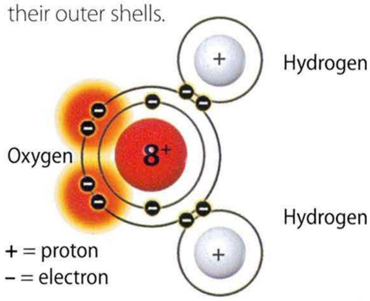
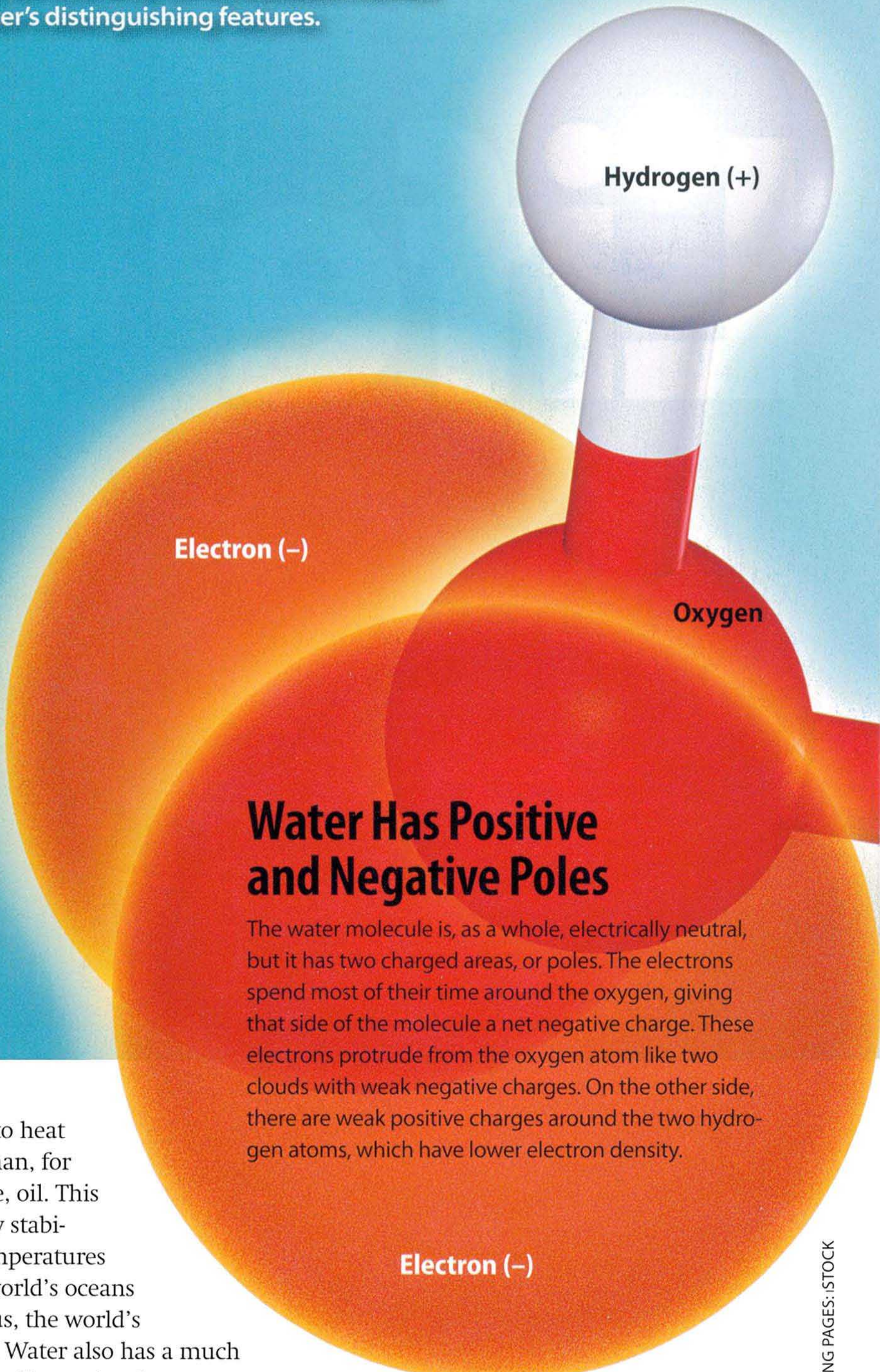
Water Has a Special Bond

In liquid water, molecules bond to one another for short periods and then break away to find new partners. These hydrogen bonds are electrical forces between the two molecules, and they contribute many of water's distinguishing features.

