The Coldest Spot in the World

It's in a vacuum tube in the low-temperature physics laboratory

by Jane Werner Watson

"The Coldest Spot in the World" has been taken from a forthcoming book, The World of Science, *by Jane Watson. The book, which is written for junior high and high school students, tells about current research in all the various fields of science.*

Most of the research projects described in The World of Science *are now going on at Caltech. Even the idea for the book came from Caltech—from Earnest Watson, in fact, dean of the faculty, who felt strongly that younger students needed, and would welcome, a greater understanding of science. Since Mrs. Watson is a skilled writer of books for young people,* The World of Science *was the natural result.*

The World of Science, *a Golden Book by Jane Werner Watson, copyright 1958 by Simon & Schuster, Inc., and Artists and Writers Press, Inc., will be published in the fall.*

What is the coldest spot in the world?

Near the North Pole? No, in its polar ice pack temperatures go down only to about —81°F. (the record for North America). Siberia's record cold was —90°F.

The South Pole? The lowest temperature reported thus far from the South Pole is —89°F.

But in a low-temperature physics laboratory in the middle of a well-protected vacuum tube or thermos bottle, the temperature may go down to —459.5°F. or even lower.

—459.6°F. is absolute zero. It is the coldest possible temperature. On the special scale used in scientific work, it is 0°K. (for Kelvin).

The helium in that thermos bottle in the physics laboratory is not at absolute zero. But it is not far from it. It is perhaps 0.01° away. At this temperature even one of the lightest, freest gases in the world has turned—if we could see it inside its silvered container—to a bubbling liquid, then stopped even bubbling and turned smooth as jelly.

This is the coldest spot in the world.

You know that atoms and molecules are always in motion. In gases they move most freely. For there they are not held together in any shape. In liquids they still slide around easily. And even in a solid—a piece of wood, for example—if you could see the molecules and atoms you would find them vibrating slightly in place.

You know that most kinds of matter can be turned from solid to liquid to gas. Let us take iron and water as two examples. Water as a solid is ice; as a liquid it is water; as gas it is water vapor. As ice, it is rather cold; its molecules move slowly. When ice warms up, its molecules move faster; at the melting point they break loose from their solid form and flow like water. As water warms up, its molecules move faster still. At the boiling point they break loose from the liquid form and leap up into the air. They can move fast enough and exert enough force to push the cover up from a pan.

So it is with iron. The molecules in solid iron ore are more tightly bound than in ice. Iron must be heated to a much higher temperature than water before it melts, before its molecules get to moving fast enough to break loose from their solid form and flow as a liquid. And liquid iron must be heated very hot indeed—specifically, it must be heated to 3032°K.—before it turns to a gas.

We see then that heat is connected with the motion of molecules. In fact, the energy in this motion of molecules is heat. When you touch a hot stove, what you feel as heat is partly the result of the rapidly vibrating molecules striking at your finger.

Cold is the lessening of that motion. And absolute zero is the point at which, practically speaking, all the motion of molecules would cease. There would be practically no energy, no heat, no motion. That is the state our low temperature physicist is trying to approach in his experiments with liquid helium.

We have said that it takes a lot of heat—or energy—to get iron molecules moving fast enough to break loose from their solid state and turn to liquid. This is mostly because the forces of attraction holding the iron molecules in place are very strong.

Water melts from its solid state of ice at a much lower temperature because its molecules are not so strongly bound. It takes less heat or energy to get them moving fast enough to break away from the solid state.

Air is the gas with which we are most familiar. Its molecules dart around freely as a gas until they are cooled down to about 85°K. or —300°F.

At 85°K. or colder, air molecules are so slowed down that they form a liquid. Moreover, this liquid air can be separated into liquid oxygen (1/5) and liquid nitrogen (4/5).

Several uses have been found in industry for liquid oxygen. You know that oxygen is necessary to keep any fire burning. Liquid oxygen is used to speed up the burning of fuel in long-range rockets and jet airplanes. It is also used in the manufacture of steel, to speed up the burning of fuels there.

