A Model of Matter: Part 5

We've been talking about evaporation. Last week we left you with these questions:

1. **What do you observe as you watch a container of water being heated?**
2. **What do you observe as the water begins to boil?**

Heating water is a common occurrence; almost everyone has observed it at some point, whether making pasta, preparing tea, sanitizing baby bottles…

We can explain much of this process with our model of matter (tiny particles in motion). However, there are also some major misunderstandings that revolve around heating water, both for students and adults. Let's first look at what's happening; then we'll examine some pervasive problems.

The process

We'll start with a beaker of water at a temperature just below room temperature, then heat it at a constant rate. What do we observe?

1. Temperature increases until it reaches about 100^{o} C. It remains at that temperature until all of the liquid water has evaporated
2. Bubbles form.
   - Where do they first form?

     If the liquid water is heated slowly and not moved or shaken, typically bubbles form along the sides of the container. These are bubbles of air that form as the liquid water

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is warmed from the outside. Because the **solubility** of gases in liquids *decreases* with increasing temperature, some of the air dissolved in the water comes out of solution. So the bubbles that form along the sides of the beaker are filled with air.

- Where do they form next?

When the liquid water reaches its boiling point, bubbles usually form at the bottom surface of the container then float to the surface of the liquid and break. (In our daily lives, we recognize this as "boiling" and know it's time to add the pasta.)

- What is in them?

What's in the bubbles when water boils? It's *not* air, as we saw earlier, when the water was being heated slowly. When the water begins to *boil*, **water vapor** is in the bubbles. The temperature of some of the liquid water has increased enough for it to change phases and become **water vapor**.

- What happens to the water vapor bubbles?

Why do water vapor bubbles form where they form and go where they go? Bubbles form where a surface is in contact with the water; often, this is an imperfection on the container or impurities in the water. This is called a **nucleation site**. Bubbles rise to the surface because they are less dense than the liquid water that surrounds them. [1]

3. The liquid water moves around the beaker. Remember, our model of matter indicates that all the tiny particles are in motion, and they move faster at higher temperatures.

The problems

We may be able to explain the process of boiling water with our model of matter, but there are difficulties here for students. Let's look at a couple of the problems that students face:

1. The first area to discuss is a common misunderstanding: what exactly is that "white substance" that forms above boiling water? What state of matter is it? Gas or liquid?

   That "white substance," which we commonly refer to as "steam," is a liquid, not a gas. It's much like a cloud in the sky: condensed water droplets. When we observe boiling water, the actual water vapor is invisible. Take a look at the picture of a teapot.

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*There is a seemingly "empty" spot between the surface of the water and the puff of "steam." That spot is actually not empty at all; it is **water vapor** formed as water evaporates. (Remember…we just talked about those bubbles of **water vapor** we see as water boils. When the bubbles reach the water's surface, the water vapor goes into the air.) As the water vapor condenses, it changes state to a liquid and becomes what we ordinarily call "steam."*

This confusion is widespread among people of all ages, and it is enhanced in this Internet age: it's on a lot of websites. There are many that cover the topic correctly, but many don't. In addition, a number of websites are not specific when they use the word "steam." This can reinforce the muddle, since the sites do not recognize and address the misconstruction. Following are just a few websites and quotes that illustrate this web-supported problem:

- http://www.nationalgeographic.com/education/windows/ax/pdf/wherewater-tg.pdf
  - "Learning that steam is a visible form of water vapor"
- http://www.ces.ncsu.edu/depts/fourh/RiversEdge/leaders/lesson5.html
  - "As the water-bearing warm air rises, it cools and a cloud of water vapor forms, just like the clouds of water vapor that are formed when you boil a kettle of water."
- http://www.iit.edu/~smart/lordbar/lesson6.htm
  - "Discuss different forms of visible water vapor such as steam rising from a hot dinner or out of a tea kettle."
- http://pd.l2l.org/success/lessons/Lesson11/ISCa4_L.HTM
  - Stress that the rising steam is the *evaporation* of water from the liquid, the drops on the spoon are *condensation* of the water vapor, and the falling drops are *precipitation.*

2. The second difficulty comes as, yet again, we perceive a difference between the scientific definition of a term and its everyday meaning.

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In an ordinary context, we call the cloud of water droplets that forms *from* condensed water vapor "steam." Yet, in science, steam is actually a *type* of water vapor: very hot water vapor. This is where the steam in steam engine comes from:

> *"Fuel such as coal or wood is burned to make fire. Heat from the fire passes long tubes in the boiler that is surrounded by water. The heat converts the water into steam, which collects at the top of the boiler and is passed along pipes into cylinders.[2]"*

What we *commonly* call "steam" is referred to as "condensed water droplets" in a *scientific* context.

It is essential that students understand that there's a difference between the substance they commonly consider steam and the superheated water vapor within the realm of science. The understanding that words have different meanings depending upon the context can be helpful in correcting the misunderstanding of the state of steam as discussed in the first problem above.

Coming up

We'll continue discussing how our model of matter explains changes. We've looked at evaporation; now we'll examine another phase change: melting. In the meantime, consider this

> You have a glass of ice water with two cubes of ice in it.
>
> What is the temperature of the water:
>
> - with both cubes in it?
> - after one ice cube has melted?
> - immediately after both cubes have melted?

What do the New York State standards say?

In the Elementary Core Curriculum, Standard 3, The Physical Setting,

Major Understandings state:

- 3.1c Objects have properties that can be observed, described and/or measured: length, width, volume, size, shape, mass or weight, temperature, flexibility,

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reflectiveness of light.

- 3.2b Temperature can affect the state of matter of a substance.

In the Intermediate Core Curriculum, Standard 3, The Physical Setting,

Major Understandings state:

- 3.1a Substances have characteristic properties. Some of these properties include color, odor, phase at room temperature, density, solubility, heat and electrical conductivity, hardness, and boiling and freezing points.
- 3.1d the motion of particles helps to explain the phases (states) of matter as well as changes from one phase to another. The phase in which matter exists depends on the attractive forces among particles.
- 3.3b Atoms and molecules are perpetually in motion. The greater the temperature, the greater the motion.

[1] This visual process of boiling lets us know when liquids are very hot. However, in a phenomenon known as **super heating**, a liquid can actually heat *past* the boiling point with no bubbles forming. Therefore, a liquid can be far hotter than it first appears. It's possible for this to happen on a stovetop, but it's more likely in a microwave. Why? Here's some information from: [1]http://www.wcsscience.com/boilovers/explained.html

[2] *"When you boil water on a **stove**, you will see bubbles streaming from various places on the bottom of the pot. Some parts of the water are reaching the boiling point before others; tiny scratches inside the pot give bubbles of gas released from the water a place to get started (process called '**nucleation**'). Because the heat is coming from the bottom, convection currents keep the water constantly in motion, so that all of it eventually gets a chance to boil.*

*In a **microwave**, however, the water stays relatively still, since it is heated everywhere at once. If you heat water in a smooth cup, there may be no places for bubbles to attach themselves. All of the water gets hotter and hotter, without boiling. In fact, the water temperature can actually get **higher than** the boiling point without the water boiling ... As soon as you add instant coffee to this superheated water, you suddenly provide thousands of particles to which bubbles can attach, and instantly all of the water begins boiling.*

*In fact, if your cup of water has been superheated without boiling, **any** disturbance, even putting the cup down on the counter, may be enough to trigger instant boiling... Flash boiling can empty the cup, spraying boiling water…"*

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[2] http://www.stormloader.com/ironhorse/steam.html

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