, point A on both diagrams represents a temperature and pressure in which the substance is a solid (*ice*). If the temperature is increased and the pressure is not changed, the substance moves to point B (liquid) and then to point C (gas). Along the way it passes through the solid line separating 'solid' from 'liquid' (*melting*) and through the solid line separating 'liquid' from 'gas' (*boiling* or *vapourizing*).

Critical thinking questions

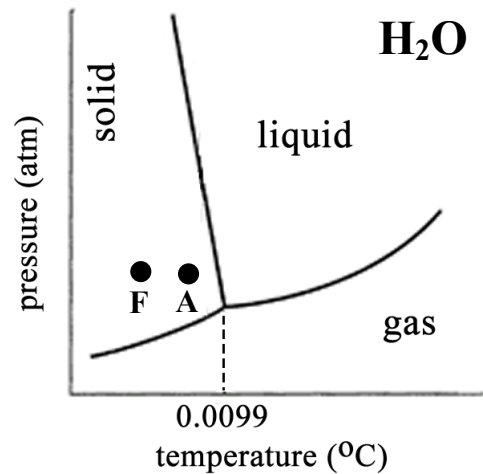
1. Water in a car radiator when the engine overheats is both very hot and under pressure. Point D on the water phase diagram represents this situation. What phase is water in at point D?
2. If the radiator cap is removed, the pressure will decrease to atmospheric pressure. What is likely to happen to the water? Draw another point (E) and an arrow on the phase diagram to illustrate this process.
3. Sequestration involves storing CO_2 , produced by burning fossil fuels, underground as a liquid. How could this be done? Draw two points and an arrow on the phase diagram of CO_2 to illustrate this process occurring at 25°C .

Model 2: Under Pressure

Snow is very loose and there is an art to make it into a snowball capable of being thrown. To make a perfect snowball, you scoop up snow in a gloved hand and squeeze it between your cupped hands.

The explanation for this lies in the almost unique* phase diagram of water. The thick line representing the solid-liquid transition slopes to the left for water. As shown in Model 1 for CO_2 , it normally slopes to the right.

This peculiarity is associated with the lower density of solid water compared to liquid water: water ice floats in a glass of water but dry ice sinks in liquid CO_2 .



Critical thinking questions

1. On a particular winter's day, the temperature is just below freezing. The snow you pick up is at point A on the phase diagram. When you squeeze the snow, what will happen to it? Draw another point (G) and an arrow on the phase diagram to illustrate this process.
2. Before throwing the snowball, you release the pressure. Describe what will happen and add another arrow to the phase diagram to illustrate this process.
3. The temperature even on a summer's day at the South Pole is very cold (around -25°C). On worlds such as Ganymede, Pluto or Mars, the temperature can be as low as -120°C . Point F represents snow on a very cold day. Can ice be welded by hand compression from this point?
4. Mars is usually so cold that CO_2 exists as a solid. By first predicting what happens if you squeeze dry ice at point A on its phase diagram (see Model 1), suggest whether it is possible to make a snowball of dry ice.

* There are other materials that have solid-liquid transition lines that slope to the left but these tend to be under conditions where humans cannot survive. You could, for example, make a plutonium snowball by squeezing plutonium dust at 640°C . Just don't take too big a handful.

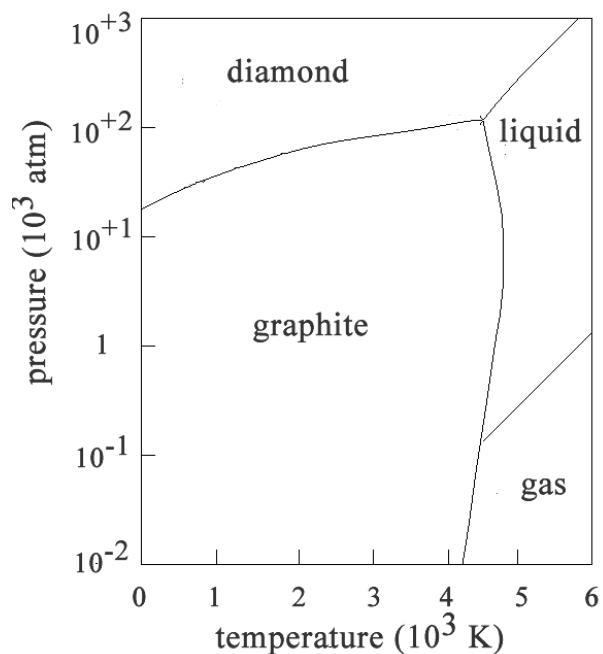
Model 3: Allotropes and Pressure

Many elements can exist as different structural forms called *allotropes*. Allotropes have different physical properties, including densities, and their stability depends on the temperature and pressure. Phase transitions between these forms can occur as well as between them and the liquid and gaseous forms of the element.

