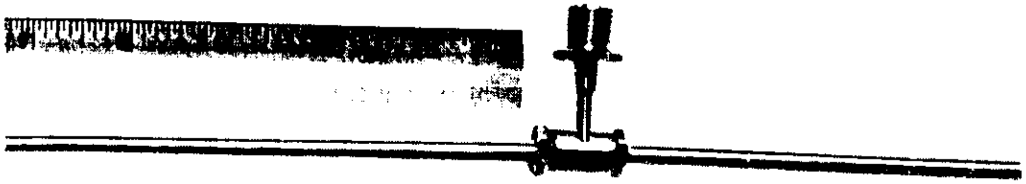
The mysterious Hilsch tube in its original form as developed in Germany is about 20 inches long.



In operation, hot air flows through the long left arm of the tube, cold air through the short right arm.

Pop Sci. May '47

Maxwell's Demon Comes to Life

THE world lifted an eyebrow in the 1870s when James Clerk Maxwell, eminent British scientist, suggested the possibility of hot and cold running air from the same faucet. It took three-quarters of a century and an obscure German physicist to turn Maxwell's idea into reality. Success, however, has bred a minor laboratory tempest over exactly what has been wrought and for what it can be used.

Maxwell's hint followed his development of "Maxwell's Law," which proved that the molecules in gases follow a pattern of arrangement and action. Some circulate at considerable speed and are hot; others remain relatively static and cold. Maxwell suggested that if they could be separated, an unusually simple method of producing hot and cold air simultaneously would be available. Facetiously, he recommended stationing "an intelligent demon" at a trap door to route the molecules along their proper paths.

Considerable comment was evoked. The editor of *Popular Science Monthly*, in the issue for July 1879, somewhat ponderously commented: "This looks to us like a somewhat ridiculous way of evading the real difficulties in the explanation of molecular motions and their effects. . . . When men like Maxwell lend their sanction to such a crude hypothetical fancy as that of little devils knocking and kicking the atoms this way and that, in order to explain the observed changes of natural phenomena, we may well ask 'What next?' "

The editor would have had a 65-year wait for his answer. It came when the Navy sent Dr. Robert Milton, a physicist, to Germany to investigate a report that the Germans possessed radically new equipment for cooling gases to within a few degrees of absolute zero. Dr. Milton set out prepared to bring back at least a ton of equipment to the United States. He found what he was looking for in a tiny laboratory in Erlangen. It was a tube about 20 inches long, less than half an inch in diameter and a few ounces in weight! Dr. Milton brought it home.

The tube, it was learned, had been perfected by Rudolph Hilsch, a bush-league German low-temperature physicist. Hilsch, who was integrated into the Nazi war effort, credits an unidentified Frenchman with discovery of the principle.

