Nature's Techno Tricks

Biomimetics: science mimicking nature

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papaWai

Published by

Papawai Press
P.O. Box 32-445, Devonport
Auckland, New Zealand

www.papawai.co.nz

ISBN 978-0-9582966-1-8

Book design and cover design by Alexandra Asher
Production by Archetype Ltd, Auckland, NZ (www.archetypeltd.co.nz)

Printed in New Zealand by GEON

Image opposite: Cranchiids are transparent, deep sea squids that maintain their position in the water column by means of a fluid-filled buoyancy device, and often have bioluminescent photophores (see pages 13 – 16 for more on bioluminescence and photophores).

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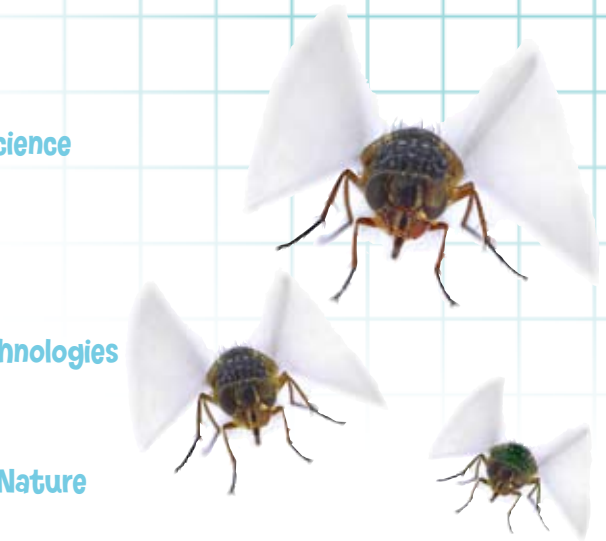

