Mentoring Advanced Placement
Physics

Topics: Vapor pressure, vacuums, pressure gradients

Quick questions:
1.) Shaking table salt into a pot of boiling water can cause the water to stop boiling. Similarly, shaking salt on ice can make the ice melt, (lowering the temperature at which slightly melted ice refreezes).

Q: What physical interaction is taking place?

2.) Does a watched pot never boil?

Q: If watching involves removing the lid from a pot and leaving it off, what affect will this have on time until boiling and boiling temperature?

Challenge Question:
1.) If you cap a tube filled with water and keep one end in a filled bucket on the ground, how high can the tube be raised before water begins flowing down the tube?

2.) The moment water begins to flow down, what is the pressure between the cap and the water's surface at the top of the tube? What affect will this have on the water?

3.) If the tube is held stationary at this height, what tool have you just created? (Hint: What would cause the water's level to vary?)

QQ Solutions:
1.) These processes illustrate colligative properties, and involve the interaction between water molecules and separated ion particles from the salts. In part, the particles act as a barrier blocking the flow of water molecules to gas, and in part the ions attract water molecules by allowing a lower energy level from the increased entropy of the water/foreign particle interaction.

There are many ways for salt particles to be arranged next to water molecules, and an increase in possible arrangements actually lowers the system's energy. (Entropy is the number of arrangements/states allowed and more molecules means more arrangements possible.) Higher entropy means lower energy, so the system will seek the lowest energy possible and keep more water molecules in liquid form.

> Entropy is quite fantastic; it ties together concepts of probability and concepts of energy such that the state of lowest energy is the state of greatest probability. So closely are these concepts related that increasing probability, in a seemingly purely numeric fashion, actually lowers a system's energy. Colligate properties are dependant only on the number of particles, not the type of particles or the bonds they are capable of forming: i.e. many particles lead to many probabilistic states and apart from all other physical interactions this probability lowers the system's energy.

For ice, molecules transitioning to the liquid state become somewhat trapped in a water/salt solution with higher entropy than exists for pure water. Re-entering the solid/pure state requires a larger reduction in energy than would be necessary for pure water, so the freezing temperature drops.

2.) A watched pot boils faster, but cooks slower. Removing the lid allows high-energy vapor molecules to exit the system and lowers the vapor pressure. A lower vapor pressure makes it easier for water to boil and lowers the boiling temperature, thus the water boils faster.

Covering a pot slows the escape of high-energy molecules, keeping the system's temperature and energy higher for a given energy input than it would be if left lidless. Because of this, food in the uncovered/watched pot will cook more slowly.

Challenge Solution and Discussion:
1.)

- To demonstrate the water column MAP has a long section of clear plastic tubing, a five gallon bucket, and is looking to procure a suitable cap.
- Walking the tube up a large flight of stairs with some central space is ideal - this will require about three flights of stairs, or can be done at nlight by climbing out the service hatch and onto the roof.

Explanation: At all times, atmospheric pressure is pushing down on the surface of water in the bucket. By keeping one end of the tube in the bucket this pressure is transmitted to the water in the tube.

At ground level, the water in the tube will be pushing against the cap with pressure equal to one atmosphere. As the tube is raised atmospheric pressure keeps it filled, and atmospheric pressure is sufficient to push water up to a height where the pressure at the base of the tube, a vertical column of water, is equal to atmospheric pressure. At this point the net weight of water in the vertical tube is equal to the net weight of atmosphere in a vertical column over the bucket and the system has reached equilibrium.

Solution:

Atmospheric pressure at sea level = 1atm = 101,325Pascal, 1 Pa = 1 $^{kg}/_{ms^2}$.

Pressure in the tube = ρgh, where ρ=1000kg/m^3 for water, and h = height of water above the point where pressure is measured.

$$101{,}325\,^{kg}/_{ms^2} = (1000kg/m^3)(9.8m/s^2)(h) \rightarrow h = 10.34m \sim 34ft.$$

2.) When the tube reaches a height of 34ft, atmospheric pressure can no longer push the water higher and this lack of pressure creates a vacuum between the cap and the water's surface.

- This is actually one way vacuums were produced for study in the 1600's.

Atmospheric pressure, from gaseous water molecules, contributes in keeping liquid water from transferring to the gas phase. As some molecules become gas others become liquid, and a balance is maintained. As pressure decreases, the vapor pressure from gas molecules also decreases, promoting transition from liquid to gas phase.

- This affect appears as a drop in the boiling point. One example is the relatively speedy boil that camping stoves can produce at high altitude.
- For the tube/water system, the vacuum greatly depresses the boiling point, such that the water at the top will boil even at room temperature.
- As more water molecules enter the gas phase they reestablish vapor pressure, and the boiling slows.

3.) If the tube is held stationary, in equilibrium, with a slight space between the cap and the water's surface, variations in atmospheric pressure will cause a measurable variation in the water's height. Higher pressure will force more water in and raise the column, lower pressure will do the opposite.

- Evangelista Torricelli noticed that this variation represented change in atmospheric pressure, and applying it thus in the early 1600's, the barometer was born.

In 1644 a friend of Torricelli created the same apparatus using mercury instead of water. Since mercury is 14 times as dense, the column's height is 1/14th that of water when mercuric pressure equilibrates with atmospheric pressure.

- This more conveniently sized barometer became popular, and measuring change in pressure as millimeter variations in height of the mercury led to mmHg as a common unit for pressure.