NOTEBOOK contains a miscellaneous collection of items all designed to aid your study of biology. Whether dealing with creatures or concepts, evolution or exams, NOTEBOOK will help, inform and remind you of things that you should find useful.

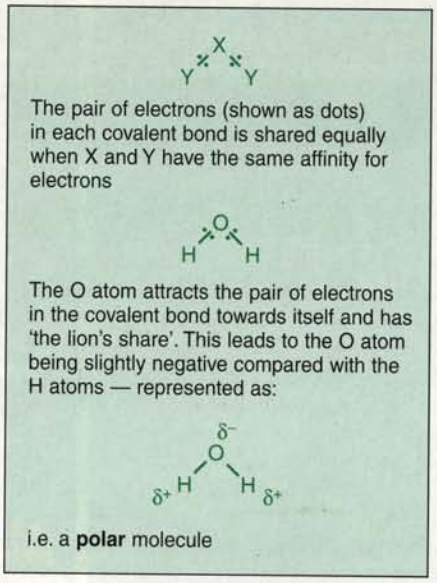
Water

What makes water so vital for life? Animals and plants living in 'normal' environments cannot survive without a regular supply of water. Species living in desert conditions have evolved elaborate mechanisms to conserve water. Organisms such as bacteria normally live in watery environments, and even dehydrated life forms like spores require water to change from a state of suspended animation to a form in which living processes can proceed. This requirement for water is absolute — no other solvent can be substituted.

The life-giving quality of water comes from its properties as a chemical compound, so how does the chemistry of water contribute to living processes?

WHY IS WATER A LIQUID?

Perhaps the most remarkable property of water is that, at normal ambient temperatures, it is a liquid. This contrasts with other molecules like nitrous oxide and hydrogen sulphide which have similar or slightly greater molecular masses but are gases. The fact that water is a liquid stems from the highly polar nature of the water molecule — in which the electrons in the bonds between oxygen and hydrogen are shared unequally (see Figure 1). The oxygen atom, which has a much greater affinity for electrons than hydrogen, takes the lion's share and gains a partial negative charge, while the hydrogen atoms are left with a partial positive charge. These partial charges provide a force that attracts water molecules together through 'hydrogen bonds', in which a hydrogen atom from one water molecule is attracted to the oxygen atom of another (see Figure 2). Hydrogen bonds are much weaker than the normal covalent bonds between oxygen and hydrogen, but in a watery solution networks of hydrogen bonds link all the water molecules together and make it much more difficult for water molecules to escape into the gas phase. This is why water must be heated to 100 °C before it will boil. In contrast, in compounds like methane the bonds between carbon and hydrogen are not polar, so the attractive forces between the methane molecules are much weaker than in water and methane is a gas at ambient temperatures (see Figure 3).



The pair of electrons (shown as dots) in each covalent bond is shared equally when X and Y have the same affinity for electrons

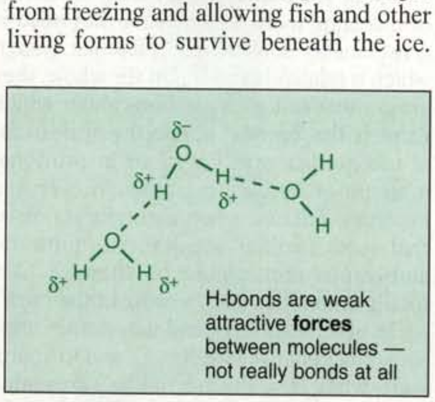
The O atom attracts the pair of electrons in the covalent bond towards itself and has 'the lion's share'. This leads to the O atom being slightly negative compared with the H atoms — represented as:

i.e. a **polar** molecule

Figure 1 The polarity of the water molecule.

