Letter From the Desk of David Challinor
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The U.S. Weather Bureau has reported that this is the hottest summer yet recorded on the east coast. There have been other summers almost as hot while at the other extreme we find the infamous year (1817) "without a summer." During 1817 New England had snow in all 12 months because of an enormous volcanic eruption in the East Indies. Heat and cold affect us greatly; this month's letter is about temperature and how it came to be measured.

Early in human history people began to measure space such as distances between two points. Markers were commonly used along the roads of ancient Greece, and scholars such as Eratosthenes in 3 BC had measured with reasonable accuracy (5%) the radius of the globe. Aristarchus in the same century estimated, also with reasonable accuracy, the size of the sun and the moon and the distance of earth from each one.

Time, however, for the ancients was more difficult to measure, but in the 16th century hour glasses and water clocks were refined as timers. It wasn't until the 18th century that long-term accurate chronometers were developed. Dava Sobel's superb book *Longitude* describes in vivid detail the race to build an accurate chronometer and how Englishman John Harrison finally won the £10,000 prize. Accurate time was crucial for determining how far east or west of the Greenwich (UK) prime meridian a ship was positioned. The calculation of latitude while under sail was relatively easy compared to determining longitude at sea, knowledge of which was crucial for any major maritime nation. The ability to measure time correctly was indeed a milestone in human progress.

Simultaneously, with the development of accurate time came an explosion of knowledge from new instruments that refined space measurement on earth and in the heavens. In the 16th century Galileo (1564-1642) and his colleagues used the lenses developed by the Dutch eyeglass makers to observe the rings of Saturn and the moons of Jupiter through their telescopes. When Galileo was convinced Jupiter's moons were indeed revolving around the giant planet, it was time to test Copernicus's (1473-1543) heliocentric theory. This was the beginning of modern astronomy. Work proceeded apace on both macro and micro measurements. The same Dutch lens makers supplied the elements for the first microscopes that enabled the subsequent exploration of the heretofore invisible microworld.

Temperature measurement inevitably followed. Although the expansion and contraction of gases had been studied as far back as 2 BC, it was not until 100 AD that Hero of Alexandria wrote *Pneumatrics,* in which he described using a thermoscope designed to measure the change in the volume of a gas as it is cooled or heated. This tome was later translated into Latin and widely read by savants of the time. According to Gino Segrè, the author of *A Matter of Degrees* (Viking Press, 2002), there is more than one claimant for the inventor of the thermometer. Several people had the identical idea simultaneously, among them Robert Fludd, a Welshman who built a prototype thermometer after reading a 13th century account of Philo of Byzantium's description of a thermoscope, which he wrote in the second century BC. A Dutchman, Cornelius Drebble, working for King James I, is said to have built a kind of thermometer. In Italy, Galileo was involved with measuring heat when his contemporary, Santorio, took the thermoscope as described by Hero of Alexandria and added a scale to measure changes from the normal temperature of a person. He was thus probably the first person to measure systematically human body temperature. Galileo may easily have made his own crude thermometer at about the same time as Santorio, but there is no evidence that it was ever used by him for health research.

A century later Ole Römer of Denmark, who incidentally was the first to measure the speed of light, thought that water's boiling and freezing points would be a good scale for measuring temperature. His colleague Daniel Fahrenheit, a German living in Holland, adopted the idea and developed the first alcohol thermometer (1709) and, five years later, the first mercury one. Fahrenheit's scale set freezing at 32° and boiling at 212°. These odd numbers were probably chosen because he set his 0° by a mix of ice, salt and water and his 100° near, but not at human body temperature. This scale was adopted in England, in Holland for a while and in the USA.

Meanwhile, Anders Celsius (1701-44), a contemporary of Fahrenheit and a Swedish astronomer, developed a thermometer whose scale used 0° as the freezing point of water and 100° as its boiling point, both at sea level. Most of the world (especially all of science) uses Celsius or the centigrade scale for temperature measurement; Fahrenheit is retained with ever shrinking use only in the USA and Canada. These holdouts, I am sure, will eventually join the rest of the world and adopt metric and centigrade scales. We would only have to teach these measurement systems in our schools for one generation to effect a relatively painless conversion in our thinking.

The concept of heat has been a difficult one to grasp. Its nature was once considered to be a substance in material that would burn and would then be released when ignited. This argument continued well into the 19th century when scientists began to understand that heat was a form of energy. This insight led to the First and Second Laws of Thermodynamics. To remind you, the First Law postulates that heat is a form of energy and that energy as a whole is conserved. The Second Law states, as Segrè wrote, "you cannot build a machine that will convert thermal energy into mechanical energy with 100% efficiency."

To simplify: it takes energy to make atoms vibrate. The more they do so, the hotter the heat source becomes. The more heat that can be generated, the more you can alter the characteristics of the object being heated. For example, when humans first began to control fire, they probably used it to keep warm, but most anthropologists agree that using fire to cook soon followed making a much expanded source of food available. Cooked meat is easier and safer to eat than raw meat; a temperature of 160°F will kill noxious bacteria in the meat and other parasites that can harm humans. Vegetables, as well, are made palatable by cooking; for example, boiling vegetable matter can dissolve silica spicules in some plant roots (jack-in-the-pulpit bulbs) so that when cooked they can be consumed comfortably.

Early man knew that blowing on a fire made it hotter and this led to the development of bellows. Using bellows, the fires became hot enough to melt such minerals as copper and lead from rocks. Smelting metal led to alloys such as bronze (copper and tin). The Bronze Age began roughly in 3,000 BC and was followed two thousand years later by the Iron Age. Exploiting iron was an important metallurgical advance, because a temperature between 2000° and 2500°F is needed to extract iron from its ore. Smelting iron is complicated and requires more than just heat. Iron is usually mined as iron oxide; to get rid of the oxide, the ore must be heated to 1500°F by introducing more oxygen into the furnace. The free oxygen added combines with the carbon in the burning charcoal or coke fuel to form carbon monoxide (CO), which in turn removes the oxygen from the iron oxide to become carbon dioxide (CO_2). The CO_2 is carefully vented out of the furnace leaving the partially purified iron behind. To complete the process, the iron has to be heated enough to melt the impurities left at about 2500°F but not so hot as to melt the iron itself (2800°F).

The availability of these high temperatures for smelting not only triggered the Iron Age, but newly achieved heat thresholds enabled the manufacture of clay pots and glazes. This is another story, but meanwhile mankind has achieved the ability to create higher and higher temperatures, culminating in the hydrogen bomb which, if exploded, reaches almost the heat of the sun. At the other end of the spectrum is the search for absolute zero or—273° Celsius which, if we are ever able to reach it, would permit electricity to pass through wires without resistance and no friction would be generated by flowing fluids. Such an achievement is entirely theoretical, of course, as it is hard to imagine any substance staying liquid at a temperature that low.

Nonetheless, physicists are at this very moment exploring these seemingly bizarre consequences of extreme temperatures—a very active field of endeavor. Who knows what they may find? Such exploration is indeed the great attraction of scientific research, and the curiosity the field excites gives scientists enough satisfaction to keep at the task of understanding extreme heat and extreme cold.

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