SUPERCOLD
SUPERHOT

AN !MPACT BOOK

SUPER COLD SUPER HOT

CRYOGENICS AND CONTROLLED THERMONUCLEAR FUSION

by Gail Kay Haines

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ABOUT THE AUTHOR

Gail Kay Haines is a native of Paducah, Kentucky, and majored in chemistry at Washington University, St. Louis, Missouri. She has worked in the analytical laboratories at a major chemical concern and also doubled as an assistant librarian in the children's section of public libraries. She is the author of several books on scientific subjects for young readers, including *The Elements* (A First Book), published by Franklin Watts. Ms. Haines now lives in Olympia, Washington.

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INTRODUCTION

Can fuel be made from water? Is it possible to produce so much **energy** that we could never run out, using the same superhot methods as the sun?

Can living cells and living organisms be frozen for long periods of time and then be brought back to life? Can rockets explore space using supercold fuel? Can scientists build better computers, do intricate brain surgery, and even learn more about the **atoms** and the particles within them by working with temperatures much colder than the coldest day at the North Pole?

Some of these questions have already been answered. Some are still being studied. But two of the most active areas of scientific research today deal with temperature: the supercold and the superhot.

Cryogenics is the study of extreme **cold.** It involves temperatures much colder than anything found naturally on earth.

At the other end of the temperature scale, **controlled thermonuclear fusion** works with temperatures so hot they could melt any material in the universe. The inside of a volcano is cool by comparison.

No ancient scientist tried to study either of these fields, because no one even knew such extremely cold and hot temperatures existed. But they did exist, in plain sight of the youngest cavechild. The vast, cold reaches of outer space are a natural cryogenic laboratory, and the sun and the stars get their enormous amounts of energy from thermonuclear fusion. Supercold and superhot temperatures have always existed, but far out of reach.

They are not out of reach today. Modern scientists, with the right knowledge and equipment, can bring these ultra-high and ultra-low temperatures into being in their laboratories.

Scientists can chill air until it turns to a liquid and then to an icy solid. They can cool a substance further and further until it almost—but not quite—reaches a temperature known as **absolute zero.** Absolute zero is colder than outer space. It is the coldest cold that can be imagined.

In other laboratories, scientists can heat **gases** so hot that their atoms begin to come apart. They can produce, for a fraction of a second, temperatures much hotter than the inside of the sun.

Scientists can do these things, but why should they? The necessary equipment is very complex and expensive. The procedures use enormous amounts of electricity. The scientists spend years learning and experimenting. Why?

There are a number of good reasons. When a rocket blasts off into space, it may be using cryogenic fuel. Cryogenic fuels made the exploration of the moon possible.

Some surgeons are already using cryogenic techniques to treat diseases. Cryobiologists are learning to freeze blood, sperm, and animal and human organs for storage and later use. Someday they may be able to freeze and revive human beings.

Steel mills need oxygen and nitrogen prepared by cryogenic processes. Molecular scientists are using cryogenic techniques to study subatomic particles. Even ecologists are finding cryogenics a new and valuable tool in the ever-growing need to recycle and dispose of waste materials.

Controlled thermonuclear fusion is a branch of science that is so new it does not yet "work." The United States is now spending millions of dollars every year to help scientists in their research.

Fusion, the forced combining of two **hydrogen** atoms into one **helium** atom, will make power just as the sun does, using hydrogen from the ocean as fuel. Researchers predict that fusion will someday be able to provide so much energy that the world will never have another energy crisis.

A science usually creates its own technology as it goes along. That means scientists are very good at finding answers to the questions that arise. But they all have to start somewhere.

No one could invent a thermometer to measure cryogenic temperatures unless he or she already knew how to measure ordinary ones. No one could figure out how to make gases superhot without understanding heat and what it is. These questions had to be answered first.

CHAPTER 1 HEAT AND MOTION

Everyone knows that heat moves. Set a pan of water on a hot stove. Heat flows from the stove to the pan to the water. Turn off the stove, and they all cool down to room temperature.

Take a tray of ice cubes out of the freezer. The cubes soon melt into water. Heat seems to flow into the tray and the water until they are the same temperature as the air in the room.