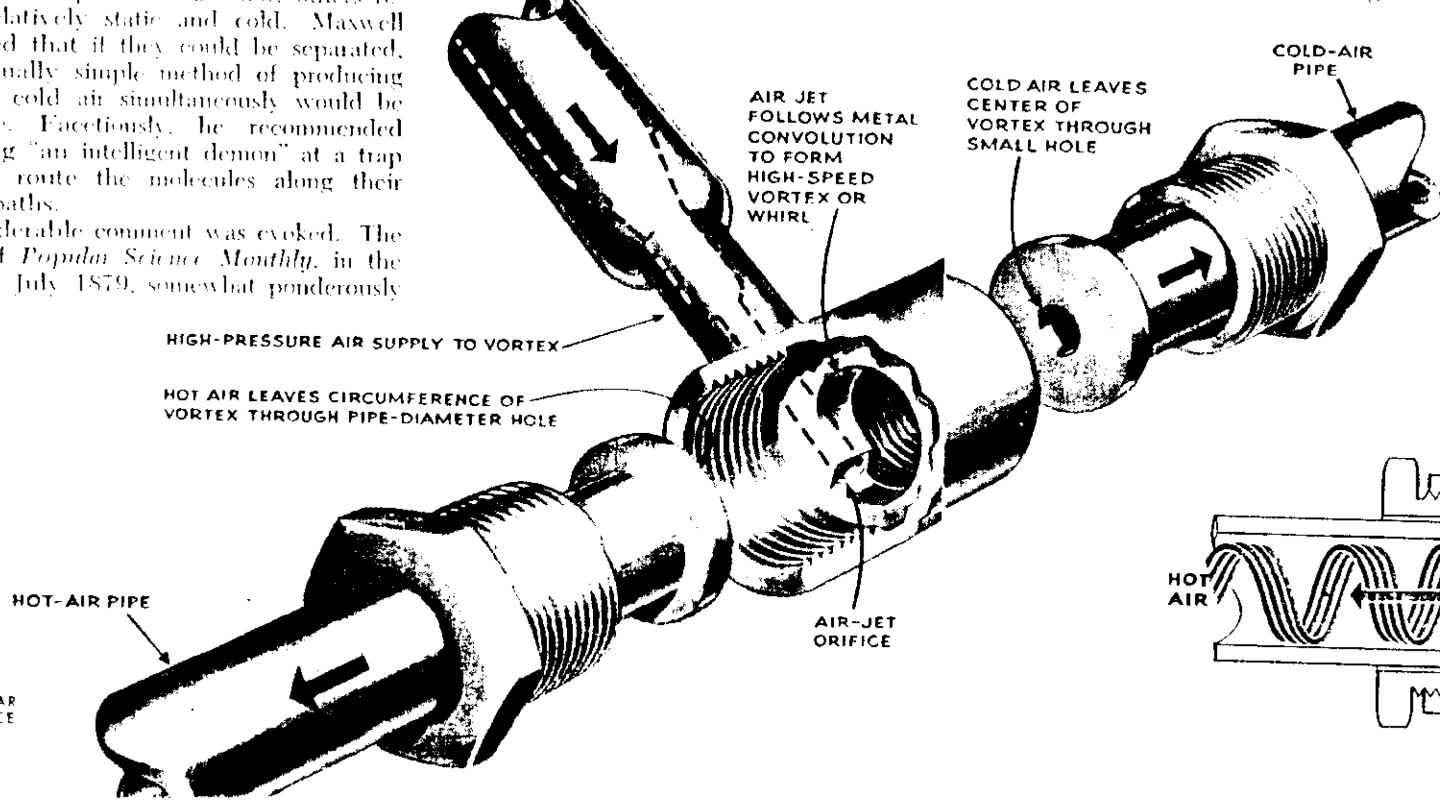
Here the muddle begins. Scientists themselves cannot agree on just how the tube works. Thousands of words seeking to reduce the mystery to formulas have been printed, along with detailed drawings of the tube. These are simple enough: The tube is divided into two arms of unequal length and width by a perpendicular, off center jet.

There is a certain amount of agreement, however, on the tube's principle. William J. Taylor, of the National Bureau of Standards, offers this general explanation: Compressed air entering the jet, passes through a nozzle, speeding up and losing heat—the gain in velocity energy being made at the expense of the lost heat energy.

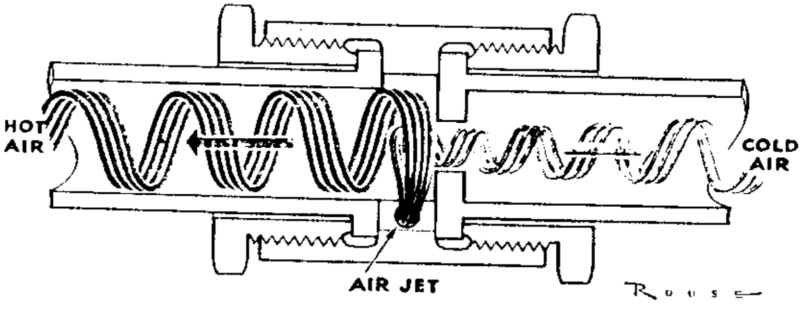
This fast, cold air is then slowed up by the spiral core of the tube. Some molecules drop toward the center. Instead of heating up as they lose speed, however, they pass along some of their energy to their next outer neighbor, and remain cool.

An additional cooling effect comes from the centrifugal force of the whirlpool itself. This force throws air molecules out to the edge of the spiral so that there are fewer molecules—and therefore lower pressure in the inner layers than in the outer ones. When air moves from the high-pressure outer layers to the low pressure inner layers, it naturally cools.

The result is a core of cold air at the center of the whirlpool and a border of hot air at the periphery. The shorter, smaller-



Cross section of the tube, below, shows how the air jet enters through hole, bottom center, and is spiraled by the shape of the tube. Drawing at left illustrates the tube's essentially simple construction.



bore arm of the tube communicates only with the center of the whirlpool and therefore draws off the cold air. The longer, larger-bore arm draws off the rest of the air —the hot molecules left at the periphery of the whirlpool.

Varying ratios of hot and cold air can be obtained by adjusting the stopcock at the warm-air end. The tube is capable of simultaneous temperatures of plus 106° and minus 56° F. At "hot" adjustment it can produce up to 350° F.

