Shining light on artificial photosynthesis

Mimicking plant life could be our way out of the energy crisis. Anna Lewcock talks to Tony Harriman to find out more

This year the Olympics come to the UK, and billions of pounds have gone into building the state of the art facilities that the athletes will compete in over the summer. But what if the Olympic stadium – or premier league football grounds – could double up as power stations, providing us with clean fuel?

The idea isn’t so far-fetched. Stadiums can be covered with solar panels to soak up energy from the sun. The problem is that the energy has to be used straight away. What would be really useful would be to find a way to store that energy, so it could be used when the sun goes down.

The seed of an idea

The idea of harnessing energy from the sun isn’t new; it’s been around for billions of years in the process that plants use to get their energy – photosynthesis. The green plant life you see around you has a perfectly developed system for absorbing sunlight and using it to convert water and carbon dioxide into oxygen and carbohydrates. The energy from the sun is ‘stored’ in the chemical bonds of the carbohydrates, ready for the plant to use later.

Scientists have been trying to crack the secret of this complex biological system for decades: ‘It’s absolutely amazing, the level of sophistication that has gone into the evolutionary process,’ says Anthony Harriman of the Molecular Photonics Laboratory at Newcastle University. And now it’s become more important than ever to try and figure out a way to try and imitate what nature has perfected.
We’re fast approaching a fuel crisis. We’ve been happily using fossil fuels like coal and oil to generate power on a huge scale since the industrial revolution, but there’s only a limited supply of these non-renewable fuels on the planet and one day we’ll have squeezed the last drop from the tank.

On top of that is the impact on the environment – burning all that fuel has pumped so much carbon dioxide and other greenhouse gases into the atmosphere that we’ve caused the planet’s temperature to rise, causing dangerous climate change. Both these things mean we urgently need to find alternative, renewable sources of power.

The only option we have is to look to the sky – the sun. ‘There is no alternative,’ says Harriman. ‘No other system known to mankind can generate the energy that we are anticipated to need over the next 20 or 30 years.’ When put that frankly, it becomes less important to be able to duplicate the exact mechanisms within a plant – ‘anything will do that will collect the sunlight and generate a useful chemical fuel.’

Capture the energy

Only a fraction of the sun’s energy reaches us, but what little that does is more than enough: more energy from the sun hits the Earth in one hour than is used by everyone in the world in one year. That’s more than we could ever hope to produce using technology alone.

You’ve probably already seen solar panels – perhaps you have them installed on your house. These show success in tackling one part of the puzzle, as they convert the energy from the sun into photons – directly into electricity. The panels are composed of many individual solar cells made of material that absorbs photons and releases electrons to carry an electric charge. ‘Electricity is fine, but all we can do at the moment is use the sun to charge up a solar panel to feed electricity into the grid, or perhaps charge a battery,’ says Harriman. Where chemistry will really come into its own is in cracking the bigger problem of how we can actually store the energy from the sunlight to use later – artificial photosynthesis.

Divide and conquer

Historically, much of the work in the artificial photosynthesis field has focused on trying to split water into its constituent parts: hydrogen and oxygen. The oxygen can be released into the atmosphere (as it is during natural photosynthesis), and the hydrogen could be put to practical use. If we can find a way to handle the hydrogen effectively, it has huge potential – we could store it in fuel cells that generate electricity without harmful byproducts, combine it with other materials to make more useful products, or perhaps find a way to make it react with nitrogen under modest conditions to create cheap fertilisers for the third world.

Water molecules can be split by electrolysis, with hydrogen gas being given off at the negatively charged cathode and oxygen given off at the positively charged anode. However, if the electricity used to drive this process has come from fossil fuels, it cancels out the benefit of generating the hydrogen to be used as a clean fuel. Work has been done to combine the technology used in solar panels with electrolysis to overcome this, but the set-up would need to be very efficient, use cheap and easily available materials and last for years to be a practical solution. At the moment, that’s not the case.

