Concept: Temperature

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1. Definition and Introduction

Temperature is defined as the degree of hotness of matter. It is thus a measure of the energy content that can be sensed, or the sensible enthalpy, of matter. The Zeroth Law of Thermodynamics states that when two bodies have equal degree of hotness, they are at thermal equilibrium. In the case of gases, the word temperature generally refers to the kinetic temperature, or the temperature that indicates the energy of random motion of molecules. Thus the absolute zero of temperature is taken to be that at which molecules remain still, with the speed of random motion down to zero. An upper limit on temperature might be that where the speed of random motion approaches the speed of light.

2. Thermometers and Temperature Scales

Several methods for measuring temperature were developed early, and led to the development of different scales of temperature. Danish astronomer Ole Christensen Rmer used the expansion of red wine as the temperature indicator in a thermometer he created in the seventeenth century. His zero reference was the temperature of a salt-ice mixture, 7.5 was the freezing point of water, and 60 was the boiling point of water. German physicist Daniel Gabriel Fahrenheit invented a mercury thermometer. On the Fahrenheit scale, 0 and 100 were roughly the coldest and hottest temperatures encountered in the European winter and summer. Swedish astronomer Anders Celsius invented the inverted centigrade scale, which was converted to the current Celsius scale by Swedish botanist Carl Linnaeus in the nineteenth century. Here 0 represents the freezing point of water and 100 its boiling point at standard sea-level pressure. British physicist William Thomson, also known as Lord Kelvin, devised the absolute scale in which absolute zero (0 K) corresponds to minus 273.15 C. Thus 273.16K is the triple point of water, defined as the temperature where all three states, i.e., ice, liquid water and water vapor, can coexist. Scottish engineer William John Macquorn Rankine extended the Fahrenheit down to absolute zero at minus 459.67 F.

2.1. Applications and Products

A wide variety of physical phenomena can be used to measure temperature. The basic principles come from college-level physics, including optics, and from chemistry. Volume expansion thermometers use the expansion of liquids with rising temperature through a narrow tube. This technology serves the range of variation typically encountered in weather sensing where humans live. The expansion coefficient, defined as the increase in volume per unit volume per unit rise in temperature, is 0.00018 per kelvin for mercury and 0.000101 per kelvin for ethyl alcohol colored with dye. Volume expansion thermometers work in the range from about 250 to 475 kelvins, but each thermometer is usually designed for a much narrower range for specific purposes. Greater precision is needed in measuring human body temperature. Bimetal strips and thermocouples are used for cooking thermometers. Mercury thermometers were used widely to measure room temperature as well as the temperature of the human body. Human body temperature is usually 98.6 to 99 degrees Fahrenheit, and varies only within a range of about 5 degrees either way except in cases of severe illness, trauma, or hypothermia.

Thermocouples were and are used extensively to measure temperature, using the electromotive force or voltage that is set up between junctions of two metal wires that experience different temperatures Pairs of metal wires such as Copper-Constantan, Platinum/Platinum-10% Rhodium, Iron-Constantan, are well-known thermocouple types, suitable for different temperature ranges and types of reacting environment. Their sensitivity to temperature is well-documented and stable. For higher sensitivity at fairly low temperatures, Resistance Temperature Detectors (RTDs) use the change in resistance of a material with temperature, to cause a voltage drop between points in a circuit. Tungsten thermocouples have been used to measure temperatures over 2000K.

Generally, non-intrusive optical methods of temperature measurement become attractive in environments where the temperature is above the melting point of most metals. These methods use the properties of the Boltzmann distribution of energy states. At equilibrium, the various energy levels and the states within those levels follow a Maxwell-Boltzmann distribution. When molecules in certain energy levels are excited, the energy in that level can exceed or fall below the equilibrium levels. Thus the temperature sensed by a method that is based on vibrational energy or electronic excitation level, can be different from the kinetic temperature. This leads to the definition of different temperatures as the translational temperature, the vibration temperature and the electronic temperature. It also illustrates why temperature is defined as a measure of the energy of molecular states.

At room temperature, the internal energy of most gases is divided between translational kinetic energy, and energy of molecular rotation (if the molecule has two or more atoms). As temperature of a gas rises, more energy can go into different modes of storage such as molecular vibration and electronic excitation. The dissociation of molecules absorbs a large amount of energy. Thus, as temperature rises into thousands of degrees, it takes a larger amount of energy to raise the temperature through a given difference. In other words, the specific heat of a gas rises in certain ranges of temperature. One result is that the temperature behind the shock that forms in front of a spacecraft returning to Earth from orbit, reaches only several thousand degrees, not the tens of thousands that would be predicted if energy could go only into translation and rotation. Air dissociates and gets ionized, and glows white-hot.

At the other end of the temperature spectrum, researchers have come very close to absolute zero Kelvin by stopping the random thermal motion of molecules using the pressure exerted by light from lasers. This illustrates the definition of kinetic temperature, as being proportional to the kinetic energy of translational motion of molecules.

Temperature is of course key to atmospheric phenomena and weather in particular. Small changes in sea water temperature are projected to have massive effects on the climate, and perhaps even a catastrophic rise in sea level as the polar ice-caps melt. Heating of the ocean is related to the formation of cyclonic storms, also known as hurricanes or typhoons. The temperature difference between air masses is related to the formation of tornadoes along weather fronts.

3. Notes

4. References

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