Entropy
Illustrating the abstract
What bright spark uses this?

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for more information please visit: www.C3L6.org
Education in Chemistry

is the only magazine in the UK aimed at teachers of chemistry at all levels. It is written by its readers for its readers, and covers the whole spectrum of chemistry teaching from balanced science in secondary schools to the final stages of undergraduate courses.

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Teaching – our life, our future

As the International year of chemistry begins, acting editor Laura Howes reflects on what’s to come.

Welcome back, I hope you had a good break and that you haven’t yet broken too many New Year’s resolutions. The International Year of Chemistry (IYC 2011) has now begun, with the theme ‘Chemistry – our life, our future’ and over the next 12 months I hope that Education in Chemistry can help you to teach your pupils and students just how vital and relevant chemistry still is.

However, I don’t just want this to be a one way communication. If we publish something you like, tell us. If you disagree with our views, write a letter. As the landscape of teaching changes, EiC will have to change with it. We have to continue to support you and more than ever we as a community need to work together. At the end of this editorial is a list of ways in which you can interact with us, and in the next issue we will be publishing a readers’ survey. The assistant editor David will be attending the ASE conference at the University of Reading in January; he wants to hear your views as much as I do.

Changes for EiC

While EiC will still be working as hard as ever to support you, there are some changes that you will notice. Infochem, our student supplement, has had a revamp. You may not be the target audience, but judging from the number of entries we receive for the prize puzzles each issue, the pupils definitely read it. Again, we’d love feedback.

We’ll also be adjusting our issue schedule slightly, to try and fit better with the school terms. It seems foolish to deliver a magazine to a closed school over the summer holidays, so we won’t.

Your next issue will arrive at the beginning of March as usual, but issue 3 will appear at the end of April. Issues 4, 5 and 6 will be delivered at the start of June, early September and November as normal.

Changes for us all

There’s been a lot of news about funding and fees over the last few months for teachers and their students to take in, and I’m sure more will come.

In Endpoint this issue, David Phillips has taken the opportunity to think about how these changes could be embraced and used to instigate reform of teaching chemical science at all levels.

Whether you agree or you disagree with his conclusions, the idea of creating something positive from what we are told is a necessity is perhaps the best way I could think of to finish this issue.

EiC has entered the whirl of social media. You can like us on Facebook, tweet us @RSC_EiC and join our readers-space on MyRSC. However, phone, post and e-mail work just as well (see the contents page for details).

2010 RSC Bill Bryson Science Communication Prize

In October, Bill Bryson and RSC President Professor David Phillips presented the winners of the 2010 RSC Bill Bryson Science Communication Prize with their prizes at a special event at the Palace of Westminster.

The overall winners were Hannah Taylor, Thomas Earl, Lucy Upot and Charlotte Norris of Aberdour School, Surrey, for their animation entitled “Our Thirsty World”, which was about issues around water supply and quality. Phoebe Devonshire, from West Hill Park School, won the prize in the Primary category for her writing about the chemistry of rocket propulsion and Emma Hopkins claimed the Secondary prize for her entry about HIV. Bryson said the entries had been of “unprecedented quality”.

Copies of all the winning entries can be found on the RSC website along with details of how to enter this year’s competition. The closing date is the 31st of March and this year celebrates the International Year of Chemistry by sharing its theme for the competition: “Chemistry – our life, our future”. In addition, there will be a new category for entries from schools outside the UK.

More information can be found at www.rsc.org/billbrysonprize

Laura Howes

IN BRIEF...

CASH PRIZE FOR NEW STUDENTS

The 2011 Corti Science Prize is now open. Currently in its fourth year, the Corti Science Prize aims to promote the study of science in higher education by awarding a cash prize to new university students studying an engineering, maths or science-based degree. To be in with a chance to win the prize of £2000, entrants must write an essay explaining a historical scientific experiment or theory, and describing its impact on society.

Applicants must be 21 or under and starting an eligible degree in 2011. Deadline for entries is the 31st of March and tips, entry forms and teacher’s packs are available at www.cortiscienceprize.org.

Laura Howes
**Diamond Light Source**

*In November, 32 RSC ChemNet members visited Diamond Light Source in Didcot. Education in Chemistry went along to find out more.*

Opened in 2007, this particle accelerator accelerates electrons to give a source of extremely intense light—rather than smashing high energy particles together like the Large Hadron Collider. It can be thought of as a gigantic x-ray machine.

