A Model of Matter: Part 7

Last week we looked at frozen water in light of our model of matter (tiny particles in motion). We wondered about the nature of thermometers:

- Could we ever use a thermometer filled with water instead of mercury?
- What are the benefits and limitations?
- What other liquid(s) can be used in a thermometer?
- How can we explain the choice of liquid using our model of matter?

The nature of thermometers

To examine these questions, we need to step back and examine a more general question:

- ***What physical property of liquids is the basis of common thermometers?***

The answer: ***expansion of liquids.***

Most substances expand with heat and contract with cold. So consider this: in a mercury thermometer, the mercury is expanding in a confined space, so it is pushed up the capillary (the small tube through which the mercury moves). However…

- ***If both the capillary and the mercury expand on heating, why is the mercury pushed up the capillary****?*

The answer: ***difference in expansion***.

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In order to see a change in a thermometer scale when there is a change in temperature, whatever the capillary is made from must expand *less* than the liquid within it. That has necessitated using a fine tube in which to place the liquid, so we have a glass capillary holding, usually, mercury or, now more commonly, alcohol.

The amount that fluids expand varies; expansion is one of the properties of a fluid. This is identified as the **volume coefficient** or **coefficient of cubical expansion**. Scientists look at how much a specific volume (often cubic centimeter) of a fluid expands for each 1 ^{o}C increase in temperature. The following are the coefficients for some materials that have been used in thermometers:

Fluid	Volume coefficient
Alcohol (ethanol)	.001120
Water (room temperature)	.000207
Mercury	.000182
Glass (ordinary)	.000027
Glass (Pyrex)	.000009

You can see that there are slight differences in expansion among alcohol, water, and mercury. The glass that is used to encase the liquids, whether ordinary or Pyrex, expands a great deal less. This is why the thermometer is such an accurate measuring tool: the great majority of change we see registered is due to the movement of the liquid within the glass, not to variation of the glass itself.

Looking at these substances raises the questions: Historically, what liquids were used in thermometers, and why?

The history of thermometers

Over the centuries, advancements in technology made it necessary to measure temperature. Working with "new" materials such as metals required some sort of control when heating a substance, but in order to "control temperature you need to be able to measure what you are controlling." [1] Some highlights in the development of thermometers:

1. Innovators attempted to mark changes between hot and cold using air and water contraptions. These **thermoscopes** consisted of "a column of air in a tube with one end in a container of coloured water."[2] A **thermoscope** has no scale and, therefore, only

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indicates a higher, lower, or equal temperature; it cannot measure the amount of difference. The rise of the liquid in the tube is due to the warming and expansion of the air in the **thermoscope**. When warmed, the air expands in a confined space, increasing the pressure on the surface of the liquid, which, in turn, pushes the liquid up the tube. View a thermoscope at http://brunelleschi.imss.fi.it/genscheda.asp?appl=SIM&xsl=catalogo&indice=54&lingua=ENG&chiave=404007

2. Galileo is often credited with inventing the first thermometer in the late 1500's-early 1600's.[1] (The credit to Galileo, however, is by no means universal and has sparked debate.) A thermometer works very simply: the liquid expands into a confined space.
3. By the mid-1600's, sealed thermometers, independent of air pressure, were introduced.
4. Most authorities agree that in the early 1700's, Daniel Gabriel Fahrenheit (yes, THAT Fahrenheit) invented the first mercury thermometer. He is also often credited with inventing the first alcohol thermometer, but this, again, is not universal recognition.

Scientists experimented with a variety of liquids in order to find the one that safely allowed for a wide range in temperature to meet a variety of needs. If we compare common fluids[3], we see clear differences in their ranges from freezing to boiling. Once a fluid approaches either of these extremes, it is no longer possible for the tool to gauge accurately.

Fluid	Freezing/melting ^{O}C	Boiling ^{O}C
Water	0	100
Alcohol (ethanol)	-114	78.5
Mercury	-39	357
Oxygen	-218.4	-183

You can imagine that, depending upon the requirements, alcohol and mercury both provide a wide range. However, the Environmental Protection Agency (EPA) has recognized mercury in thermometers as "a significant source of mercury to the environment."[4] The EPA recommends replacing them with safer thermometers (e.g., alcohol or digital electric) and deposing of mercury thermometers in a "hazardous waste collection."[4]

In any case, the invention of thermometers made it possible to accurately control temperatures, enabling (among other things)

- Further explorations and explanations of the natural world

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- Ability to control temperature accurately
- Greater advancement in technology

More for students

Here's a common experiment[5] that's designed to allow students to create their own thermometers.

But consider this:

1. How do we define a **thermometer**?
2. What must it do?

Materials:

- Tap water
- Rubbing alcohol (**do not drink this**)
- Clear, narrow-necked plastic bottle (11-ounce water bottles work well)
- Food coloring
- Clear plastic drinking straw
- Modeling clay

Procedure:

1. Pour equal parts of tap water and rubbing alcohol into the bottle, filling about 1/8 to a 1/4 of the bottle.
2. Add a couple of drops of food coloring and mix.
3. Put the straw in the bottle, but don't let the straw touch the bottom (**DO NOT DRINK THE MIXTURE**).
4. Use the modeling clay to seal the neck of the bottle, so the straw stays in place.
5. Now hold your hands on the bottle and watch what happens to the mixture in the bottle.

Our Analysis:

By definition, a **thermometer** has a scale that allows the reader to note degrees of difference between temperatures. It was this need that prompted scientists to move beyond thermoscopes and invent thermometers. The website that this version of the experiment is taken from *does* include the following caveat, but not all sources do:

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"Of course, in order to accurately read the temperature, you will need to buy a real thermometer that is carefully calibrated for temperature changes. This one is to see how a thermometer works -- just for fun." [5]

Coming up

For several weeks we've been discussing our model of matter (tiny particles in motion) in terms of evaporation and melting. Student investigation of these topics can enhance understanding of the concepts involved and get beyond rote memorization. Think about this:

What things should teachers consider when helping students design scientific investigations?

Answer:

1. Consider identifying the question
2. Consider scoring the question

What do the New York State standards say?

In the Elementary and Intermediate Core Curricula, Standard 1, Scientific Inquiry,

Key Ideas state:

1. The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.
2. Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures…
3. The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

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, reflectiveness of light.

2.1d Measurements can be made with standard metric units and nonstandard units.

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

3.2c Changes in the properties or materials of objects can be observed and described.

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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.

3.1c 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] http://www.capgo.com/Resources/InterestStories/TempHistory/TempHistory.html
[2] http://www.guardian.co.uk/weather/Story/0,2763,1013366,00.html
[3] All but oxygen has been used in thermometers.
[4] http://www.epa.gov/region1/eco/mercury/spillstherm.html
[5] This version is from http://www.energyquest.ca.gov/projects/thermometer.html

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