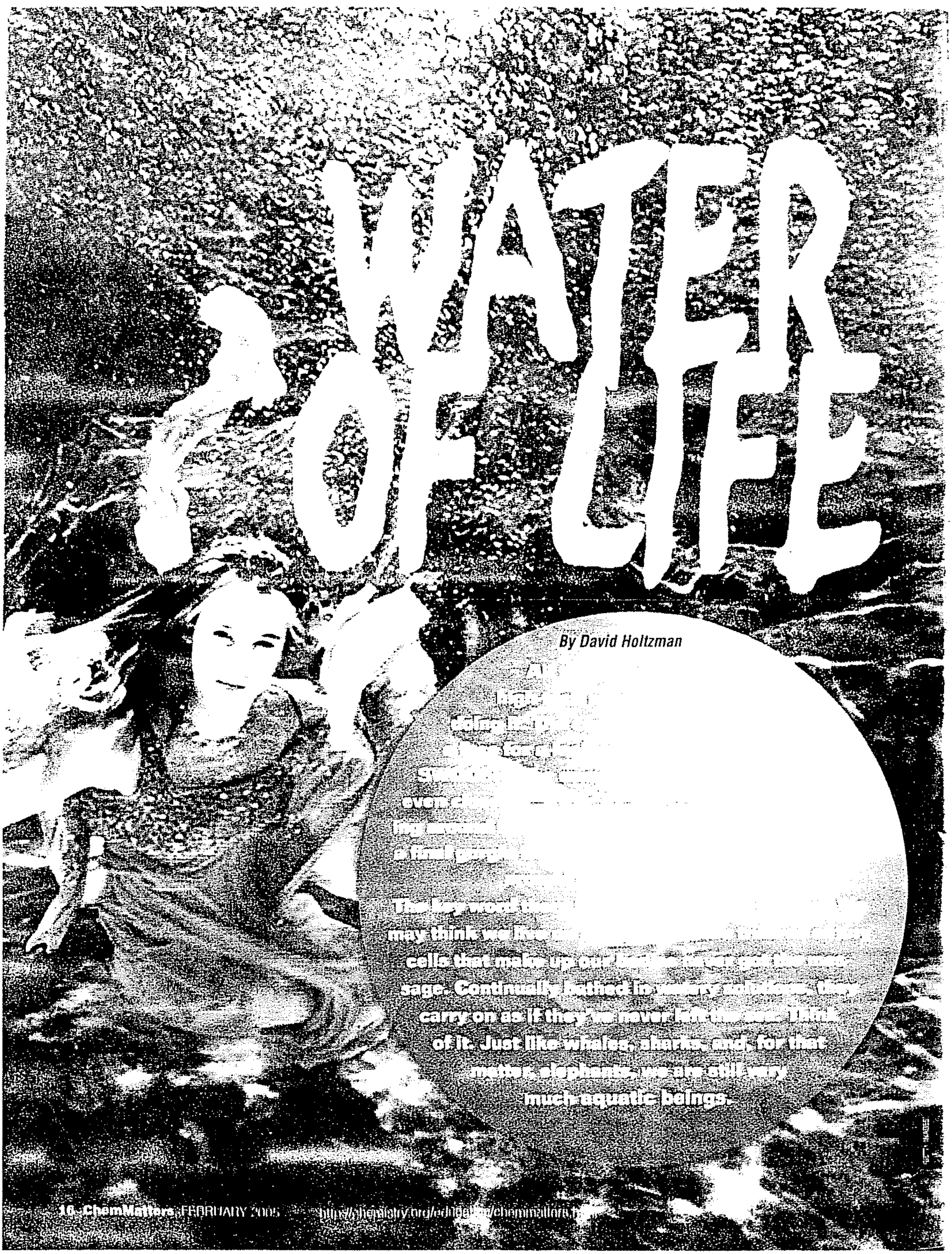

WATER OF LIFE

By David Holtzman

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The key word [illegible] may think we live [illegible] cells that make up our bodies [illegible] sage. Continually bathed in watery solutions, they carry on as if they've never left the sea. Think of it. Just like whales, sharks, and, for that matter, elephants, we are still very much aquatic beings.