Oxygen Atoms Borrow Electrons from Hydrogen

A water molecule (H_2O) consists of one oxygen atom and two hydrogen atoms. Oxygen has eight electrons, with two in the inner electron shell and six in the outer shell, where there is room for two additional electrons. Hydrogen atoms have one electron each, with room for one more. In the water molecule, the oxygen atom binds to the two hydrogen atoms with a covalent bond, meaning they share each other's electrons. In this way, they both fill their outer shells.





Water Has Positive and Negative Poles

The water molecule is, as a whole, electrically neutral, but it has two charged areas, or poles. The electrons spend most of their time around the oxygen, giving that side of the molecule a net negative charge. These electrons protrude from the oxygen atom like two clouds with weak negative charges. On the other side, there are weak positive charges around the two hydrogen atoms, which have lower electron density.

For most of us, water is fairly ordinary: We drink it, bathe in it, garden with it, and even play in it. Chemically speaking, however, it's extraordinary. Water possesses convenient characteristics that, in combination, distinguish it from other chemical compounds. Many of these special qualities are utterly essential for life on Earth to exist. Here's just a small sample:

- Water has a high heat capacity, which means it takes much more energy to heat water than, for example, oil. This property stabilizes temperatures in the world's oceans and, thus, the world's climate. Water also has a much higher boiling point than structurally similar compounds—about 288°F higher, for instance, than hydrogen sulfide, a colorless gas best known for smelling like rotten eggs. If that weren't the case, liquid water would be replaced by vapor. And without liquid water, no known form of life would exist.

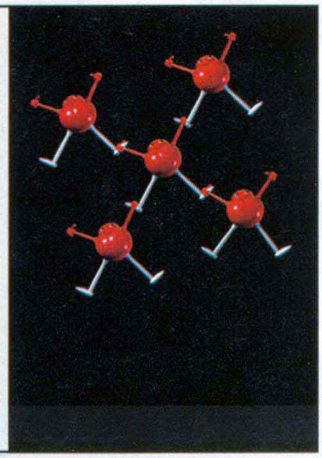
CLAUS LUNAU; PRECEDING PAGES: iSTOCK

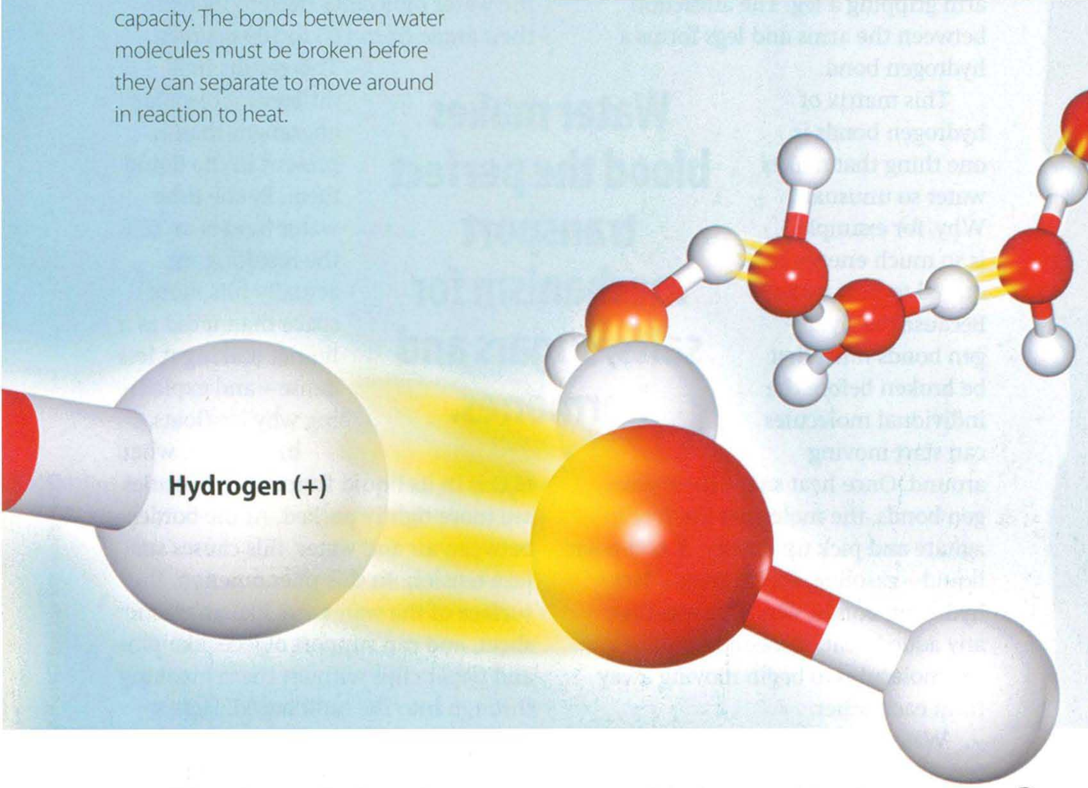
Water Has Polar Charges . . .