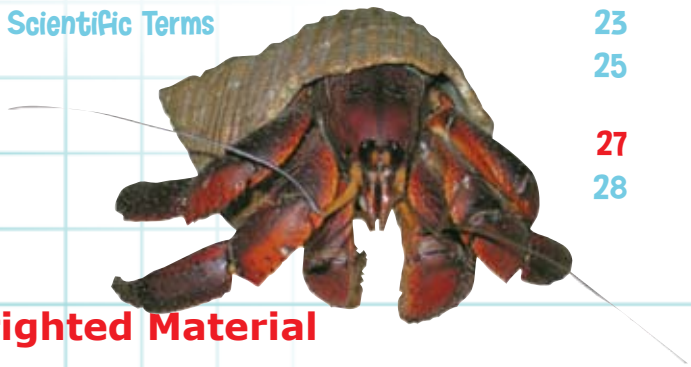

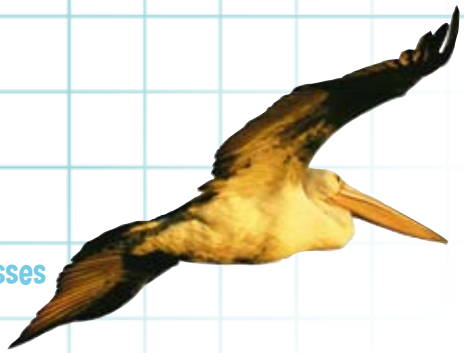

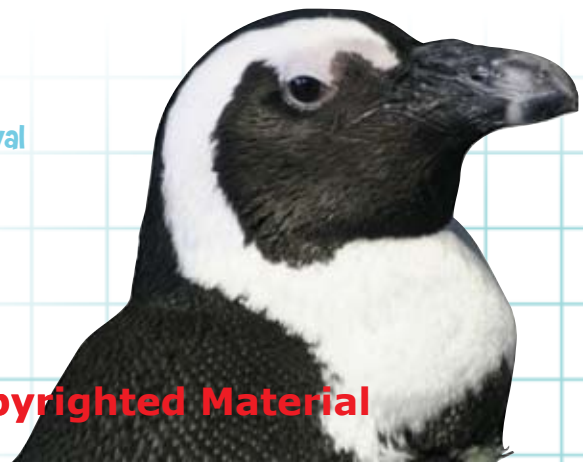

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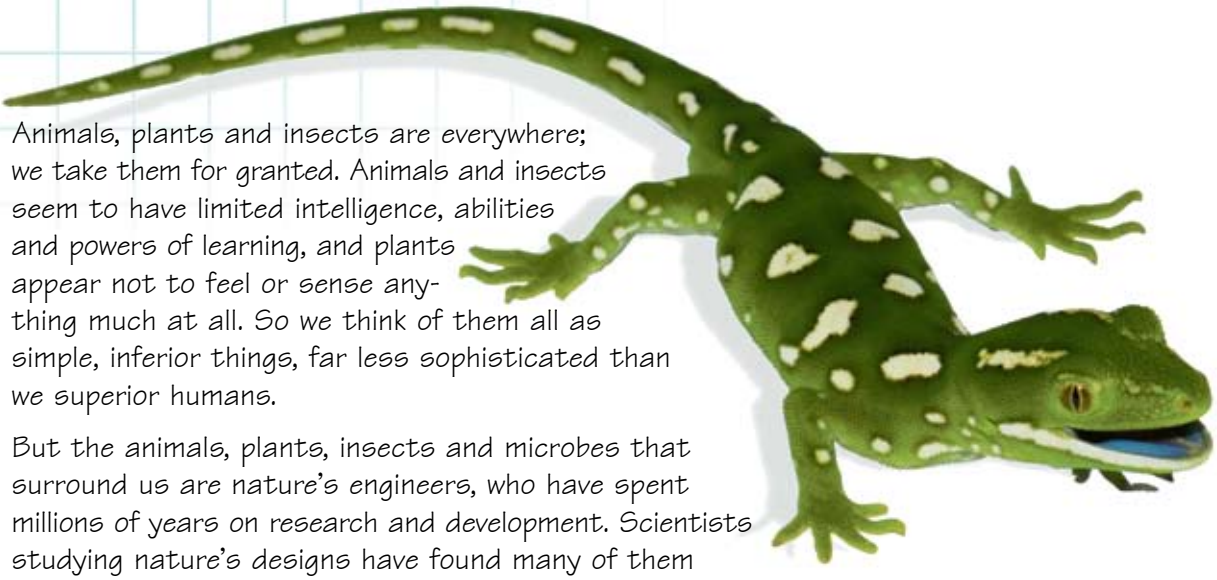


Animals, plants and insects are everywhere; we take them for granted. Animals and insects seem to have limited intelligence, abilities and powers of learning, and plants appear not to feel or sense anything much at all. So we think of them all as simple, inferior things, far less sophisticated than we superior humans.

But the animals, plants, insects and microbes that surround us are nature's engineers, who have spent millions of years on research and development. Scientists studying nature's designs have found many of them difficult to understand just because the designs are so very complex.

Using tiny cell factories and DNA blueprints, nature builds and rebuilds, designing organisms that are custom-made to survive in their special environment. Nature has been so busy perfecting the principles of chemistry, biology and physics that when you take a closer look you will discover many clever examples of nature's technologies; many clever technological tricks that are fascinating not just to scientists but to all of us.

Leonardo da Vinci, who designed this aerial screw, was one of the first people to practice biomimetics.

Today, scientists all over the world are studying the designs and processes used by nature to discover how to manufacture new products or invent new technologies. This new science is called biomimetics, the science of "applying designs from nature to solve modern problems in engineering, materials, science, medicine and other fields" (Tom Muller, Biomimetics; Design by Nature, *National Geographic*, April 2008).

Chemical Defence Weapons

Beetles That Use Pure Rocket Science

Imagine a bomb-making beetle with a machine gun in its abdomen! When under attack the Bombardier Beetle uses just such a machine gun with its rapid-fire revolving gun turret to spray its very own chemical bomb over attacking insects.

