Phase Diagrams

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Concept 1 Phase Diagrams

Lesson Objectives

The student will:

- read requested information from a phase diagram.
- state the primary difference between a generic phase diagram and a phase diagram for water.

Vocabulary

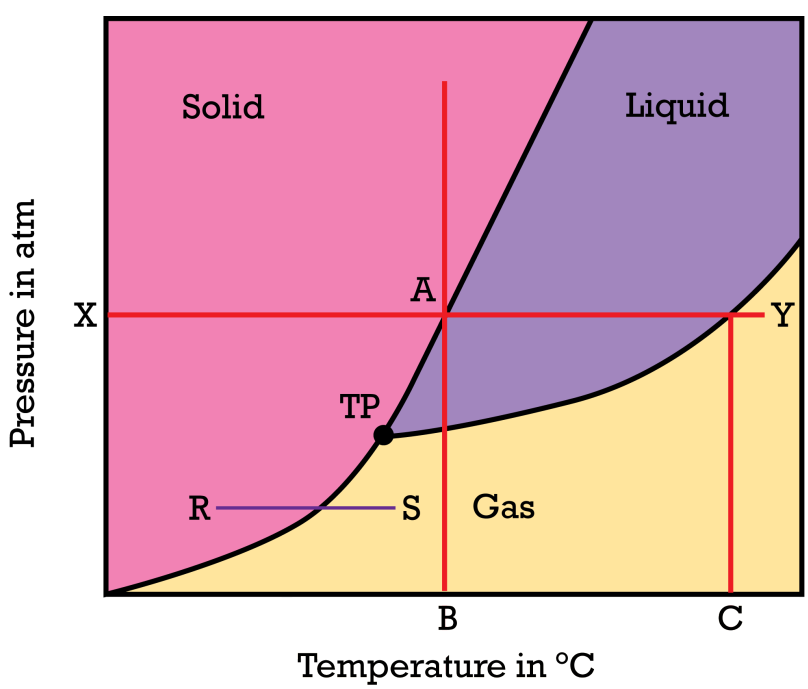
- critical pressure
- critical temperature

Introduction

A phase diagram is a convenient way of representing the phase of a substance as a function of temperature and pressure. Phase diagrams are produced by altering the temperature of a pure substance at constant pressure in a closed system. This process is repeated at many different pressures, and the resultant phases charted.

Generic Phase Diagrams

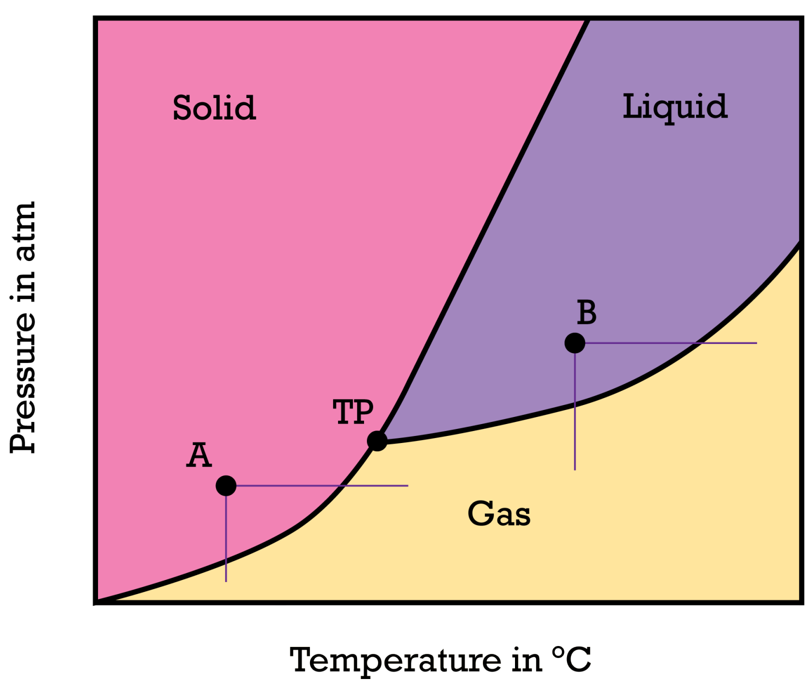
The phase diagram seen below is a generic phase diagram that would be produced by many pure substances. Differences in the diagram would be in the specific thermodynamic points, such as the melting point and boiling point, and in the slopes of the curved lines.