The group that Education in Chemistry accompanied was allowed up close to this gigantic device. Over 2000 research groups use this world class facility each year and during our visit we learnt how different chemists use the synchrotron. Previous work at Diamond has included: Understanding corrosion processes to allow better design of construction materials; analysis of the distribution of the minerals in grains to produce more nutritious foods; and investigations into the design of novel hydrogen fuel storage materials.

Diamond’s electron beam is sped up and then sent around a circular storage ring by magnets. Our guide took the pupils up close and into the storage ring section, which is kept behind 1.5m of concrete shielding. Inside, the ring is kept at a vacuum pressure equivalent to 10 miles high in space, so that the electron beam does not lose electrons due to collisions. More magnets turn the electron beam into x-rays before the x-rays are filtered and focused before they reach whatever is being studied.

When operational, the machine runs 24/7, so scientists work in shifts to make the most of their allocated slot. Our tour guide observed that it’s not unusual to see PhD students arrive with a box of samples and a packet of biscuits to sustain them through the night.

Diamond Light Source was directly mentioned in the Comprehensive Spending Review, when the funding for its Phase III expansion was confirmed. Mark Basham, a scientist working at the Diamond Light Source, said that “The Phase III expansion will make more adventurous and cutting-edge experiments possible.”

Diamond Light Source has an excellent educational website, http://insidediamond.org/, with overviews and case-studies of the machine, how it works and what it’s used for.

Diamond holds open days throughout the year for the general public and families as well as hosting visits from schools. In addition there are work placements and internships available for interested pupils and university students.

Further information is available at www.diamond.ac.uk/Home/Teachers.html.

David Sait

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**IN BRIEF...**

**IYC 2011 ART EXHIBITION**

The RSC will be running an international art exhibition as one of its IYC 2011 events. Students aged 10–15 from Europe and Africa are being invited to submit artwork that addresses the question ‘Water: Refreshment or Responsibility?’ to the RSC by the 2nd March 2011. The collection is intended to draw attention to the role of chemistry in providing safe and clean water and will tour Europe in the summer and autumn. For more details, please contact childrenonwater@rsc.org, 01223 420066, www.rsc.org/childrenonwater.

**SCORE 2011**

The 2011 SCORE annual conference, titled ‘Assessment of science at 14–19; Is it fit for purpose?’, will take place on 11 February 2011 at the Royal Society, London. The conference will provide a range of perspectives of assessment in science at 14–19 and explore the challenges the community currently faces. It will offer delegates the opportunity to discuss the purposes of assessment, comparability issues and maintaining standards. This conference is free to attend and registration is available on the SCORE website www.score-education.org/events/score-annual-conference-2011.

**RE-DISCOVER MATHS**

Discover Maths for Chemists, the website launched by the RSC in 2009 has been updated. The site now hosts a unique ‘compass’ tool to link together chemical and mathematical concepts and more context-based resources. The free to use site, which is tailored to the needs of chemistry students, now has over 1200 monthly users and is still growing and developing. To see more, visit http://discovermaths.rsc.org.

**GOOGLE SCIENCE FAIR**

Google will soon be launching the first ever Google Science Fair. In co-operation with NASA, CERN, National Geographic, Scientific American and LEGO, Google Science Fair is intended to be the largest global STEM competition ever and will be open to pupils aged 13–18 around the world. To find out more and sign up for more information, visit www.google.com/sciencefair.
O₂ learn launched

Telecommunications company O₂ has launched a new competition for UK secondary school teachers with a flair for video. Teachers who enter could win up to £50,000 for themselves.

Teachers are invited to upload video clips of showcase lessons, aimed at pupils aged 13–18. As well as creating a free online teaching resource, the users of the resource will vote for their favourite lessons.

Every fortnight until July 2011, the teacher who produced the most watched and best-rated lessons will win £2,000, plus £2,000 for his or her school. There will be 18 such awards totaling £72,000.

In addition, O₂ Learn will assemble a panel of headteachers and members of teaching unions to shortlist eight of the 18 fortnightly winners to go through to a grand final in the autumn of 2011 where, with the help of the public, they will decide on the winning three UK teachers. The winner of the O₂ Learn award will receive £50,000 and a further £100,000 for his or her school. The runner up will win £20,000 and £40,000 for his or her school, and a third prize will also be awarded of £10,000 for the teacher and an additional £20,000 for the school.