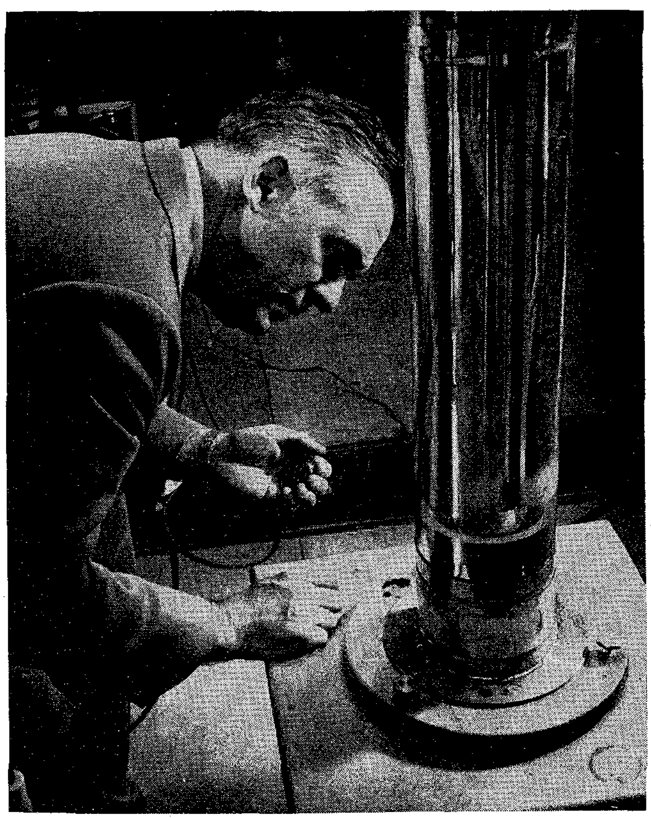
Liquid oxygen has enough industrial uses so that it is shipped by tank-carloads. And scientists are busy looking for new uses for the liquid nitrogen which is left over in the separation. One possible use is a liquid nitrogen bath (at —320°F.) for steel, which can then be rolled to extreme hardness.

But there are gases even better than oxygen and nitrogen for low-temperature work. There is hydrogen, which does not slow down into a liquid until 20.38°K. It does not slow down into a solid, or freeze, until it reaches 14.04°K. Unfortunately hydrogen is too explosive for safe industrial use.

Then there is helium. Although it is not as light as hydrogen, its molecules need even less heat or energy to keep moving freely as a gas. They do not slow down into a liquid until 4.22°K. In fact, there is a light isotope of helium, He^3, which does not liquefy until 3.20°K.

That is the lowest natural boiling point for any liquid. It is the reason low-temperature physicists use helium when they are trying to get as close as possible to absolute zero.

How do you go about cooling helium down almost to absolute zero? You use every method of cooling you can think of.



John R. Pellam, Caltech professor of physics, is timing the cooling of liquid helium in this dewar. Submerged within the liquid helium is a small glass vial of condensed helium and helium 3, the rare light isotope which will not liquefy until nearly absolute zero temperature.

Restaurants and physicists

How do restaurants keep certain foods ice-cold while they serve them? They set the dishes containing the foods in bowls of ice. Physicists use this method, too.

They may surround the tank of helium gas with liquid nitrogen at about 77°K. to start the cooling process. They also compress the helium into a small space. The work of doing this heats it up, of course, but the heat is absorbed in the packing of liquid nitrogen. When the helium is allowed to expand again, it cools down still more.

Physicists also use already-cooled helium to help them cool more. On the way to the cooling box, the gas is piped through coils of tubing. Coming up through other coils is helium which has already been cooled. The two sets of coils are wrapped together. So the already-cooled helium helps cool the incoming gas. That brings the temperature down some more.

Heat is energy, we have said. You know one way to use up energy—doing work. So the physicists make the helium do work. Inside the cooling machine is a small engine. There are two cylinders with pistons in them. The pressure of the helium gas pushes up the pistons. That means the gas is doing work. It is using energy. It loses heat in the process.

You know that in a steam engine water is heated until it turns to steam, and the pressure of this steam pushes up the piston in a cylinder. Doing this work cools the steam so that it turns back into water and more fuel has to be burned to heat it to steam again. In the same way, doing the work in this engine cools the helium a bit more.

