PHILIP BALL INTERVIEW

Explain this idea of “the material is the mechanism”.

It’s about moving away from the classical idea of materials – inert stuff that serves a structural role – towards the more contemporary notion of materials. More and more, materials are active and respond to stimuli in their environment. Materials can light up when an electric current is passed through them; materials can swell and contract in response to changes in temperature or acidity. Increasingly, there’s a blurring of boundaries between what is a material and what is a machine.

If you were to draw a materials family tree, where would you begin and what would be its main branches?

The main branches are ceramics (including rocks), which is the oldest branch of materials; natural materials (wood, leather, plant fibres, etc.), also very old; metals; and synthetic polymers. Since the 20th century, it would be fair to say that the introduction of synthetic polymers has been the biggest change we’ve seen in materials science. Things now, of course, are very diverse. The branch tips have split into countless categories, many of them overlapping. But one of the most significant has to be semiconductors.

Which natural materials have changed our lives or have the hope to change our future?

In addition to the ones I’ve already mentioned, there’s paper, which enabled the printing revolution. Looking ahead, we’re starting to explore nature more closely and use its principles to make new types of materials. Biological materials are made from either protein, where the raw materials are amino acids, or nucleic acids like DNA and RNA, or polysaccharides (carbohydrates), where the raw materials are sugars. Biology manages to do an incredibly wide range of things with proteins, in particular: horn, skin, tendon, and transparent material that makes up the lenses of our eyes. So materials scientists are inspired to look to proteins to see how they might be able to redesign them. For example, genetically engineered bacteria can produce new kinds of proteins that might create novel and biodegradable plastics.

What about the metals family?

There is still plenty of work going on in good old-fashioned metallurgy, although it’s certainly not old-fashioned anymore. Nowadays, some researchers use computer calculations to come up with promising combinations of metallic elements. There’s also the combinatorial method, where an entire “library” of new materials is produced: an array of combinations of elements in very small quantities. We then have to develop a way of testing the relevant properties of these substances to find those combinations that seem most promising. This automated approach to materials discovery has come about in the last ten years or so.

And polymers?

The earliest human-made polymers were derived from natural ones. Celluloid was made from chemically treating plant-derived cellulose. Vulcanized rubber was made from vulcanizing, or stiffening, the gum from rubber trees. These were the first semi-synthetic polymers. In the early twentieth century, techniques for making more versatile polymers were developed, generally starting from the raw building blocks of the polymers’ chain-like molecules. Rayon, which is also a semi-synthetic cellulose-based polymer, was used for making fibres and textiles. Nylon came next, which was a hugely successful completely synthetic polymer. Polystyrene and polyethylene also were early examples of totally synthetic, petrochemical-based polymers.

Imagine putting together a superhero team of materials. What would the super-lightweights be?

I'd go with polymers quite generally, and also with aerogels, which can be made from a whole range of materials. Aerogels consist of tiny particles – these could be made of carbon, metals or, most commonly, ceramic materials – joined together in a web-like three-dimensional structure and surrounded by air. They're mostly empty space. In fact, you can make aerogels that are 99% empty space! They're translucent and are often talked about as "frozen smoke." But they're also stiff, like a block of ice, and strong enough to support things standing on them.

How about the smart materials?

Shape memory metal alloys and shape memory polymers, since they remember their shape. You can take a straight wire made from Nitinol, a metal alloy made of nickel titanium, bend it into a shape, stick it in a cup of hot coffee, and the wire straightens out again. Shape memory polymers change in response to light and have biomedical uses: artificial muscles or self-tightening suture threads. They might also be used as tiny components in machines, as pumps or valves that have no moving parts. Piezoelectrics are also smart materials. When squeezed, they produce an electric field. When voltage is put across them, they contract or expand. Piezoelectrics are used in loudspeaker drivers and microphones, which interconvert electric signals and acoustic signals (sound waves).

Massive Change Radio is a project by Jennifer Leonard, Bruce Mau Design, the Institute without Boundaries, and CIUT FM, Toronto.

And in the realm of the very, very small?

This is where the line between what's material and what's a device begins to blur. A nice example of what you can do at very small scales using simple, cheap chemistry is provided by self-assembled monolayers. These are very thin films of organic material that can be patterned at high spatial resolution and easily applied to the surface of gold or silica, on a silicon chip. One can make patterns that are smaller than what's used for shaping conventional micro-electronic circuits, which is one of the big concerns of the information technology industry. So, rather than developing expensive methods for carving silicon chips into ever-smaller wires and transistors, you might use self-assembled monolayers. You can basically just stamp the surface of the chip with a rubber stamp covered with a kind of "ink" that forms a self-assembled monolayer on the chip. These films act as a mask for etching circuit patterns into the chip; the silicon gets etched away in only the places where you want it.

Which materials have super-strength?

Carbon nanotubes have potential to be stronger and stiffer than just about any other material we know. These are like very, very narrow drinking straws made of carbon. Their width is typically about ten nanometers or so, which is 10 millionths of a millimeter. That's tens of thousands of times narrower than a human hair. The current challenge is to grow them long enough to have practical application.

Is biomimetics at play in all of the above?

Biomimetics – basically, learning tricks from nature – is currently a strong theme in materials science. In making tough materials, materials that don't break easily, the inspiration from nature is the mollusk shell – mother-of-pearl, or nacre, for example. This is a composite material, a mixture of sheets of mineral-like material and thin films of proteins. The combination of a hard and brittle material (ceramic) with a soft, organic material produces a very tough substance.

When IBM famously manipulated atoms to spell out their corporate logo, what was the significance?

It showed us very vividly how much control we have over matter at the scale of individual atoms. There's a big question about whether the way they did that is really going to be useful in building materials, however. I think that one can probably get a lot further by using clever chemistry than by pushing single atoms around with a tiny tip, to get them to go where you want them to go. But there's no question that writing the IBM logo in atoms was something of a landmark in showing that technology, in the broadest sense of being able to manipulate matter, now reaches down to the smallest scales we can really imagine.

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