Another approach is known as ‘photoelectrochemical’ water splitting, and is used in what scientists have described as ‘artificial leaves’. In this arrangement sunlight hits semiconductors that use the energy to directly split water molecules. But finding materials that can work well when in contact with water, as well as being efficient, stable, cheap and durable is still an unfulfilled goal.

A challenge to store electrons

The real challenge for chemists says Harriman, is designing systems that will store electrons – not electricity – for enough time to be able to carry out useful chemical processes. When you’re dealing with photochemistry (ie using light), one photon impact frees up one electron. ‘If you want to generate oxygen from water you need to accumulate four electrons before it’ll work – so you need four photons to get four electrons,’ explains Harriman. But more than that, you need all the electrons at the same place at the same time – ‘and that’s very difficult because they’re highly reactive and tough to control.’ When chemists started working on this several decades ago, they were happy if they managed to hang on to an electron for a nanosecond – one billionth of a second. ‘It was a massive challenge,’ says Harriman. ‘Now we can do it for one second. But I think probably we need 30 seconds before we can do the kind of job that we’re looking for.’

New materials that can cling on to those electrons for long enough are an active area of research, as are new catalysts that will help make the process more efficient. In nature, enzymes act as catalysts and can produce hydrogen from water very effectively. If we can develop...
Most leaves are green due to chlorophyll, an important molecule in photosynthesis. In this experiment, you can separate the different pigments present in a leaf using paper chromatography (PDF) for yourself.

Artificial leaf (silicon solar cell coated with catalyst) splits the water into H2 and O2 as light shines on it

Try it yourself

Recycling CO2
The other process that is a hot area of research in artificial photosynthesis is carbon dioxide reduction. Finding an effective way to convert CO2 into hydrocarbons would not only create another fuel source, but would allow all that waste CO2 we’re currently producing to be put to good use. Ideally we’d be able to pull apart the CO2 molecule and make different fuels like methane (CH₄) or methanol (CH₃OH). The problem is that carbon dioxide molecules are quite happy as they are, and breaking up such a stable molecule is difficult. Some catalysts can help the process along, and researchers are particularly looking at photocatalysts that can be activated by light from the sun. Scientists are making progress in this area, but there’s still a lot of room for improvement.

Solar fuels are likely to be the key source of much of our energy in the future. The developed world has accepted the need to cut down on carbon dioxide emissions, and that means switching away from fossil fuels to renewable sources of energy. The sun gives out more energy than we’re ever going to need, is environmentally friendly and doesn’t cost anything – all of which makes it a logical choice for our future fuel source. But that means a lot more than sticking solar panels on your roof – for artificial photosynthesis to have a real impact there’s an awful lot to be done to improve how we capture the sun’s energy, how we convert it to forms we can use, and how we can store it effectively.

‘This is not a scientific problem that has been solved,’ says Harriman. ‘Many people coming into the field will be able to participate, and there’s room for a lot of different approaches and an awful lot of innovation.’

Although artificial photosynthesis has been studied now for several decades, it is the coming years that will see the crucial research and developments that will help it move out of the lab and towards our rooftops — perhaps even generating power from the sun while footballers and athletes expend their energy on the tracks and pitches beneath.
Animals release pheromones for all sorts of reasons – not just to indicate their availability for breeding. Pheromones are used as an alarm to warn of predators, as a trail to help guide others to food and as a boundary to mark out territory.

Did you know?

Sex pheromones

I was fascinated by the story of bombykol, the sex pheromone of the female silk moth, otherwise known as 10,12-hexadecadien-1-ol. This is a molecule consisting of a chain of 16 carbon atoms, an alcohol group at one end and two carbon-carbon double bonds, one cis and one trans, towards the other end.

The story starts in the 1880s when the Frenchman Jean-Henri Fabre started messing around with silk moths. In a key experiment, Fabre placed a female silk moth in a box for a few hours. He then removed her, and left the box overnight. The next morning he found that male moths were strangely attracted to the empty box, as if some kind of enticing scent had been left for them by the female.

We now know that chemical trail was a pheromone – a chemical secreted by an organism which is then picked up by other members of the same species and elicits a behavioural response.