Inside your cells, tiny biochemical machines copy your DNA. Other molecular machines convert food molecules into energy. Still others build new machinery for life's processes as old machinery breaks down. All this work takes place in solution, because without water, the cellular machinery would function about as well as a jellyfish washed up on the beach.

We are not alone in our thirsty dependence. Planet-wide, the solvent of choice for living things—plants and animals alike—is water, and we all rely on it for nutrition, transport, reproduction, you name it. No doubt that explains the current scientific searches for water beyond our own planet. Long before spaceships were sent to Mars last year to look for evidence that water might have flowed there, scientists have discussed how its presence would signal that signs of life—past or present—might turn up as well.

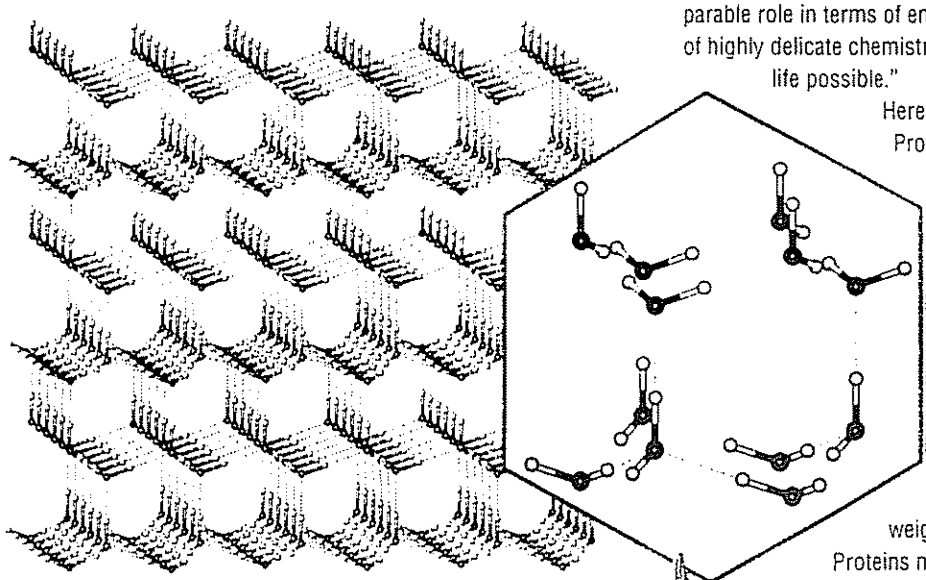
Water, so common, so unique

Water is a fascinating substance, easily taken for granted. It is there, in its abundance, covering three-quarters of Earth's surface, raining down upon us, emerging from our faucets at the flick of a handle. And it's likely that water is not just a local substance, but undoubtedly exists throughout the universe. Hydrogen is the most abundant element, and oxygen, following helium, is number three. All of which makes it very likely that water, with all of its life-friendly properties, is almost bound to show up in many galactic neighborhoods.

Fascinating? Let's start with freezing. Water, unlike most substances, expands when it freezes and becomes less dense, so ice floats. Most solids sink to the bottom of their liquid phase. And for living things, this might prove disastrous.

Consider this. If ice sank, solid ice would rapidly accumulate on the bottom of a lake in winter. There it would form an insulating layer separating the frigid lake waters from the warmer earth below, while continuing to expose liquid water to the cold air above. The ice layer would grow, eventually turning the whole lake into a solid mass of ice, leaving no refuge for living things that depend on liquid water. Even worse, the huge slowly melting body of lake ice might fail to fully thaw in the summer.

Solid water's unique properties are explained by the way individual molecules pack together upon freezing. The most common form of ice is called hexagonal ice. In this frozen form, water molecules pack together in repeating hexagonal units to form a solid with a lower density than liquid water. Ever wonder why snowflakes have hexagonal shapes? Think small. It's actually caused by this hexagonal packing of the water molecules at the molecular level.