The mutual attraction between the positive and negative charges of different water molecules creates hydrogen bonds. They function like magnets connecting water molecules, and in liquid water the bonds can be made and broken continuously. Hydrogen bonds give water some of its unique qualities— for example, its high heat capacity. The bonds between water molecules must be broken before they can separate to move around in reaction to heat.

. . . Which Make Them Look Like Short, Fat Skydivers

We can imagine the water molecule as a short, chubby skydiver whose body is the oxygen atom. The man has two outstretched arms corresponding to the electron clouds around the oxygen atom, and two outstretched legs corresponding to the two hydrogen atoms. When many water molecules are together, each of them seeks to hook up with four other water molecules. The negatively charged arms grab their neighbor's positively charged legs.





Water has high surface tension, which makes it possible for paper clips to float.

ADAM HART-DAVIS /SPL/FOCI

• Water is one of a few substances that become less dense upon freezing, so ice floats to the surface. If it didn't, the oceans would have frozen from the bottom up during the ice ages, killing all marine life.

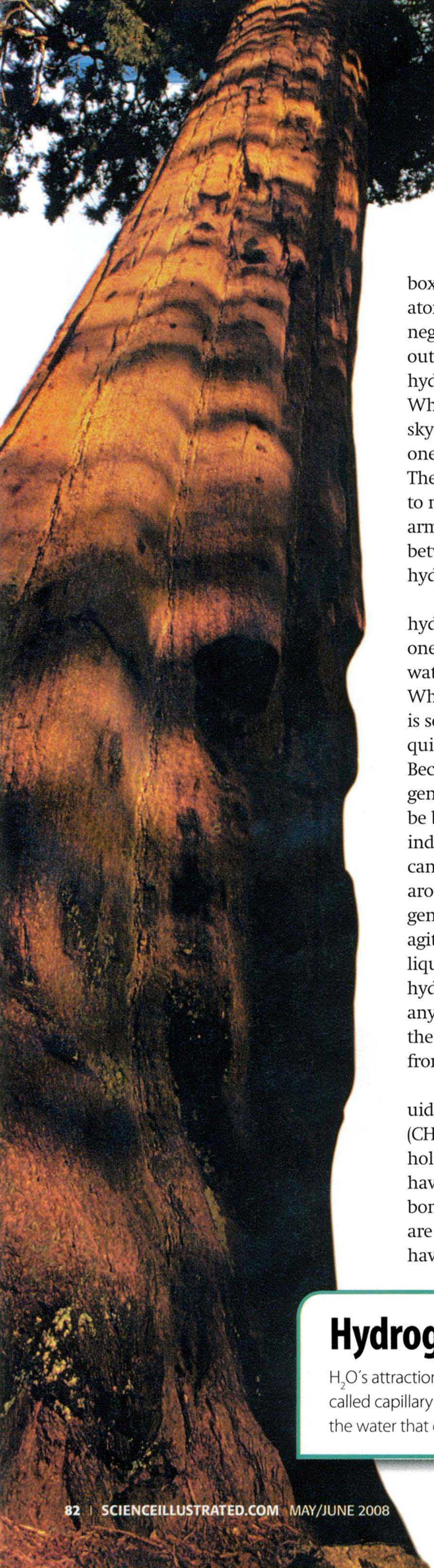
• Water is a good solvent, which means a great many substances will dissolve into it. This enables it to transport nutrients throughout our bodies and in plants and animals.

• Water also helps our bodies grow. At the molecular level, it lets proteins—long chains of amino acids responsible for everything from making fingernails to facilitating chemical reactions—assume complicated three-dimensional shapes. These shapes, which assemble in a process called folding, define the protein's function. New research also points strongly to water participating actively in the communication between DNA and proteins, and without those interactions, life—you guessed it—could not exist.