Extraction and purification

It was the German chemist Adolf Butenandt who worked out what was really going on. He started by taking the pheromone glands from the female silk moth and extracting the chemicals they produced. Since bombykol is only ever produced in tiny quantities by the moths, he needed lots of glands to get even the tiniest amounts of material to work with.

Once he had the crude pheromone mixture, Butenandt purified it by fractional distillation. The problem of working out which fraction contained the bombykol would be the work of a few hours with modern NMR and mass spectrometry techniques, but Butenandt had none of this. He used the male moths to work out which fractions contained the pheromone, noting that they began flapping their wings like crazy whenever they were exposed to a bombykol-containing fraction.

Spectroscopy and identification

After many cycles of purification, Butenandt started to work out the chemical structure of the molecule. He used infrared spectroscopy to reveal that there is an alcohol group and two carbon-carbon double bonds present. He used a variety of chemical degradation methods to work out the length of the carbon chain and the position of the double bonds.

Butenandt managed to confirm the structure by synthesising bombykol from scratch. He prepared all four of the possible geometric isomers of the double bonds, and found that one of them was at least a billion times more effective at exciting the male moths!

A chemical weapon

For farmers, keeping insects away from their crops can be a matter of life and death. Pheromones provide an effective chemical weapon against many insects. Rather than killing pests with poisons which they might become immune to over time, farmers often make use of pheromones to confuse and divert insects – they go after the pheromones rather than the crops.
Avogadro’s lab

In this issue: The shapes of molecules

Investigating why molecules have different shapes with Paul Hogg

The shape of a molecule affects how it interacts with other molecules and that in turn can give rise to all kinds of interesting phenomena. One important area is how drugs work in the body. Using this as an example, the drug – a molecule with a specific shape – will commonly interact with a larger molecule, such as a protein. This causes a chain of events which give the drug its specific medicinal properties. Understanding how molecules have their particular shapes is therefore very important for chemists, especially when we want to design a new drug to fight a particular disease.

Explaining molecular shapes

One way to explain the shape of a molecule is called the Valence Shell Electron Pair Repulsion Theory or VSEPR Theory. If you think of the valence electrons as occupying orbitals, that are similar in shape to party balloons, then it is not too difficult to see how different molecules get their particular shapes. For large molecules, such as proteins, the overall shape will be due to the bonding between atoms as well as other electrostatic and steric effects.

VSEPR theory is used to explain the 3D shape around an atom in a molecule and for small molecules this can give the overall shape.

Lone pairs of electrons play a significant role in the shape of molecules but it is not always easy to see why. This is especially true when we draw molecules, because we tend to omit lone pairs for clarity. VSEPR theory uses lone pairs to provide many of the observed shapes.

Using the VSEPR model structures, we can predict the shape based on three simple rules:

1. Count how many atoms (we’ll call them ‘X’) are connected to the atom of interest (we’ll call that ‘A’). (Double and triple bonds are each counted as just one bond, since only one ‘X’ atom will be connected to atom ‘A’.)
2. Count how many lone pair electrons (we’ll call those ‘E’) surround atom ‘A’.
3. Find a structure from the VSEPR model that fits the number of bonding atoms and lone pairs you have just counted.

An example would be methane, CH₄, (or AX₄ using the method above) where we would look at the carbon atom, count the bonds to hydrogen (4 in this case), then count the number of lone pairs (0 in this case). Using this, VSEPR predicts the structure of methane to be tetrahedral, which is correct.

Try it out

1. Take some coloured playdoh and shape it into small balls, to represent atoms.
2. Cut some drinking straws into 4 cm long pieces, to act as the bonds between atoms.
3. Try and make the following molecules using the rules of VSEPR theory (tip: use a red balloon shaped piece of playdoh to represent lone pairs).
   - CO₂ (don’t forget double bonds are counted as single bonds)
   - NH₃ (don’t forget the lone pair on nitrogen)
   - H₂O (more lone pairs!)
   - XeF₂, BF₃, PCl₅, SF₆.