Of course a steam engine has to have lubricating oil to keep the piston from sticking. For years men thought it would be impossible to run an engine with helium or cooled air because it would be working at such low temperatures that any lubricating oil would freeze solid. How could they keep the pistons from sticking? In these engines, a thin film of the gas itself provides the lubrication!

Next, some of the helium is allowed to expand through a small nozzle leading into another container. In this expansion, some of the small amount of heat still remaining in the gas is used to separate the atoms. This "work" against the natural force of the atoms' attraction for each other cools the helium so that it turns to liquid. Its temperature is now 4.2°K.

Keeping cool

What do you use to keep lemonade cool for a picnic? You use a thermos bottle. That is what the physicists use for their liquid helium, too. But what a thermos bottle!

Outside are two layers of silvered glass with a vacuum between. Next comes a layer of liquid nitrogen, itself very cold. Again, inside this, is a double layer of glass with another vacuum between the two glass walls. And finally comes the liquid helium.

This sounds like real protection. But there are still difficulties. One is that the vacuum must be pumped out repeatedly, because helium can leak even through pyrex glass walls!

For the final chilling steps, the liquid helium is pumped through vacuum-protected tubes into a dewar vacuum tube waiting in a special laboratory.

Then a sample of a certain material called a paramagnetic salt is suspended inside a tube of rarefied helium gas in the middle of the liquid helium.

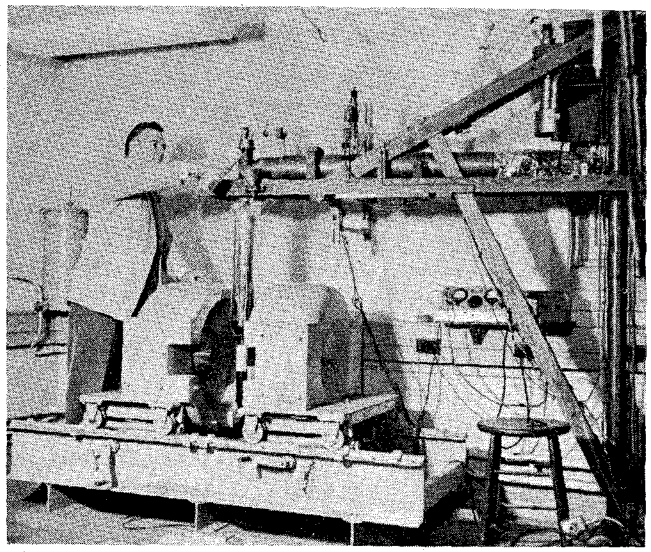
When all is ready, the physicist swings the tube around to an electromagnet (as shown in the picture at the top of the page), whose two sections roll shut around the tube. The time has come for the last steps down toward absolute zero.

The paramagnetic salt has a special quality. When a magnetic field is applied to it—when the big electromagnet is turned on—its molecules line up magnetically like tiny iron filings near a bar magnet.

We have said that it was the disorderly motion of molecules, called thermal chaos, which causes heat. Now, this magnetic lining-up of molecules is just the opposite of disorder or chaos. So what it does is force heat out of the salt.

The heat flows from the salt into the rarefied helium gas around it. This gas carries the heat out to the surrounding liquid helium. Now, to prevent the heat from flowing back in again by the same route, this gas must be pumped out by a vacuum pump. At these extremely low temperatures, atoms move very slowly indeed. So it may take as much as 20 minutes to complete the pumping out.

Then the magnetic field is removed. The lined-up salt molecules can turn in all directions again. This movement takes some energy, and therefore uses up some heat, which cools the salt as a whole.



This powerful electromagnet helps to produce temperatures close to absolute zero. Liquid nitrogen, a cooling agent, is being poured into a dewar which surrounds a container of liquid helium. When the silver dewar is swung into position, the two heavy iron sections of the electromagnet are rolled shut and the cooling procedure begins.

Down goes the temperature of the salt in the half second it takes to turn off the current, down to perhaps 0.001°K.

By now the glass of the tube is at such low temperature that it does not conduct heat well. So, even if room temperature heat should strike the outside surface, it would have a hard time flowing all the way in. Inside the vacuum protection, it will take seven or eight hours for the precious salts to warm up even to .01°K.