What makes water and its extraordinary properties possible? It all comes down to chemistry.

Property #1: Water Has Groupies

One thing that contributes to water's uniqueness is the way H_2O molecules hook up: through hydrogen bonds. A water molecule consists of just a single oxygen atom bound to two hydrogen atoms; the three atoms "share" negtively charged particles known as electrons. These shared electrons hover closer to the oxygen atom than the hydrogen atoms, creating two negatively charged regions around it and a single positively charged region around each of the hydrogen atoms. The result



is an uneven charge distribution, like in batteries, that makes the water molecule "polar."

Think of a water molecule as a short, chubby skydiver [see box on previous page]. The oxygen atom is his round torso and the two negatively charged electron clouds his outstretched arms. His legs are the two hydrogen atoms: the positive charge. When water molecules gather, these skydivers fly into formation, with each one trying to grab hold of four others. The positively charged legs are drawn to negatively charged arms, with each arm gripping a leg. The attraction between the arms and legs forms a hydrogen bond.

This matrix of hydrogen bonds is one thing that makes water so unusual. Why, for example, is so much energy required to heat water? Because the hydrogen bonds must first be broken before the individual molecules can start moving around. Once heat snaps the hydrogen bonds, the molecules are free to agitate and pick up energy. A non-polar liquid—gasoline, for instance—lacks hydrogen bonds, which means that any added heat immediately gooses the molecules to begin moving away from each other.

Water is far from the only polar liquid. Other examples include methanol (CH_3OH), which is known as wood alcohol, and ammonia (NH_3), both of which have about half as many hydrogen bonds as water does. But since there are fewer bonds to break, these liquids have lower boiling points than water.

Water makes blood the perfect transport mechanism for salts, sugars and hormones.

Property #2: Water Is a Shape-Shifter

The way the individual H_2O molecules bond with their neighbors is dramatically affected by heat and cold. Dropping temperatures cause the molecules to adjust formation.

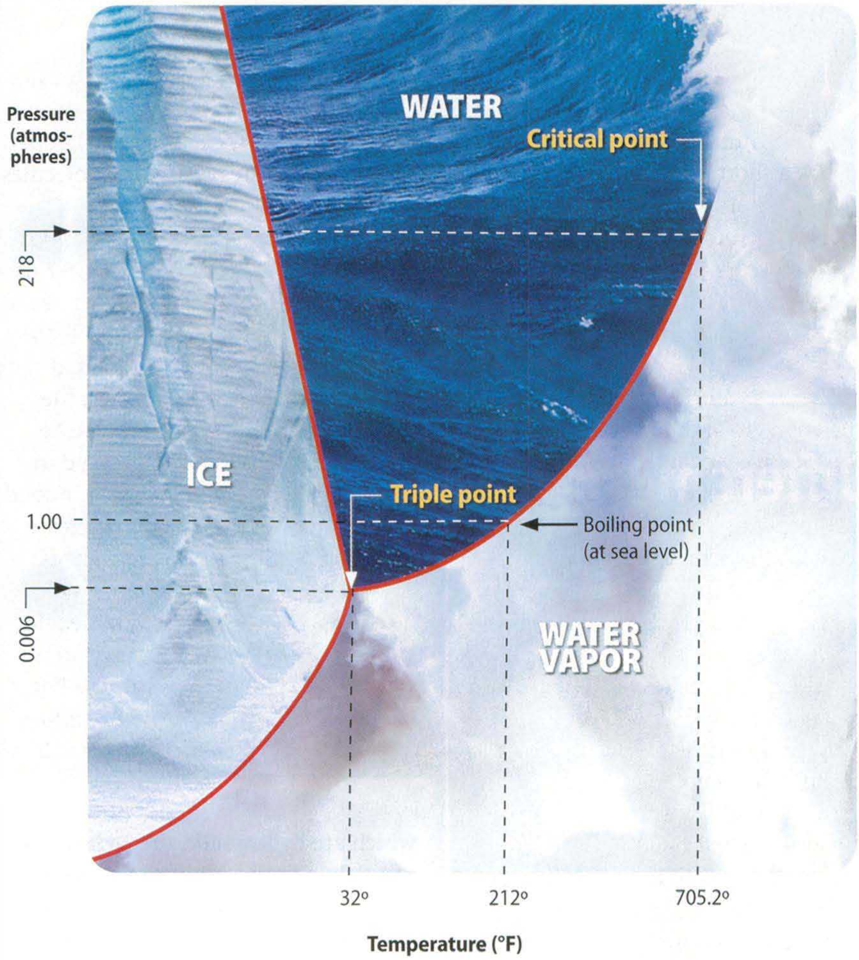
When water cools to below 39°F, it suddenly become less dense. Why? As water cools, its individual molecules move slower and lose their ability to overcome the attractive forces that bind them together. As a result, the hydrogen bonds are less likely to be broken. In order to form the rigid, repeating pattern characteristic of a solid, the water molecules need to increase their angle from 105 to 109 degrees. This results in a different molecular alignment than is present in the liquid form. By the time water freezes at 32°F, the resulting ice actually fills more space than it did as a liquid, making it less dense—and explaining why ice floats.