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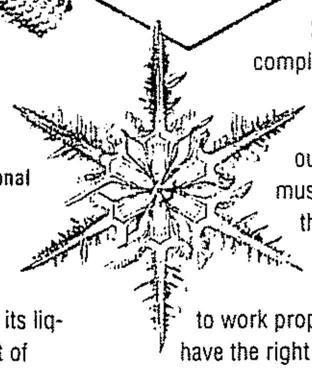

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In ice, water molecules pack together in hexagonal units. This arrangement causes ice to be less dense than liquid water. It's also responsible for the hexagonal shape of snowflakes.

Here's another life-friendly property of water: The temperature range of its liquid phase is generous compared to that of many substances. H_2O is liquid from 0 °C to 100 °C, thereby offering an ample temperature range in which life processes can take place. True survivors, various species of bacteria have adapted to live and even thrive over this entire range.

What explains these remarkable life-favoring properties? Water owes many of its virtues to the powerful hydrogen bonds that its molecules form with each other, and with many surrounding substances. Hydrogen bonds elevate water's boiling point, allowing water to remain a liquid at temperatures well above those at which compounds of similar molecular weight become gases. For example, hydrogen sulfide (H_2S) boils at a very cold −60.7 °C, while hydrogen selenide (H_2Se) boils at a somewhat warmer −41.4 °C—both well below the freezing point of water.

When it comes to the chemistry of living things, water is a key part of the act. Philip Ball, author of *Life's Matrix: A Biography of Water*, describes water's role in living things as unique. In an interview published in *Astrobiology*, he stated, "... we find that even for the simplest organisms, many of the molecular interactions are facilitated by water in an extremely fine-tuned way. I'm not sure we know of any solvent that can play a comparable role in terms of enabling the kind of highly delicate chemistry that makes life possible."

Here's an example. Proteins are basic building materials from which living things build structures that may be as delicate as a mosquito's wing or as sturdy as a weightlifter's bicep. Proteins may also be complex enzymes—catalysts that organize, regulate, and enable the numerous chemical reactions that must take place for a living thing to move, grow, metabolize, and reproduce. But, for a protein to work properly, it must not only have the right composition; it must also have the right shape.

All proteins are polymers composed of chains of linked amino acids. Different proteins come with different shape-determining folding patterns. Shape matters. If a protein folds the wrong way, it won't fit, it won't catalyze, and in short, it won't work. Genetic mutations can eliminate, displace, or substitute amino acids so as to change the way a critical protein folds. The result is often an unfortunate, sometimes fatal, genetic disease.

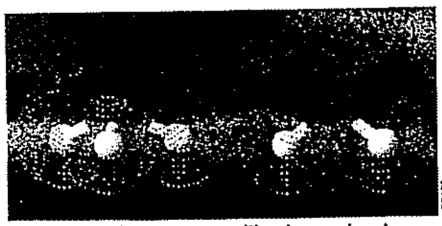
But even a correctly constructed protein can fold incorrectly. Sometimes temperature is the factor. A cooked egg looks different from a raw egg because the cooking has changed the folding pattern of the egg proteins.

Water has a significant effect on protein folding. Some amino acids have side chains, which may be charged, polar, or electrically neutral. The charged and the polar side chains form hydrogen bonds of varying strengths with water, the neutral ones do not. As a result, proteins tend to fold with the charged and polar amino acids on the protein's surface.

Water's polarity is also critical to the construction of cell membranes, structures that regulate the flow of materials such as food, waste, toxins, and ions in and out of cells. Typical cell membranes are made up of two layers of compounds called "phospholipids". Each phospholipid has a polar "head" capped by an $-NH_3^+$ group, and two nonpolar hydrocarbon tails. Water on either side of the cell membrane draws the polar heads of each layer, while the nonpolar hydrocarbon tails attract each other, holding the two layers of the membrane together. In short, water keeps the cell from falling apart.

What about ammonia?

Because water's polarity is so important to life on Earth, exobiologists—biologists who consider whether there is life beyond our planet—tend to dismiss the possibility that a nonpolar solvent such as methane or gasoline might bathe the machinery of life. But some suggest that liquid ammonia could be the solvent that makes life possible on some distant planet, because ammonia has many chemical similarities to water.



