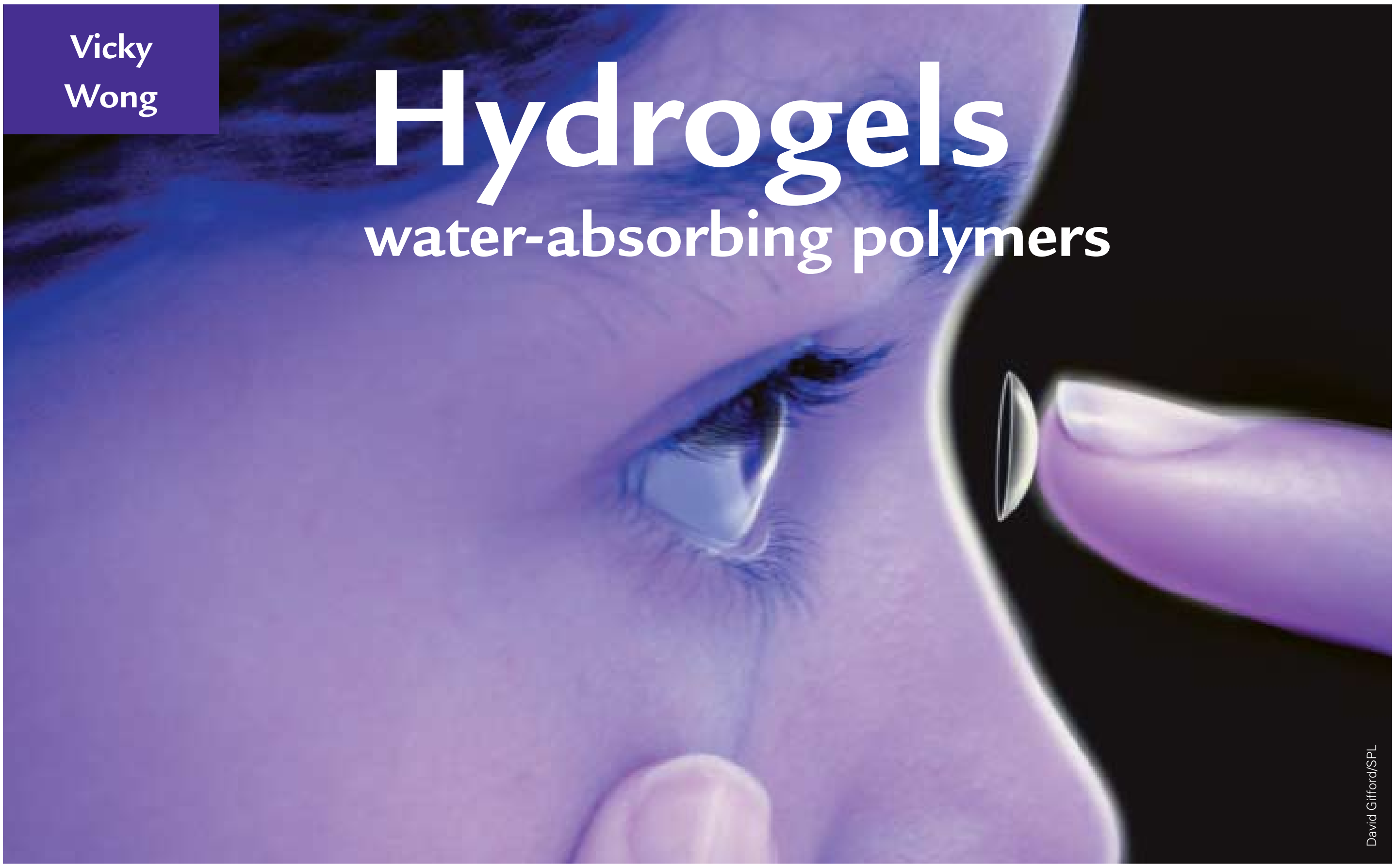
Vicky Wong

Hydrogels

water-absorbing polymers



Key words
Polymer
Bonding
Biocompatibility
Smart materials

What is the connection between soft contact lenses, disposable nappies, hair gel and plant water crystals? The answer is that they all make use of substances called hydrogels. These are polymers which have the unusual property of being able to absorb huge quantities of water.