In contrast, when H_2O is in its liquid form, the molecules are more tightly packed. At the border between air and water, this causes surface tension. In this phenomenon, the surface of the water acts like an elastic sheet, and can support objects like pins and paper clips without them breaking through into the bulk liquid. Here's how: In the middle of a liquid, the molecules interact with one another in all directions. Those at the surface, however, want to interact with one another more than they do with the air. Most liquids display some surface tension, but water's is one of the highest, thanks to how well the shape of

Hydrogen Bonds Make for Life in the Treetops

H_2O's attraction to itself through strong hydrogen bonds pulls water up a tree, in a phenomenon called capillary action. This allows large trees, such as a 350-foot-tall California redwood, to replenish the water that evaporates off the top of the tree.

P. SCHERMEISTER/CORBIS/SCANPIX; FACING PAGE, FROM TOP: CLAUS LUNAU; DR. TIM EVANS/SPL/FOCI



This phase diagram shows the temperature and pressure conditions where water is liquid, ice and steam, and the various points where it changes between these states.

Getting to the Point

Like every other chemical compound, water can inhabit three states—solid, liquid and gas. This phase diagram shows the pressure and temperature conditions under which water exists as either ice, liquid or steam. In addition, ice can take on several different crystalline forms.

The triple point is the precise combination of temperature and pressure where all three states can exist simultaneously. Here, tiny changes in pressure or temperature can cause sudden shifts from one state to another.

Water also has at least one critical point, where the distinction between two states becomes blurry. The critical point between water and steam happens at 705.2°F and a pressure of 218 atmospheres. Here, the densities of the liquid and gaseous states become equal, making it impossible to distinguish between them. Some researchers also believe that there must be a critical point between two forms of ice, but its existence is disputed and its probable location unknown.

H_2O molecules fit together. This is why objects like paper clips, despite being more dense than water, will float on it.

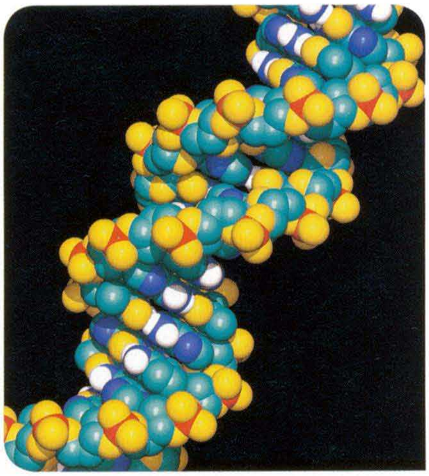
Property # 3: Water Is Solution-Oriented

Another quality of water is its ability to dissolve many other substances. Take table salt, for instance. It's made of two electrically charged ions: sodium and chloride. When you add them to water, the sodium and chloride bond breaks. Water molecules encase each ion, turning their negatively charged arms toward the positive ions (sodium) and their positively charged legs toward the negative ions (chloride). Water thus dissolves the salt, creating an evenly mixed solution. That's why water-based liquids, like blood, are perfect transporters of essential substances such as salt, sugars and hormones.

