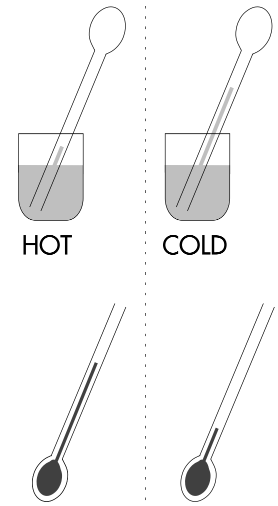
PhyzGuide: Measuring Temperature

THE THERMOSCOPE AND THE THERMOMETER



Galileo is given credit for developing the first temperature-measuring device toward the end of the 1500s. Air in a tube with a bulb at the top is heated. The open end of the tube is immersed in water or wine. As the air in the tube cools, it contracts and is drawn into the tube. Once an equilibrium point is established, a rise in temperature increases the volume of the gas, forcing fluid back down; a fall in temperature reduces the volume of the gas, drawing more fluid into the tube. This device was Galileo's *thermoscope*.

Early in the 1700's, Gabriel Daniel Fahrenheit developed a more reliable temperature measuring device. A thin glass tube holds a volume of mercury in a bulb at the bottom. When heated, the mercury expands upward in the tube. The tube could be sealed and allowed for accurate, reproducible temperature readings. Because this device could be reproduced and marked with a numerical scale, it was called a *thermometer*.

FAHRENHEIT AND CELSIUS: UNRELATED RELATIVE SCALES

As inventor of a reliable thermometer, Fahrenheit was afforded the luxury of developing a temperature scale to his liking. He defined a temperature scale on which 0 was the coldest temperature he could reproduce in the lab (the temperature of an ice-salt mixture) and 96 as human body temperature. The fact that 96 is divisible by 2, 3, and 4 made it easy to mark off increments on the glass tube between 0 and 96 once those endpoints were established. Water was found to freeze at 32 and boil at 212. Actually, the 212 was a mistaken measurement but was retained (and the rest of the scale adjusted) to preserve a subtle coincidence. Indeed the units—degrees—may arise from the fact that there are 180 increments between freezing and boiling of water. These "opposite" processes lie 180° apart on the Fahrenheit scale.

Anders Celsius, on the other hand, arbitrarily chose 100 to be the freezing point of water and zero to be the boiling point of water. This "backwards" scale was later changed so that zero represented the freezing point of water and 100 represented the boiling point. Since there were 100 increments between the freezing points and boiling points of water, Celsius called his scale the centigrade scale. It is commonly used where the metric system is in place. Did you know "Celsius" has two *s*'s and only one *c*?

FROM WATER-BASED TO ATOM-BASED: THE ABSOLUTE SCALE

The Fahrenheit and Celsius scales are termed **relative scales.** Any measure of distance is "absolute" since a measurement of 0m is the shortest distance—no distance—and nothing can be "–3m long." But the two temperature scales mentioned above are not absolute. An object can be colder than zero on the Fahrenheit scale or zero on the Celsius scale. Fahrenheit's zero was based on the temperature of an endothermic chemical reaction; Celsius's zero was based on the temperature of a phase change for water. Negative temperatures on both scales are common.

Since temperature is related to the motion of atoms or molecules, zero should represent the smallest motion physically possible. Such a scale would be an **absolute scale**. Absolute temperature scales do exist. The Kelvin scale (named after William Thomson, Lord Kelvin) uses the same size increments as the Celsius scale, but has its 0 at a temperature that is the coldest theoretically attainable. The Rankine scale (named after William Rankine and pronounced *Rain keen*) is the absolute scale whose increments are the same size as those in the Fahrenheit scale. Absolute temperatures are expressed without reference to degrees: room temperature is 293K, not 293°K.

TYPICAL TEMPERATURES

The chart below gives commonly referred to temperatures on all four temperature scales.

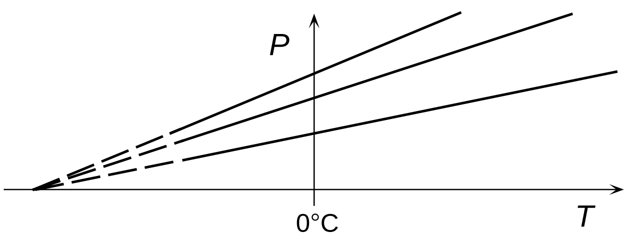
Fahrenheit	Rankine		Celsius	Kelvin
212°F	672 R	WATER BOILS	100°C	373 K
68°F	528 R	ROOM TEMPERATURE	20°C	293 K
32°F	492 R	WATER FREEZES	0°C	273 K
–460°F	0 R	ABSOLUTE ZERO	–273°C	0 K

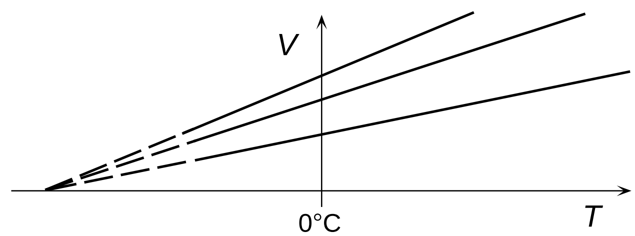
On the Fahrenheit and Rankine scales, there are 180 graduations between the freezing and the boiling points of water. Now that's a lot of Pomp and Circumstance!

On the Celsius (centigrade) and Kelvin scales, there are 100 graduations between the freezing and boiling points of water.

ABSOLUTE ZERO: IS IT TRUE WHAT THEY SAY?

1. Where is it and who has been there? You may have heard that physicists have yet to produce absolute zero in the laboratory. This is true. So far, 0.000 000 02K is as cold as they've seen. But they do know where it is. Here's how they figured it out. If a fixed volume of gas is heated and cooled, the pressure of the gas rises and falls, correspondingly. If a plot is made, it looks like the diagram below to the left. Likewise, if a gas at constant pressure is heated or cooled, its volume will increase or decrease correspondingly. If a plot is made, it looks like the diagram below to the right. Different quantities of gas give plots with different slopes, but all plots converge on a common point: absolute zero. The plots must be extended (extrapolated) to cross at absolute zero since that temperature has yet to be achieved.





2. What happens to atoms at absolute zero? You have also heard that at absolute zero, all atomic or molecular motion ceases. This is not true. Atoms never lose their zero point energy (the minimum kinetic energy atoms always have). Our understanding of this comes from quantum theory.

3. Negative absolute temperatures? Say it isn't so! The whole point of having absolute scales was to have a zero that meant something: a bottom temperature below which no temperatures exist. But temperatures do exist below absolute zero. Negative absolute temperatures have been recorded. A population of atoms has a negative absolute temperature under very unusual circumstances, and by a definition of temperature more sophisticated than the one we have used. Strangely enough, negative absolute temperatures represent collections of particles that are "hotter" than they would be with positive temperatures of equal value. When something cools from a negative absolute temperature, say –100K, its temperature falls to $-\infty$, which is a temperature equivalent to $+\infty$, then proceeds to cool through the range of positive absolute temperatures. It doesn't pass through absolute zero. Sound confusing? It is. Want to know more? Study more physics. I mean serious, graduate-level physics!

KINETIC THEORY

When measured on an absolute scale, the average kinetic energy KE_{avg} of the random translational motion of the particles in a sample is related to the temperature T of the sample by the relation $KE_{avg} = {}^{3}/_{2}kT$, where k is Boltzmann's constant. In SI units, $k = 1.38\text{x}10^{-23}$J/K.