And finally...

The shapes of molecules are ultimately governed by the valence electrons and as a chemist you will often have to visualise molecules in your mind. Whether they are flat structures or 3D, the shapes given by VSEPR theory will almost certainly guide you in that process.

![Fascinating fact](image)
The tetrahedral nature of a water molecule together with hydrogen bonding is what makes ice less dense than liquid water. This is why ice floats on water.
Choosing the best experience

Choosing a university course has never been harder, with a wider choice on offer than ever before. The increase in tuition fees has further added to the pressure of students to make the right decision. Universities will have to publish Key Information Sets from 2013–2014 onwards (http://bit.ly/hefcekis), aimed at standardising the information they provide to prospective students and many are starting to compile it already. However, there is a risk that potential students can find themselves lost in a maze of numbers and data sets. As chemists, we are trained to analyse data and use this to make our decisions. Does this work for something as big as choosing your degree course, a decision that will shape the rest of your life – both personal and professional?

See the whole picture

With the rush to market universities on the basis of 'student satisfaction', prospective students run the risk of ignoring other factors that can have a big influence on their success in studying. Too much emphasis on facilities or the quality and availability of accommodation can blind students to other factors which are equally important to a successful student experience – amount and quality of teaching, the location of the university etc. Whilst these are all often recorded in student satisfaction surveys (http://unistats.direct.gov.uk), what does ‘90% satisfied’ actually mean to an individual looking in from the outside and how should they use this info when making their decisions? Satisfaction surveys and sifting through sets of stats should certainly play a part in decision making and can be useful for short-listing potential universities to apply to, but they don’t always tell you the whole story.

Open days

To see the whole picture, nothing beats visiting a university in person. As a prospective student, you should make sure you go to open days at the universities you are interested in applying to (www.opendays.com). Use this opportunity to talk to current students about what it’s like to actually study there. Quite often the decision about where to go is influenced by the atmosphere or feel of a place. These are often intangible things that you can’t put a numerical value on and these don’t show up in university comparison websites or surveys. So while the stats and surveys are important, they shouldn’t be only factor in choosing your course or university.

Find out more

For more information on things to consider, access the booklet to choosing a chemistry degree online at www.rsc.org/chooseadegree. You should also come to Meet the Universities on 30 June 2012 at the Chemistry Centre in London. This major RSC ChemNet event offers you, as a prospective student, the chance to talk to over 30 UK university chemistry departments and undergraduates face to face in one place. More details can be found in the next issue of The Mole and on the ChemNet page on MyRSC (http://my.rsc.org/chemnet).

Robert Bowles

www.rsc.org/TheMole

ChemNet events are supported by an education grant as part of the Reach and Teach program funded by the Wolfson Foundation

Dates for your diary

ChemNet Events:

► Harnessing the light fantastic
13 March 16:30–19:00
The Chemistry Centre, London
Nick Terrill, from Diamond Light Source, will explain how intense light produced at the UK’s national synchrotron science facility is being used to produce colour changing polymers, understand the structure of natural pigments and research the next generation of photovoltaics.

► Look what chemistry has done for me
22 March 19:00–21:00
Royal Society of Chemistry, Cambridge
Find out more about careers in chemistry from a range of people using chemistry everyday.

► Visit to MRC human nutrition research
27 June 10:00–12:00
Elsie Widdowson Laboratory, Cambridge
An introduction to human nutrition research from fundamental principles to applied public health. There will be an opportunity to tour the laboratory and see some of the scientists in action. This will be followed by short talks on how members of the research team have reached their current positions and how chemistry plays a role in their work.

ChemNet is supported by RSC ChemNet: www.rsc.org/chemnet

Choosing the best experience

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Emma Shiells

Picture editor at the Royal Society of Chemistry (RSC)

Emma works on magazines and books, sourcing scientific illustrations and photographs

Let sleeping vets lie
It’s not often you hear someone refer to themselves as both a scientist and artist, but Emma counts herself as one of the lucky ones. If you had asked her 15 years ago what she wanted to be when she grew up, she would have said ‘a vet’. That changed when studying chemistry at A level, with the help of a truly inspirational teacher. Emma soon realised there was more to it than just salts, acids and alkalis. She continued studying chemistry at university and discovered her passion for practical lab experiments. Two chemistry degrees later, she decided to hang up her lab coat and venture into the world of chemistry publishing.