The pink area in the diagram represents the solid state, the purple area represents the liquid state, and the yellow area represents the gaseous state. Following a constant pressure line, such as line X, shows that the phase of the substance at different temperatures at this pressure. Since the line crosses from solid into liquid at point A, this temperature would be the melting point of the substance. Continuing along the line, we see it crosses from liquid to gas at the point corresponding with temperature C. This is the boiling point of the substance at pressure X.

The line between the pink and purple areas represent the various melting points at different pressures, while the line separating the purple area from the yellow area represents the boiling point at various pressures. At the melting points, both solid and liquid can exist at the same time as the phase changes occurs. Similarly, at the boiling points, the substance may exist in both liquid and gas phase at the same time. There is one point on the diagram where all three phases may exist at one time. This point is called the triple point. The pressure at this point is called the triple point pressure, and the temperature at this point is called the triple point temperature.

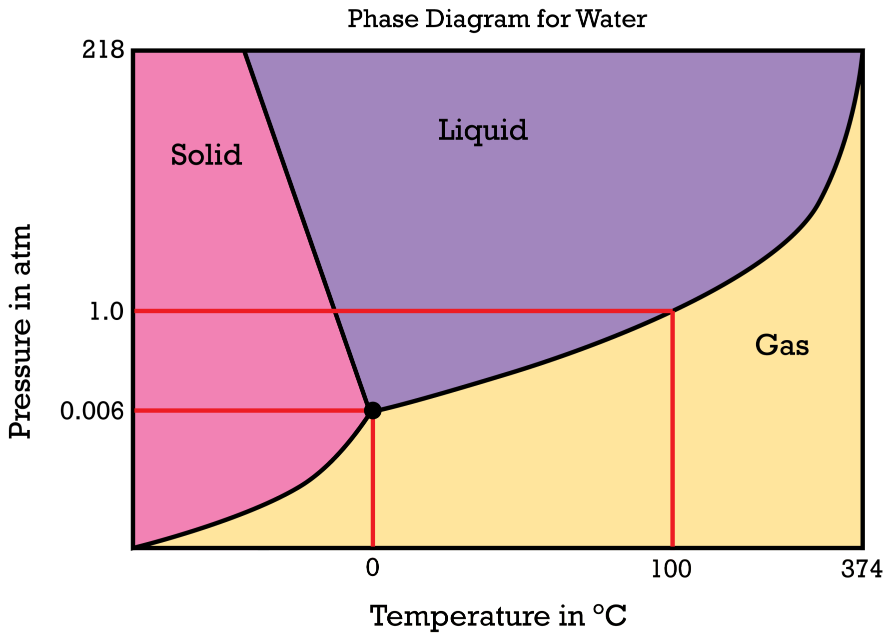
There is also a line separating the pink area from the yellow area. This line represents the phase change in which a solid changes directly to a gas without passing through the liquid phase. This phase change is known as sublimation. All substances undergo sublimation at the appropriate pressures. We do not see sublimation often because the pressures are frequently quite low. One example of sublimation that we can observe at normal atmosphere (1.00 atm) is carbon dioxide, CO_2, in its solid form, which is also known as dry ice. If you have seen dry ice, you would notice that the substance goes from the solid phase to the gaseous phase at room conditions without passing through a liquid phase. In the phase diagram for dry ice, we would see that the triple point is above normal atmospheric pressure, so at standard conditions, carbon dioxide undergoes sublimation.



