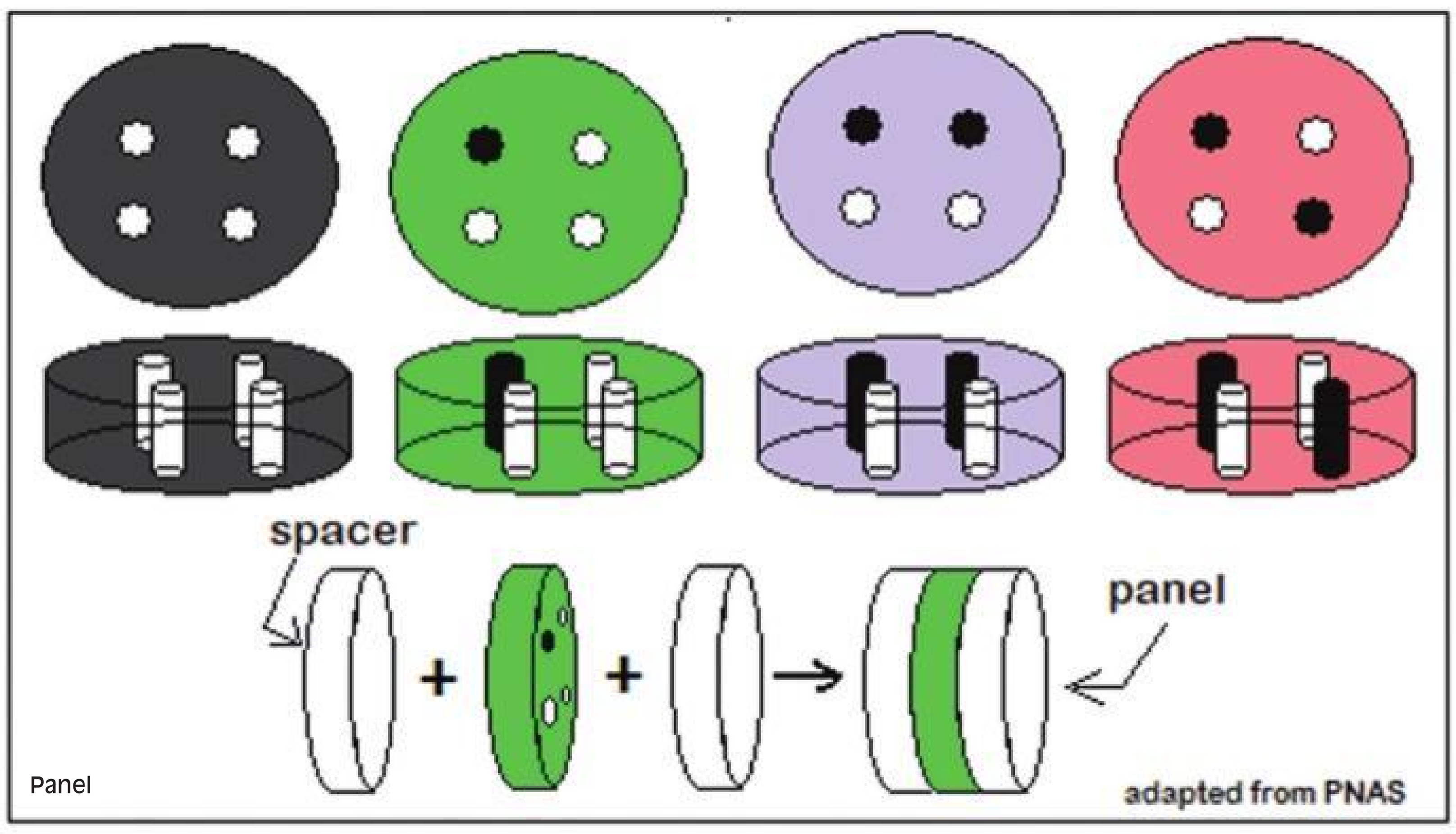