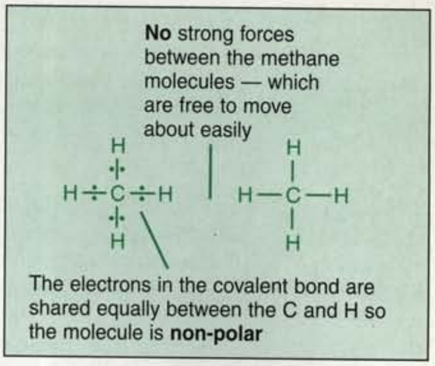
ICE

Hydrogen bonds are also of great importance when water freezes. In ice the arrangement of hydrogen bonds between water molecules is more regular than in liquid water, making ice a semi-crystalline solid. Ice forms on the top of ponds and other areas of water because the density of ice is less than that of water at temperatures just above the freezing point. This is vital for pond life because the surface ice insulates the water beneath, preventing it from freezing and allowing fish and other living forms to survive beneath the ice.



H-bonds are weak attractive **forces** between molecules — not really bonds at all

Figure 2 Hydrogen bonding between water molecules.



No strong forces between the methane molecules — which are free to move about easily

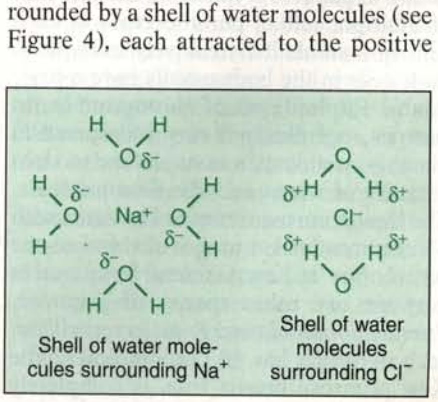
The electrons in the covalent bond are shared equally between the C and H so the molecule is **non-polar**

Figure 3 Non-polar covalent bonds.

On the other hand the high concentration of salts in the sea allows the water in the Arctic and Antarctic oceans to remain liquid at below 0 °C. This is because many water molecules are bound to sodium and chloride ions (see below) and this interferes with the formation of ice crystals. The sea temperatures are low enough to freeze the body fluids of some fish. As an adaptation to this environment, fish like the winter flounder have developed a biological antifreeze to protect themselves. Their blood contains a special glycoprotein (made chiefly from the amino acids alanine and threonine and the sugars galactose and N-acetyl-galactosamine) which inhibits the growth of ice crystals that might otherwise cause damage to the tissues (see BIOLOGICAL SCIENCES REVIEW, Vol. 4, No. 5, pp. 5–7).

WATER AS A SOLVENT

In living organisms many biochemical reactions take place in the cytoplasm or in other watery fluids such as blood. Here water serves as a solvent which holds ions such as potassium and chloride and organic molecules as diverse as glucose and proteins in the liquid phase. Solubility of these substances depends on the ability of water to interact with them, and again the polarity of water plays a critical role. Cations like sodium and potassium become surrounded by a shell of water molecules (see Figure 4), each attracted to the positive



