5.4: Open Versus Closed Systems

In our discussion, the container of water vapor (gas) is our system: the part of the universe we are observing. It is separated from the rest of the universe (its surroundings) by the walls of the container (its boundary).[12] When we remove energy from the system or add energy to it, that energy goes to or comes from the surroundings. Our system is not an isolated system. If it were, neither energy nor matter would move between the system and the surroundings. In practice it is difficult to construct a perfectly isolated system (although an insulated or styrofoam coffee cup with a lid on is not a bad approximation.) We can also distinguish between open and closed systems: in an open system both matter and energy can enter or leave (we can keep track of both) whereas in a closed system the amount of matter is constant and only energy can enter or leave. Whenever we look at a system our first task is to decide whether the system is isolated, open, or closed. All biological systems are open (both energy and matter are being exchanged with the surroundings.) In the absence of such an exchange, a biological system would eventually die.[13]

Let us consider a beaker of water without a lid as our open system. As the temperature rises, some of the water molecules have enough energy to escape from the body of the water. The liquid water evaporates (changes to a gas). Any gases that might be dissolved in the liquid water, such as oxygen (O_2) or nitrogen (N_2), also move from the liquid to the gaseous phase. At the boiling point, all the energy being supplied to the system is being used to overcome the intermolecular forces, as it was at the melting point. However, this time the molecules are completely separated from one another, although they still collide periodically. Thus energy is used to overcome attractive forces and the individual molecules fly off into the gas phase where the distances between them become so great that the attractive forces are insignificant.[14] As the liquid boils, its temperature does not rise until all of it has been transformed from liquid to vapor. As the gas molecules fly off, they carry with them some of the system's energy.

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Questions to Answer

- Begin with an ice cube in a beaker and end with water vapor. Draw a graph of the energy input versus the temperature of the system. Is your graph a straight line?
- What would happen to the mass of the beaker and water during this process?
- Can you reproduce the hexagonal symmetry of ice by using a model kit? What property of hydrogen bonds makes the structure so open?
- As the temperature rises in liquid water, what do you think happens to the density? Draw a plot of density versus temperature for a mass of water beginning at $-10^\circ C$, up to $50^\circ C$.
- What happens when the temperature has risen such that the molecules have enough energy to overcome all the attractions between the separate molecules? Focus not on the covalent bonds but the attractions between separate molecules.

Questions to Answer, continued

- During evaporation and boiling do water molecules ever return to the liquid?
- Estimate the temperature at which the bonds within a water molecule break. How does that temperature compare to the boiling point of water? Why aren't they the same temperature?
- How would an open and a closed system differ if you heated them from 30 to $110^\circ C$?

Questions to Ponder

- Are boiling and evaporation fundamentally different processes?
- Under what conditions does evaporation not occur? What is happening at the molecular level?
- What is in the spaces in the middle of the hexagonal holes in Ice Ih?
- What would be the consequences for a closed or isolated biological system?

Questions for Later

- As you heat up a solution of water, predict whether water molecules or dissolved gas molecules will preferentially move from the liquid to the gaseous phase (or will they all move at the same rate?). What factors do you think are responsible for "holding" the gas molecules in the water?
- What do you think happens to the density of the gas (in a closed system) as you increase the temperature?
- What would happen if you captured the gas in a container?
- What would happen if you took that gas in the container and compressed it (made the volume of the container much smaller)?