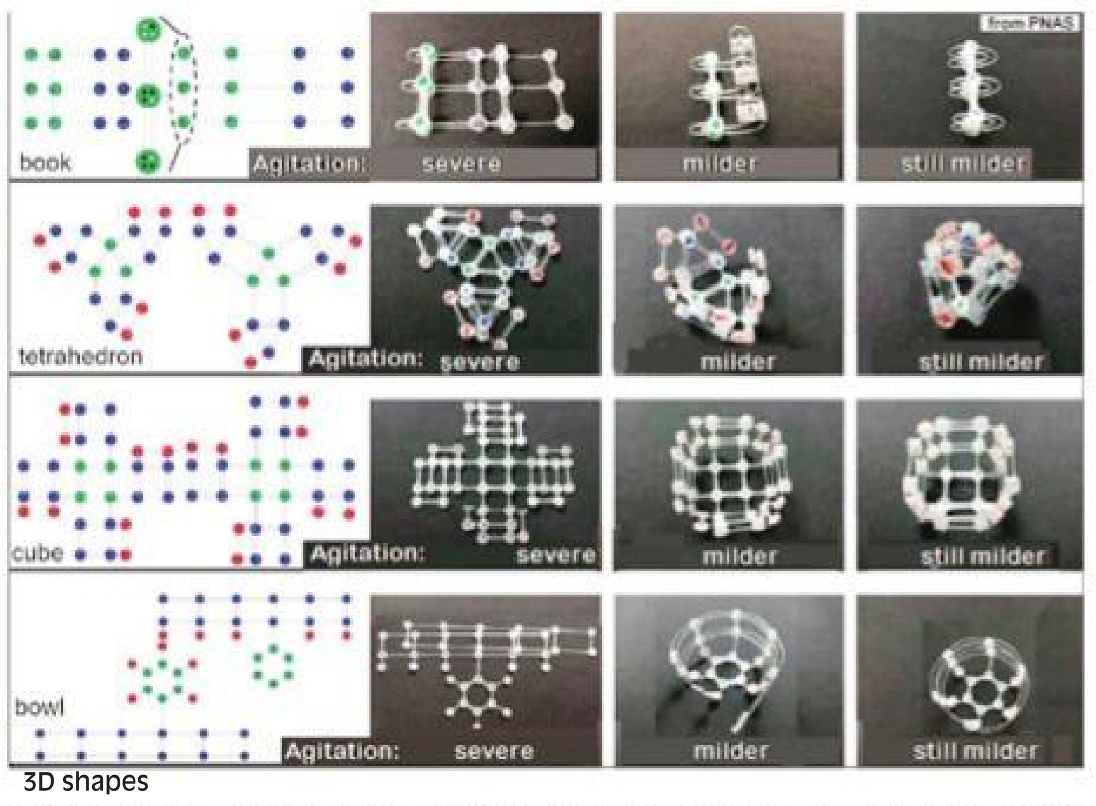
Material that self-assembles