Art of science
Emma’s first few years at the RSC saw her working on chemistry journals, handling submissions, sending papers for peer review, commissioning new articles and launching a new journal. She was lucky enough to travel the globe for various scientific conferences and meetings along the way. Now Emma is part of the RSC design team, sourcing pictures and illustrations for the organisation’s magazines. Emma said ‘I never thought I would end up working on scientific magazines looking at pictures day in, day out. This is the best job in the world and I’m loving every minute of it’.

Left brain: right brain
Neuroscientists agree that the left side of the brain is used for logical thinking such as for science, maths and languages. When it comes to images, imagination and perception we use the right side of our brains. Emma says it’s interesting to know her job requires both her scientific knowledge and artistic skills on a daily basis, so we can confidently assume that her whole brain has a workout each day!

A picture paints a thousand words
No two days are the same. In a typical day, Emma sources images for Chemistry World online stories that are published daily. Time is of the essence as often a science journalist will have a breaking news story, so she needs to be quick in finding the most suitable picture to accompany the story. ‘Sourcing images is usually straightforward when you know where to look,’ says Emma. ‘Luckily I have access to several online image libraries where I can view up to tens of thousands of images.’ Emma has introduced more illustrators and cartoonists to the magazines, to help bring more light-heartedness to the stories and balance out the more serious news being reported.

One of the tasks Emma enjoys most is the challenge of finding a striking image for the front covers that has a ‘wow factor’. ‘It’s exhilarating to know that up to 50 000 people read a magazine I have helped produce and are admiring some of the artwork and images used. Even if the illustration has just helped someone understand the science better, or a photograph has stopped someone in their tracks and made them want to find out more by reading the article, then I know I have played my part. I like to think I am helping to advance the chemical sciences in some way, even if it’s just through eye catching imagery – as they say, a picture paints a thousand words.’
With the increasing energy demands of the 21st century creating a pressing interest in alternative power sources, the demand for high performing, state-of-the-art fuel cells has never been greater. However, these fuel cells require the precious metal platinum to generate their high power output. This drawback has led scientists in Taiwan to develop a competitive replacement by combining carbon, and curiously, vitamin B₁₂.

‘The limited abundance of platinum and other noble metals on Earth restricts the development of fuel cells. Searching for a non-noble-metal catalyst is a major issue,’ explains Kuei-Hsien Chen, from the Institute of Atomic and Molecular Science, Taipei, who, along with other colleagues, has developed this peculiar solution.

To generate electricity, most modern fuel cell devices require an oxygen reduction reaction (ORR) at the cathode of the cell, whilst another chemical (often hydrogen) is simultaneously oxidised at the anode. This redox reaction for power generation has been limited by the slow ORR process, which needs complex enzymes to proceed at any meaningful rate.

Although scientists have been investigating methods for speeding up the ORR, it has been really difficult to produce a cathode that can achieve this. So they have had to resort to loading high amounts of expensive platinum onto the cathode to generate the required ORR rate.

Chen and his co-workers have been able to do away with the need for platinum altogether, by using cheap carbon that has vitamin B₁₂ dispersed throughout to form the cathode of their polymer electrolyte fuel cell (PEFC). The performance of this cathode doesn’t quite match that of platinum based cathodes, but at a fraction of the cost, this cathode could open up real opportunities for the practical application of these fuel cells.

Fuel cell expert John Varcoe, from the University of Surrey, UK, thinks that Chen’s advance clearly shows ‘promise for use as a fuel cell catalyst’. However, he urges caution by saying that the fuel cell’s performance over ‘many thousands of hours will need to be demonstrated before it will rival current (more expensive) fuel cell catalysts’.