The figure above shows the same generic phase diagram we looked at earlier. Two points have been added to the diagram, labeled A and B. You should note that the substance at point A can be caused to go through a phase change from solid to gas (sublimation) in two different ways. The substance could be heated at constant pressure, or the substance could undergo a lowering of pressure at constant temperature. Both of these procedures would cause the solid to undergo sublimation. Point B is similar except that the substance begins as a liquid. The liquid at point B could be caused to under a phase change into a gas by either heating the liquid at constant pressure or by lowering the pressure at constant temperature. You might also note that the substance at the triple point will become a solid if the pressure is increased and will become a gas if the pressure is decreased.

The Phase Diagram for Water

The phase diagram for water has one very interesting difference from the generic phase diagram. Please note that this diagram is not drawn to scale. If the distance between 1.0 atm and 218 atm was drawn to scale, the difference between 1.0 atm and 0.006 atm would be invisible. The diagram is drawn just to show specific points of interest.



The primary difference in the shape of this diagram and the generic diagram is that the solid-liquid equilibrium line has a negative slope. A positive slope indicates that as pressure increases, the melting point increases. In other words, more pressure on the surface would require a higher temperature to overcome that extra pressure to melt the substance. The negative slope of this line in the water diagram indicates that as the pressure increases, the melting point of water decreases. The reason this occurs is because the increased pressure breaks some of the hydrogen bonds in the water, so less thermal energy is needed to melt ice at higher pressures.

This property of water is evidenced in various situations. We all think of ice as being a very slippery substance, but the surface of ice is no different from the surface of many other solids. The reason that we slip on ice is because when you stand on ice, the pressure of your weight causes the ice to melt, which causes the surface to be slippery. Another example of this is in the track of the blade left by an ice skate. If you look closely at the track, you'll see that the track is filled with liquid.

If you follow the line at a pressure of 1.0 atm for water, you see that the temperatures at the melting and boiling points are what we expected. The triple point for water is at 0.006 atm and 0.0098°C, which also means that the pressure and temperature at which ice water sublimates to water vapor are very low. There are commercial processes that make use of the sublimation of water. Foods that are referred to as "freeze dried" have the surrounding pressure and temperature reduced to a point below the triple point. The food is then heated while a vacuum pump removes vapor to keep the pressure below the triple point pressure. This causes the water in the food to sublimate, which is drawn off by the pump. The end result is that all the water will be removed from the food.

As the temperature of liquid is raised, the amount of pressure that is required to keep the substance in liquid form also increases. Liquids will eventually reach a temperature at which no amount of pressure will keep it in the liquid form. The substance at that temperature will vaporize regardless of the amount of pressure on it. The highest temperature a liquid reaches and can still be maintained as a liquid is called the **critical temperature**. The pressure that is required at the critical temperature to force the substance to stay in liquid form is called the **critical pressure**. The critical temperature and pressure for water is 374°Cand 218 atm.

Lesson Summary

- Phase diagrams show the phase of a substance at various temperatures and pressures.
- The phase diagram for water is different from most phase diagrams because the melting point of water decreases as pressure increases.