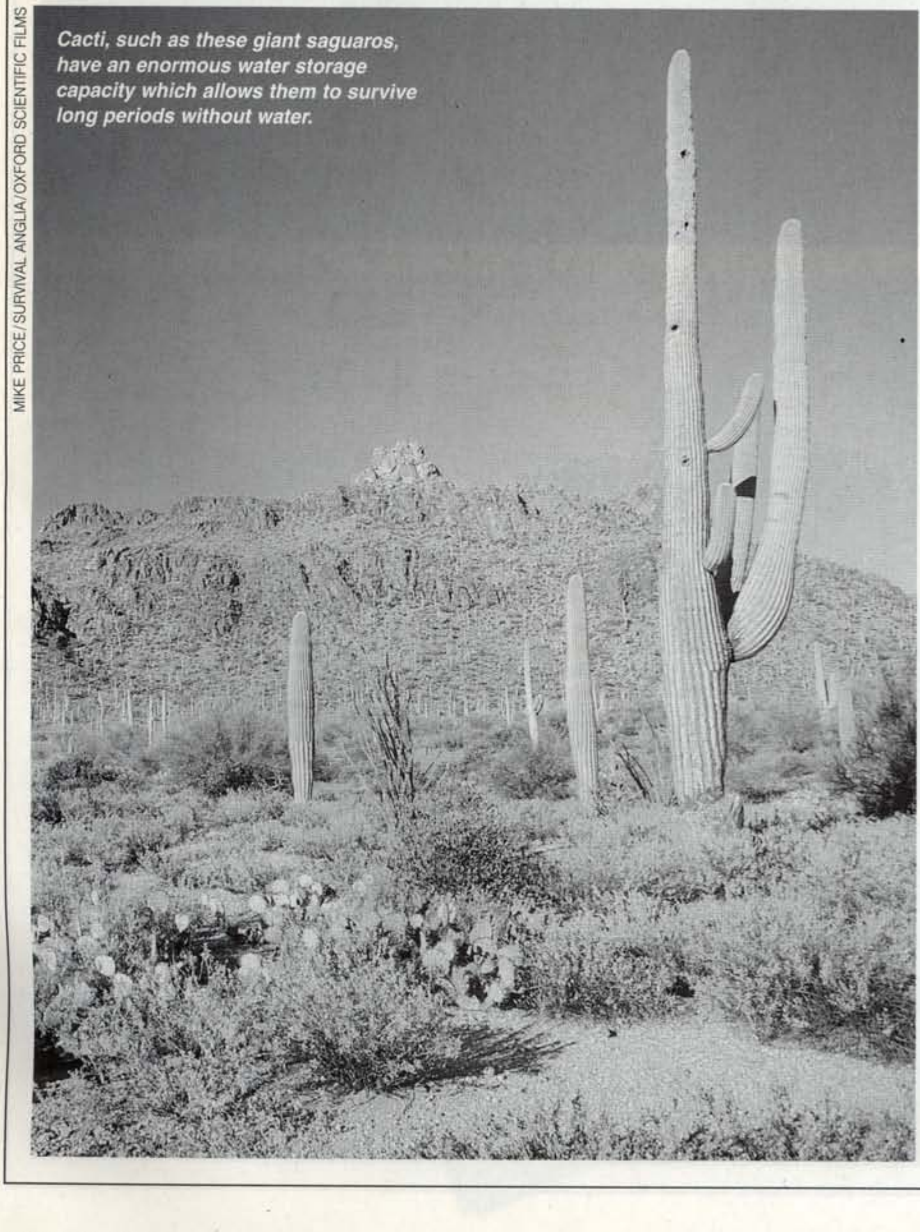
Shell of water molecules surrounding Na^+

Shell of water molecules surrounding Cl^-

Figure 4 Interactions between water and sodium and chloride ions.


TOPHAM

Surface ice insulates the water beneath — it does not freeze, so life goes on!


MIKE PRICE/SURVIVAL ANGLIA/OXFORD SCIENTIFIC FILMS

Cacti, such as these giant saguaros, have an enormous water storage capacity which allows them to survive long periods without water.

charge by the partial negative charge on the water-oxygen atom. In a similar way anions are hydrated (usually less so than cations) through attraction of the partially positive charges on the water-hydrogen atoms to their negative charge(s).

The solubility of organic molecules in water also depends on their ability to complex with water, either through the binding of water to charged parts of the molecule, such as carboxyl groups ($-COO^-$) or protonated amino groups ($-NH_3^+$), or the formation of hydrogen bonds. Such hydrogen bonds are often formed between the hydrogen atoms of water and oxygen atoms in, for example, sugars or the $-OH$ side group of some amino acids. On the other hand uncharged molecules like mineral oils, which lack oxygen or similar electronegative atoms, fail to interact with water molecules and are insoluble.