O₂ Learn launches with the support of five partners – The National Union of Teachers, The Teaching Awards, Teach First, Parentline Plus and Teaching Leaders – and seven founder schools, a mixture of independent and state-funded schools, whose teachers have uploaded 100 lessons.

O₂ Learn is part of O₂’s Think Big strategy which seeks to inspire young people, and those that help young people, to make a positive change to the community. To find out more visit www.o2learn.co.uk.

Laura Howes

Salters’ events and news

The Salters’ Institute announces details of chemistry events for 2011.

Festivals of Chemistry 2011

The Salters’ Institute, in partnership with the RSC, will be holding 51 Salters’ Festivals of Chemistry between March and June. These one-day events will be held at various Universities throughout the UK and the Republic of Ireland.

Each festival will feature hands-on practical chemistry challenges in university laboratories, chemical demonstrations and a prize giving ceremony.

All pupils taking part will receive fun prizes and participation certificates. Prizes will be awarded to the winning schools and members of the winning teams will receive individual prizes and certificates.

Entry is restricted to one team of four students from Years 7 and/or 8 (Years P7 and/or S1 in Scotland, Year 8 and/or 9 in Northern Ireland and final year primary school and/or first year secondary school in the Republic of Ireland).

Places are allocated on a first come first served basis and the closing date for entries is 31 January.

To apply online visit www.festivalsofchemistry.co.uk, or contact 020 7628 5962 ext 224, festivals@salters.co.uk.

Chemistry Camps

19 Salters’ Chemistry Camps will be held between June and August 2011. These three day residential events at universities throughout the UK are for Year 10 pupils (Year S3 in Scotland, Year 11 in Northern Ireland, Year 3 in the Republic of Ireland) from all secondary schools in the UK.

Teachers may nominate four students to experience hands-on practical chemistry, a taste of life in the university halls of residence, lively chemical demonstrations and evening social activities. A maximum of two students of the four will be selected for each Camp.

Applications will be considered in the order that they are received and no closing date has been set. Therefore, pupils are advised to apply as early as possible.

Salters are also looking for teachers with a minimum of two years’ experience in teaching chemistry to teach at their Camps in 2011 and future years.

To nominate pupils or apply to work at the Camps yourself visit www.chemistrycamps.co.uk or contact the Salters’ Camps Administrator on 020 7628 5962 ext 213 or camps@salters.co.uk.

Awards for technicians

Nominations are open for the Salters’ National Awards for Science Technicians.

The awards were established in 2002 in collaboration with the Association for Science Education, CLEAPSS, the Institute of Physics, The Royal Society, The Royal Society of Chemistry and The Society of Biology and are open to science technicians in schools and colleges who have a total of 5 or more years’ experience (either full-time or part-time).

The aim of the Awards is to acknowledge publicly the contribution that science technicians make to the well-being and success of schools and colleges and, in particular, to science departments.

Headteachers or Heads of Science can nominate a technician using the methods outlined below and the closing date for nominations is 1 March 2011.

You can find further information and an online nomination form at www.salters.co.uk/institute/technicians_about.html. Alternatively, the Salters’ Publicity Co-ordinator can be contacted on 020 7628 5962 ext. 260 or at publicity@salters.co.uk

Laura Howes
Spotlight on Scotland

The Scottish Curriculum for Excellence has been announced and the RSC hosted an event at the Scottish Parliament, Laura Howes reports.

In November the Royal Society of Chemistry (RSC) hosted its annual Science and the Parliament event in Edinburgh, to bring together MSPs, civil servants and the scientific community. Over 300 delegates attended and Iain Gray MSP, leader of the Scottish Labour Party, led the event.

In his opening address Gray, who originally trained as a maths and physics teacher, assured the attendees that he believed that science education must be protected. He added ‘we need more science in our schools and further and higher education. We need more bursaries and scholarships to support the skills pipeline.’

In a panel question and answer session, several questions focused on education, although education spending is devolved to local councils. All the panel agreed that science teaching in schools needs to be supported, with Liam McArthur MSP saying ‘it’s a false economy to cut funds for practical teaching.’

It was suggested that secondary STEM teachers could be used in primary schools to help enthuse young children and that to ease the transition, a cross-curricular approach be taken for teaching STEM subjects at secondary schools.

Curriculum for excellence

One development that was welcomed by the attendees at the Scottish Parliament event was the introduction of the new Curriculum for Excellence (CIE), which was implemented for the 2010–11 academic year in Scotland.