In the 1950s German scientist, Dr Hermann Schildknecht, an expert on delicate chemical ana-lysis at the Erlanger University's Institute for Organic Science, discovered how the bombardier beetle uses rocket science to defend itself. He found that there was a bomb-making factory in the beetle's abdomen, with cells that make two very dangerous chemicals – hydroquinone and hydrogen peroxide – which are stored in special balloon-like sacs.

When under attack, simulated in this photo by the tweezers gripping the beetle's front leg, the beetle squirts the chemicals towards his attacker!

When in danger of attack by other creatures, such as ants, the beetle's muscles contract, squirting the stored chemicals out through valves into thick-walled, heart-shaped blast chambers, where glands release peroxidase.

Peroxidase acts like a detonator, triggering an explosion, and the resulting pressure blasts the corrosive chemical mix out through twin nozzles in the tip of the abdomen.

Light and the Magic of Iridescence

Properties of Light and New Technologies

Sir Isaac Newton (1642-1727) first discovered that white sunlight is composed of a mixture of colours when he passed a narrow beam of sunlight through a glass prism. The colours he saw were those you see in a rainbow – red, orange, yellow, green, blue, indigo and violet.

Light comes in a variety of wavelengths, which travel very fast. These wavelengths are made of tiny particles called photons and they have both electrical and magnetic fields.

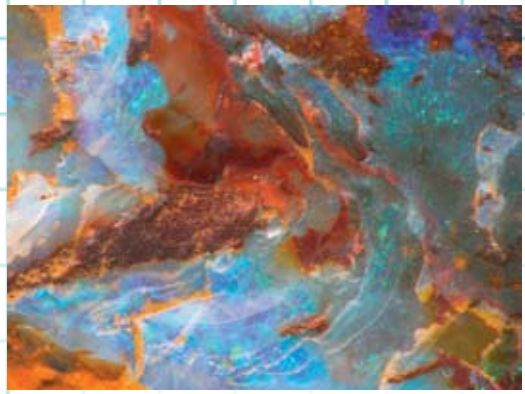
The movement of light waves can be controlled using diffraction gratings, a set of narrow reflective parallel slits that redirect light waves. The colours of the light spectrum that are reflected depend on the spacing of the veins and slits within the grating. An example of this technology that you see every day is the iridescent hologram on a credit card or a compact disc.

When the movement of light waves is controlled using diffraction gratings, optical discs like CDs and DVDs can use lasers to read information. This new science of diffractive optics – using lenses that scatter light waves instead of focusing or reflecting them – is providing scientists with ideas for new technology.

Optics, the science of light, is leading to many new discoveries. Both diffraction gratings and another light reflecting medium, the photonic crystal, are changing the way scientists think about optical lenses and offering exciting new opportunities in electronics and for designing solar cells, lighting, lasers and optical switches.

Light is increasingly being used to transmit and store information. Optical fibres continue to replace electrical cables for transmitting very fast signals over long distances.

A Bit About Photonic Crystals



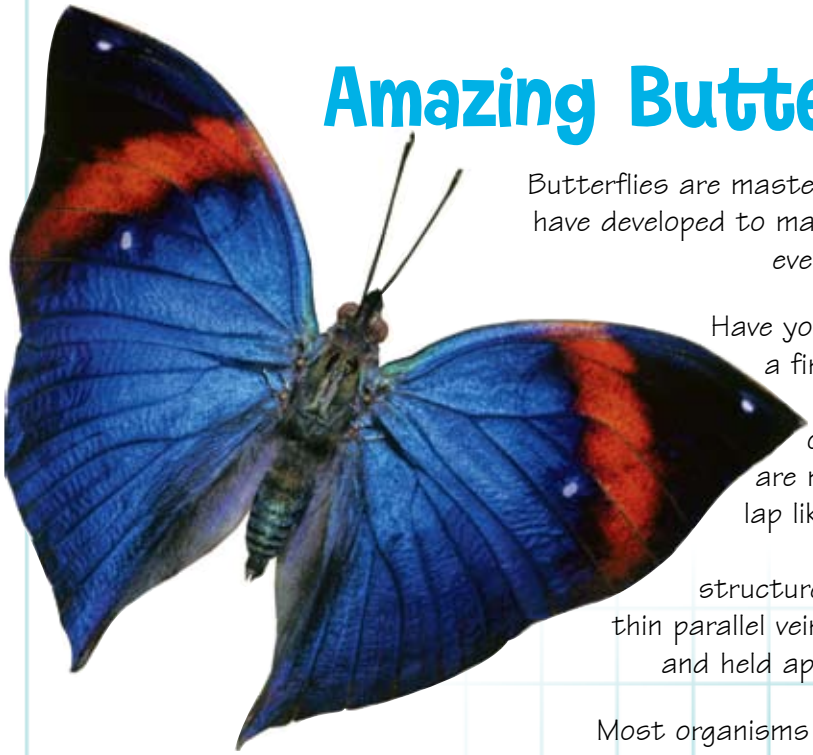
This opal contains a natural periodic microstructure responsible for its iridescent color. It is essentially a natural photonic crystal.