Panel



3D shapes

3D printing technology could be used to fabricate magnetic elements, and the patterns could be written out by a computer, says a paper in the *Proceedings of the National Academy of Sciences*

S ANANTHANARAYANAN

The ultimate examples of things that build themselves from basic components are living things. While living things grow from a single cell to their final form, doing something like this with materials has been the dream of material scientists, architects and engineers.

Ran Niua, Chrisy Xiyu Du, Edward Esposito, Jakin Ng, Michael P Brenner, Paul L McEuen and Itai Cohen from Cornell and Harvard universities reported what looks like a positive step towards realising this dream, in the *Proceedings of the National Academy of Sciences* (PNAS). The paper in the journal describes a set of centimetre-size discs, embedded with magnetic domains of just four kinds, which are able to fall into programmed patterns and shapes just by being put together and shaken about.

The ability to follow rules in interactions with one another, so that they connect or repel in specific orientations, is a property of matter of very small dimensions. Atoms and molecules are ready examples. They form specific compounds simply by being in contact at the right temperature and pressure, and the existence of the chemical industry would not be possible if compounds had to be individually assembled. Forming specific links is also true of very small objects, which interact based on their shape alone or arrange themselves so that the arrangement is energetically the most efficient.

A far more powerful device of self-organisation is what is followed by living things, which programme the interaction of their cells through DNA. The DNA is a millions-of-units long chain molecule, the segments of which contain the code for the production of specific proteins. This programming of cells guides different cells to interact and grow into different organs, according to the shape and structure of the living thing.

The coding for the different proteins that cells produce comes about through a set of four kinds of "side chains" that protrude, in succession, from the backbone of the DNA molecule. Triads, or sets of three side chains, are used to code for 20 components of proteins, called amino acids, and with different sequences of amino acids, different proteins can be constructed by the cell.

DNA technology has been used in a "bottom-up fabrication approach" in the laboratory, by exploiting the intrinsic properties of atoms and molecules and getting them to self-organise. Experiments using segments of DNA, or related molecules, have succeeded in creating some simple, self-constructing nano-structures, square, discs or stars, some 100 nanometres across. The field has grown to be known as "DNA Origami" and complex shapes, like letters, a helicoid and a teddy bear, have been created. Larger and more complex, functional structures may soon be possible.

These successes, however, the PNAS paper says, are limited to very small sizes and involve complex and time-consuming processing. The structures themselves are not hardy, as they are built with the help of thermal motion of atomic or molecular components, and are held together by weak, inter-molecular forces. The work u i bu the authors have reported jo QOBT explores the possibility of stronger, and longer-ranged boding interactions. One such, they say, is the force between components that consist of magnetic elements, and they propose a method of self-assembly of a set of components that interact based on the magnetic information that is embedded within them.

The components are a set of discs, just 0.9 cm in diameter, which contain a pattern, an array, of a single, or a pair, or a triad, of magnets, and are capped on either side by spacers. The tendency of a panel to bind with another depends on the magnet pattern in the discs. Because the ratio of how strongly the discs bind depends only on the pattern, the behaviour of such a set of discs remains the same even if their size is changed all the way down to 10 nanometres- below that we cannot have the magnetic regions on the discs, the paper says.

The key behavior of the discs is that discs with similar patterns bind or repel readily, and even more readily when they are placed on a surface that is agitated, to help overcome friction with the surface. The attraction (or repulsion) is the strongest when the agitation just cancels gravity. And again, if the agitation is a lot stronger, it can cause bonded panels to separate. The agitation thus acts just like thermal agitation in a solution or a gas, the paper says, where gentle motion would promote reaction, but high temperature may result in dissociation.

The level and kind of interaction between panels depend both on the way the panel is oriented as well as what patterns of magnetism the panels have. This results in a scale of weaker to stronger interactions. The strongest boding is found between panels with the same pattern, except with the green panels, which bind more strongly with the black panels. The strength of binding varies according to the alignment of the patterns and again, the relative strengths change when the degree of agitation is varied.

With the binding strength following a pattern, it becomes possible to build chains of panels with successive panels in a given order. Variations were tried by creating panel pairs which looked different from different sides and again, at different levels of agitation, to produce differing patterns, including branching chains of panels.

The next thing tried was to link panels by gluing them to an elastic backbone. Now, the order in which the panels were attached to the elastic specified the panels that would attach to the string, as in the case of the side chains along a single strand of DNA. Variations in the spacing of panels along the elastic could be made to promote bending of the chain and then the formation of shapes, like an S-bend. And there could even be a spiral form with control over the level of twist.

Yet another possibility was when the elastic backbone took a two-dimensional shape. Now, it became possible to vary the panels chosen, their orientation and spacing as well as the shape of the backbone. The picture of 3D shapes, which is taken from the paper, shows the shapes of a folded book, a tetrahedron, a cube and a bowl, generated by the panels that are attached to the programmed backbone.

"These examples illustrate the potential for building hierarchically complex structures and the need for further development of systematic approaches for implementing these strategies," the paper states.

Nano-scale magnetic elements and nanometre-thick elastic elements are now feasible and the platform demonstrated, at centimetre scale, could be repeated at the micro- or nano-scale. 3D printing technology could be used to fabricate the magnetic elements, and it is conceivable that magnetic element patterns could be written out by a computer. The technology would lead to micro-scale structures or even the self-assembly of machines, that can be controlled by external magnetic fields, the paper states.

