

Cryogenics*

Ray Radebaugh

National Institute of Standards and Technology
Boulder, Colorado

Cryogenics is the science that addresses the production and effects of very low temperatures. The word originates from the Greek words 'kryos' meaning "frost" and 'genic' meaning "to produce." Under such a definition it could be used to include all temperatures below the freezing point of water (0 °C). However, Prof. Kamerlingh Onnes of the University of Leiden in the Netherlands first used the word in 1894 to describe the art and science of producing much lower temperatures. He used the word in reference to the liquefaction of permanent gases such as oxygen, nitrogen, hydrogen, and helium. Oxygen had been liquefied at -183 °C a few years earlier (in 1887), and a race was in progress to liquefy the remaining permanent gases at even lower temperatures. The techniques employed in producing such low temperatures were quite different from those used somewhat earlier in the production of artificial ice. In particular, efficient heat exchangers are required to reach very low temperatures. Over the years the term cryogenics has generally been used to refer to temperatures below approximately -150 °C.

According to the laws of thermodynamics, there exists a limit to the lowest temperature that can be achieved, which is known as absolute zero. Molecules are in their lowest, but finite, energy state at absolute zero. Such a temperature is impossible to reach because the input power required approaches infinity. However, temperatures within a few billionths of a degree above absolute zero have been achieved. Absolute zero is the zero of the absolute or thermodynamic temperature scale. It is equal to -273.15 °C or -459.67 °F. The metric or SI (International System) absolute scale is known as the Kelvin scale whose unit is the kelvin (not Kelvin) which has the same magnitude as the degree Celsius. The symbol for the Kelvin scale is K, as adopted by the 13th General Council on Weights and Measures (CGPM) in 1968, and not °K. Thus, 0 °C equals 273.15 K. The English absolute scale, known as the Rankine scale, uses the symbol °R and has an increment the same as that of the Fahrenheit scale. In terms of the Kelvin scale the cryogenic region is often considered to be that below approximately 120 K (-153 °C). The common permanent gases referred to earlier change from gas to liquid at atmospheric pressure at the temperatures shown in Table 1, called the normal boiling

Table 1. Normal boiling points of common cryogenic fluids.

Cryogen	(K)	(°C)	(°R)	(°F)
Methane	111.7	-161.5	201.1	-258.6
Oxygen	90.2	-183.0	162.4	-297.3
Nitrogen	77.4	-195.8	139.3	-320.4
Hydrogen	20.3	-252.9	36.5	-423.2
Helium	4.2	-269.0	7.6	-452.1
Absolute zero	0	-273.15	0	-459.67

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point (NBP). Such liquids are known as cryogenic liquids or cryogens. When liquid helium is cooled further to 2.17 K or below, it becomes a superfluid with very unusual properties associated with being in the quantum mechanical ground state. For example, it has zero viscosity and produces a film that can creep up and over the walls of an open container, such as a beaker, and drip off the bottom as long as the temperature of the container remains below 2.17 K.

The measurement of cryogenic temperatures requires methods that may not be so familiar to the general public. Normal mercury or alcohol thermometers freeze at such low temperatures and become useless. The platinum resistance thermometer has a well-defined behavior of electrical resistance versus temperature and is commonly used to measure temperatures accurately, including cryogenic temperatures down to about 20 K. Certain semiconducting materials, such as doped germanium, are also useful as electrical resistance thermometers for temperatures down to 1 K and below, as long as they are calibrated over the range they are to be used. Such secondary thermometers are calibrated against primary thermometers that utilize fundamental laws of physics in which a physical variable changes in a well-known theoretical way with temperature.

The production of cryogenic temperatures almost always utilizes the compression and expansion of gases. In a typical air liquefaction process the air is compressed, causing it to heat, and allowed to cool back to room temperature while still pressurized. The compressed air is further cooled in a heat exchanger before it is allowed to expand back to atmospheric pressure. The expansion causes the air to cool and a portion of it to liquefy. The remaining cooled gaseous portion is returned through the other side of the heat exchanger where it pre-cools the incoming high-pressure air before returning to the compressor. The liquid portion is usually distilled to produce liquid oxygen, liquid nitrogen, and liquid argon. Other gases, such as helium, are used in a similar process to produce even lower temperatures, but several stages of expansion are necessary.

Cryogenics has many applications. Cryogenic liquids, such as oxygen, nitrogen, and argon, are often used in industrial and medical applications. The electrical resistance of most metals decreases as temperature decreases. Certain metals lose all electrical resistance below some transition temperature and become superconductors. An electromagnet wound with a wire of such a metal can produce extremely high magnetic fields with no generation of heat and no consumption of electric power once the field is established and the metal remains cold. These metals, typically niobium alloys cooled to 4.2 K, are used for the magnets of magnetic resonance imaging (MRI) systems in most hospitals. Superconductivity in some metals was first discovered in 1911 by Onnes, but since 1986 another class of materials, known as high temperature superconductors, have been found to be superconducting at much higher temperatures, currently up to about 145 K. They are a type of ceramic, and because of their brittle nature, they are more difficult to fabricate into wires for magnets.

Other applications of cryogenics include fast freezing of some foods and the preservation of some biological materials such as livestock semen as well as human blood, tissue, and embryos. The practice of freezing an entire human body after death in the hope of later restoring life is known as cryonics, but it is not an accepted scientific application of cryogenics. The freezing of portions of the body to destroy unwanted or malfunctioning tissue is known as cryosurgery. It is used to treat cancers and abnormalities of the skin, cervix, uterus, prostate gland, and liver.

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Cryogenic Society of America, Cold Facts Newsletter, available from www.cryogenicsociety.org.