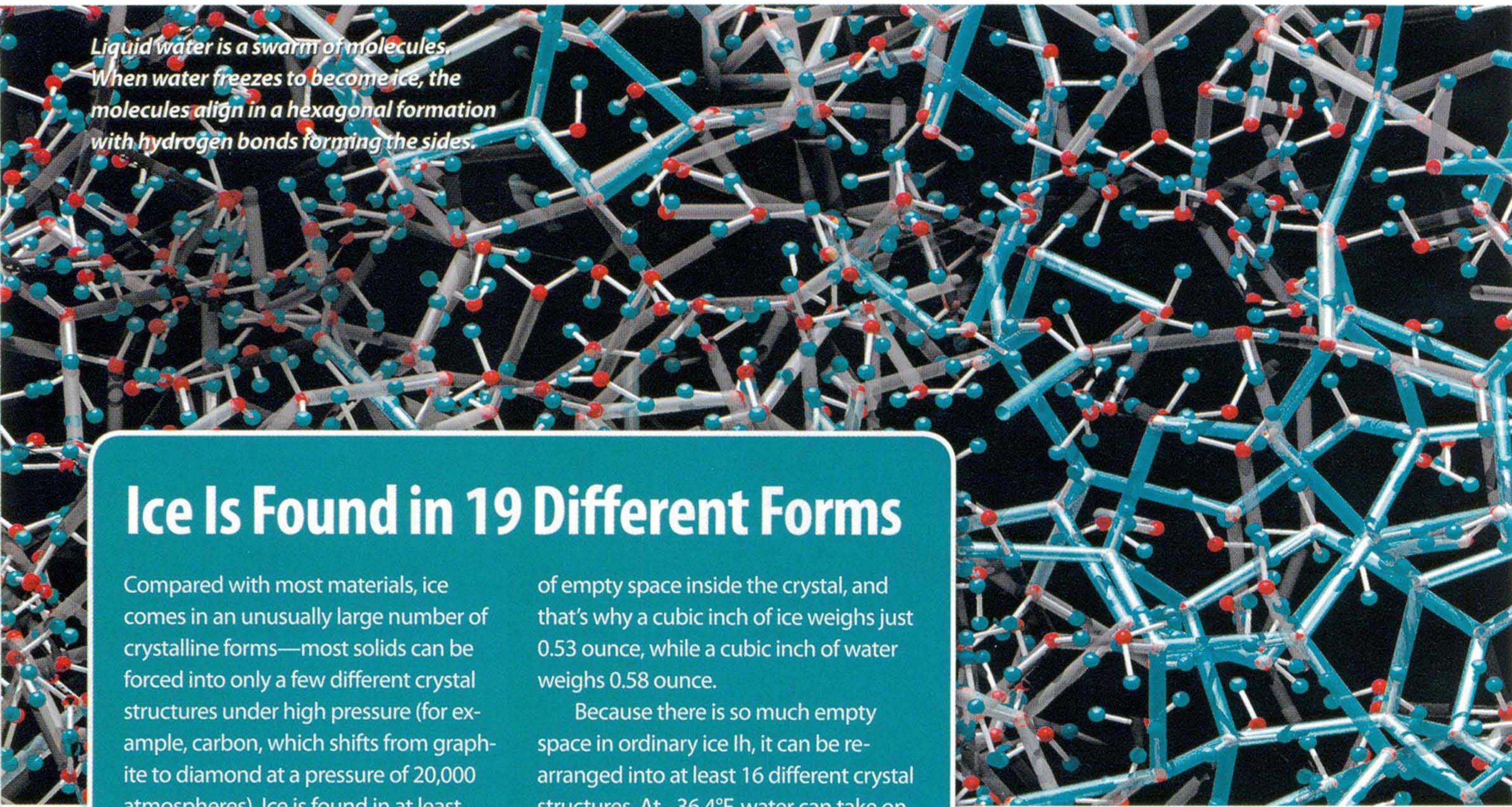
On the other hand, although electrically charged and polar substances dissolve well in water, the opposite is true for non-polar substances like oils, which don't always mix with water.

Property #4: Water Is a Multitasker

Many of the body's most basic—and vital—processes depend on water. Take protein assembly, for example. Some amino acids—the building blocks of proteins—are hydrophobic, meaning they're repelled by water; others,



Water molecules may help guide enzymes to the proper bonding sites on DNA [above].



Liquid water is a swarm of molecules. When water freezes to become ice, the molecules align in a hexagonal formation with hydrogen bonds forming the sides.

Ice Is Found in 19 Different Forms

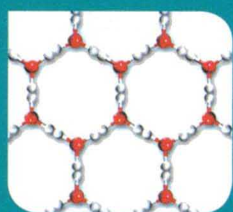
Compared with most materials, ice comes in an unusually large number of crystalline forms—most solids can be forced into only a few different crystal structures under high pressure (for example, carbon, which shifts from graphite to diamond at a pressure of 20,000 atmospheres). Ice is found in at least 19 known forms, many of them existing only in the laboratory.