Animals like us have evolved biochemical ways of dealing with the problem of eliminating hydrophobic molecules (these include many drugs) from the body. Such molecules are first hydroxylated in order to introduce a hydroxyl group, which is then esterified to a sulphate group. Sulphate

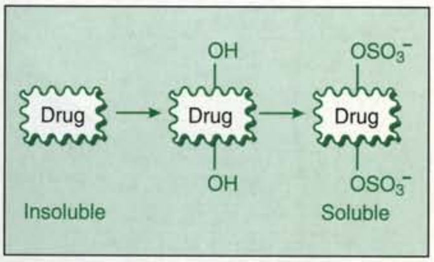
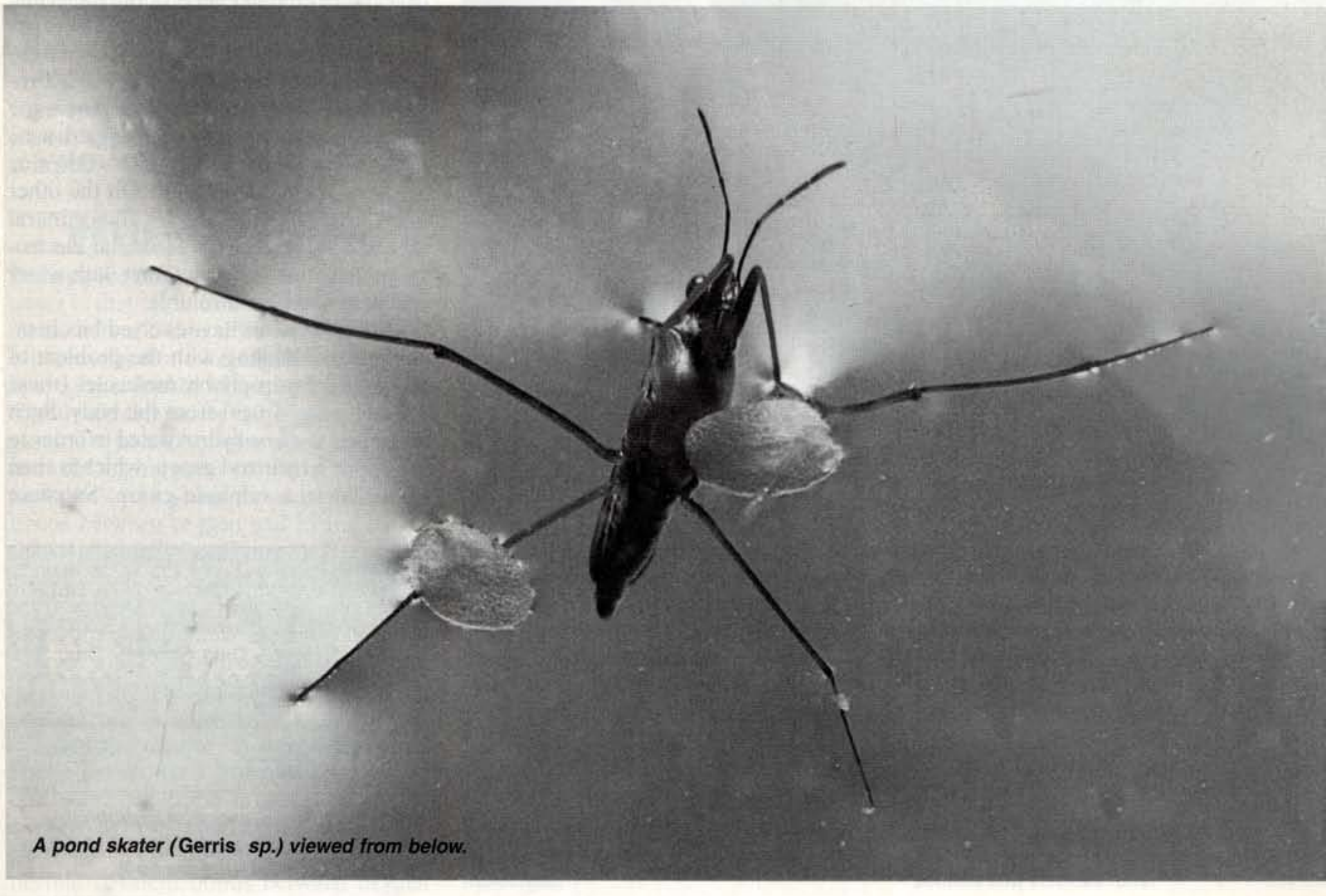


Figure 5 The conversion of hydrophobic drugs to water-soluble derivatives that can be readily excreted from the body.