This new school reform calls for a decentralised programme and encourages variation amongst schools and classrooms, however, this diversity has been criticised by the RSC with regard to the level of detail on the scientific knowledge and skills required at each stage ( Educ. Chem., 2009, 46, 103).

In 2009 the RSC, in partnership with the Royal Society of Edinburgh (RSE), launched a project to support teaching CIE. Funding chemistry teacher Shona Scheuerl, on a one-year, part-time secondment from Dollar Academy, the project was to develop examples of what chemistry will be taught in the new curriculum, and how it might be taught. This process is now complete.

The RSE and the RSC launched the materials at Craigmount High School in Edinburgh in October. All the materials including teachers’ guides, pupils’ guides and other relevant details can be found at http://www.rsc.org/InvestigateChemistry with web links to this from the Royal Society of Edinburgh, SSERC, LTS and GLOW. The Societies hope that this approach will encourage comparable initiatives in other areas of the curriculum.

chemlingo

Peter Childs, University of Limerick, investigates words in chemistry.

In this issue: As thick as treacle

Water is a liquid that flows easily and we say that it has a low viscosity and pours readily. Blood, on the other hand, is thicker than water and so does not flow as easily (although the proverb is about familial relationships not intermolecular bonding).

When a liquid is too thick, i.e. too viscous, we can thin it with ‘thinner’, using a different solvent of lower viscosity. Thus you can buy ‘paint thinners’, which are organic solvents used to thin solvent-based paints.

People with high blood pressure are often given drugs, like warfarin, to ‘thin’ the blood and thus lower the blood pressure. We also thicken soups and sauces using flour, turning a runny liquid into something as ‘thick as gravy’, where gluten acts as the active agent in thickening.

A number of common words are used to describe the thickness or thinness of a liquid. A liquid can be syrupy or treacly, meaning that it flows with difficulty and both words describe the behaviour of concentrated sugar solutions — syrup and treacle. One of the joys of eating porridge is to allow a spoonful of syrup to trickle lazily down from the spoon onto the porridge, tracing patterns on the surface. The milk does not behave like this because it has a low viscosity.

The word viscous comes from the Latin word viscum, which means something sticky, a word easily attached to treacle. Viscosity is measured in units called poise, named after the French scientist, Jean Louis Marie Poiseuille (1797–1869).

Some substances have the amazing property of changing their viscosity when shaken or stirred. This is known as thixotropy from Greek: thixi = touch and tropos = change ie it changes on stirring. This is now familiar from the gelatine-based sweet, the famous gummi bear.

So thick as treacle and thick as blood have similar meanings, but thick as a brick means something very different. Viscid is another word for viscous and both can mean thick or sticky. Muclilage originally meant a viscous liquid but was used to mean adhesive from 1839. Because of that, mucilaginous came to mean gluey.

Mucous membranes secrete mucus or phlegm, which are sticky, viscous fluids. A phlegmatic person is cool, dull, sluggish — phlegm being the one of the four humours that was associated with the described temperament.
Carbon’s noble matchmaker makes Nobel

Negishi, Suzuki and Heck were honoured for their pioneering work on palladium catalysis, David Bradley reports

**The 2010 Nobel Prize in Chemistry**

was awarded jointly to Richard Heck of the University of Delaware, Newark, Ei-ichi Negishi of Purdue University, West Lafayette, Indiana, USA, and Akira Suzuki of Hokkaido University, in Sapporo, Japan, for their pioneering work on palladium-catalysed cross-couplings in organic synthesis. This seemingly innocuous phrase belies the power of a process that allows chemists to join carbon atom to carbon atom and to quickly build complex organic molecules.

Carbon atoms are uniquely promiscuous in their ability to react with other elements giving rise to an incredibly diverse range of molecules throughout nature from the simplest methane to the proteins from which living things are composed and the nucleic acids that provide the genetic instructions for making those proteins. In between lie millions of natural products and synthetic compounds from ethanol and aspirin to chlorofluorocarbons and polyvinyl chloride. Carbon is the building block on which life on Earth is built and the building block of many of the materials on which we depend.

Despite the incredible molecular diversity of natural carbon compounds and the ability of chemists to build novel organic materials, carbon atoms are relatively stable entities and do not tend to react with each other. Forming carbon—carbon bonds with a view to building up a sophisticated organic chemical is a tricky process. Early efforts used methods to make carbon more reactive, which is perfect for building a small number of organic compounds, but that increased reactivity makes it difficult to produce sophisticated molecules with different functional groups because the reactivity takes the carbon atoms down different pathways leading to by-products and low yields of the desired substance.