STAFF

Ammonia and water—can either be a solvent of life?

There is a whole system of organic and inorganic chemistry that takes place in ammonia. In fact, ammonia dissolves most organics as well as or better than water. Unlike water, it can dissolve many elemental metals, including sodium, magnesium, and aluminum, directly into solution. Several other elements like iodine, sulfur, selenium, and phosphorus are also somewhat soluble in ammonia with minimal reaction. And just like water, ammonia forms hydrogen bonds, and supports acid-base chemistry.

Despite all of its impressive properties, ammonia's potential as life's solvent is doubted by many scientists. For one thing, ammonia is so much less polar than water that it would be far less effective than water in holding cell membrane layers together. The temperature–pressure ranges for its solid, liquid, and gaseous phases hold even less promise.

At one atmosphere, the atmospheric pressure at sea level on Earth, ammonia is a gas. It takes a frigid Arctic temperature of –33 °C to liquefy, and an even more frigid temperature of –78 °C to freeze. The speed at which life processes take place varies with temperature, and so life in liquid ammonia would be life in the very, very, VERY slow lane.

But let's think big. A larger planet, with greater atmospheric pressure, could harbor liquid ammonia at terrestrial temperatures. After all, melting and boiling points depend on both temperature and pressure. But problems remain. Any planet containing ammonia is likely to have even more water. Why? Because nitrogen, the fourth most common element in the universe, is not as common as oxygen. Moreover, at temperatures and pressures where H_2O is still a solid rock, ammonia becomes a gas. As such, ultraviolet solar radiation breaks it down, says David J. Stevenson of the California Institute of Technology. Alternatively, ammonia gas could escape a smaller planet's gravity over millions of years, leaving water behind.

Finally, on a planet with a temperature–pressure regime conducive to liquid ammonia, ponds, lakes, and even oceans of ammonia could still freeze solid in winter.

But wait! What if life evolved underground on our distant planet? Maybe living off some source of geothermal energy, as some bacteria do far beneath the surface of the ocean? Such life forms might enjoy a stable thermal environment. It's also possible our ammonia-based organisms might simply be able to tolerate freezing, since ammonia ice—unlike water ice—would not burst their cells by expanding.

Don't be so terracentric!

The general view is that ammonia is an unlikely solvent and that other, nonpolar solvents are even more far-fetched. As a team, carbon and water are "so powerful, it's almost inconceivable that there would be other forms of life," says Eric Chaisson, professor of physics and astronomy and director of the Wright Center for Science Education, Tufts University. "Silicon-based life in ammonia would be unable to compete with carbon-based life in water", but then he adds that "I can easily imagine under bizarre conditions of temperature and pressure, carbon-based life in water would not emerge, so it's not inconceivable that other forms of life could eke out a very creepy, crawly existence."

But from our tiny corner of the Milky Way galaxy—one galaxy in an estimated 1,000,000,000,000—it's hard to get a universal perspective on the chemistry of life, says Steve Benner, a chemist at the University of Florida. He warns that "there is this problem of 'terracentricity' [focusing on Earth], and you see this all over the literature."

In fact, life as we terracentrics know it, has overcome problems that could easily be seen as insurmountable to alien scientists of a different chemical makeup. It's fun to think of them out there somewhere, contemplating these chemistry questions from their own perspectives. No doubt they would question whether life could evolve and thrive on a planet with so much oxygen!

Oxygen, so vital to Earthlings, is also highly toxic, and our bodies expend a great deal of energy protecting us from its ravages, says Benner. "Life as it exists on Earth today could hardly have gotten started in the now highly oxygenated atmosphere.

In fact, these alien chemists would have a problem imagining water as being anything other than a nuisance. As Benner puts it, "Organic chemists do not do chemistry in water, as a rule, because there is too much hydrogen bonding and too much reactivity in water's oxygen."

He suggests some thinking outside the planet. Putting aside our watery views, we might begin to imagine a world in which life forms are swimming in nice cool seas of liquid ammonia. ▲

David Holtzman writes about science and technology for a variety of publications and lives in Lexington, MA.
(www.daviddarling.info/encyclopedia/alphindexa.html).