The science of photonics is similar to electronics except that in photonics, photons are used to carry information instead of the electrons.

Atoms in photonic crystals are spaced so precisely that they can capture light waves while controlling the direction of reflection. Photonic crystals act like mirrors reflecting the light at different angles, thus creating iridescence.

Because photonic crystals must be made on the same scale as the wavelength of light, they are very difficult to engineer without using the new science of nanotechnology. Nevertheless, scientists are excited by the challenge of creating photonic crystals that are so precise that only certain chosen wavelengths can pass through.

Amazing Butterflies



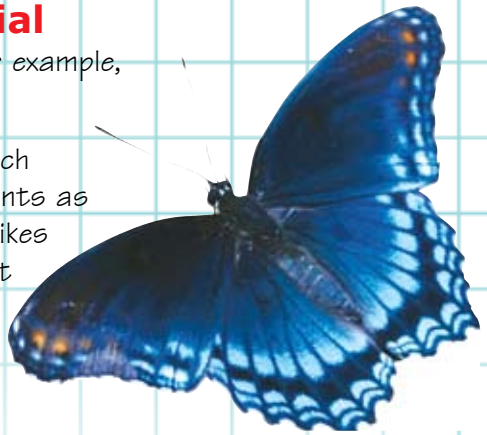
A Blue Morpho butterfly

Butterflies are masters of optics; the clever tricks they have developed to manipulate light with their wings rival even our advanced optical technology.

Have you ever handled a butterfly and felt a fine dust or powder on your fingers? The dust on your fingers is made of butterfly scales. Butterfly wings are made entirely of scales which overlap like the tiles on the roof of a house. And each scale is a complicated structure covered with diffraction gratings, thin parallel veins separated by hollow air pockets and held apart by vertical rods (see page 10).

Most organisms contain biological chemicals called pigments which give them their colour. Pigments work by absorbing some colours and reflecting others. When light strikes an organism, some of the wavelengths are absorbed and others reflected, giving

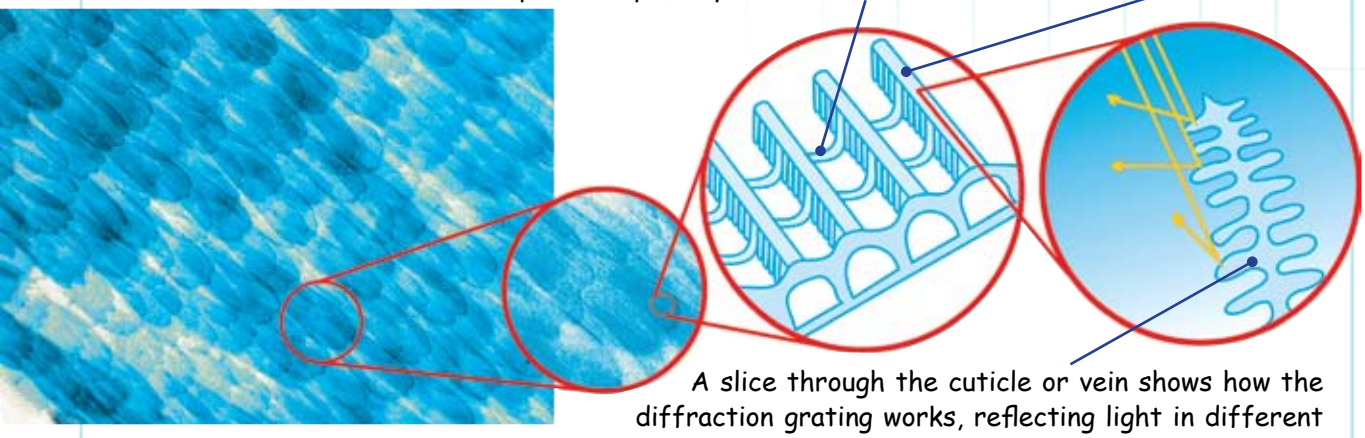
an appearance of one colour or another. In green leaves, for example, green is reflected and all other colours are absorbed.