Ordinary ice, called Ih (pronounced "one H") is the dominant form on Earth. Here the water molecules take on a hexagonal structure in which the molecules are stretched out. This creates masses of empty space inside the crystal, and that's why a cubic inch of ice weighs just 0.53 ounce, while a cubic inch of water weighs 0.58 ounce.

Because there is so much empty space in ordinary ice Ih, it can be rearranged into at least 16 different crystal structures. At –36.4°F, water can take on a cubic form instead, called Ic, which is found in the upper atmosphere in small droplets. There are also three principal forms of amorphous ice, which is often found in interstellar space. In amorphous ice, the water molecules are not arranged in a regular crystal structure.

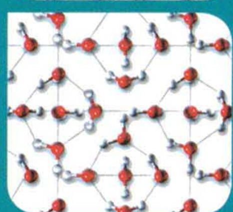
IH ICE

The least dense form of ice is Ih, and it is the ordinary ice we find on Earth. Here the molecules are elongated so that they form a hexagonal crystal. Ice Ih (the "h" is for hexagonal) is formed at normal pressures and at temperatures between 32°F and –35°F.



ICE VI

The crystal structures become tighter as the molecules are rearranged. In Ice VI, for example, hexagons are replaced by tetragons.



ICE X

This is the densest form of ice. A single cubic inch of it weighs 1.46 ounces. Ice X is created in the lab by subjecting ice VII to a pressure of 600,000 atmospheres. Here the hydrogen bonds are equally divided between surrounding molecules.

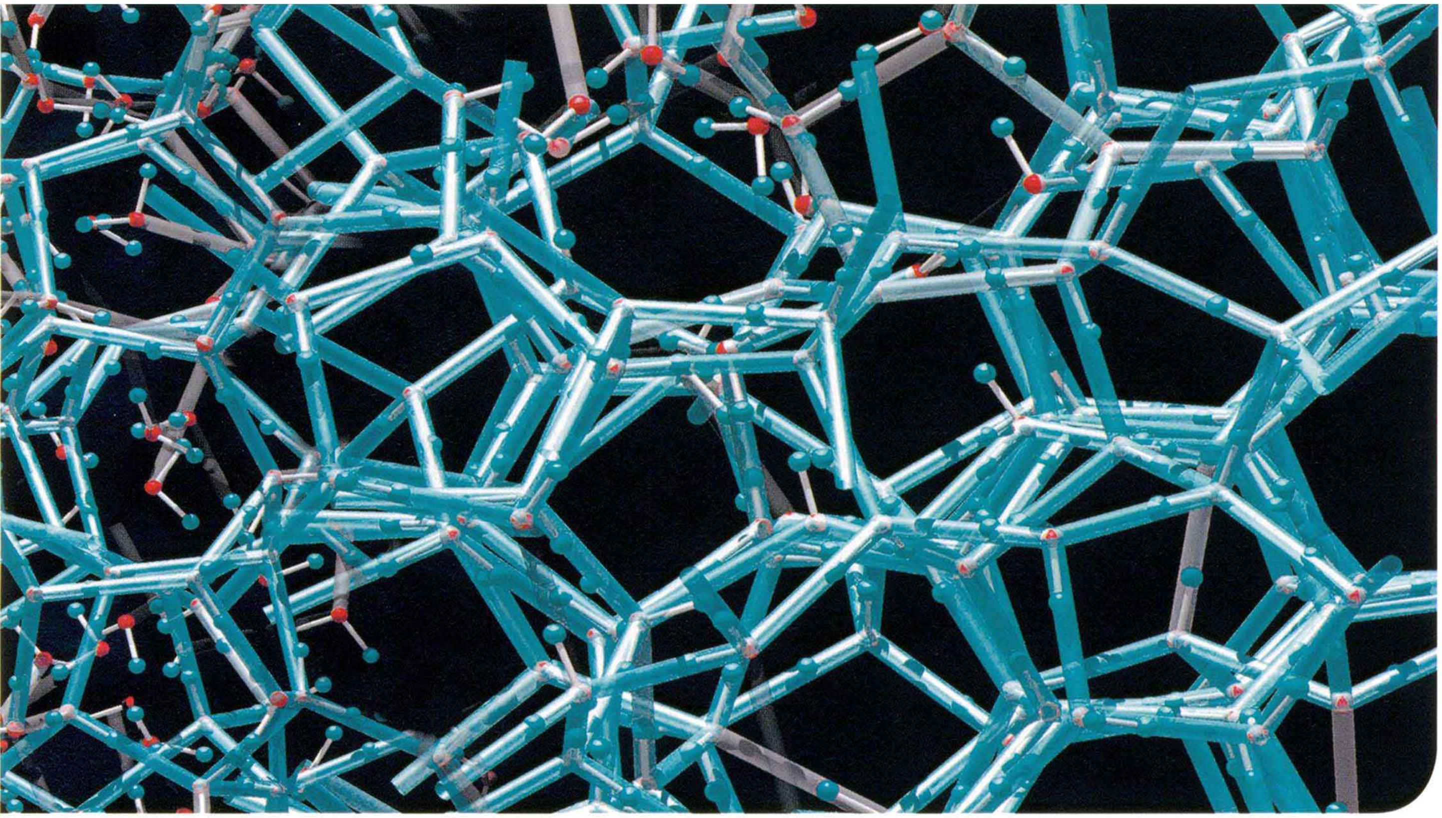
which are hydrophilic, are attracted to water. In a liquid environment such as the inside of cells, these properties dictate how a protein "assembles," or folds.