Chen hopes to continue to develop his PEFC to make the cathode more effective. In the meantime, this research may make fuel cells more accessible as a power source for the world’s future energy needs. Ross McLaren
Nanoear listens in on cellular motoring

To test this, the team used a camera to record the movement of an optically-trapped gold nanoparticle in the presence of a sound source. Using a Fourier transform, they were able to disentangle the motion caused by the sound waves from that of normal Brownian motion. The result, says Feldmann, is ‘a highly sensitive acoustic detector that provides a very local source of information about the microworld’.

Feldmann says that the nanoear could be useful in studying cellular processes. Gail McConnell, a research fellow in biophotonics at the University of Strathclyde, UK, agrees. ‘It would be marvellous if mutants of the motor proteins that impair function could be listened to, to see if there was a change in the humming of the motor,’ she says. McConnell notes, however, this is only possible if the vibrations are powerful enough to be noticeable above the background Brownian noise.

Another limitation is the size of the nanoparticle, says Ricardo Arias-González, who leads the optical manipulation lab at the Madrid Institute of Advanced Studies in Nanoscience in Spain. Arias-González suspects that molecular motors may be out of earshot but that the nanoear could listen to processes that involve many proteins working together. ‘It is highly innovative,’ he says. ‘I would find it quite exciting characterising the noises in the vicinity of an individual cell. This might provide information on collective tasks that may not be easy to inspect with microscopy.’

Phillip Broadwith

Just as the macroscopic world is filled with the rattle and hum of machinery, the actions of molecular and cellular ‘machinery’ also produce tiny vibrations that resonate throughout the microscopic world. The sound a car engine makes can indicate if there’s a fault and, by extension, the sounds made by the ‘machines’ that control cells could also provide useful information about the processes they control. Listening to these sounds, however, is currently beyond even the keenest ears.

Inspired by this, Jochen Feldmann and colleagues at the Ludwig Maximilian University of Munich have developed a ‘nanoear’, that is capable of detecting these tiny vibrations. Feldmann’s nanoear is an adaptation of optical tweezers: a technique that uses laser beams to trap an object within a fixed volume of space, commonly used to manipulate objects and perform measurements at the microscale and nanoscale.

On observing the movements of such a trapped particle, Feldmann proposed that the particle’s response to an acoustic wave should reliably correspond to features of the wave. ‘Imagine an apple hanging on a branch of an apple tree and being shaken by wind,’ explains Feldmann. ‘By observing the apple’s motion one could derive properties of the wind.’

An optically trapped nanoparticle can act as an ultrasensitive detector of sound
On-screen chemistry

Jonathan Hare explains...

Breaking Bad III – thermite break-in

The thermite reaction produces very high localised temperatures that can be used for welding metals.

In *Breaking Bad* Walt is a high school chemistry teacher turned bad, ‘cooking up’ amphetamine (crystal meth) with his partner Jesse. Their starting material for the crystal meth is an over-the-counter drug from the pharmacist. Unfortunately the pharmacist is only legally allowed to sell a couple of packets to one person, so Jesse has to organise a whole host of ‘Smurfs’ (‘dudes’ prepared to go into loads of pharmacists) to go out and collect enough.

**Reaction**

To bypass this obvious limitation, Walt suggests an alternative precursor which they have to steal from a lockup. They burn out the security lock using a thermite reaction and in a very humorous clip, reminiscent of a scene from Laurel and Hardy, they make away with a large drum. Afterward the local drug squad watch the CCTV footage and enjoy laughing at their antics – carrying the drum rather than rolling it along. In the programme Walt enthusiastically describes the basic chemistry of the thermite reaction to Jesse – something that doesn’t happen very often in a Hollywood film!

The thermite is a classic reduction-oxidation reaction.

\[
\begin{align*}
\text{Fe}_2\text{O}_3 + 2\text{Al} & \rightarrow \text{Al}_2\text{O}_3 + 2\text{Fe} \\
\end{align*}
\]

The further apart the two metals are in the electrochemical series, the faster and more furious the reaction.\(^2\) I won’t ever forget the explosion and ‘fallout’ that took place in our lab when my inspiring middle school science teacher heated a crucible of lead oxide and magnesium thermite powder!

