Hydrogels

The International Union of Pure and Applied Chemistry (IUPAC) defines a *gel* as a 'non-fluid... polymer network that is expanded throughout its whole volume by a fluid' and a *hydrogel* as a 'gel in which the swelling agent is water' [1].

Figure 1 *- Contact lens (© Eitan Tal (איתן טל))*

This swelling is such that hydrogels are nearly all liquid, over 99% in some cases, but they behave like solids due to a three-dimensional cross-linked network within the liquid: it is this cross-linking that gives a gel its structure. Thus gels can be considered as molecules of a liquid dispersed within a solid, having properties ranging from very weak and soft to hard and tough. The term *gel*, incidentally, was coined by the 19th-century Scottish chemist Thomas Graham.

Hydrogels are formed from highly absorbent natural or synthetic polymers. When hydrated, they possess a degree of flexibility very similar to natural tissue, due to their significant water content. This sounds rather technical, and indeed some of the chemistry is very advanced but there are many everyday examples of hydrogels:

Jelly - this is a hydrogel formed from a protein network of gelatin.

Disposable nappies - these contain dried sodium polyacrylate. This polymer can rapidly absorb a large amount of water, up to 500x its mass of distilled water and over 90x its volume of urine. This time the cross-linking is largely due to hydrogen bonding.

Artificial snow - another use for polyacrylate.

Alginate balls - the algal beads beloved of biologist are made by cross-linking alginate with calcium ions. The same method is used in molecular gastronomy to make 'fruit caviar' and similar exotic foods.

Polymer slime - the PVA/borax slime we all love playing with so much is another example of an ionically cross-linked hydrogel, this time the linking agent is the borate ion.

Contact lenses - soft contact lenses are made from cross-linked, usually silicone, hydrogels.

More recently hydrogels have been developed to act as gel explosives, biosensors, fire retardants, fertiliser/water release controls in plants and for a variety of biomedical uses.

Hydrogels in the curriculum

CfE - There are numerous activities that can be done with hydrogels at this level, though the chemistry behind the behaviour of the materials may be quite complex.

National 5 - where they form that basis of the exemplar investigation for the Assignment.

Higher (*CfE*) - It could be argued, though, that they fit more naturally here: in the structure and bonding section of Chemical Changes and Structure, it states: Hydrogen bonding is at the heart of 'hydrogel' materials.

Figure 2 *- Green Jello (© Gisela Francisco).*

Some simple activities

(Details of all these activities can be found on the SSERC website [2]).

Ionically cross-linked hydrogels

Making simple hydrogel balls
Take a 2% solution of sodium alginate and let drops fall (from close to the surface) into a 2% solution of calcium chloride. Leave for a few minutes and then remove (using a sieve is easier) and inspect the properties.

Investigating cross-linking
The procedure above can be expanded by using a variety of different cross-linking ions: Fe2+, Fe3+, magnesium, aluminium and others. Changing the ion can dramatically alter the nature of the gel.

Using hydrogel balls to model drug-release systems
Using the same system as above, mix some food colouring (or other dye) into the alginate so you get coloured balls.

The effect of salts on ionic cross-linking
If you get a blob of (cheap) hair gel and sprinkle some salt on it, the gel will rapidly liquefy as the ionic cross-linking is disrupted. Showing that the same does not happen with sugar is a good demonstration of a difference between ionic and covalently bonded substances.

Figure 3 - Sphérification (© Javier Lastras).

Figure 4 - Disposable nappies.

It is possible to extend this and investigate the effect of concentration on the rate of dissolution or the effect of different salts.

Hydrogen bonded hydrogels

Extracting a hydrogel from a nappy

These are sodium polyacrylate. It is possible to extract them from (clean!) disposable nappies. The process is rather messy though because of the large amount of fibrous material present. The larger the size of nappy, the more hydrogel you get out.

Investigate the absorption of a nappy hydrogel

Take a known mass or volume of your hydrogel, add 50 cm^3 of distilled water and stir. This will solidify in a few seconds. Keep on adding samples of water until the gel becomes liquid and record the volume. (The change from solid to liquid is a continuous spectrum so you will have to make a judgement about where you draw the line as to the gel's solidity).

You can then repeat the experiment using tap water or fake urine (0.9% sodium chloride with a bit of yellow food colouring in is a good recipe).

Once these are removed and rinsed with distilled water, place a known number of balls in a test tube with some distilled water. The dye will slowly leach out of the balls and colour the solution. Samples can be taken every few minutes and examined in a colorimeter (or simply by eye).

Using hydrogel as a fire retardant

This works best with the polyacrylate taken from nappies or using 'magic snow'. Take a wooden splint, spray with water (or dip it in) and hold it in a hot Bunsen burner flame, timing how long it takes to catch fire. Then take another splint and coat it with the hydrogel. Hold this in the flame and see the difference in tame taken to burn.

Using 'water beads'

These are hydrogel beads used in flower arranging to retain water. They swell up from a couple of millimetres to more than a centimetre in diameter (over a few hours). The will eventually dry out again and can be re-used.

The colourless ones can be used to demonstrate refractive index - as they are almost all water, they are all but invisible in water so you can offer someone a glass with water in and when they put their hands in they feel these slippery spheres.

The size the balls swell to is affected by the ionic content of the water. If you take a range of salt solutions and put beads in them, they will all expand to different amounts and it is possible to get a measure of the concentration by seeing the diameter of the beads.

Gel formation and temperature

Methylcellulose is an interesting material in that gels formed from it behave in the opposite manner to what we normally expect. When the gel is heated, instead of melting, like gelatin, it solidifies: a property that allows for interesting uses like hot ice-cream.

In the classroom, investigations can be done into how the physical properties of different gels vary with temperature.

Obtaining materials

It is possible to obtain hydrogels from a number of sources:

- The usual suppliers such as Scientific & Chemical (http://education.scichem.com/Catalogue/Search) sell polyacrylate hydrogel and 'magic snow'; as do mindsets (www.mindsetsonline.co.uk).
- Water beads can be obtained for a few pence from Amazon or EBay, or from florists.
- Nappies, gelatin and hair-gel can be obtained from any supermarket. (For nappies, get the largest size as these will contain the most hydrogel).
- Sodium alginate will almost certainly already be in your school (if not it is cheap and easy to obtain from the usual suppliers). Biologists use the cross-linking reaction with calcium ions to make algal balls.
- Methylcellulose can be obtained from suppliers but it is also the main component of wallpaper paste. Normal wallpaper paste is not really suitable (especially for younger pupils) because of its fungicide content. It is possible, however, to buy fungicide-free wallpaper paste.

The term hydrogel covers a vast range of materials will all sorts of properties and the field is constantly evolving. In particular there is exciting work going on regarding the use of hydrogels in medicine for wound dressing, controlled-release devices for drugs, scaffolds for tissue engineering and many more. We will, without doubt, be re-visiting this subject in the not too distant future.

References

[1] http://goldbook.iupac.org/HT07519.html.

[2] http://www.sserc.org.uk/index.php/new-cfe-higher-chemistry/chemical-change-and-structure-h/3073-hydrogels.