To create a protein, a cell's protein "factory" produces long chains of amino acids. A complete chain, called a protein, will fold itself into a three-dimensional shape, hiding the hydrophobic bits inside while keeping the hydrophilic parts outside, where they are exposed to water. Water thus indirectly shapes proteins.

A solitary water molecule also plays an active role in helping our bodies process carbon dioxide. Here's how: When CO_2 dissolves in a liquid (like blood), it produces an acid. The water molecule helps an enzyme maintain proper blood acidity through carbon dioxide regulation. And if blood becomes too acidic, the molecule helps pull CO_2 out to the lungs, where it can be exhaled.

DNA, too, depends on water. Experiments have shown that the double helix of DNA would fall to pieces without H_2O. This is because water molecules help form hydrogen bonds between DNA's phosphate groups.

FROM TOP: MASAKAZU MATSUMOTO/NAGOYA UNIVERSITY; CLAUS LUNAU; FACING PAGE: TIM HAWLEY/GETTY IMAGES

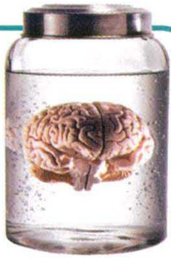


Property #5: Water Is a Guiding Force

Beyond the double helix, today biochemists think that water molecules may have an active role in the interplay between DNA and enzymes. When enzymes, which are essential proteins, bind with DNA, for example, how do they know exactly where to go?

Experiments carried out by Monika Fuxreiter of the Institute of Enzymology of the Hungarian Academy of Sciences in Budapest show that water molecules spend more time around certain areas of DNA than others. When the cell divides, it first needs to copy its entire complement of DNA, a process that is kick-started by certain enzymes binding to the DNA. But there are only certain spots on the DNA where these bonds will happen. These locations are surrounded by water, which may act as a signal to guide the enzymes.

Water on the Brain



Even our most abstract and beautiful thoughts owe their existence to water, which makes up as much as 80 percent of the brain by weight and contributes to biochemical reactions. (In contrast, the rest of the body contains only approximately 60 percent water.) When brain tissue converts glucose into energy, water is a by-product. The less-than-50 milliliters of water produced each day by the average person's brain could replenish the organ's total H_2O content—one liter—about every three and a half weeks.

Life on Earth hinges on water, but alien life may not.

Property #6: Water May Be an Alien's Best Friend

All known life on Earth is dependent on water. But no one knows whether, in other parts of the universe, there might be fundamentally different life-forms that can exist without it. Much of the research on this question focuses on enzymes. Typical enzymes, just like DNA, need to be surrounded by water to function properly. Could enzymes function in another liquid? Or could life exist *without* enzymes?

The Royal Society, a British consortium of scientists, debated the issue in 2004 and concluded that life without water could not be ruled out as a possibility. If space agencies focus only on water when they search for life-forms in space, the scientists reasoned, "they may miss something very interesting."

Their conclusion is worthy of consideration, but general agreement among biologists is that NASA has chosen the correct strategy in its search for life in other parts of the solar system: Follow the water. ■