ChemShorts

Ice spikes

Talk about your strange, yet ordinary things—ice spikes are real oddities. It's even possible you've seen them in a freezer near you! They grow out of ice cube trays, forming curious-looking peaks up to 5 cm high.

Under the right conditions, ice spikes grow as water freezes in an ice cube tray. Put a tray in the freezer, and you will notice that freezing begins at the edges of the tray. As surface freezing moves in from the edges, a small hole can be left at the top of each cube. At the same time, the bottom and sides of the cube are also freezing. As you know, when water freezes, it expands and becomes less dense. The pressure from the expanding ice forces the remaining unfrozen water up through the hole. It eventually forms a spike.

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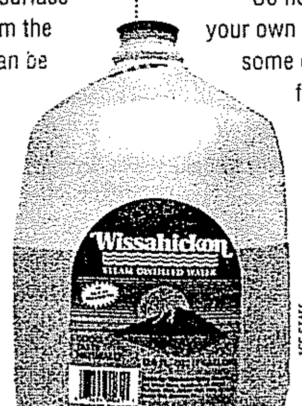
You've never seen them? The reason could be related to the purity of your water. According to research mentioned on the Web site SnowCrystals.com, the presence of even small amounts of NaCl can reduce spike production.

So how do you make your own ice spikes? Buy some distilled water and fill up your ice trays. If you can't make ice spikes after a few tries, consider raising the temperature of your freezer to just below freezing. Your freezer might be too cold to allow the formation of spikes.



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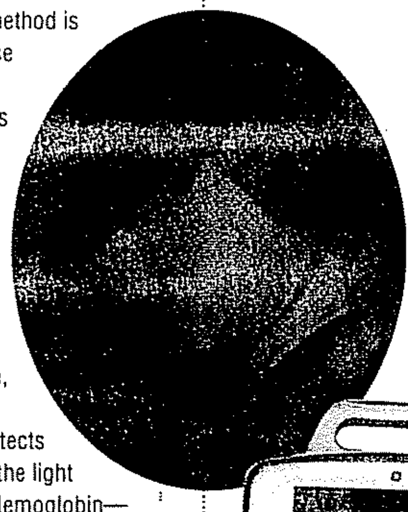
Pulse oximetry

If you've visited someone at the hospital recently, you might have seen a clip attached to their finger with a red light coming out of it. The clip is actually a probe attached to a monitor that gives pulse rate, as well as the percentage of oxygenation of the blood—important information for a doctor to know from moment to moment. This noninvasive method is known as pulse oximetry.

How does it work? The probe shines two wavelengths (650 and 805 nm) of light through the finger, earlobe, or foot of the patient and detects how much of the light is absorbed. Hemoglobin—the oxygen-carrying protein in blood (see "The Silent Killer" in this issue)—absorbs light at different wavelengths depending on whether oxygen is attached to it. Measuring the absorption of light at two wavelengths enables a computer processor to quickly calculate the percentage of hemoglobin saturated with oxygen. If oxygen saturation falls below a predetermined level, say 90%, an alarm bell sounds to alert medical staff.



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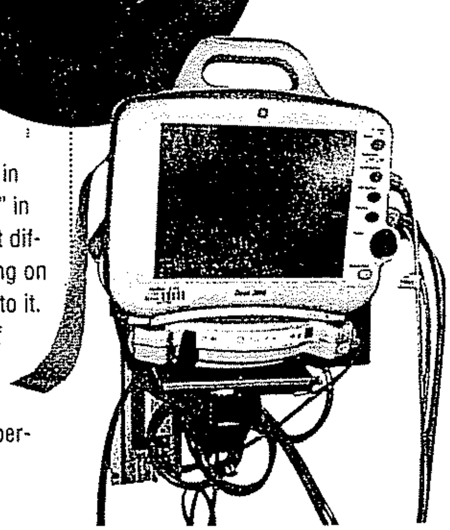

The red glow comes from a probe attached to a baby's foot. Pulse oximetry allows doctors to continuously monitor percent blood oxygenation.