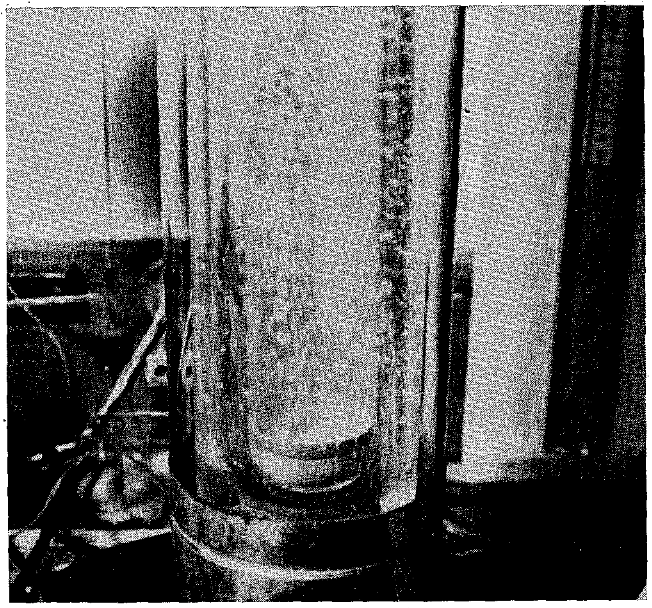
No excitement

"Why try to approach absolute zero?" people used to ask low-temperature physicists. "When you get there, everything will be motionless as death. There will be no excitement."

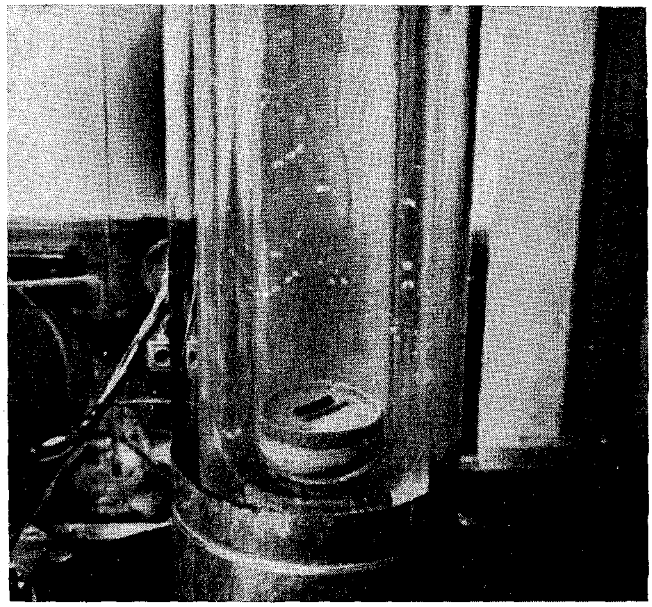
The scientists themselves did not know just what they would find down near 0°K. But they kept working toward it. And just a few years after they first managed to liquefy helium (which had been done in 1908) they made a surprising discovery which has not lost its excitement in 50 years.

This discovery was superconductivity. You know that some substances are better conductors of electricity than others. Wood is no good at all. Among metals, lead is not very good. Tin is fairly good. And copper is very good. Now it was discovered that, at very low temperatures, certain metals, including lead and tin, become superconductors.

This is how the experiment works. The physicist takes a small ring of lead and places it in a container planned



In this experiment a small magnet is dropped into a container filled with liquid helium. As long as the temperature is kept below 7.2° K., the magnet will float instead of dropping to the bottom. The magnet can hardly be seen in this picture because, at 3° K., the helium is still boiling violently.



In this phase of the experiment the liquid helium has been cooled to just a couple of degrees above absolute zero. The boiling has ceased and the liquid is smooth as jelly—in fact, it is the most quiescent substance known. The floating magnet can now be plainly seen through the clear windows in the silvered sides of the dewar.

for liquid helium. Around the thermos bottle he places a coil of wire through which a steady d-c electric current is set running. The starting up of this current sets up a temporary current in the lead ring. But it almost immediately dies out, because of resistance in the lead.