Scientists have discovered that the iridescent colour of each scale in a butterfly's wing is created not so much by pigments as by the structure of the individual scales. When sunlight strikes the edges of the diffraction gratings in the scales, the light is split apart, wave by wave, and dispersed in many directions. When these light waves interfere with each other they produce the shimmering iridescent blues and greens, purples and yellows without the need for pigments.

Butterfly scales viewed under a microscope.

Detail of the scale showing the thin parallel veins held apart by vertical rods.



A slice through the cuticle or vein shows how the diffraction grating works, reflecting light in different directions.

The microscopic scales on the butterfly's wings also contain photonic crystals, which act like mirrors, reflecting the light at different angles, and creating even greater iridescence. Butterflies use iridescence to attract mates and deter predators.

In addition to diffraction gratings and photonic crystals, butterfly wings have a third light trick, a biological structure similar to the high-efficiency human technology called LEDs, or light-emitting diodes. LEDs are like tiny pieces of rock made up of various minerals, such as silica and gallium, the type and arrangement determining what colour is produced. Diodes in LEDs are illuminated by the movement of electrons in a semi-conductor material, and the technology is found in computer and television screens, digital displays and other objects, which light up without using light bulbs.

Portable Light Technology: weaving with light

The Huichol people of the Sierra Madre mountains in Mexico travel long distances and have no source of light at night. Researchers discovered a way to weave LEDs into the textiles woven by the Huichol people. They developed flat flexible solar panels that could be stitched onto the woven bags the Huichol carry, and then connected these to tiny batteries which were in turn connected to the LEDs. The solar panels collect the sun's energy during the day, and the bags become torches providing the people with bright white lights at night.

The Humpback Whale

The mighty humpback whale (*Megaptera novaeangliae*) is an awesome mammal, approximately 14 metres long and weighing an average of 30,000 kilograms, yet it is able to leap right out of the water (known as breaching).

Under water, humpbacks are able to bank while making tight turning manoeuvres. Their ability to make tight circles allows groups of humpbacks to catch prey by encircling them in bubble nets. These narrow cylindrical walls of bubbles are made by expelling air through the blowhole as whales spiral upwards towards the surface underneath their prey.

How can animals as big as a bus move with such acrobatic agility? Scientists studying the humpback whale have discovered that the secret lies in the hydrodynamic lift generated by bumps called tubercles on the whale's long pectoral flippers. The humpback whale flipper is unique. The tubercles, which are located on the leading edge of the flipper, give the surface a scalloped appearance. These tubercles redirect the flow of water into the scalloped channels between each tubercle, causing swirling vortices that roll up and over the flipper creating lift while decreasing drag.

Seabirds With Sunglasses

Seabirds such as gulls, terns, skuas and gannets have built-in sunglasses. All day long, as they glide over the ocean looking for food, the glint of sunlight on the waves reflects back into their eyes. Fortunately, the retinas of their eyes contain minute droplets of reddish oil, which act like sunglasses, filtering the light entering their eyes. The droplets screen out much of the sun's blue light, cutting out the glare.

