CHEMISTRY

Water

Fluid Which Makes Up Most of Earth's Surface and Life on It Is Full of Big Holes of Empty Space

ALL life on earth, chemically, involves reactions of water solutions. Any human being is two-thirds water. Approximately 78 per cent of the brain is water. The muscles with which man moves are 75 per cent water; even his teeth are one-tenth water and his bones one-sixth. The earth itself—at least its surface and possibly to some distance into its interior—is composed in part of this same water in various forms. It covers three-fourths of the outside of the globe.

Since water is of such basic character, a complete understanding of the structure and properties of this liquid is essential, but only within the past few years has much light been shed on these.

There is intoxicating water, exploding water, sour water, water that will burn through glass or steel, solid water—all forms, actual or theoretical, of pure water. By its supreme solvent powers it spreads chemical action through the earth's crust. It is the active agent in volcanoes. It dissolves materials and transports them to concentrated deposits, available to man. It washes the surface of the earth into the oceans, which give it back again, millenniums later, as limestone and other deposits.

Much remains to be learned and much that has been determined has yet to be correlated into a consistent picture. Why is this liquid so near to being an ideal solvent and how do its properties in this respect change with changing physical conditions? These are subjects of intensive study at present at the Geophysical Laboratory of the Carnegie Institution of Washington.

Concept Has Changed

During the past few years the concept of the nature of liquids, as distinguished from gases and solids, has undergone revolutionary changes.

All three are composed of much the same kinds of molecules. In gases these are comparatively far apart and are distributed at random. In solids they are very close together and arranged in definite orders. A gas can be changed into a solid by bringing its molecules near each other, by means of cooling or pressure, so that they will be arranged in stable patterns by the distribution of their own attractive forces. Likewise a solid can be changed into a gas by heating—that is, by imparting to those molecules sufficient energy to break loose from these attraction bonds—or by release of pressure.

But in either direction this transformation usually passes through a liquid phase. Liquids used to be considered as gases in which the molecules had come very close together but were not yet arranged in any definite order.

This concept has been somewhat revised from studying the way in which X-rays are scattered in passing through a liquid, which in turn indicates the distribution of the molecules.

A liquid is now considered in some respects not as a compressed gas but as a melted solid—perhaps a hair-splitting difference, but of considerable significance in interpreting liquid behavior. The properties of a liquid now can be seen to depend on the "neighborliness" of its molecules and the nature of the spaces between them.

Water Is Unique

In these respects water is unique in nature. The molecule may be pictured as a sphere with electrical charges at four points which are the vertices of a tetrahedron. Two of these charges are positive and two negative. When these spheres are placed in contact so that the positive poles of one touch the negative poles of the other, there is built up a structure in which each water molecule is surrounded by four nearest neighbors. This makes the structure a very open one. Molecules arranged in such a fashion trap a lot of empty space. In other words, water is full of big holes.

Ordinarily when a liquid is heated it expands. The molecules are given more energy of motion and tend to get farther apart. But when they are arranged in the water structure and given more energy, the effect is quite complicated. They tear away from their positions in the structure, but there is no way in which they can arrange themselves easily which provides more space between them. Distorting the structure actually produces a tendency toward contraction. But at the same time these molecules share with those of other liquids the tendency to get away from each other as their energy is increased.

Thus there is set up a tug-of-war between the two tendencies of contraction and expansion. If the temperature is increased sufficiently the expansion drive wins and the liquid becomes steam. But at low temperatures the expansion is very little. Between zero and 25°C it is only a fourth of what would be expected of a normal liquid. At temperatures close to freezing the contraction becomes predominant, and there is actually contraction between zero and 4°C. This is one of the most important facts in nature. It means that as water reaches the solid, or ice, stage it is lighter, volume for volume, than at slightly above freezing. So ice floats, lakes freeze from above downward.

Why It Is Good Solvent

The open structure of water explains its properties as a solvent. Small, positively charged ions, such as those of lithium and magnesium, can get into the space between four firmly bound water molecules and, by repelling the positive poles, tend to increase the volume. The larger sodium and potassium ions, on the other hand, tend to pull the water molecules closer together.

There are at least 18 kinds of pure water. For a decade the familiar chemical H_2O, a molecule made up of two atoms of hydrogen and one of oxygen, has meant only the most abundant and best-known water existing in nature.

There are three isotopes (forms with different weights) of the hydrogen atom. One, deuterium, is twice the weight and another, tritium, thrice the weight of ordinary hydrogen. These three can be combined in all possible combinations of two to form water.

There are also three isotopes of the oxygen atom—O_{16}, O_{17}, and O_{18}. Regardless of which isotope is combined with the two hydrogen atoms, water is formed.

Only one of the variants from ordinary water is well known to physicists: the so called "heavy water," composed of two atoms of deuterium and one of oxygen 16. This has been prepared approximately 99 per cent pure and displays peculiar properties now under investigation in many laboratories.

Tritium, or triple weight hydrogen, is a radioactive element. Half of it explodes every 250 days. Since the amount originally present on earth has decreased by half approximately every year since the cooling of the planet, only an infinitesimal amount of it can be left. Nevertheless, it can be assumed, there is an occasional atom combined with some form of oxygen to form a molecule of water. Hence there may be "exploding water"

As the earth grows older, probably the amount of deuterium relative to the amount of ordinary hydrogen increases because, being heavier, it is less apt to escape into space.

