

## Does water exist primarily as a polymer?

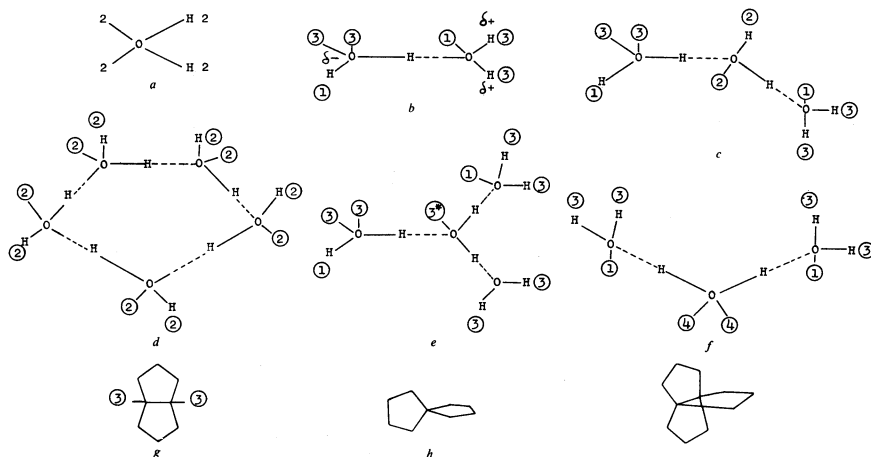
Water, the most familiar liquid, is also a very unusual one. It not only expands when it is heated; it expands when it freezes. That is why ice floats instead of sinking to the bottom. The crystalline structure of ice is rather well known, but the structure of liquid water is still something of a mystery to chemists.

There are many theories and suggestions. In the Sept. 29 NATURE M. C. R. Symons of the University of Leicester in England points out that most of the models so far put forth are designed to reproduce selected characteristics of liquid water, for example, its temperature of maximum density (about 4 degrees C.) or its X-ray scattering pattern. Most of the theories suppose that much of the structure of ice is retained in the liquid water. They range from models in which ice structures are mixed with monomers (single water molecules) to models in which two different ice structures change into each other rapidly in such a way that they remain in equilibrium with each other.

Symons rejects these models in favor of what he calls "early ideas of water as a polymer." The idea is based on a simple chemical property: Water is amphoteric, capable of reacting either as an acid or as a base. The amphoterism greatly enhances its chances of reacting with itself.

Symons envisions a situation that begins with very little water dissolved in a "hypothetical, inert but completely miscible solvent." Gradually the amount of water in the solution is increased. At first the water will be in single molecules, each of which has two places where it can react with a base and two places where it can react with an acid. Gradually it begins to form dimers (two molecules conjoined), and each dimer has three acid and three basic sites. The chemistry thus favors a process in which remaining monomers are more likely to attach themselves to dimers. If this process continues, larger and larger polymers will form until all the water is bound in one structure. Such an outcome is prohibited, however, for a number of chemical reasons that Symons sets forth, including the fact that the new binding sites that form as the polymer grows do not all have the same reactivity. What tends to form are large three-dimensional bound structures. Fluidity is explained as the result of bending and breaking of bonds and their reformation with other neighboring structures.

Symons cites some experimental work that tends to favor his ideas. One



Symons/Nature

Possible water polymers. High number means a more reactive bonding site.

item is a survey of published infrared data on water, which he completed with L. M. Kleiss and H. A. Strobel. It indicates that concentration of monomers in liquid water under normal conditions is "undetectably small." Other results include X-ray scattering studies and computer simulations of molecular dynamics.

So far no proposed model has been convincing enough to gain the general assent of chemists. Perhaps, if experimental evidence continues to favor it, Symons' will. □

## Did the moon form in a perpendicular orbit?

The moon's composition is not at all what it should be had the moon been formed in its present orbit around the earth. Lunar scientists have been coming up with all kinds of exotic models to try to explain the moon's anomalies (its enrichment in calcium, aluminum, titanium, barium, strontium, thorium and other rare-earth elements and its depletion in iron and volatile elements and compounds).

Now Don L. Anderson of the California Institute of Technology reports in the Sept. 29 NATURE a model that accounts for these differences: a moon that accreted at high temperatures but at lower pressures than terrestrial planets. He does this by having the moon in a highly inclined orbit around the earth—almost perpendicular to the ecliptic.

He incorporates the theory that the solar nebula out of which the solar system condensed dissipated before everything had condensed and that the temperatures remained high. Within the disk-shaped nebula, the temperatures fall off roughly as the square root of the distance. Different substances condensed at distances and times that depended on their concentrations and vapor pressures. Thus, the refractory

silicates and iron condensed in the inner part of the solar system and the volatiles in the outer part.

But opacity, density, pressure and temperature in the nebula also vary with height above the median ecliptic plane. Lunar samples indicate that the moon's surface is made up of material that should have condensed out of the nebula first—before iron. Anderson hypothesizes that, while off the ecliptic plane, the future lunar material remained at high temperature but its gas pressure decreased. So it condensed later than did the same material in the ecliptic plane.

In Anderson's model, the earth would be more than 50 percent assembled before the moon started accretion, and the earth would have swept up most of the iron. After the moon nucleated, the earth would still get most of the remaining iron and later condensates, since it spent all of its time in the median plane.

The moon in Anderson's model is composed chiefly of compounds that condensed before iron, and the volatile content of the moon was brought in as a thin veneer after the solar nebula dissipated. The bulk composition may be similar to the calcium-aluminum rich inclusions in Type III carbonaceous chondrites. (The inclusions were first discovered in 1968.)

If lunar accretion—when it finally began—were rapid, the moon could be chemically zoned. In the model, the moon is enriched in the refractory elements and the interior devoid of iron, but the iron content increases with the radius. Rapid accretion, high temperatures and high uranium and thorium contents would all lead to high initial temperatures, which is consistent with the need for early differentiation of the moon.

The inclination of the moon's orbit would decrease with time due to gas drag and tidal interactions to end up at its present value. □