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Transport processes

Most of the substances that move across membranes are not macromolecules, but dissolved ions and small organic molecule-solutes

TAPAN KUMAR MAITRA

The Hydrophobic interior of a membrane makes it an effective barrier to the passage of most molecules and ions, thereby keeping some substances inside the cell and others out. Within eukaryotic cells, membranes also delineate organelles by retaining the appropriate molecules and ions needed for specific functions.

However, it is not enough to think of membranes simply as permeability barriers. Crucial to the proper functioning of a cell or organelle is the ability to overcome the permeability barriers for specific molecules and ions, so that they can be moved into and out of the cell or organelle selectively. In other words, not only are membranes barriers to the indiscriminate movement of substances into and out of cells and organelles, but they are also selectively permeable, allowing the controlled passage of specific molecules and ions from one side of the membrane to the other. It looks at the ways in which substances are moved selectively across membranes and considers the significance of such transport processes to the life of the cell.

An essential feature of every cell and sub-cellular compartment is its ability to accumulate a variety of substances at concentrations that are often strikingly different from those in the surrounding milieu. Some of these substances are macromolecules, which are moved into and out of cells and organelles by mechanisms. Specifically, endocytosis and exocytosis are bulk transfer processes whereby substances are moved into and out of cells enclosed within membrane-bounded vesicles.

As important as these topics are, most of the substances that move across membranes are not macromolecules, but dissolved ions and small organic molecule-solutes. These solutes cross membranes single file, one ion or molecule at a time. Some of the more common ions transported across membranes are sodium (Na+), potassium (K+), calcium (Ca2+), chloride (CI-), and hydrogen (H+). Most of the small organic molecules are metabolites-substrates, intermediates, and products in the various metabolic pathways, that take place within cells or specific organelles. Sugars, amino acids and nucleotides are some common examples.

Such solutes are almost always present at higher concentrations on the inside of the cell or organelle than on the outside.

Very few cellular reactions or processes could occur at reasonable rates if they had to depend on the concentrations at which essential substrates are present in the cell's surroundings. In some cases, such as electrical signaling in nerve and muscle tissue, the controlled movement of ions across the membrane is central to the function of the cell.

