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Hot Enough for You? Scientists Ask, Fast Enough for You?

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Today, temperatures in New York City are expected to be in the 90's, and most New Yorkers will think of the temperature as a warm, soggy, sensation on the skin.

Physicists have a different notion. To them, temperature is, in a simple sense, speed. "It's some measure of the random motion of the various degrees of freedom," said Dr. Robert J. Schoelkopf, a professor of applied physics at Yale.

For example, molecules of air or water bounce into one another like the Ping-Pong balls in the machine that picks lottery numbers. The collisions transfer energy between the molecules, producing a bell-curve distribution of speeds, and the average kinetic energy of the molecules corresponds to temperature. While the speeds of individual molecules constantly change, the distribution of speeds remains the same, determined by the temperature. The higher the temperature, the faster, on average, the molecules jostle into one another; at cooler temperatures, the molecules move more languidly.

While scientists have a precise definition of temperature, measuring it precisely is an art still being refined.

Most thermometers, including the familiar mercury thermometer invented by Daniel Gabriel Fahrenheit in the early 1700's, have been based on the fact that the jostling of molecules causes gases and liquids to expand when heated. Technological innovations have led to new types of thermometers, including those that use temperature-dependent electrical resistors or measure infrared light radiating from warm bodies. At the frontiers of science, scientists have devised techniques to take the temperatures of ultracold atoms, surfaces of distant stars and trillion-degree firestorms of colliding atoms.

Biologists have also only begun to understand how living creatures measure and regulate temperature.

Dr. Schoelkopf and colleagues at Yale have invented a thermometer that measures temperature based on electrical noise not that different from the static heard on radios. (Radio static is itself a sort of temperature measurement. Radiation left over by the Big Bang has cooled to a few degrees above absolute zero in the past 13 or so billion years, suffusing the universe in a bath of microwaves that can be picked up by microwave receivers and heard as a static hiss.)

The new thermometer, described last month in the journal Science, consists of two pieces of metal on a silicon chip separated by a thin strip of insulator. Under the strange rules of quantum mechanics, electrons can occasionally hop back and forth across the gap — a low hiss of electrical noise. With rising temperatures, electrons bounce off one another and the atoms in the metal with more momentum, producing more electrical noise. The loudness of the noise thus gives the temperature.

That idea is not new but until now such thermometers have needed to be carefully calibrated.

The innovation of Dr. Schoelkopf's group is to apply a voltage that pushes a number of electrons across the gap, regardless of the temperature. That allows the thermometer to calibrate itself.

"It has a certain simplicity, which is attractive," said Dr. Wes Tew, a physicist at the National Institute of Standards and Technology in Gaithersburg, Md., who was not involved with the research.

The device's simplicity and accuracy over a wide temperature range could make it useful as a reference thermometer, especially at ultracold temperatures.

The study of heat goes back at least as far back as the second century B.C. when an engineer named Philo of Byzantium observed that gases expand when heated and contract when cooled. Galileo Galilei is generally credited as the first to turn this observation into a thermometer around 1600. But while early crude thermometers could measure relative rises and falls in temperature, the lack of a universal temperature scale made it difficult to compare readings of different thermometers.

Fahrenheit, the German physicist who invented the mercury thermometer, devised the temperature scale still in use in the United States, setting the freezing point of water at 32 degrees and the boiling point at 212 degrees. Anders Celsius, a Swedish astronomer, set up a competing temperature scale in reverse, putting the boiling point of water at zero degrees and the freezing point at 100 degrees. Others later inverted the scale, putting the freezing point at zero and the boiling point at 100.

Experiments showed that under constant pressure, any gas steadily shrinks in volume as the temperature drops. In 1848, a Scottish chemist, William Thomson, later Lord Kelvin, realized that extrapolating this trend, the shrinking gas would disappear entirely at about minus-273 degrees Celsius, and he proposed a new temperature scale that defined the new zero as the temperature where the gases would disappear.

Because temperature is a measure of speed, this coldest possible temperature, known as absolute zero or minus-459.67 degrees on the Fahrenheit scale, is where everything comes to almost a complete stop.