Catalysts provide the answer by lowering the activation energy of a reaction and allowing otherwise stable chemicals to connect on a much shorter timescale than is otherwise possible. In the 1950s the German chemical company, Wacker Chemie AG, used the noble metal palladium as a catalyst to help it transform ethylene, a petrochemical feedstock material, into acetaldehyde, which is a precursor for plasticisers, acetic acid and many other useful chemicals.

The interest of Richard Heck was piqued by the notion of using palladium more widely. He began experimenting with different reaction conditions and his successful results culminated in a series of scientific papers published in 1968 in which he showed that it was relatively straightforward to link a ring of carbon atoms to a shorter fragment of carbons to make styrene, the monomer used to make polystyrene. The styrene synthesis was just one of several palladium-catalysed reactions, which became known generally as the Heck reaction, which share a common feature in creating single bonds between carbon atoms.

The Heck reaction involves the reaction of an unsaturated halide or trilate with an electron-deficient alkene (such as an acrylate ester or an acrylonitrile) and a base and the organopalladium catalyst (eg the catalyst can be tetrakis(triphenylphosphine)palladium(0), palladium chloride or palladium(II) acetate), to form a substituted alkene. Today, the Heck reaction is used to manufacture the anti-inflammatory drug naproxen, the asthma drug montelukast and the painkiller morphine.

In 1971, Japanese chemist Tsutomu Mizoroki extended Heck’s work and that of Shichiro Teranishi (1969) to coupling between iodobenzene and styrene to form stilbene. His research is recognised in the fact that the Heck reaction is often known as the Mizoroki–Heck reaction.

The second joint winner of this year’s Nobel chemistry prize is Purdue’s Ei-ichi Negishi. In 1977, he developed a variation on the well-known Grignard reagent. The Grignard reagent is based on magnesium and boosts carbon’s reactivity but is highly sensitive to water, even to the humidity of the laboratory. Nevertheless, it is useful in some circumstances for coupling together carbon atoms. Negishi reasoned that a zinc-based version of the Grignard reagent would not be so sensitive to water but suffer from lowered carbon reactivity. This reduced reactivity could then be overcome by using it in conjunction with a palladium catalyst.

Two years on, Akira Suzuki turned to boron, which is the mildest activator for carbon coupling but is non-toxic – a major benefit for large-scale manufacture. Suzuki’s version of carbon–carbon coupling is, for instance, used in the commercial production of thousands of tonnes of the agricultural fungicide, Boscalid.

Palladium cross-coupling reactions developed by this year’s winners have been used in the syntheses of countless medicinal compounds, including the anticancer drug Taxol, originally identified in the bark of the Pacific yew tree, and the novel drug lead discodermolide, a toxin found in a Caribbean marine sponge, as well as plastics and many other materials. Researchers have even used the method to functionalise graphene, a carbon allotrope which earned its developers, this year’s Prize in Physics.
Friday scribble yields Nobel Prize

David Bradley on the strongest, thinnest material known to man

The 2010 Nobel Prize in Physics could have almost been awarded as the chemistry prize as it featured the fabrication and science of the uniquely fascinating carbon allotrope known as graphene. Nevertheless, Russian-born Andre Geim and Konstantin Novoselov, both currently working at the University of Manchester, this year share the physics glory for what the Nobel committee describes as ‘groundbreaking experiments regarding the two-dimensional material graphene.’ The Prize comes with a cash award of 10 million Swedish Kronor (almost £1 million).

Graphene can be thought of as a single sheet of the more familiar graphite (of pencil lead fame) where each carbon atom is bonded to three others in a flat, two-dimensional array, forming a network of hexagons resembling chicken wire. The sheets are so thin that 3 million piled on top of each other would be no more than one millimetre thick. Despite it being merely one atom thick, graphene is the strongest, thinnest material known. It has many bizarre and unexpected properties, for example even though it is transparent, graphene is so dense that not even helium gas atoms can pass through. Since its rediscovery in the mid-2000s, researchers have started making graphene transistors and other devices that might one day lead to computers that use arrays of molecules instead of silicon chips. The work by Geim and Novoselov on graphene is equally bizarre and unexpected. Geim explains that the pair discovered how to make graphene in a ‘fun Friday afternoon experiment’ where they used adhesive tape to peel off the top layer of carbon atoms from a pencil mark on a glass surface and, with repeated folding and peeling of the sticky tape, were able to whittle the deposit down to a layer one single atom thick. Of course, the fine details of this ‘cleavage’ technique and its implications for science were published in research papers with rather esoteric, yet intriguing, titles such as Electric Field Effect in Atomically Thin Carbon Films in the journal Science in October 2004 and Two-dimensional atomic crystals in Proceedings of the National Academy of Sciences in 2005.