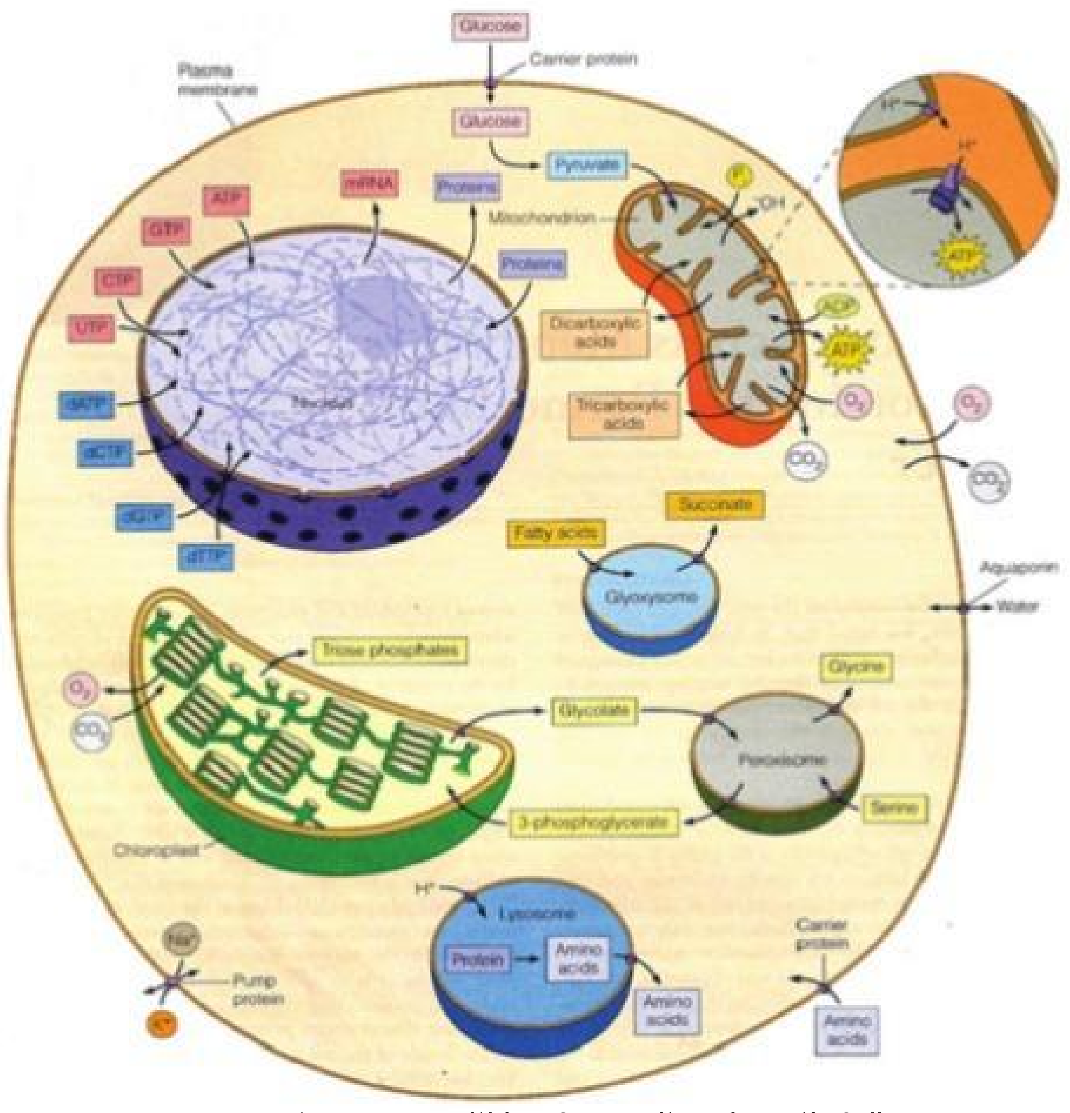
A central aspect of cell function, then, is transport: the ability to move ions and organic molecules across membranes selectively. The importance of membrane transport is evidenced by the fact that about 20 per cent of the genes that have been identified in the bacterium Escherichia coli are involved in some aspect of transport. Some of the many transport processes occur within eukaryotic cells.

Three different mechanisms are involved in the movement of solutes across membranes. Certain small, non-polar molecules, such as oxygen, carbon dioxide, and ethanol move across membranes by simple diffusion-direct, un-aided movement of solute molecules into and through the lipid bi-layer in the direction dictated by the difference in the concentrations of the solute on the two sides of the membrane.

For most solutes, however, movement across biological membranes at a significant rate is possible only because of the presence of transport proteins — integral membrane proteins that recognise substances with great specificity and increase the speed of their movement across the membrane. In some cases, transport proteins are involved in facilitated diffusion of solutes, moving them down their free-energy gradient (a gradient of concentration, charge, or both) in the direction of thermodynamic equilibrium. In other cases, transport proteins mediate the active transport of solutes, moving them against their respective free-energy gradients with transport driven by an energy-yielding process, such as the hydrolysis of ATP or the concomitant transport of another solute, usually an ion, such as H+ or Na+, down its free-energy gradient.

The movement of a molecule that has no net charge is determined by the concentration gradient of that molecule across the membrane. Facilitated diffusion of a molecule involves exer-gonic movement down the concentration gradient, whereas active transport involves movement up the concentration gradient and requires some driving force.

The movement of an ion, on the other hand, is determined by its electrochemical potential, which is the sum or combined effect of its concentration gradient and the charge gradient across the membrane. Facilitated diffusion of an ion involves exergonic movement in the direction dictated by its electrochemical potential,



Transport processes within a Composite Eukaryotic Cell

whereas active transport involves movement against the electrochemical potential for that ion.