The phase diagram opposite is that of carbon showing regions due to diamond and graphite.

It shows that graphite is more stable than diamond at lower pressures and diamond is more stable than graphite at higher pressures.

There are 2 triple points on the phase diagram.

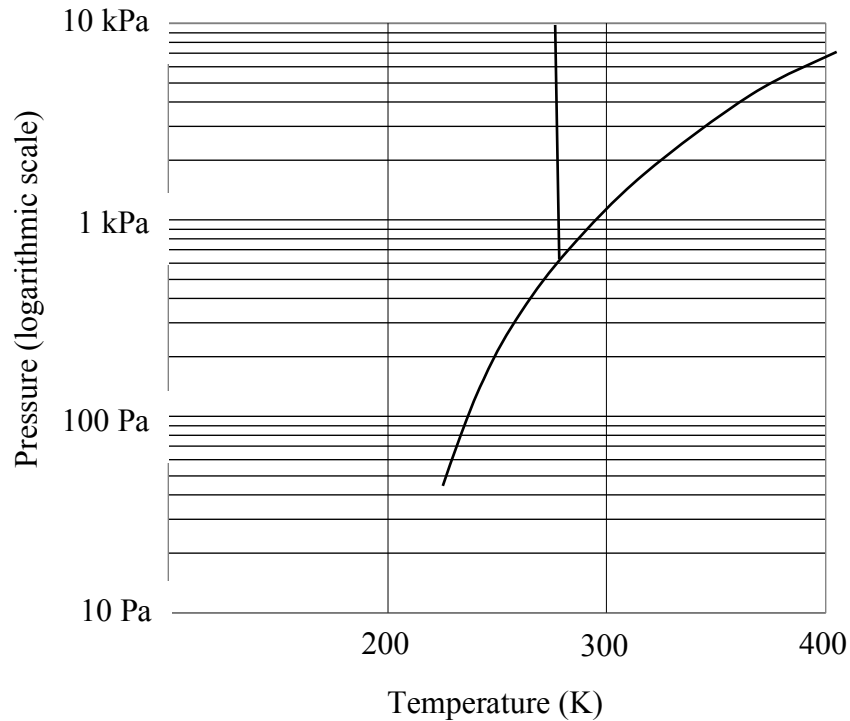


Critical thinking questions

1. Describe the phase change(s) that occur when graphite at room temperature and pressure is heated to 5000 K.
2. Label the 2 triple points and describe which phases are in equilibrium at each.
 - (i)
 - (ii)
3. Is the phase diagram consistent with graphite or diamond being more dense? Explain your answer.
4. Explain how your answer to Q3 is compatible with your knowledge of the structures of these 2 allotropes.

- The diagram below shows part of the phase diagram of water.

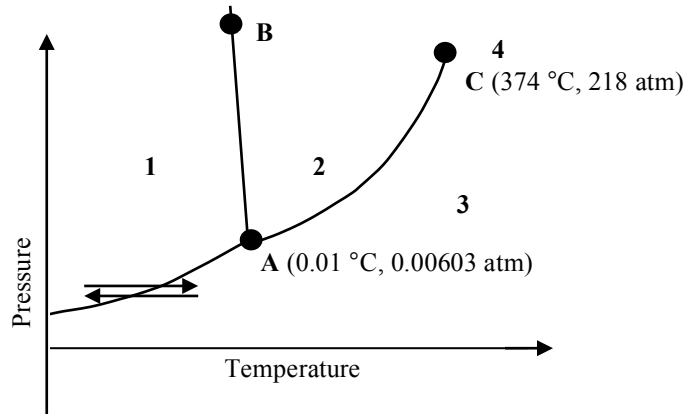
Marks
5



The average pressure on the surface of Mars is around 0.6 kPa. If the night time temperature is $-60\text{ }^{\circ}\text{C}$ and a summer day temperature is $20\text{ }^{\circ}\text{C}$, describe what happens to any water on the surface of Mars as the sun rises.

The highest surface pressure on Mars is thought to occur at the Hellas Basin, a low-lying area created by the impact of a large asteroid. If the pressure in this region is 1.2 kPa, use the phase diagram to estimate the temperature range in which liquid water will occur. Show your working on the phase diagram.

- A phase diagram of water is shown below.



Identify the four phases shown as 1-4 in the phase diagram.

1:	2:
3:	4:

What are the phase changes highlighted by the forward and reverse arrows called?

Forward:	Reverse:
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What names are given to the points A and C?

A:	C:
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The boundary line A-B is slightly tilted to the left. What are the physical and biological significances of this?

What are the physical characteristics of water in phase 4?