Smart molecular materials

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What are Smart Materials?

Smart materials are molecular based structures that respond adoptively to changes in the environment. They can be represented as

Input, stimulus ⟶ active martial ⟶ output response

The input or stimulus can be a change in temperature, pH or even in a magnetic field.
The material intrinsically responds with an output, which can be a change in length, viscosity, colour or conductivity. Hence smart materials can range from photochromic lenses, which automatically darken or lighten in response to change in sunlight to electrorheological fluids which alter their viscosity in response to electric fields.

There are innumerable areas where the application of such smart materials can bring about dramatic results. Smart molecules can be exploited for varied purposes in almost every branch of science and technology.

Smart materials in the development of artificial muscles:

Recent research in polymer based artificial muscles indicates that soon there will be devices that can 'move' like biological organisms. Certain polymers based on polyacrylonitrile (PAN) whose physical properties are midway between glass and plastic contract dramatically when there is a change in pH. In less than 20 milliseconds the fiber can shrink and the decrease in length is 20 % in 2/10 th of a second, almost as fast as a muscle .Not only that, they are also found to be as strong as any human muscle. Hence such 'smart muscles' can find wide applications in robotics and medical implants[1,2].

Researchers at Columbia University, Ohio, have designed implantable capsules perforated with microscopic holes to dispense medication. Each hole is guarded by a tiny ring of artificial muscle. They call these capsules 'smart pills' though they cannot be swallowed[3]. Beyond just dispensing drugs to patients such as insulin to diabetics, these smart capsules can be made to deliver chemicals in right quantities at the right instant by putting suitable sensors outside. When the sensor detects that a patient needs medication, the artificial muscles will shrink away from the holes in the wall to let the medicine pass into the blood stream. Once the right amount of medicine has left the capsules, the muscles will swell up, and plug the holes once again.

Smart Molecules as molecular traffic lights:

Many biological processes involve interactions within organized assemblies of molecules held together by supramolecular electrostatic interactions rather than traditional chemical bonds. One such example is chlorophyll in green plants. Light energy is captured by chlorophyll, which triggers the transfer of electrons across the assembly. This results in charge separation and provides energy to drive the plant's biochemistry.

Dr Zoe Pikramenou of Birmingham University has created a smart system based on this principle[4]. Rare earth metals like europium and terbium are attractive luminescent probes, which can give out visible light. Pikamenou's team has developed a molecular ' ball' with a metal core surrounded by organic units. The outer units will capture all the light that comes and will transfer the energy to the metal core which in turn will emit visible light. The choice of metal will determine the colour of the emitted light, red and green for europium and terbium. Once a system that emits orange colour is devised there will be a set of molecular traffic lights!

Smart switches to turn proteins on and off

Researchers at the University of Washington have come close to unravelling the mystries of protein biinding to other molecules[5]. This discovery has a number of applications ranging from medical diagnosis to environmental sensing and computer engineering.

The group has figured out that a tiny 'smart' polymer thread, activated by temperature, coils to block an attachment site on the protein. When the temperature drops, the polymer uncoils and allows a molecule to access the site. By changing the temperature, it is possible to push a molecule off the site!

Computers operate in a binary system, relying upon on and off states. Typically, this is done with non-biological components. The diminutive size of proteins and molecules involved could open avenues into advanced concepts like' lab on a chip'- the ability to fit full range of laboratory functions on a single computer chip .Based on the same idea, disposable smart biochips are being developed for various biochemical analyses which include glucose sensors, blood analysers and bio chemical warfare detector systems.

Smart Gels:

Smart gels are a special class of smart materials that expand or contract when triggered by minute changes in temperature, light, solvent, or other stimulus. The ability of gels to undergo large but reversible change in volume allows unique systems to the made that can encapsulate and release the right materials at the right time . Smart gels can be engineered to clean up pollutants and oil spills, or device system such as sensors, acyuators, for biological and chemical separations or in cosmetics to hold and release fragrance in respond to factors like skin pH.

The novel concept of 'smart gels' emerged in a big way when Prof Toyochi Tanaka of MIT discovered that certain synthetic (polyacrylamide) gels had some unusual properties[6]. In the mid 1970s,Tanaka discovered that these gels could be fine tuned to undergo radical changes with some kind of 'phase transition" when they encounter either a chemical compound or a change in condition.

In 1992, recognizing that the technology has become ripe for commercialisation, Tanaka, along with an entrepreneur G.W. Mc Kinney founded a company called Gel Sciences at Massachusts, to pursue industrial applications. Two years later, McKinney along with able chemist Eyal S. Ren started a subsidiary to pursue only medical applications of smart gels. It was soon realised that the medical side of the business could blossom while the industrial parent company was limping behind. Recently the two companies merged into Gel Science/gel Med Inc.

Smart gel is not the only success story of Tanaka's company . Soon a similar product, smart hydrogel was also developed for controlled release and other applications It was observed that not only that this smart hydrogel responded to temperature, but it could also adhere to a biological tissue. This makes it a promising matrix material for longer lasting eye drops, nasal sprays and other medical formulations. The complex and challenging stage of Tanaka's research remains as to develop' smart' gels which imitate proteins by reorganizing conditions and responding to environment[7].

However the trick is to engineer the gels so that they are balanced on a knife-edge between forces of expansion and contraction and at present the idea is more of a dream than reality.

Active research on smart gels is being carried out on this side of the globea as well. At NCL Pune, research is being carried out to understand the volume transitions in poly-N-isopropyl acrylamide (PNIPAM) hydrogels. The laboratory has also patented a 'gelofuel', which retains large quantities of a clean fuel such as methanol, ethanol and slowly releases it on burning[8].

In short, light bulbs that last half a century, shoes whose insoles mold to the Contours of our feet, or a highway bridge that never crumbles are no longer dreams and we are already in the in the age of made to order materials We have begun to understand the secrets of matter at the atomic level and thus aim to design materials one atomic layer at a time. There are laboratories where scientists are trying to copy nature to replicate the strength of spider silk, the sticki ness of barnade's glue, the toughness of abolone shells and the like with the hope to create the super materials of the future.

However it should never be forgotten that all molecules are 'smart' in some way or the other. Otherwise, they wo'nt be what they are, in states of perfect structure, periodicity ,stability and yet maintaining reactivity. But, may be like how George Orwell , in his famous work 'Animal Farm'classifies the inmates of the form as 'equals and more equals,' we can also say that all molecules are smart but some appear to be smarter when a 'smart' scientist takes a fancy to them!

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