Scientists still do not fully understand how hydrogels manage to absorb so much water, and there is still plenty of ongoing research into their properties and uses. Understanding the structure and bonding of these advanced materials helps to explain these properties; this in turn helps chemists to design new hydrogels which can perform different functions.

Structure and bonding

Many hydrogels are **polymers** of carboxylic acids. The acid groups stick off the main chain of the polymer (Figure 1). When these polymers are put into water, the hydrogen atoms react and come off as positive ions. This leaves negative ions along the length of the polymer chain.

When polymer chains are in solution, they tend to coil up (Figure 2). However, the hydrogel now has lots of negative charges down its length (Figure 3).

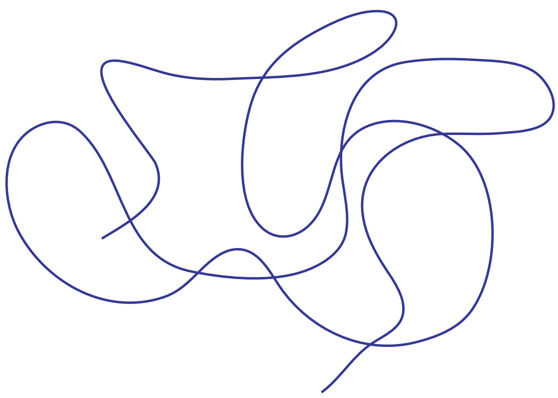


Figure 2 *A polymer chain coiled up in solution*

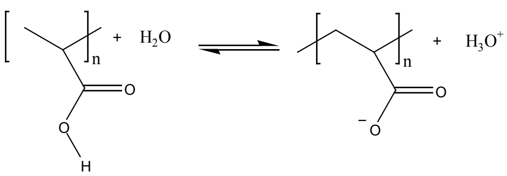


Figure 1 *The polymer chain of a hydrogel. Note: H_3O^+ is another way of writing H^+ and shows an acid.*

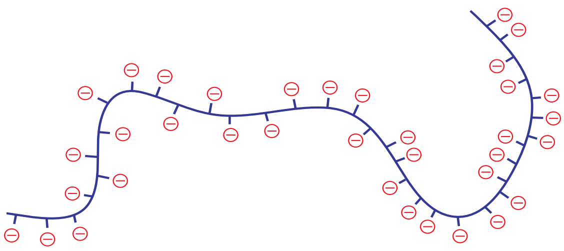


Figure 3 *A hydrogel polymer chain with lots of negative charges along its length*

These negative charges do two things:

· They repel each other. This forces the polymer chain to unwind and open up.

· They attract water molecules.

A water molecule is H_2O; it has two hydrogen atoms attached to a central oxygen atom. It is a covalent molecule and not ionic, and overall has no electric charge. However, the oxygen atom is better at pulling electrons towards itself than the tiny hydrogen atoms. This causes the oxygen atom to be very slightly negative and leaves the hydrogen atoms very slightly positive (Figure 4). The charges are tiny – far smaller than the negative and positive charges in something like sodium chloride – but they are big enough for the negative charges on the hydrogel polymer to attract them. The water molecules stick to the hydrogel polymer and force it to open up even further.

The combination of the polymer opening up and the water molecules sticking to it make a solution of the hydrogel get thicker and more viscous (sticky).

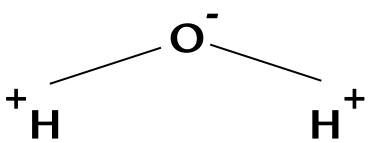


Figure 4 *A water molecule showing the very small negative and positive charges on the atoms.*

Drier babies, wetter plants

Disposable nappies make use of the ability of hydrogels to take up and retain water, even under pressure. They contain small crystals (about 1 mm in diameter) of hydrogel in the fluff at the core of the nappy (see Box 1). They absorb the urine and swell up. Because they do not easily give the water back, the child stays dry.