Now liquid helium is poured into the container, around the lead. The lead cools to an extremely low temperature, of course. As it falls below 7.2°K., the lead becomes a superconductor. Again, changing the current in the coil outside induces a current in the lead ring as before. But with a difference. Now the current in the outer coil of wire can be turned off. But the current thus induced in the lead ring will run on and on, presumably forever, as long as the lead is kept so extremely cold. For there is no resistance to electricity in the lead to slow down and stop the current, so close to absolute zero.

The physicist holds up a compass close to the thermos bottle or vacuum tube. And the magnetic field set up by that current in the lead ring is strong enough to attract the compass needle!

Next he lowers a small lead plate to the bottom of another container of liquid helium. Then he lets down a small magnet into the helium. You would expect it to fall to the bottom too. But it does not.

What happens? The magnet sets up a mirror image of itself in the lead plate. Since like poles of a magnet repel each other, the mirror image repels the magnet. And just enough electric current is generated in the lead plate to balance the power of the magnet and hold it suspended above the lead. It would remain thus suspended forever if the temperature could be kept permanently below 7.2°K.

Why is this "mirror image" set up? Why is there no resistance to electricity at these very low temperatures? Why does the current seem to run on forever like a perpetual motion machine?

These are questions no one has been able to answer in 50 years. Perhaps the answer is hidden in the perpetual motion within atoms. For electrons, you know, whirl forever around their nuclei with no loss of energy. You may be the one to find the answers to these and other questions in electricity and magnetism, if you make low-temperature physics your field.

A more recent surprise in low-temperature physics is what happens to helium itself. At 4.2°K. it settles into a liquid, boiling with small, lively bubbles. The vapor which keeps forming at the top is drawn off through a vacuum line. And the temperature keeps going down.

At 2.19°K. the boiling stops. The liquid is smooth as jelly, as you can see through the small clear windows in the silvered sides of the Dewar jar.

Has the helium frozen into a solid state comparable to ice? No. There is a solid state of helium, but it has so far been reached only under a combination of low temperature and very high pressure.

It is still liquid, but some of it has a new form. It is called a superfluid. And it has been given the name helium II.

Why is it called a superfluid? Because it can do things other liquids or fluids cannot do. Most liquids do not flow perfectly freely. There is a certain amount of resistance, or friction, which we call viscosity. But helium II flows with perfect ease through the tiniest openings.

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Water seeks its own level within one container. But helium II does more. If you lower an empty tube into helium II, the helium will creep up the sides of the tube and fill it to the level of the liquid outside.

Lift the tube containing some helium *II* and hold it above the level of the rest of the helium II, and the liquid in the tube climbs out and down to join the rest.

Perhaps strangest of all, there is the mysterious phenomenon called "second sound."

Helium II is a perfect conductor of heat. We would scarcely be inclined to think of heat at a temperature equal to —459°F. But there is a very small amount of heat or motion of molecules left in the liquid helium. If a very small bit of additional heat is applied, we can observe its movements through the superfluid. And a strange sort of movement it is!

In most materials—from air to a rod of gold—heat moves slowly, spreading out gradually by what we call diffusion. But in helium II heat travels in sharp little pulses, very much like sound waves. In fact, this method of heat movement is called "second sound."

Back in the nineteenth century, when scientists were just finding out about sound waves, it was discovered that these waves could turn aside a hanging disk of metal called a Rayleigh Disc.

When low-temperature physicists started finding out about "second sound" in helium II, one of them recalled this old-time experiment and dangled a tiny Rayleigh Disc in liquid helium. Sure enough, it turned as the "second sound" waves of heat struck it.

Of course these waves of "second sound" cannot be heard. They cannot be picked up with microphones. Since they are really temperature waves, special receivers have had to be made to receive them. These are tiny plates of carbon with a small constant current of electricity flowing through them. The colder they are, the less well they conduct electricity. The warmer they are, the better. One of these receivers is placed in the liquid helium. The current changes ever so slightly each time a "heat wave" strikes it and warms it a bit. And these changes in voltage can be amplified enough for a physicist to record.

These experiments with "second sound," or thermal waves, are very delicate. As we have seen, it is a slow and difficult process to make the liquid helium needed just to start the experiments. And what will they prove? What use can be made of the knowledge?

There is a saying among scientists to answer questions like this. "What good is a new-born baby?" they ask. In other words, "Give us time. Who can say what our experiments may lead to? Only time and testing will tell."