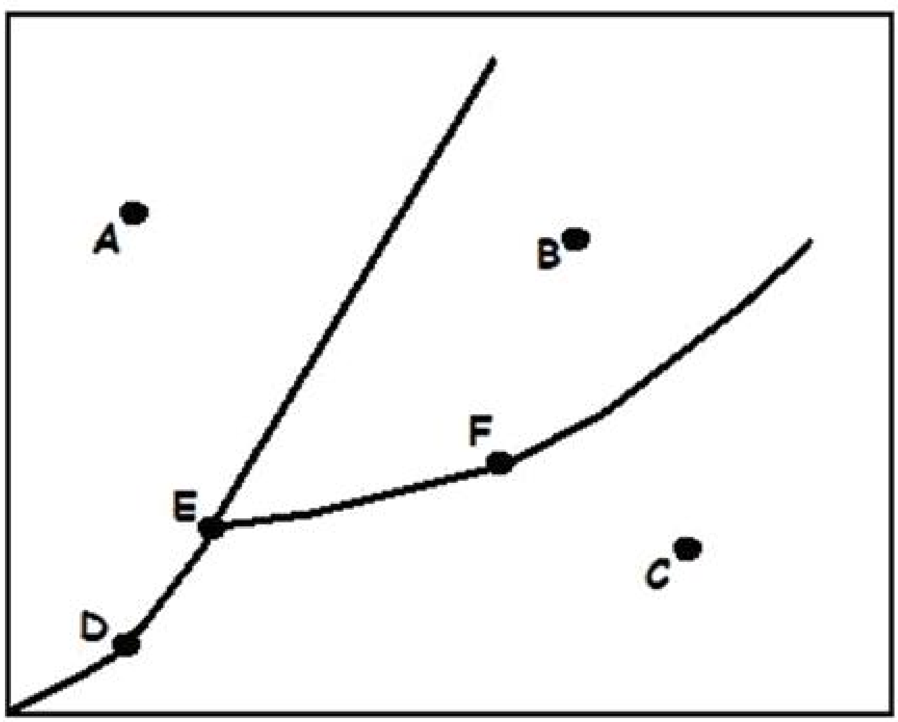
Further Reading / Supplemental Links

To look at more phase diagrams, visit the website:

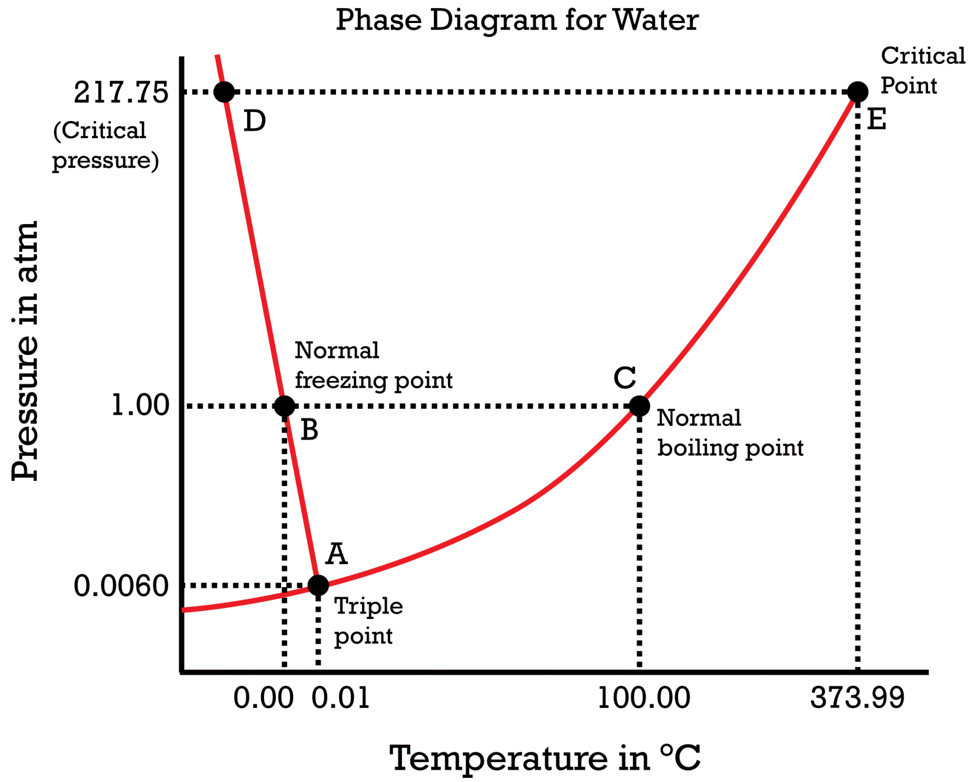
- http://www.kentchemistry.com/links/Matter/Phasediagram.htm

Review Questions

1. Consider the phase diagram below. Name the phases that may be present at each lettered point in the diagram.



Use the phase diagram for water below to answer the remaining questions.



2. What is the state of water at 2.0 atm and 50.°C?
3. What phase change will occur if the temperature is lowered from 80.°C to −5°C at 1.0 atm?
4. You have ice at −10°C and 1.0 atm. What could you do in order to cause the ice to sublime?

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