**Really hot!**

The thermite reaction is not an explosive but the energetic reaction can produce very high localised temperatures that can be used for welding or ‘cutting’ through metals. The reaction with aluminium is particularly useful as it melts at relatively low temperatures so the reaction is easy to start. Aluminium also has a high boiling point and so the reaction can reach very high temperatures of around 2500°C and so be used to weld railway tracks together for example. The army use the reaction for a variety of on-the-spot applications. In the right quantities it is certainly capable of creating the sustained heat to melt a lock, although it could easily have set fire to the door and surroundings!

**References**

2. *Education in Chemistry*, January 2011, p10 (www.rsc.org/ElCO111p10)
Puzzles

Wordsearch

Find the 30 words/expressions associated with buckminsterfullerene hidden in this grid (contributed by Bert Neary). Words read in any direction, but are always in a straight line. Some letters may be used more than once. When you have found all the words, use the remaining letters to make an 8-letter word.

```
S F N O I T A S I L A C O L E D E
D A F U L L E R E N E C A G E X G
N C D O D E C A H E D R O N P A R
O E N O R D E H A S O C I E R T A
B S E X A B V B C E S E R R E A P
N N C F I U T U U G Y I S T S D H
O Q U I S C N C B D M H I E O H I
B R R V O K O K E E M O N S N T T
R D V E L Y I Y N R E R G S A G E
A E A F A B T T E U T I L E N N H
C H T O T A A U N T R Z E L C E E
N Y U L E L T B A C Y O B L E L X
O L R D D L O E L U A N O A F D A
B O E A I S R S P R X T N T O N G
R P T X E T R E V T I A D I R O O
A A C I A N G L E S S L E O M B N
C L A S E R A B L A T I O N S S S
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Angles: DODECAHEDRON
Axes: EDGES
Axis: EXPERIMENTAL DATA
Bond length data: EXPERIMENTAL DATA
Buckyballs: FIVE FOLD AXIS
Buckytubes: FULLERENE CAGE
Carbon carbon bonds: GRAPHITE HEXAGONS
Cube: HORIZONTAL
Curvature: Icosahedron
Delocalisation: ISOLATED

January wordsearch solution and winner

The winner was Alice Rotti from London. The 10-letter word was WAVELENGTH.

Chemical acrostic

Complete the grid (contributed by Simon Cotton) by answering the 10 clues to find the answer in the shaded box, which is a non-metallic element, originally isolated in 1669 from urine.

```
1. Transition metal that forms a black oxide but a blue sulfate
2. Gas formed when magnesium reacts with many acids
3. Transition metal with common oxidation states of +2 and +3
4. Transition metal that forms a white insoluble chloride
5. Compounds of this metal can be used to treat cancer
6. An atom found in sucralose molecules but not in glucose
7. Noble gas whose name means ‘new one’ in Greek
8. Gas formed by the alpha decay of radium
9. Only non-metallic element with name ending in ‘ium’
10. Once extracted by the Frasch process, now obtained from natural gas and crude oil
```

January acrostic solutions and winner

The winner was Jaina Shaha from London. The answer was GADOLINIUM.

Submit your answers online at http://goo.gl/ovSTJ by Monday 12 March.

A correct answer for each puzzle, chosen at random, will win a £25 Amazon voucher.

www.rsc.org/TheMole
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- e-magazines
  Access *Chemistry World* and *The Mole* online, for cutting-edge research, news analysis, podcasts and webinars

- Visits to universities and industry
  Experience what life is like as a student and see where chemistry can lead in the future

- Careers advice
  Access advice on scientific careers through the RSC's online careers fair, ChemCareers

- Specialist university information
  Attend ‘Meet the Universities’ event and take part online to get assistance with making university choices

- Online chemistry network
  Join discussion groups, explore blogs and connect with other RSC ChemNet members

www.rsc.org/chemnet