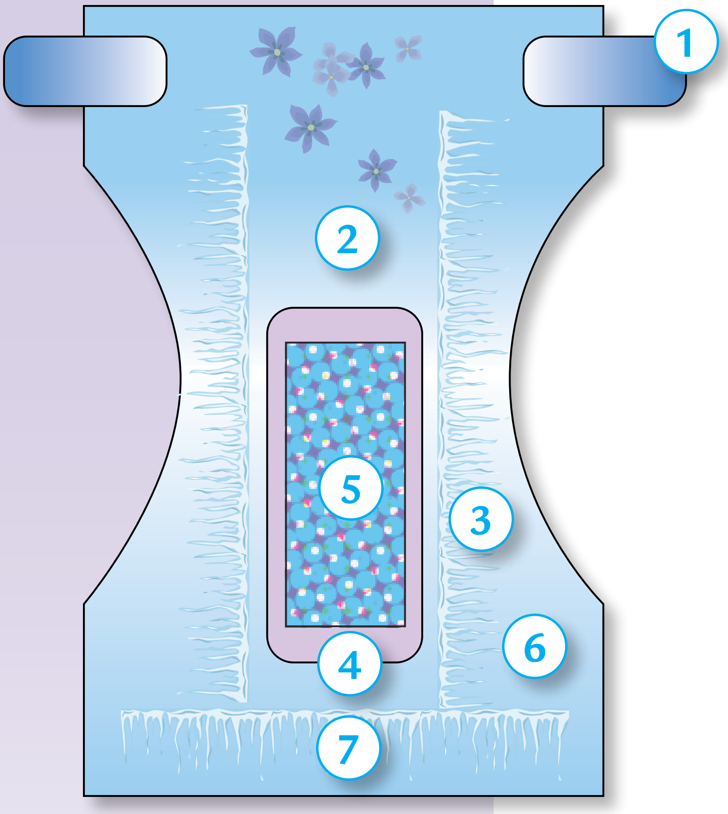
Plant water storage crystals are similar. They absorb water and swell up. If they are put in with plants in tubs or hanging baskets, they will slowly release the water as the soil dries up and extend the amount of time required between waterings, for example when you go on holiday.

Plant gel crystals

Box 1 What's in a nappy?

Over 17 billion disposable nappies are sold in Europe each year. They have replaced traditional cotton nappies: 97% of babies use disposables.

A nappy may seem a mundane, everyday product, but there is a lot of technology in its design. For each part, a material is chosen with the correct properties – smooth, waterproof, sticky etc. And at the heart is the water-absorbent hydrogel which can retain urine even under pressure.



1 *tape/loop & hook closure system*
2 *absorbent hydrogel core*
3 *leg elastic*
4 *transport layer*
5 *acquisition layer*
6 *plastic film backsheet*
7 *elastic waist band*

Some medical applications of hydrogels

- breast implants
- wound dressings
- pressure sensors
- drug delivery systems
- lens replacements

Medical benefits

Hydrogels also have several major medical uses and you are likely to know someone who is benefiting from them as they are used in 'soft' contact lenses. However, scientists are discovering that hydrogels can be used for several other medical applications. There are many reasons for this including their amazing ability to absorb water. As they can hold so much of it they can have a similar water content to body tissue and can transport nutrients and waste.

They are also biocompatible. This means that they do not harm the body or stimulate an immune reaction.

As the hydrogels are known to work quite happily in the eyes of millions of contact lens wearers, it makes sense for scientists to look at ways in which they can be used to treat physical damage to the eyeball. In the USA, a hydrogel has been developed which it is hoped will be used to replace diseased and ageing lenses. As we age the lens of the eye gradually loses its ability to adjust its focus. The hydrogel has similar mechanical properties to the lens in the eye and the scientists hope that it will possible to inject the hydrogel into the eye to help restore sight.

An Italian company is testing hydrogel tablets as a slimming aid. A single tablet, less than 1 cm across, swells in the patient's stomach to hundreds of times its original size. This causes the patient to feel full and suppresses their appetite. However, some doctors warn that this is no substitute for a reduction in calorie intake.

Smart materials

On top of these benefits, hydrogels are also smart materials. A smart material is one which changes its shape (or some other property) in response to changes in its environment. Different hydrogels can be made to change shape in response to changes in pH, temperature, salt concentration and many other factors.