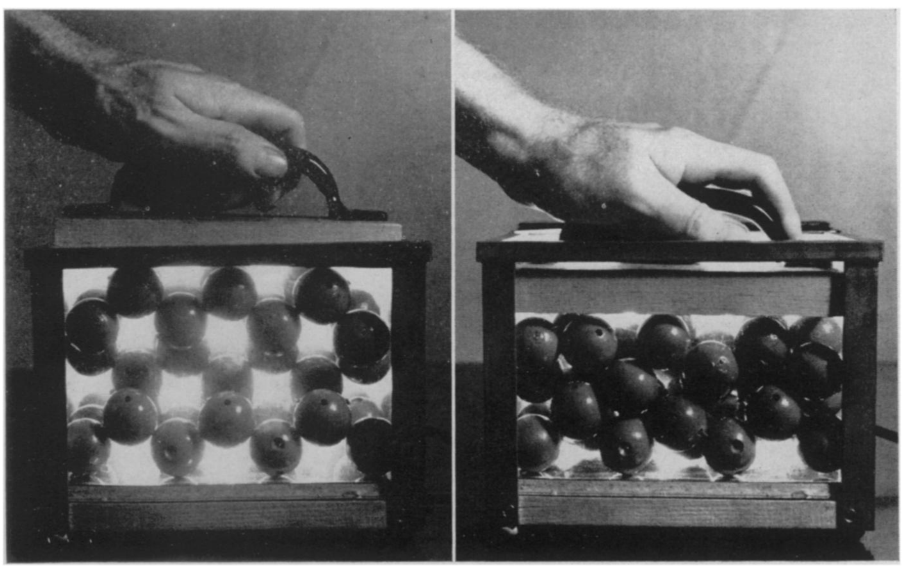
Chemically the properties of the 18 kinds of water presumably are identical. Physically and physiologically there may be wide variations. The heavier the water in protoplasm, it was thought at first, the slower would be the complex phenomena of life. Hence DDO (heavy water) was the subject of some speculation as a possible prolonger of existence.

A problem of great theoretical interest concerns the practical possibility of changing water into "glass," that is, into a non-crystalline solid. When water crystallizes to form ice, usually at zero centigrade, it increases in volume. Now every cell of every living thing contains water. When this freezes the expansion presumably breaks the cell walls. The result is death of the cells and, if the process is wide-spread, death of the individual. But if the cell water could be solidified without increasing its volume, life processes might be suspended indefinitely without being brought to an end.

It has not been actually demonstrated that death from freezing is due to bursting of cell walls because of the expansion of water. Other life mechanisms are affected and it is possible that changes in some of these, such as salt concentration, due to rapid freezing may explain the reported phenomenon.

This much can be said: water does not necessarily change into ice at zero centigrade. It has been brought down to the neighborhood of minus 24° and remained liquid. There must be a nucleus around which crystallization starts. This may be a speck of impurity in the liquid, or a motion. If absolutely pure water could be kept absolutely motionless it is difficult to say how low a temperature could be achieved without freezing.

The super-cooled water presumably is a little more viscous—that is, a little thicker—than ordinary water, although the difference is not superficially discernible. Presumably as the temperature sank lower and lower it would pass through the consistenecy of molasses and finally glass. There would be no increase in volume.



WHAT PRESSURE DOES TO WATER

These two photographs illustrate how the molecules are arranged in liquid water at low temperatures (left) and what happens (right) when the water is squeezed by enormous pressure. Each ball represents one water molecule, and each is joined to four neighbors by weak forces (rubber bands in the model). These illustrate that, although water is usually regarded as a very incompressible substance, it would be even more incompressible if the molecules were not arranged in this unique way.

In the earth's interior, there is water at very high temperatures and under very great pressures. The properties of this form of water are the particular interest of Dr. R. E. Gibson and his associates at the Geophysical Laboratory. Upon such properties depend some of the phenomena of volcanology.

It is known that the greater the pressure, the more corrosive water becomes. Under very high pressures, combined with high temperatures such as would be encountered 40 or 50 miles below the surface, it would eat its way through the walls of almost any imaginable container. Its acidity increases under pressure.

A strange form is "liquid steam." This is water far above the boiling point—100° centigrade at sea-level pressures—where it normally evaporates.

It can be kept a liquid, or at least something superficially indistinguishable from a liquid, at temperatures of from 500 to 600°C by increasing the pressure upon it as the heat is increased. Such actual temperatures have never been obtained because, apart from the technical difficulties involved, water at such pressures would be transformed into an acid that would eat its way through walls of steel a foot thick.

Exists at Great Depths

Certainly such water exists at great depths. A predominating proportion of the gases emitted in a volcanic eruption are "water." It differs from ordinary water largely because of the changes produced in its internal structure by enormous pressures. In the Carnegie laboratory it can be placed under pressures thousands of times that of the sea-level atmosphere.

As the pressure increases, the curious arrangement of its molecules in groups of five, with four arranged at equal distances about one vibrating in the center, tends to be changed into the 12-in-a-pile structure of most other liquids.

The solubility increases as the pressure goes up, in spite of the fact that there are smaller and smaller "holes" for the foreign substance. This is due, Dr. Gibson says, to the fact that a group of water molecules at ordinary pressures seems to constitute a very self-satisfied population group. But as the structure is changed, the "happy family" arrangement comes to an end and the molecules begin actively to draw to themselves the foreign particles, despite the fact that there is less room for them.

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