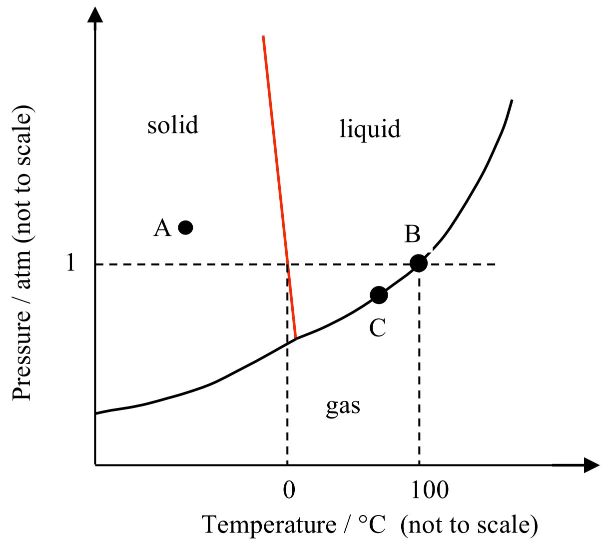
Marks
6

- Consider the pressure/temperature phase diagram of H_2O shown below.



Which phase exists at the point labelled A? **Solid**

What are the temperature and pressure for the normal boiling point of water?

Temperature = 100 ^{o}C or 373 K. Pressure = 1 atm. This is labelled as point B.

Use the phase diagram to explain why it takes longer to hard boil eggs on the top of a 4000 m high mountain rather than at sea level.

The pressure at 4000 m is considerably lower than at sea level. At lower pressure, the water boils at the temperature corresponding to the new position on the liquid – gas line in the phase diagram, represented as point C.

The boiling point at lower pressure is lower: water boils at a lower temperature on the mountain. It is not possible to heat the water above this temperature, as it boils away. Because the water used to cook the egg is at a lower temperature, it takes longer to cook it.

Use the phase diagram to explain why ice cubes float in water.

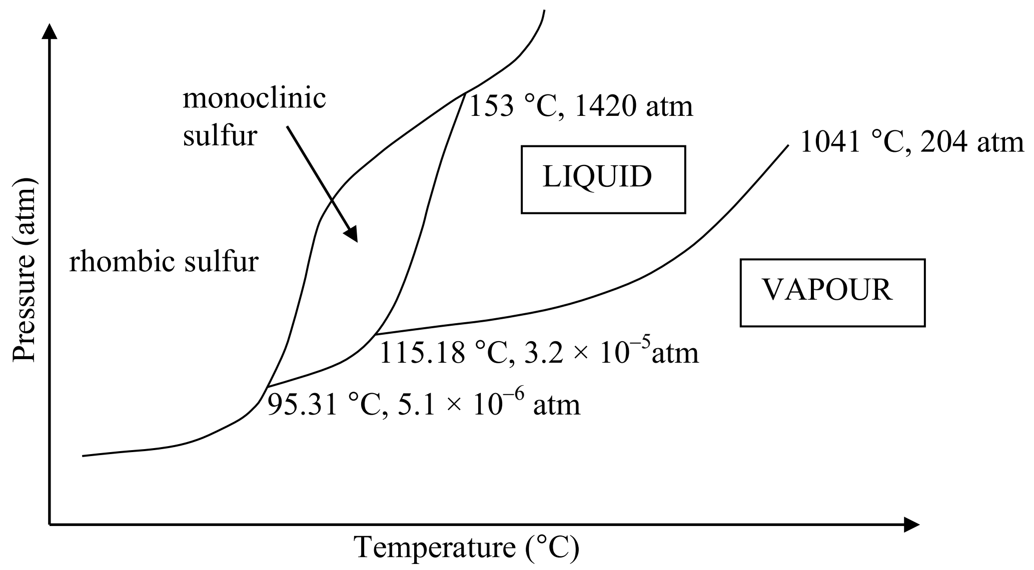
The equilibrium line between solid and liquid slopes slightly to the left. Increasing the pressure lowers the melting point: the liquid phase is favoured over the solid phase by increasing pressure.

This behaviour results from the solid occupying more volume than the liquid. If the pressure increases, the system responds by favouring the liquid as it takes up less space.

The solid has a lower density than the liquid form.

Marks 9

- Solid sulfur can exist in two forms, rhombic sulfur and monoclinic sulfur. A portion of the phase diagram for sulfur is reproduced schematically below. Complete the diagram by adding the labels "vapour" and "liquid" to the appropriate regions.



Which form of solid sulfur is stable at 25 °C and 1 atm? **rhombic**

Describe what happens when sulfur at 25 °C is slowly heated to 200 °C at a constant pressure of 1 atm.

It changes into the monoclinic form and then it melts.

How many triple points are there in the phase diagram? **3**

What phases are in equilibrium at each of the triple points?

