

ABSOLUTE ZERO TEMPERATURE AND THE THIRD LAW OF THERMODYNAMICS.

By

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In the last article I wrote about the laws of thermodynamics. I concentrated almost entirely on the first and second laws and merely mentioned the third law. The third law is the subject of this article. The third law concerns itself with the realm of the very cold and the concept of absolute zero temperature. The third law is not treated with the same respect as the first and second laws, and sometimes attempts are made to prove it wrong.

Let me first of all briefly state the first and second laws of thermodynamics again. The first law, the law of conservation of energy, states that energy can neither be created nor destroyed. Don't trust anyone who tries to sell you a machine that generates more energy than it consumes. The second law states that when any physical or chemical process occurs, the entropy (disorder) of the universe increases - this is because during every transformation of energy, a certain amount is dissipated and becomes unavailable for doing work. Beware of anyone who tries to sell you a perpetual-motion machine.

Heat is the most familiar form of energy, and temperature is a measure of the degree of hotness of a body. As you remove heat from a body, its temperature decreases, and if you could remove all the heat, you would have a temperature of absolute zero. The two most familiar temperature scales are the Celsius scale and the Fahrenheit scale. Water freezes at zero degrees Celsius and boils at 100 degrees Celsius. The two corresponding Fahrenheit temperatures are 32 degrees and 212 degrees Fahrenheit.

It is a relatively straightforward matter to calculate a theoretical value of absolute zero temperature. Take a fixed quantity of a gas, and measure its volume at 100 degrees Celsius. Now remove heat and measure the volume of the gas at temperatures of 75 degrees, 50 degrees, 25 degrees, zero degrees, minus 25 degrees Celsius, and so on down. Eventually the gas will liquify (e.g. at about minus 196 degrees Celsius in the case of nitrogen). Now plot a graph of volume versus temperature and extrapolate the line down to zero volume. The corresponding temperature is minus 273.15 degrees Celsius. This must be the lowest possible temperature, since it cannot be possible to go to a negative volume. The absolute scale of temperature, also called the Kelvin scale, starts at zero for absolute zero and goes upwards in absolute degree units, each equal in size to one unit on the Celsius scale. The freezing and boiling points of water on the Kelvin scale are therefore 273.15 and 373.15 degrees Kelvin respectively.

The Austrian physicist Ludwig Boltzmann defined temperature as a measure of the speed of molecules in a substance. In a hot gas, the molecules are moving about at great speed. When the gas is cooled, the molecules move about more slowly. At absolute zero, pictured in this way, molecules and atoms come to rest. Boltzmann proved that the total amount of disorder increases when heat flows from a hot to a cold body. Also, of course, in a single body, disorder generally increases as temperature rises and decreases as temperature drops. And this is where the third law of thermodynamics comes in. It was proposed in 1906 by Walther Nernst (1864-1941) of the University of Berlin, for which he won the 1920 Nobel prize in Chemistry. The quantum mechanical description of matter emerging at that time says that atoms can never come to complete rest. Even in their lowest energy state (ground state) they still 'vibrate'. This ground state energy cannot be shared with other atoms and doesn't count as heat or disorderliness.

Nernst defined absolute zero temperature in terms of absence of disorder, rather than in terms of absence of motion. The third law states that the entropy, or disorder, of a perfect crystal is zero at absolute zero temperature. Some years later when studying the amount of heat lost per increment of temperature drop as you approach absolute zero, he noted that each step is more difficult than the preceding one - temperature decreased less with each successive removal of heat. He concluded that an infinite amount of effort would be required to reach absolute zero and added a rider to the third law to the effect that a temperature of absolute zero can never be attained experimentally.

A somewhat equivalent invisible barrier to the one that prevents the experimental attainment of absolute zero is the barrier that precludes the acceleration of any material body to the speed of light. When a body accelerates, its mass increases by a small amount, but this increase becomes very significant at speeds approaching the speed of light. As the mass increases rapidly it becomes progressively more difficult to further accelerate, and an infinite amount of effort would be required to accelerate to the speed of light, which is therefore precluded.

It is not difficult to appreciate in a qualitative way why it would be impossible to reach absolute zero temperature in an ordinary lump of matter. Such a lump will contain many trillions of molecules at least, and, in accordance with the definition of temperature, at absolute zero temperature each and every molecule must be in its ground state. Even if a few molecules start to jiggle about the temperature will rise above absolute zero. It would seem to be a statistical impossibility to dragoon each and every one of such an enormous number of molecules into absolute immobility.

On the other hand, a single atom could readily fall into its ground state. Does this therefore mean that, in this instance, the achievement of absolute zero temperature is experimentally possible? Well, no, because temperature is a statistical property and depends by definition on numbers of molecules that can interact with each other. But somewhere between the single molecule and the large lump of matter is a grey area which has just enough molecules to make the concept of temperature feasible, but is still very small - objects of this size are said to be mesoscopic. Some scientists feel that it just might be possible to experimentally persuade this number of atoms to sit quietly and therefore to achieve the Holy Grail of cryogenics (low temperature science) - a temperature of absolute zero. Elaborate experiments are in place at several centres in order to try to achieve this. I am not sure what the current record of achievement of low temperature is, but some years ago it stood at 12 microkelvins, i.e. 12 millionths of one degree above absolute zero.

I will be surprised if absolute zero temperature is ever attained. In order to record the event, a thermometer will have to adjudicate. I cannot imagine how it will ever be possible to intervene sufficiently to measure the temperature without adding a tiny bit of heat and thereby inevitably 'spooking' the quarry into a last-minute getaway.

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