People have always known that heat moves, just from looking at the world around them. But it is not easy to figure out how heat moves, and why.

Long ago, some scientists invented a *theory* to explain heat. A theory is an idea. Scientists often make up a theory that includes all the facts they know about some problem, and then they test it to see if it is really true.

They decided that heat was a weightless, invisible fluid, which they named *caloric*. When a pan was heated on a stove, caloric "flowed" from the stove into the pan. When ice melted, they thought caloric was flowing into the ice. When wood burned, the caloric "trapped inside" was thought to come pouring out.

The Caloric Theory, as it was called, became very popular. It seemed to explain everything about heat. But there was one big problem with this theory. It could not be tested. If caloric was weightless, no one could measure it. If it was invisible, no one could see it. There was simply no way to tell for sure if caloric really existed.

Another important theory was being studied at about the same time, and this theory finally solved the mystery of heat. The **Atomic Theory** said that everything in the world is made of atoms. All the rocks and trees, all the buildings and streets, and even all the animals and people are built from tiny atoms too small to be seen by even the best microscopes.

This theory *could* be tested. And while researchers were testing it, learning more and more about atoms, they discovered that atoms and the combinations of atoms called **molecules** do not sit still. They are always moving, inside even the most solid-looking solid.

When atoms and molecules move, they have energy. It is a special kind of energy called **kinetic energy,** the energy of motion.

A person running or riding a bicycle has kinetic energy. So does a falling tree. So does a ball flying through the air or a hammer being swung. Everything has kinetic energy.

A racehorse speeding around the track has more kinetic energy than a turtle plodding over the ground. The amount of kinetic energy in atoms and molecules is harder to see, but it can be felt. The temperature of any object or substance depends upon how fast its molecules are moving.

Molecules, even in the same object, do not all move at the same speed. There are always some very fast-moving molecules and some very slow ones. And there are lots of other molecules moving at speeds in between.

Since molecules move around in a random, zigzag pattern, they often bump into each other. When they do, they share energies. Fast-moving molecules may give some of their energy to the slower ones.

Moving molecules answered the riddle of moving heat. A hot stove shares energy with the molecules in a skillet, and the skillet shares energy with the bacon inside. The sun radiates energy to a snowman and starts its molecules moving fast enough to melt it into a puddle.

As new theories about atoms and kinetic energy began to be accepted, more and more scientists realized that the Caloric Theory had to be wrong. Heat is not an invisible fluid. Heat is energy. Heat is the energy that makes atoms and molecules move.

Finally, scientists could explain what they really mean by the words **heat** and **temperature.** Heat is the total amount of energy in an object, while temperature depends upon the average speed of its molecules.

Since heat is a total amount, there is more heat in a large chunk of ice than in a teaspoonful of boiling water. This is because the ice has many more molecules than the tiny amount of water. And even though most molecules in the ice have far less energy than those in the boiling water, the *total amount* of heat is greater in the ice.

Temperature measures the average speed of an object's molecules. If most of them are fast, the average will be high. If most of them are slow, the average will be low. A teaspoonful of boiling water has a much higher temperature than a whole mountain full of ice, since its molecules are moving faster.

Kinetic theory also makes it possible to define cold. Cold is simply the absence of heat, just as dark is the absence of light. Hot things have lots of energy, and cold things have less.

When a substance gets hot, its molecules need more room to move around. This causes most materials to expand, or get bigger when they are heated.

Molecules that are moving slowly need less room. The material usually contracts, or gets smaller.

Knowing about this change in size gave scientists a way to measure heat. It made possible the invention of the thermometer.

CHAPTER 2

HEAT AND MEASUREMENT

A thermometer is any instrument used to measure temperature. Today there are many different kinds of thermometers, each one designed to do a special job.

But scientists did not always have reliable ways to measure heat. In 1593 an Italian scientist named Galileo Galilei invented the first thermometer, which he called a *thermoscope.*

A thermoscope was a long glass tube with a bulb on one end. The other end of the tube was open, and Galileo placed it in water. He measured how far up in the tube water came as the air inside the tube was heated or cooled. By measuring the water, he could measure how much the air was expanding or contracting with heat. Unfortunately, the thermoscope was not very accurate.

