Look around and you’ll see many little chemical factories in nature that are nonpolluting and environmentally friendly. Inside a leaf or a bug, there lies some sophisticated chemistry, often turning out incredible materials that are the envy of today’s chemists and engineers.

In fact, you might say that today’s industrial chemists are developing a green thumb. Green chemistry is the design of chemical products and processes that reduce or eliminate the use and production of hazardous substances. Green chemists look for new ways to do chemistry that is benign by design, thus preventing pollution before it starts.

Why are chemists turning to nature for ideas? Think about it. Nature uses renewable sunlight for energy and recycled starting materials to make a lot of things. Organisms synthesize medicines, plastics, and all kinds of other useful materials without releasing toxic chemicals into the environment or using large amounts of heat or pressure. Nature’s chemistry embodies many of the principles of green chemistry, using processes that have met the tests of time.

Scientists call the study of these natural chemical processes biomimicry, a term that means imitating life and involves applying nature’s lessons to new human inventions. Janine Benyus, the author of Biomimicry: Innovation Inspired by Nature, calls it “the conscious emulation of life’s genius”. But that’s not to say that every process in nature is nonpolluting. For example, it is well known that animals release carbon dioxide and methane, greenhouse gases, into the environment.

Although biomimicry is getting increased attention today, several famous inventions of the past were inspired by nature. Take the telephone, for instance. Alexander Graham Bell studied the human tongue and eardrum to help him design the first telephone. The Wright Brothers watched birds gliding in the wind for shaping airplane wings before taking the first flight. And nearly everyone is familiar with synthetic Velcro, which was inspired by the way the tiny hooks on seed pod burrs attach to the loops of thread in cloth.

Whether forms, processes, or systems, biology includes a wealth of ideas for chemists and engineers. When scientists apply the methods and systems practiced in nature to cutting-edge research challenges, creative and amazing scientific breakthroughs often occur.

**Spiders spin webs stronger than steel**

Dragline silk from a golden orb weaver spider is five times stronger than steel (when compared gram for gram),
and can absorb five times the impact force of Kevlar—the synthetic fiber of bullet-proof vests—without breaking. What’s more, it can stretch 40% longer than its original length. For the spider, the durability and strength of silk means food. And for humans, it could mean an amazingly useful fiber that can be made from safer and less hazardous chemistry. Science writer Steve Miller describes the properties of good web fiber in a February 2001 ChemMatters article: “It must be strong enough to bear the weight of a bungee-jumping spider, flexible enough to withstand the impact of a flying insect, and stable enough to last for days. And it cannot require more raw material than the spider can replenish from ordinary food resources.” Even the U.S. military has taken notice. The U.S. Army has interest in a manufactured version of dragline silk for applications such as catching fighter jets as they land on aircraft carriers.

How does a spider make such an incredible fiber that humans have not yet fully reproduced? Scientists are still studying the chemical composition of the spider’s silk. Scientists know that spider silk is a protein and have identified the amino acids that are its building blocks. Glycine and alanine are the most abundant amino acids in the silk (see Figure 1). The three-dimensional structure of the fiber, which gives it the strength and flexibility, results from how the amino acid building blocks interact with each other. As a result of the diversity of amino acid interactions, some parts of the silk fiber are highly oriented, like uncooked spaghetti, and other parts are very nonoriented like cooked spaghetti.

To make the silk fiber, the spider synthesizes liquid protein by putting together the amino acid molecules and squeezing the protein through a spinneret (i.e., to spin the fiber). When it exits the spider, the soluble liquid protein becomes an insoluble, highly ordered, and extremely strong fiber. With this knowledge, scientists are trying to make a fiber that is similar to spider silk. This much is certain: spiders don’t use the high pressures, high temperatures, or corrosive acids often used in chemical syntheses. In manufacturing Kevlar, for example, industrial chemists rely on hot concentrated sulfuric acid. Nylon fiber, used in ropes and cords for rock climbing and parachuting, is manufactured under conditions of high pressure and temperature. The golden orb weaver spider manages to produce a high-performance fiber using chemistry mild enough to occur inside their bodies.

**The bombardier beetle bomb**

Bombardier beetles can fire, literally, a mixture of chemicals at predators. To prepare for attack, the beetles produce and store two chemicals, hydroquinone (C6H4O2) and hydrogen peroxide (H2O2).

When the mixture of chemicals is pushed from the storage reservoir into the firing chamber, enzymes in the chamber wall react to release free oxygen (O2) and steam (H2O). They also oxidize the hydroquinone to benzoquinone, which is an irritant (see Figure 2). The resulting reaction is extremely exothermic. Heat and pressure force the chemical spray out an opening in the beetles abdomen with a loud bang. “The chemistry is simple, but the biology is beautiful” said Jerrold Meinwald, a researcher at Cornell University. Despite the heat, pressure, and irritating chemicals emanating from its body, the beetle remains largely unaffected. Unfortunately, the news isn’t as good for its enemies.

**Blue mussels make glue**

Visit the seashore and you’ll find mussels clinging steadfastly to rocks, despite the crashing surf. How do they do it? Professor J. Herbert Waite from the University of Delaware has been researching this question for more than 30 years. The mussels are able to apply their protein-based glue underwater, where it cures and sticks to nearly anything amidst the harsh ocean. “They do it with chemistry” Waite realizes. But so far, no chemist has successfully synthesized this incredible marine superglue. Clearly, the product would be a boon to boaters of all descriptions. With a glue like that, they would no longer have to dry-dock boats for repairs.
He noticed that the chemical structure of the proteins in the mussels’ glue included a lot of ringed hydroxyl chemical structures. By modifying soy protein (e.g., tofu) to incorporate more of these types of structures, Li has developed a new glue that is stronger and more water-resistant than the traditional formaldehyde-based adhesives used to make plywood. Even better, the glue doesn’t release hazardous air emissions during manufacturing processes or from the finished plywood boards. That’s good news for the environment, for plywood manufacturers, and for consumers of plywood.

**New directions in biomimicry research**

Writer Alexandra Goho, in a *Science News Online* February 12, 2005, article, highlighted several chemists who are using nature for inspiration in their laboratories. For example, Dr. David Liu at Harvard University has found ways to use one of nature’s premier templates, DNA, like a molecular laboratory for synthesizing chemicals in miniscule batches. DNA controls the order and amount of chemicals that react during a given process, limiting the number of undesired by-products.

At Cornell University, Dr. Tyler McQuade looks to cell biology for inspiration to develop an assembly-line system to make drugs like Prozac. His microcapsule enzyme-mimic approach, controls the order in which reactions take place, minimizing separation and purification steps that typically generate large amounts of waste.

Dr. John Warner at the University of Massachusetts-Lowell recognizes seashells as models for lowering the energy required to produce solar cells. To make their shells, mollusks rely on small organic molecules to choreograph the assembly of calcium carbonate (CaCO₃) into elaborate mineral structures. When Warner looked at films of titanium dioxide (TiO₂), used as an alternative to silicon (Si) metal for solar material, he saw a resemblance to the structure of seashells. So, Warner tried using small organic molecules with multiple carboxylic acids (RCOOH) to assemble titanium dioxide particles into films of solar material. He was able to accomplish it at room temperature, a tremendous energy savings over traditional manufacturing methods that require heating titanium dioxide (TiO₂) films at 500 °C.

The examples above show the incredible variety in the research chemists’ and engineers’ approach using biomimicry. Imagine what we can create, using examples in nature to find new and better ways to design materials, processes, and systems.

**References**


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