Glare occurs when light from the sun hits the water surface. Light vibrates at right angles to the line in which it is travelling. Ordinarily, the planes of vibration are in every direction. But when light is reflected from a smooth, non-metallic surface, the light becomes polarised. This means it vibrates in only one direction – a direction parallel to the reflecting surface.

So how do polaroid glasses work? They have a built-in filter made of microscopic crystals all lined up vertically. The reflected light from the surface of the water vibrates horizontally and cannot get through the filter. When the polarising filter reduces glare it allows you to see through the surface of the water.

Now you can understand how gannets diving from such great heights can catch fish swimming under water.

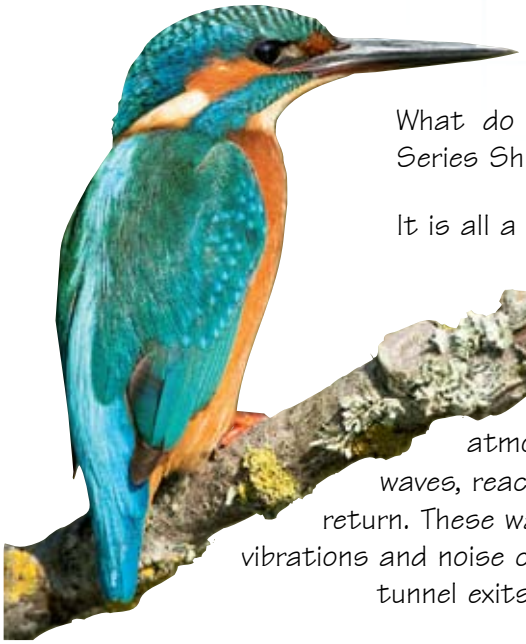
Fly Eyes

Scientists have discovered that fly eyes have a series of ridges and grooves, and instead of reflecting light these parallel ridges allow light to pass through the eye. This techno trick allows the fly to soak up light coming from all different angles, helping it to see in very low levels of light.

Scientists have used this information to develop new synthetic light-capturing material. When used on solar panels these synthetic fly eyes increase the ability of the panels to capture the sun's energy!

Nature Thought of it First

High Speed Trains



What do kingfishers have to do with the high-speed 500 Series Shinkansen electric bullet train in Japan?

It is all a matter of aerodynamics.

Half the Shinkansen line consists of tunnel sections, and these sections presented the train designers with a problem. When a train rushes into a narrow tunnel at high speed, atmospheric pressure waves rise up, grow to be like tidal waves, reach the tunnel exit at the same sonic speed and then return. These waves are called tunnel micro-pressure waves and the vibrations and noise created environmental problems for people living near tunnel exits; inside the train the passengers were not affected.

Designers knew that the shape of the nose of the train affected the air resistance. They turned to nature to find the answer to the sudden changes in air resistance.

They studied the beak of the kingfisher!

The Shinkansen Series 500 bullet train.

When the kingfisher dives through low resistance air into high resistance water, it faces the same pressure wave problems as the train faced when going through the tunnel. On closer study, scientists observed that the upper and lower beaks of the kingfisher have an almost wedge shape – the ideal shape to suppress pressure waves. The kingfisher provided the answer to the train designers' problems. Using kingfisher technology, they designed a train with a long, wedge-shaped, bird-like nose. Copying the design of the kingfisher's beak allowed the bullet train to reach speeds of 300 kilometres per hour without creating noise or vibrations.

Hypodermic Needles

Nature used the hypodermic needle long before doctors did. Jellyfish, spiders, scorpions, stingrays, snakes, stinging nettles, bees, wasps, stonefish and the male duckbill platypus can all inject poison hypodermically through a sharp pointed tube.

A Bit About Mosquitoes

Mosquitoes live and breed on the surface of water. Their feet are equipped with hooked claws for clinging to skin and they use a hypodermic needle to extract blood, but it is their ability to walk on water that gives mosquitoes the best techno trick. They have extremely water repellant (superhydrophobic) legs. Their legs have feathery scales a few microns across that are covered with a nanoscopic ribbing. Scientists have found that each of the mosquito's six legs can repel water so well that they could support 23 times the insect's weight.