It is, in fact, the active transport of ions across a membrane that creates the charge gradient, or membrane potential (Vm), across the membrane, which means that one side of the membrane has a net negative charge and the other side has a net positive charge. Vm is expressed either as volts (V) or millivolts (mV). Most cells have a negative membrane potential, which by convention means they have an excess of negatively-charged solutes inside the cell. This charge difference favours the inward movement of cations and the outward movement of anions and opposes the outward movement of cations and the inward movement of anions.

Strictly speaking, the term "electro-chemical potential" is used to describe the combined effect of the concentration gradient and the membrane potential when discussing ion transport. For many readers, however, the term "electrochemical gradient" is probably easier to understand. We will use the two terms interchangeably, but with a preference for electrochemical potential.

The most extensively-studied transport proteins are, therefore, among the best understood.

Vital to the erythrocyte's role in providing oxygen to body tissues is the movement across its plasma membrane of 02, C02, and bicarbonate ion (HC03) as well as glucose, which serves as the cell's main energy source. Also important is the membrane potential, maintained across the plasma membrane by the active transport of potassium ions inward and sodium ions outward. In addition, special pores or channels allow water and ions to enter and leave the cell rapidly in response to cellular needs.

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PLUS POINTS

About to explode

Betelgeuse, normally one of the brightest stars in the sky, has started to behave strangely.

Astronomers think the unusual dimming could be a sign that it is about to explode into a spectacular supernova; though nobody really knows for sure what will happen to the famous star.

The dimming has been noted in recent weeks and has been a gradual process. Each time astronomers observed the star through December, it seemed to be less bright. Now, it has reached a point when it has become dimmer than ever before.

Astronomers think that the behaviour could indicate that something might happen to the star.

Betelgeuse is already approaching its death: it is relatively young, but red giants like Betelgeuse burn bright and then die away in a spectacular supernova. If that happens, it will be visible in detail from Earth. Betelgeuse is only 700 light years away, and so its explosion into a supernova would be clearly visible from Earth, giving astronomers a chance to watch one of the universe's most intense and spectacular events from relatively nearby.

But while the dimming is clear — it has dropped by a factor of two, enough to be seen with the naked eye — there is nothing to say for sure about whether it could be a sign that it is about to go supernova. And even if it does, there is no indication that it will happen anytime soon.

Betelgeuse is famous in part because it is so bright. It is the biggest of any star we can see apart from our own Sun, and is traditionally one of the 10 brightest stars in the sky.

But its recent unusual behaviour has led it to drop out of that chart. It has become so dim that it has lost its place even in the top 20, astronomers say.

The change has meant that the night sky could look unusual, even to a casual observer using the naked eye. Betelgeuse makes up an important part of Orion — sitting on its shoulder, and that has changed as the star has become less easy to see from Earth.

The independent

The pinhole effect

Most eyes in Singapore on Boxing Day were trained on the Sun, as a rare eclipse took place. But a few onlookers posted pictures of many strange crescent-shaped light patterns they noticed on the ground.

These shadowy patterns dotted pavements and walkways on the afternoon during the annular solar eclipse and coincided with the height of the astronomical event when the Moon covered the centre of the Sun to create a "ring of fire" effect at around 1:30 pm.

The eclipse, which was seen recently in Singapore for the first time in two decades, lasted from 11:30 am to 3:20 pm.

While the patterns on the ground might have puzzled some people, there is an explanation. According to US space agency Nasa's website, the effect that created these solar images is similar to that used in pinhole cameras.

A pinhole camera is one without a lens, but with a small hole on one side. Light passes through the hole and projects an inverted image on the other side of the box, a phenomenon called the pinhole effect. For this eclipse, the pinhole effect happened when light passed through patches between leaves of trees and projected crescent-shaped patterns mirroring the eclipse's "ring of fire" on the ground.

"The light from the Sun passing through gaps in leaves and objects can project a round image of the Sun every day. It is because of the solar eclipse, which projects a different light pattern, that people noticed it on the ground," said Albert Ho, president, The Astronomical Society of Singapore. He added that when light passes through multiple gaps between tree leaves, it causes multiple images to form. And during the recent eclipse, this created many crescent-shaped patterns.

The straits times/ann