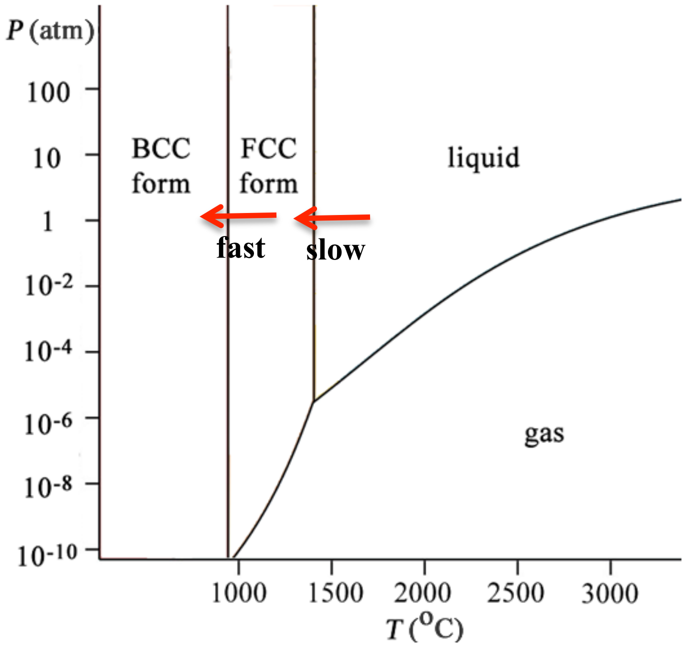
- **rhombic, monoclinic and vapour (at 95.31 °C and 5.1 × 10^{-6} atm);**
- **monoclinic, liquid and vapour (at 115.18 °C and 3.2 × 10^{-5} atm);**
- **rhombic, monoclinic and liquid (at 153 °C and 1420 atm);**

Which solid form of sulfur is more dense? Explain your reasoning.

Rhombic is denser. If you start in the monoclinic region and increase the pressure at constant temperature *(i.e.* draw a vertical line upwards) you move into the rhombic region. Rhombic is thus the more stable form at higher pressures, so must be denser.

Marks
5

- A simplified phase diagram for iron is shown below.



Which form of iron is stable at room temperature and pressure? **BCC form**

If molten iron is cooled slowly to around 1200 °C and then cooled rapidly to room temperature, the FCC form is obtained. Draw arrows on the phase diagram to indicate this process and explain why it leads to the FCC form.

See diagram above.

The rapid cooling from 1200 to 25 °C does not allow time for the atoms in the FCC arrangement to reorganise themselves into the more stable BCC structure. The atoms have insufficient energy for the considerable re-arrangement of their positions to occur.

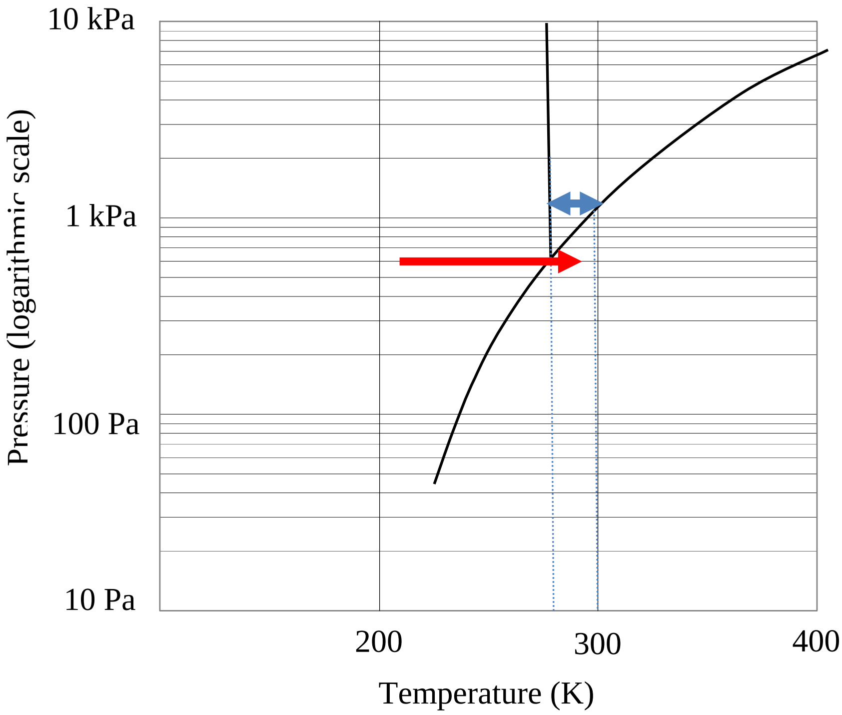
The line dividing the BCC and FCC forms is almost, but not quite vertical. Given that the FCC form is more efficiently packed, predict which way this line slopes. Explain your answer.

FCC is more efficiently packed so is more dense. Increasing the pressure favours the more dense form.

The BCC/FCC equilibrium line slopes to the *left* so that moving vertically (i.e. increasing pressure) at the BCC/FCC equilibrium leads to FCC.

Marks
5

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



The average pressure on the surface of Mars is around 0.6 kPa. If the night time temperature is –60 °C and a summer day temperature is 20 °C, describe what happens to any water on the surface of Mars as the sun rises.