Over the next hundred years or so, many different thermometers were made. Some had open tubes and some had sealed tubes. Some used water, some used alcohol, some used different gases. Finally a French scientist, Guillaume Amontons, thought of using mercury.

Mercury was a good choice for a thermometer, because it is liquid over a long range of temperatures. Mercury also has a larger and steadier change in volume as the temperature changes than most other substances used in early thermometers.

But it did very little good for each scientist to have a thermometer of his own, even an accurate one. He still had no way of comparing temperatures with scientists using different thermometers.

In 1714 a German scientist named Gabriel Daniel Fahrenheit put together the ideas of several thermometer makers and added an important idea of his own. He sealed very pure mercury inside a narrow glass tube. Then he set up a temperature scale, with measurements that always meant the same thing.

To set his coldest point, Fahrenheit mixed salt with ice water. Salt makes ice water colder than normal, as anyone who has ever used an ice-cream freezer knows. Fahrenheit called this temperature "zero."

He next measured the temperature of a normal human body, which doctors already knew was about the same for most healthy people. He called that temperature "96 degrees," or 96°.

Then Fahrenheit used his thermometer and temperature scale to measure the freezing and boiling points of water. To make them come out with even numbers, 32° for freezing and 212° for boiling, he had to change the figure for body temperature slightly, to 98.6°. Fahrenheit marked off 180 degrees between the freezing and boiling points of water.

Now people could measure the temperatures of different things and compare them with the results of other scientists. All they had to do was get a sealed mercury thermometer and calibrate it so that ice water measured 32° and boiling water 212°, marking off 180 even divisions between them. This is called the **Fahrenheit scale,** and it is still used in the United States to measure most things.

The Fahrenheit scale was the first one to become widely known, but it is not the only temperature scale. In 1742 a Swedish scientist, Anders Celsius, developed an even more convenient scale. It has one hundred degrees between the freezing (0° C.) and boiling (100° C.) points of water.

The **Celsius scale** is used in most countries, and by scientists everywhere. It is very likely that the United States will soon begin using it.

A special formula is needed to change Fahrenheit temperatures into Celsius. In the Fahrenheit scale, normal body temperature is 98.6°. To convert that to Celsius:

$$C = (F - 32)\,\frac{100}{180} = (98.6 - 32)\,\frac{5}{9} = \frac{333}{9} = 37^\circ$$

When the United States begins using the Celsius scale, doctors will think of 37° C. as "normal" body temperature, and a comfortable room will be around 22° C. A temperature of 32°, which is freezing on the Fahrenheit scale, will mean a hot summer day. 32° C. = 90° F.

Another important temperature scale used by scientists was developed by a British physicist, William Thomson, who was better known as Lord Kelvin. Lord Kelvin's scale begins far below the freezing point of water, at a temperature known as absolute zero, the coldest imaginable cold.

Chapter 3 will explain how Lord Kelvin found the temperature of absolute zero. It was not a temperature he could measure, since nothing in the universe has ever been quite that cold.

The number turned out to be –273.15° C., or –459.67° F. That means 273.15 Celsius degrees colder than ice water.

The degrees on the **Kelvin scale** are the same size as Celsius degrees, which is convenient for scientists because they do not need a complicated formula to change from one to the other. All they must do is add or subtract 273.15.