ALASTAIR MacEWEN/OXFORD SCIENTIFIC FILMS

The raft spider (*Dolomedes *sp.), Britain's largest spider, uses the surface of the water instead of a web to detect vibrations caused by passing prey.

G.I. BERNARD/OXFORD SCIENTIFIC FILMS



A pond skater (*Gerris *sp.) viewed from below.

groups are amongst the most hydrophilic anionic groups and their interactions with water make the intruding molecule soluble and excretable in the urine (see Figure 5).

THE COHESIVENESS OF WATER

The hydrogen bonds that hold water molecules together give water a cohesiveness which we can see when a drop of water is put onto a polished surface. The drop remains intact and hardly wets the surface, whereas under similar circumstances a drop of alcohol would spread across the surface. At first glance this property seems unimportant to life, but to many plants, especially large trees, it serves a vital function. The great cohesiveness and high surface tension of water means that long columns of water remain intact when travelling up capillaries like those in xylem. Thus transpiration is able to carry water to the highest leaves of trees 30 m tall, an achievement that would be impossible with liquids like ethanol or olive oil. This same property of water is exploited by insects like the water strider, which are able to 'skate' over the surface of ponds and streams. This is possible because the waxy cuticle of the insect prevents wetting and the insect's weight is not great enough to break through the surface of the water.

OSMOSIS

Whenever living cells are in contact with a fluid, whether it is the water in which the organism lives, or the extracellular fluid of a higher organism, it is possible for water to diffuse either into or out of the cells. This process is known as osmosis. The direction of movement of water depends on the concentration of solutes (including ions like sodium and chloride, metabolites and large molecules like proteins) in the cytoplasm relative to the concentration of solutes in the surrounding solution. Solutes become associated with some of the water molecules (as described above) and this lowers the concentration of free water in the solution. As a result the water potential is highest when solutes are absent and decreases as the concentration of solutes increases (see BIOLOGICAL SCIENCES REVIEW, Vol. 7, No. 3, pp. 14–16). Water moves from the compartment with high potential to that with low potential, or from the compartment with low solute concentration to that with high solute concentration. The result of an osmotically driven movement of water can be seen very clearly when red blood cells, which contain a fairly high concentration of salts and protein, are placed in water. Water rapidly enters the cells causing an increase in cell volume followed by bursting of the cells (**lysis**), which occurs when the cell membrane cannot stretch enough to accommodate the increase in volume caused by water entry. In contrast to red blood cells, many plant cells do not lyse when placed in solutions of low salt concentration. This is because the osmotic entry of water is opposed by the strength of the cell wall. The system reaches a balance when the pressure exerted by the osmotic inflow of water is exactly matched by the inward pressure (or turgor pressure) exerted by the stretched cell wall. At this point there is no net movement of water into or out of the cells and the cells are relatively stiff or turgid. On the other hand, when similar cells are placed in a solution with a higher solute concentration than their cytoplasm, water leaves them until the solute concentrations are equal inside and outside the cell. This loss of water is accompanied by a shrinking of the cytoplasm and the cell wall relaxes to its unstretched size, losing turgor pressure. Under these circumstances the cells become flaccid. You can easily test this by putting two similar thin slices of potato into (a) water and (b) a concentrated solution of salt or sugar. ■

FURTHER READING

Starr, C. and Taggart, R. (1989) *Biology: The Unity and Diversity of Life*, Wadsworth, pp. 36–47 and pp. 267–276.

Lowe, A. (1995) 'pH and buffers', *Biological Sciences review*, Vol. 8, No. 2, pp. 24–26.

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