Scientists have since refined the temperature standard several times. Because the boiling and freezing points of water vary with altitude, the Kelvin scale is now set by the triple point of water — a precise temperature and pressure where ice, liquid water and steam coexist. The triple point is, by definition, 273.16 kelvin. "That's the only temperature we know," Dr. Tew said. "All the other temperatures must be experimentally determined."

In the latest tweaking of the standard in 1990, water at one atmosphere's pressure no longer boils at exactly 100 degrees Celsius, but 99.974 degrees (or in Fahrenheit, the boiling point is no longer 212 degrees, but 211.95 degrees).

To help people calibrate thermometers, the standard offers 17 well-measured temperatures including the triple point of hydrogen (minus-434.8 degrees Fahrenheit), the melting point of gallium (85.6 degrees Fahrenheit) and the freezing point of copper (1,984 degrees Fahrenheit).

Dr. Schoelkopf has begun testing his noise thermometer against some of the standard temperatures. He believes that it should work for temperatures ranging from very cold — about one-hundredth of a degree above absolute zero — to room temperature, although accuracy tails off at the upper end of that range. "We can try to see what the limits of our thermometer are," he said.

But the noise thermometer, or indeed any other thermometer, is useless for experiments where physicists cool atoms to a few billionths of a degree above absolute zero. It would be impossible to cool a thermometer to the temperature it was trying to measure. "We're talking really, really cold," said Dr. William D. Phillips, a physicist at NIST who shared the Nobel Prize in Physics in 1997 for developing techniques to cool atoms with lasers.

Instead, physicists revert to the notion of temperature as speed. They turn off the electromagnetic fields that trap the atoms and then a short time later, shoot a flash of laser light to illuminate the size of the expanding cloud. "That will give you a good measure of what the velocities of the atoms are," Dr.

Phillips said.

At the high end of the temperature spectrum, astronomers use a different trick. Since they cannot stick thermometers into distant stars, they take advantage of a property of matter: heated, it emits light. The distribution of wavelengths of emitted light follow a characteristic bell curve, but the peak shifts depending on the temperature. The peak wavelength of light from the sun, for example, is green, which corresponds to a surface temperature of about 10,000 degrees Fahrenheit. The hiss from the cosmic background microwaves tells the average temperature in the universe: minus-454.8 degrees Fahrenheit, a few degrees above absolute zero.

Ear thermometers that measure body temperature work by the same concept. People also emit light, but at longer infrared wavelengths not visible to the human eye. A sensor in the thermometer scans for the peak wavelength of infrared light, which tells the temperature of the ear drum area. The ear drum shares the same blood vessels as the hypothalamus, the region of the brain that regulates body temperature.

No one yet knows how internal thermometers work, and only in the past few years have biologists begun to understand how the body senses external temperatures.

In 1997, researchers led by Dr. David J. Julius, a professor of cellular and molecular pharmacolocy at the University of California at San Francisco, were the first to identify a protein used as a temperature sensor by nerve cells. At temperatures above 108 degrees Fahrenheit, the protein, which threads several times through the cell wall, opens a pore to let in sodium, calcium and potassium ions. The ions charge up the nerve cell, which then fires a message of pain to the brain.

"Most mammals, certainly humans and primates, have a pretty well-defined threshold for where hot stimuli become noxious," Dr. Julius said. (The same protein responds to capsaicin, a molecule in chili peppers, producing the fiery taste.) Three other proteins that detect various degrees of warm and hot have since been found.

A couple of years ago, Dr. Julius isolated a protein that sends sensations of cool at temperatures below 77 degrees Fahrenheit.

In March in the journal Cell, Dr. Ardem Patapoutian, a professor of cell biology at the Scripps Research Institute in San Diego, reported finding a protein receptor that detects painfully cold temperatures below 59 degrees Fahrenheit. Dr. Patapoutian's group has spliced the gene that produces this protein in other types of cells like hamster ovaries that then became sensitive to cold.

In the Cell paper, Dr. Patapoutian quoted from a John Updike essay: "Cold is an absence, an absence of heat, and yet it feels like a presence."

Dr. Patapoutian has been meaning to tell Mr. Updike of his research findings. "I have to send him these papers because that's how it works," Dr. Patapoutian said.

For the living creatures, cold is a separate sensation, although probably not one that will be felt today.