Look again at Figure 1. The polymer changes when water is added and there is a $\rightleftharpoons$ sign in the equation. This sign shows that the reaction is reversible. If water is added, the equation moves to the right. If water is removed, it moves to the left. On the right hand side, H_3O^+ is acidic. If more acid is added the equation will move to the left; if acid is removed (for example by adding some alkali) the equation will move to the right. As the polymer on the left hand side is the collapsed form and the one on the right is large and viscous there is a considerable change in the properties as the pH changes. It is this shape change which makes the hydrogels 'smart'.

Many scientists are researching ways in which hydrogels can be used as drug delivery systems. When you take a medicine or drug by mouth it is dispersed throughout your body. This means that if you take a paracetamol for a headache, the drug reaches not just your head but also your arms, legs, stomach and the rest of you. In the case of paracetamol, this is not usually a problem but some drugs have unpleasant side effects. What a drug delivery system aims to do is to deliver the drug to the site where it is needed, but to keep it tied up and unavailable to cause problems when it is in the rest of the body. So scientists hope to load the drug onto a hydrogel and have it released at the place where it is needed. The diseased site may have different chemical properties which the hydrogel could recognise and therefore release the drug it is holding only at that point.

Growing new body parts

The technology is still a long way off, but scientists are hopeful that some time in the future it will be possible to grow replacement body parts in hydrogels. Cells of the required tissue will be added to the hydrogel and injected into the body where they are needed. The hydrogel will take the place of the damaged tissue and also allow nutrients to pass through it to the cells inside. Over time, the cells will grow and the hydrogel be degraded by the body until new tissue is in place to repair the damage.

Hydrogels are still a long way from being used in hospitals and whole organs grown on hydrogels are even further away, but researchers in the USA recently managed to grow lung tissue in a hydrogel which demonstrated that this idea has potential.

Hydrogels, then, are both readily available in such everyday items as nappies and hair gel and the focus of cutting edge research around the world.

Vicky Wong teaches and writes about chemistry. She is an editor of CATALYST.

Jerry Mason/SPL

Cleaning up with hydrogels

Dr Nicholas Crowther and Dr Donald Eagland of Bradford University have invented a 'supergel' for use in combating environmental pollution. This hydrogel is much stronger than other hydrogels, and is capable of absorbing large amounts of oil. A sheet of the polymer can be thrown over an oil slick; when the oil has been absorbed, the gel is rolled up and removed.

Testing hydrogels

Try This

Hydrogels are polymers with a great capacity for absorbing water - see the article on pages 18-20. Here are some experiments to try on a couple of domestic products that make use of hydrogels: hair gel (cheap and cheerful is fine, from any supermarket or chemist), and plant water storage crystals (also known as water-retaining gel, from garden centres).

Experiment 1: Hair gel

Put a large blob of hair gel into each of two old yoghurt pots. To one add some salt, to the other some sugar.

You should be able to see a clear difference with the salt (an ionic compound) and the sugar (a covalent compound). The ions in the salt cause the hydrogel to collapse and quickly turn into a liquid (see the Hydrogels article on pages 18-20 for more about this). As the sugar does not contain any ions it does not cause the hydrogel to collapse.

Why do you think this hair gel contains hydrogel? What would happen if you went swimming in the sea while using this gel?

Experiment 2: Plant water storage crystals

Put a teaspoonful of the crystals into a yoghurt pot. Add a measured amount of purified water to the crystals. Try to work out how much water the crystals will absorb (they will take several minutes to finish absorbing the water). How much larger are the crystals when they are soaked in water than they were at the start?

Repeat with tap water in a second pot. Is there a difference? Can you explain it? There is likely to be a greater difference in hard rather than soft water areas. Why?

Some hydrogels can absorb as much as 600 times their original volume of water. They will absorb more purified water as it contains fewer ions. Tap water contains ions, so the hydrogel will not absorb as much tap water as purified water.

Put the remains of these experiments into the bin and not down the sink.

The hydrogel can look like colourless jelly, but it is not edible so don't eat it!

If you know someone who wears disposable contact lenses you may be able to persuade them to give you a pair. You can try Experiment 1 on a much smaller scale with the contact lenses – but do check first that they have definitely finished with the lenses and don't want them back!