How_Cold_is_Cold:_What_is_Temperature?

Hi. My name is Rick McMaster and I work at IBM in Austin, Texas. I'm the STEM advocate and known locally as Dr. Kold because of the work that I do with schools in central Texas.

Think about this question. Was it cold today when you came to school? Was it hot?

We'll come back to that shortly, but let's start with something that I think we would all agree is cold, ice. Here's a picture of a big piece of ice. An iceberg, in fact. Now take a few minutes to discuss how much of the iceberg you see above the water, and why this happens.

Welcome back. The density of water is about 0.92 grams per cubic centimeter, and sea water about 1.025. If we divide the first by the second, you see that about 90% of the iceberg is below the surface, something for a ship to watch out for.

Why did we start with density and not temperature? Density is something that's a much more common experience. If something floats in water, it's less dense than water. If it sinks, it's more dense. That can't be argued.

Let's take a little more time to talk about water and ice because it will be important later. So why is ice less dense than water? The solid form of water forms hexagonal crystals with the Hydrogen atoms shown in white, forming bonds with neighboring Oxygen atoms in red. With the water molecules no longer able to move readily, the ice is less dense and the iceberg floats. We'll talk more about the one reason this is important to you later.

You've probably held a piece of ice and I expect that most of you think it's cold. Here are a few terms that people use to describe the reaction to perceived temperatures. Discuss in your class what these words mean and how they might vary on where you have lived. Your teacher will have a short experiment for you to do in class. I'll do the same while you try the experiment in your classroom.

Let's just take a look at the temperatures I have. My ice water bath is at zero Celsius. My intermediate is at 20 Celsius. And my hot water is at 45 Celsius.

Did you all agree on what the different words mean in terms of temperature? Probably not. And how about if somebody came from a different location, with a different climate? Would they have the same interpretation? How did you react to the three different waters?

If I put my hand in the ice water, leave it for a few minutes, and then transfer it to the middle container, the water feels warm. On the other hand, if I go with the warm water first, and then move it to the middle container, the water feels cool. So it's really a relative term in terms of the words that we're using to describe temperature.

Our perception of temperature also depends upon how quickly heat moves either to or from our body to the subject that we're touching. Air at 80 degrees will feel quite different than water at 80 degrees, or metal, or plastic. So the whole concept of temperature becomes very important to us. Discuss why we need temperature scales and I'll see you in a few minutes.

Let's discuss what temperature is. It's tied directly to how fast, on the average, that particles are moving. Their kinetic energy.

In a gas or a liquid, they are moving around freely. In a solid, they're vibrating.

What you see on the screen is a simulation of particles in a gas moving about. If they move faster, the temperature is higher. Slower, the temperature is lower.

Your teacher has an excellent reference to “What exactly is temperature”. It has more details about temperature.

There are two common temperature scales in use in the world, Celsius and Fahrenheit. Only the US and Belize use the Fahrenheit scale. The Celsius scale has the advantage that there are 100, or 10 squared, degrees between freezing and boiling water at standard pressure. Powers of ten make things much easier.

Most of you know the formula that relates these to temperature scales, but with your teacher, use the data given on the screen to derive the formula. And also determine at what temperature the two have the same numerical value. See you soon.

Many people memorize the formula that relates Fahrenheit to Celsius. F equals 9/5 C plus 32. But who needs to memorize that? You know that the temperature difference between freezing water and boiling water is 180 degrees Fahrenheit and 100 degrees Celsius. That's the same as 9/5 times C.

At zero degrees C, the temperature in Fahrenheit is 32. So we just add 32. So if you remember the boiling and freezing points of water on both temperature scales, you don't need to memorize the formula.

And how about that other question? We said F equal to C in the formula, and solve to get C. We get C equals F at negative 40.

Let's move on to some other temperatures. You can see a range here starting with the hottest recorded temperature on the surface of the Earth, and working down to the coldest. I've rounded off most to the nearest degree.

Time for some more questions to discuss. What is dry ice and why is it called dry ice? What do you think will happen if I drop some in soapy water?

Dry ice is the solid form of Carbon Dioxide. Why is it called dry ice? It's called dry ice because it goes directly from a solid to a gas. It sublimates.

So what happens if I drop some in some soapy water? Let's give it a try. We'll add a little bit more.

As you can see, bubbles are forming that have a combination of Carbon Dioxide and water vapor inside of them. So I can actually pick them up.

Luckily dry ice is denser than water, so it sinks to the bottom. That allows me to act like a mad scientist should I want to do that. We put just a little bit of dry ice in here, it sinks the bottom. We have a smoking liquid which is just carbonating the water. And so I can drink it.

So I do have to be very careful in handling the dry ice because it is so very cold. So I handle it with tongs or with a glove, so it is not in direct contact with my skin, where it can cause instantaneous frostbite. The only reason I'm able to do this is the dry ice is denser than water and sinks to the bottom. And I'm careful only to do things on the surface of the water.

Notice that we have negative temperatures on both the Celsius and Fahrenheit scales. Remember what we said earlier about temperature. It is a measure of the average kinetic energy of the particles.

So we need another temperature scale that starts at zero and is only positive. Absolute zero is determined through the fundamental laws of thermodynamics as negative 273.15 degrees Celsius, negative 459.67 degrees Fahrenheit.

There are two absolute scales. The Kelvin scale, based on the Celsius increments, and the Rankine scale, based on Fahrenheit increments. The Kelvin scale is used more often in science and engineering.

Now that we've introduced the Kelvin scale, let's look briefly at some of the very cold, or cryogenic, liquids. We'll start with the noble gas Xenon that boils at 165 Kelvin. Krypton, at about 120 Kelvin, Oxygen, which makes up about 21% of our atmosphere, 90 Kelvin. Argon, 87 Kelvin. Nitrogen, which is about 78% of our atmosphere, 77 Kelvin. Neon, 27 Kelvin. Hydrogen, 20 Kelvin. And Helium, at 4.2 Kelvin under one atmosphere.