While the fundamental scientists have been arguing, the applied scientists of the refrigerating industry have been doing some experimenting of their own. Industry overlooks no bets that may involve discarding methods laboriously and expensively developed. At least three big concerns have had a look at the tube. At Westinghouse, Gaylord W. Penney, manager of the Electrophysics Department, has built a model three times the diameter of the original tube. He reports:

"Not efficient for refrigeration. The tube's highest utility is as a laboratory device. For instance, it could be used as a cold trap for mercury. It could also be used to cool gases, such as helium, prior to liquefaction."

Physicists of other companies, together with those of the National Bureau of Standards, generally agree that the Hilsch tube has no particularly rosy industrial future for the time being. They point out that while the tube gives 15 to 20 times more cooling than the ordinary laboratory method—expansion of gas through a nozzle under the Joule-Thomson principle—it has refrigerating efficiency of only 20 percent, as against 70 percent in household refrigerators and close to 90 in larger cooling installations.

They are loath, however, to disregard the provocative commercial possibilities of the tube. A more highly refined model might attain the thermodynamicists' dream of a double-purpose unit, on which one switch produces heat; another, cold.

Maxwell and his intelligent demon are probably smiling quietly at some astral laboratory bench. END

The Ranque–Hilsch Effect

Physics Today
Jan' 84

Researchers at the University of Tennessee Space Institute have emerged with a radical explanation of the Ranque–Hilsch effect, a spectacular and mysterious separation of air in swirling motion into hot and cold streams, and have traced the cause to a whistling sound present in the vortex flow.

In 1933, Georges Ranque, a French engineer, uncovered a striking phenomenon: when compressed air was introduced into a pipe through tangential injection holes (imparting a swirling motion) the temperature near the tube centerline became freezingly cold, while the temperature near the tube periphery exceeded its inlet value. This temperature separation took place without the aid of any external mechanical device. The effect became popularized later through a paper by Rudolf Hilsch, a German scientist. The device which became known as the Ranque–Hilsch tube or vortex tube is now commercially available; it is routinely used as a refrigerator without a motor or other moving parts for such purposes as machining operations and protection of electrical equipment, since even with inlet air at room temperature and at readily attainable pressure of a few atmospheres, cold air below 0°F can easily be obtained.

In spite of the simplicity of the Ranque–Hilsch tube, the mechanism of temperature separation has been a matter of long-standing dispute. Despite many attempts, the process eluded an adequate explanation; some attributed this, in a lighter vein, to Maxwell's demon, an imaginary being invented in the nineteenth century by James Clerk Maxwell. This microscopic demon would divide up the air by storing faster-moving molecules in one compartment and slower-moving molecules in another.

It had now long been recognized that a high-intensity whistling sound—the so called vortex whistle—emanates from vortex flow in general and from the Ranque–Hilsch tube in particular. Although previously regarded merely as an annoying by-product of such swirling flows and nothing more, the Tennessee scientists hypothesized that this vortex whistle was, in fact, the main cause of the Ranque–Hilsch effect.[1]

In order to verify this, they installed acoustic suppressors, specially designed and tuned to the frequency of the vortex whistle, on a Ranque–Hilsch tube. When the pitch of the vortex whistle, which increases as the flow through the tube is increased, hit the tuned frequency, the sound level suddenly tumbled by 25 dB, changing from an ear-splitting whistle to a muffled hiss. At that very instant, the tube centerline temperature, which had gone down to as low as −32°F, immediately leapt upwards to +33°F (a temperature jump of 65°F), while the temperature near the tube periphery plummeted by 10°F. This supported the theory that the vortex whistle was indeed the main cause of the Ranque–Hilsch effect.

The sound deforms the distribution of swirl velocity in the radial direction through the mechanism of acoustic streaming. Acoustic streaming, or sonic wind, is in general a phenomenon in which sound or alternating currents of flow modify the time-averaged, or direct, currents of flow; it is, in a sense, analogous to the more familiar generation of electric heat by alternating current. Owing to this acoustic streaming induced by the vortex whistle, the flow becomes distorted in such a pattern that the swirl velocity, with a zero velocity near the centerline, continues to increase in the radial direction, like the rotation of a car tire. When the air eventually comes to rest, the higher velocity near the periphery is converted into warmer temperature while the lower velocity near the centerline is converted into colder temperature.

M. Kurosaka, University of Tennessee

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[1] M. Kurosaka, J. Fluid Mech. 124, 139 (November 1982).