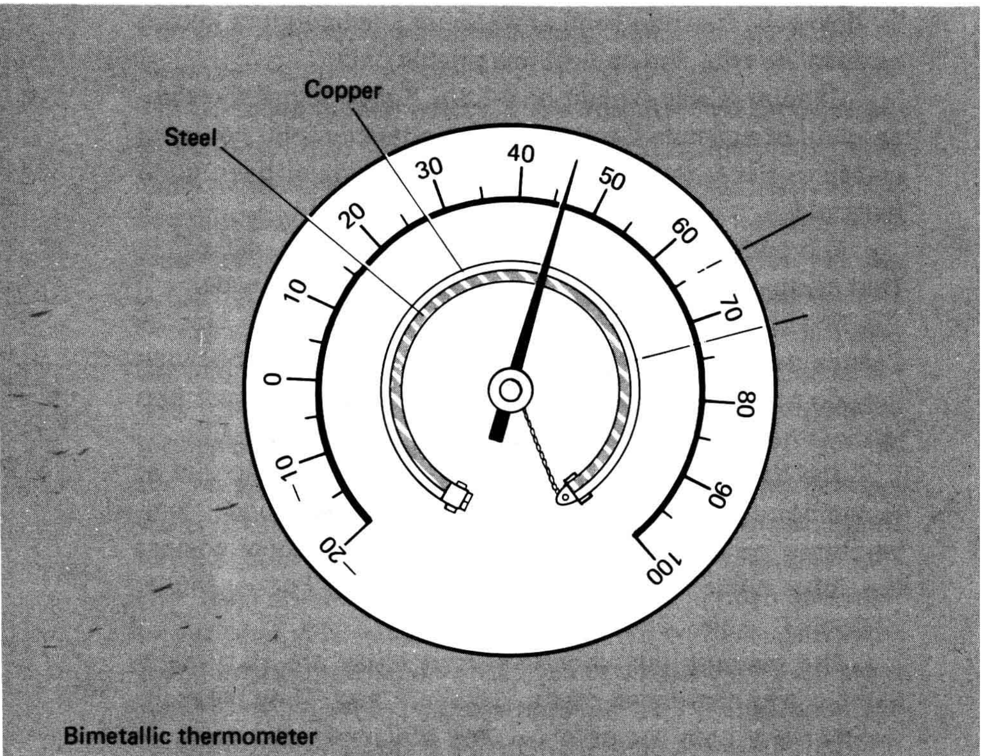
The **Kelvin** degree is now the standard scientific unit of temperature. Because it is a unit, like feet or pounds, temperatures on the Kelvin scale should be written without the little circle (°) which means degree. For example, –273.15° C. = 0 K., and 0° C. = 273.15 K.

The mercury thermometers used today are very much like the one Fahrenheit made 250 years ago. They measure weather and body temperature very efficiently. But mercury freezes at about –40° C. and boils around 375° C. Temperatures hotter or colder than those must be measured in some other way.

All metals expand with heat and contract with cold. The changes are small and hard to measure, but some metals expand and contract more than others. Scientists use this fact to make a *bimetallic* (two-metal) *thermometer.*

One kind of bimetallic thermometer fastens two metal strips together, back to back. One strip may be of brass, which has a large expansion. The other may be steel, which has a small one.

Since the strips are attached, they cannot simply grow and shrink as the temperature changes. They have to push against each other, until the strip with the larger expansion bends them both. A dial at the end of the strip shows how much it bends with each degree of change in temperature.



Bimetallic thermometer

This type of *aneroid* (not liquid) thermometer is used in thermostats on furnaces, in toasters, and to operate electrical switches. But it is not much use at very low or very high temperatures. High temperatures can melt the strips, and at very cold temperatures, below 60 K., the bending becomes too slight to measure.

Another kind of bimetallic thermometer is the **thermocouple.** Two wires made of different metals are joined end to end, at both ends. One junction, the place where the wires join, is kept at a known temperature. The other junction is placed at some higher, unknown temperature.

When the thermocouple is in place, with one junction warmer than the other, a tiny electrical current begins to flow. The heat energy in the wires produces electricity.

This tiny amount of current can be measured, and how big it is depends upon the difference in the two temperatures. Since one temperature is already known, scientists can calculate the other.

A good, high-temperature thermocouple can measure up to about 1450° C., but this is far below the temperatures needed for thermonuclear fusion. Some low-temperature thermocouples can measure liquid nitrogen at 77 K., and some special ones have measured temperatures as low as 4 K. That is useful, but not always good enough for cryogenic scientists.

The superhot temperatures needed for thermonuclear fusion cannot be measured directly. No metal, no substance in the universe can be used to make a thermometer that can be placed inside a fusing chamber, as a clinical thermometer can be placed inside a patient's mouth. Extremely hot gases must be measured in the same way astronomers measure the temperature of the sun and stars.

Of course, no one can put a thermometer inside the sun. It is much too hot and much too far away. But the sun is always sending out rays of light and heat, and these rays *can*