This is Helium-4. The much rarer Helium-3 isotope boils at 3.2 Kelvin. Helium has a unique property that it remains a liquid under its own vapor pressure. Any other liquid will freeze at some point when its vapor pressure is sufficiently reduced.

We'll add liquid Nitrogen and liquid Helium to our list of temperatures. Before we leave the discussion of temperature scale, let's mention a few more that are useful for specific applications, and acknowledge the scientist for which each is named.

Let's start with Fahrenheit. This temperature scale was proposed in the early 1700's by the Dutch and German polish physicist Daniel Gabriel Fahrenheit. Swedish astronomer Anders Celsius developed the temperature scale on which water boiled at zero and froze at 100. It was reversed by Carl Linnaeus, but is named after Celsius.

The Kelvin scale was named after the Belfast born engineer and physicist William Thompson, or Kelvin, who wrote of the need for an absolute, thermometric scale. The Rankine scale is named after the Scottish engineer and physicist William John Macquorn Rankine.

There are four more that we will discuss briefly. The Delisle scale was invented in 1732 by the French astronomer. Delisle chose his scale using the temperature of boiling water as the fixed point zero and measured the contraction of mercury with lower temperatures in hundred thousandths. The Delisle thermometer remained in use for almost 100 years in Russia.

The Newton scale is a temperature scale devised by Sir Isaac Newton. He took a container of linseed oil and measured its change of volume against his reference points. He found that the volume of linseed oil grew by 7.25% when heated from the temperature of melting snow to that of boiling water. He then defined the zeroth degree of heat as melting snow, and 33 degrees of heat as boiling water.

The Reaumur scale defines the freezing and boiling points of water as zero and 80 degrees respectively. Its only modern use is in measuring of milk temperature and cheese production.

Finally, the Romer scale was named after a Dutch astronomer who proposed it in 1701. The zero was initially set using freezing brine. The boiling point of water was defined as 60 degrees.

Here's a comparison of the eight temperature scales graphically with some of the points marked that we've already discussed. As you can see, there are two absolute scales, Kelvin and Rankine. The Celsius and Kelvin scales are parallel, as are the Fahrenheit and Rankine. Only the Delisle scale has a negative slope, as expected.

One cup contains very hot water, and the other one liquid Nitrogen. How can I determine which is which by just looking at them from a distance? Discuss in your class and we'll see you in a few minutes.

So how can I tell the hot liquid from the cold liquid? In the case of the hot liquid, the hot vapors rise from the cup. In the case of the cold liquid, the vapors coming off sink. The hot vapors are less dense and rise, the cold vapors are denser than the air, and they sink. That's how I could tell the difference between the two.

Welcome to the teacher's guide for the BLOSSOMS video, how cold is cold: temperature? Temperature can be a challenging concept to convey, since our perception is tied to the words that are relative to our experience and varies quite a lot.

The first segment gives us a commonplace start, solid H20, or ice. We don't start with the temperature of the ice, but rather its density, which you can readily see in comparison to the surrounding water. If the students are not yet familiar with Archimedes principle, you can briefly discuss it after the first segment.

Density is something that is more obvious. Ask your students how many have picked up something, expecting it to weigh a certain amount, but found that it was much heavier or lighter.

In part two of how cold is cold: the properties and materials, we talk about the expansion of water and why that's an important consideration in handling dry ice, liquid Nitrogen and other cryogenic liquids. In segment two, we introduced some of the common terms that are used to describe temperature. I suggest that you discuss the terms and what they mean among the students before trying the activity.

The absolute temperatures of the water in the three containers are not important, other than making sure there is no danger of burns from the water that is too hot, or pain from water that is too cold. Having one bath slightly above freezing, and one at about 45 centigrade, with the center one near the midpoint, should allow the students to experience a relative terms of warm and cool.

Make sure to have plenty of dry towels for the students. After the cold and hot water activities, the students should be ready to discuss why temperature is important.

Segment three starts with a discussion that it is not only the temperature of an object, but how fast heat flows to and from our body, that determines what we call hot or cold. The class can also discuss how many temperature scales there are.

Most will be familiar with Celsius and Fahrenheit since they are in common usage. Kelvin will also be known to most, but it is rare to go beyond these three.

In segment four, the concept of temperature as a measure of kinetic energy is introduced, as well as temperature scales. The reference link on the BLOSSOMS page for this lecture is an excellent-- and provides some detail beyond what is discussed in the video.

Encourage your students to derive the formula that relates Celsius to Fahrenheit rather than just writing it down from memory. Solving the other part of the problem should be an easy algebra problem for most of the students.

In segment five, after discussing the questions, we introduced some other common temperatures, stopping with dry ice for a discussion of what it is, and what happens when it is dropped in some water. Dry ice is not readily available everywhere, but if you decide to bring it into the classroom, please be very careful in handling it with gloves or tongs, and ensure the students are properly cautioned as well.

Most students will know the transition from a solid to a gas is sublimation. You can discuss the reverse, which many will not know as deposition. Encourage some creative thinking on what will happen when the dry ice is in the soapy water.

In the next segment, dry ice is discussed, and what happens to it in water is demonstrated. Then we move to the concept of absolute zero and add the Kelvin scale to the slide show.

The temperatures of some cryogenics liquids are discussed and various temperature scales are introduced. With the formulas given, you can explore the numerical values in which each of the various temperature scales cross.

The final question is how to tell from visual observation alone, which cup contains hot water and which contains liquid Nitrogen. The second BLOSSOMS video, how cold is cold, properties and materials, picks up at this point.