This process is illustrated by the red arrow in the phase diagram above. The process occurs just *below* the triple point so the phase changes from solid (at –60 °C) to gas (at 20 °C).

Water sublimes as the sun rises on Mars.

(Note the logarithmic scale on the graph. Each horizontal line between 100 Pa (0.1 kPa) and 1 kPa (1000 Pa) represents an increase of 100 Pa (0.1 kPa).)

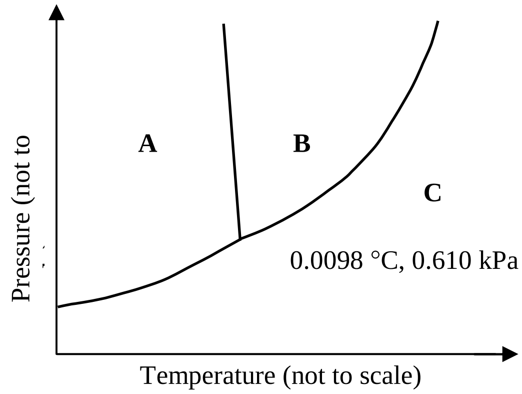
The highest surface pressure on Mars is thought to occur at the Hellas Basin, a low-lying area created by the impact of a large asteroid. If the pressure in this region is 1.2 kPa, use the phase diagram to estimate the temperature range in which liquid water will occur. Show your working on the phase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

At 1.2 kPa, water is a liquid in the temperature range covered by the double-headed blue arrow in the phase diagram above.

Within the accuracy possible on the diagram, this corresponds to the temperature range 272 – 305 K.

Marks
6

- Consider the pressure/temperature phase diagram of H_2O shown below.



Which phase exists in the fields labelled **A**, **B** and **C**?

A: solid	**B: liquid**	**C: gas**

What are the temperature and pressure for the normal boiling point of water?

100 °C and 1 atm

Use the phase diagram to explain why it takes longer to hard boil eggs on the top of a 6000 m high mountain rather than at sea level.

The air pressure is lower at 6000 m than at sea level.

The boundary line between regions B and C shows that lowering the pressure lowers the boiling point. When the water is boiling, it will be at a lower temperature at 6000 m than at sea level.

If the temperature is lower, a longer period of time is required to effect the same level of cooking.

The unusual property of water, with the solid being less dense than the liquid, can be deduced from the phase diagram. How?

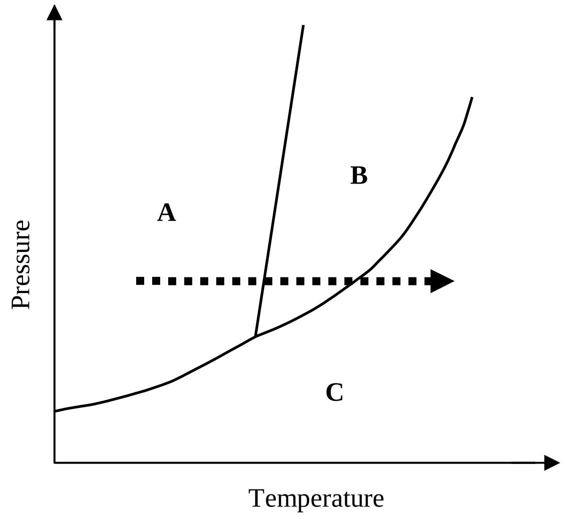
The equilibrium line between the solid and the liquid (represented by the line between regions A and B) slopes to the left.

If you begin in the solid region close to this line and you increase the pressure, you will cross the line vertically and go into the liquid region.

The liquid is *more* stable at *higher* pressure so it must be more dense than the solid.

Marks 6

- Examine the following pressure/temperature phase diagram for a one component system.



Which phase exists in the fields labelled **A**, **B** and **C**?

A: solid	**B: liquid**	**C: gas**

Explain your assignment of these phases.

The dotted arrow on the phase diagram above passes through all three regions. It represents an increase in temperature at constant pressure. At low temperature, the particles in the system have low energy and so exist as a solid in phase A. As the temperature is increased, they gain energy and pass from solid to liquid, in phase B. At even higher temperature, they have sufficient energy to pass to gas, in phase C.

What do the lines in the diagram represent?

The lines represent the boundaries between phases. At each temperature and pressure on a line, both of the phases to the left and to the right of that point are in equilibrium and co-exist.

What happens when you move across a line either by changing temperature or pressure?

Moving across a line corresponds to a phase change.

ANSWER CONTINUES ON THE NEXT PAGE

For a compound with this phase diagram, would the solid be denser than the liquid or vice versa? Explain your answer.

The solid is denser.

The gradient of the line between A and B is positive. If the system is at the phase change between solid and liquid (i.e. a point on the line) then increasing the pressure (moving vertically upwards on the diagram) will move the system to the solid phase.

This is because the solid takes up less volume: increasing the pressure favours the solid over the liquid. If the solid takes up less volume, it must be denser.