The seemingly simple way in which graphene was made by Geim and Novoselov confirms what is, in hindsight, obvious: that fragments of graphene are formed every time graphite is abraded, such as when a pencil scribbles on a sheet of paper and leaves behind its visible residue. The idea of producing a monoatomic layer of carbon atoms was first posited back in the 1930s although at the time scientists assumed they would be too unstable to be fabricated. It wasn’t until the early 1960s that German chemist Hanns-Peter Boehm coined the name graphene by combining the root of graphite and the chemists’ suffix for alkenes, and synthesized single graphene sheets.

Given how relatively easy it is to make graphene today, researchers the world over are now working on possible applications in microelectronics, display technology, touch-screens, and quantum computing.

On learning that he was to be awarded the 2010 Physics Prize, Geim remarked, how ‘sometimes there are very simple experiments and very simple discoveries to be made using what is at hand.’ This is perhaps one simple discovery that might ultimately revolutionise technology in the coming years.

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Is caffeine safe?

Simon Cotton takes a look at those compounds that find themselves in the news or relate to our everyday lives. In this issue: caffeine

**IS CAFFEINE SAFE?**

Why do you ask?

**WELL, IT’S BEEN IN THE NEWS THAT A YOUNG MAN DIED FROM CAFFEINE POISONING**

Yes, a 23 year old from Mansfield took two spoonfuls of caffeine dissolved in an ‘energy drink’ and was soon unwell. He later died in hospital, where they measured his blood caffeine level as 251mg l⁻¹.

**AND THAT’S LETHAL?**

The coroner said it was 70 times more than usually obtained from a high energy caffeine drink. ‘Normal’ doses of caffeine are around 50–100mg per cup of tea or coffee. A lethal dose of caffeine is above five grams, which would correspond to rather a lot of cups.

**WHAT ABOUT AN ENERGY DRINK?**

The amount of caffeine in a 250ml can of cola is 25–35mg – less than a cup of tea. A can of Red Bull is said to contain about 80mg of caffeine, so this is safe but don’t overdo it. The real problems come with people taking solid caffeine and there have been fatalities with people consuming several whole packs of caffeine ‘energy tablets’, such as 100 x 100mg tablets and 400 x 50mg tablets.

**WHY DOES CAFFEINE GIVE ME A BUZZ?**

Caffeine has a similar structure to adenosine and thus binds to adenosine receptors in the body, this leads to increased dopamine and glutamate activity, and ultimately to more adrenalin production. Because of this, caffeine is an addictive drug – a cardiac stimulant with mild diuretic effects. It is not just humans who are affected by caffeine. NASA scientists tested the effects of a range of drugs on house spiders, finding that caffeine had the most effect upon them, their webs lacked patterns and consisted of relatively few, random threads.

**WHY DO PLANTS MAKE CAFFEINE ANYWAY?**

Caffeine is 1,3,7-trimethylxanthine; it is found especially in coffee, tea and the cola nut. These plants make it as a ‘secondary metabolite’ to protect themselves against insects; methylxanthines inhibit insect feeding and are also pesticides, as they inhibit phosphodiesterase activity.

**CAN YOU GET DECAF COFFEE PLANTS?**

At present, decaffeinated coffee is produced by using a solvent like supercritical CO₂ to dissolve the caffeine out of the beans (which can be then used to make ‘energy drinks’) … . When the coffee plant makes caffeine from xanthosine, key steps involve the introduction of methyl groups. Scientists have isolated the genes that encode for the N-methyltransferase enzymes and when they expressed these genes in tobacco plants, they found that the plants would make caffeine and repel the normal insect predators. Scientists are now engineering low-caffeine plants.
ARSENICAL WALLPAPER

In the November issue of Infochem (No. 125), mention was made of the unusually high arsenic content of Napoleon's hair. This could have arisen from a successful attempt to murder him, or from his self-medication with arsenic-containing patent medicines, or from the volatile products released from the pigment Scheele's Green (principally Cu(AsO₂)₂) used to colour the wallpaper in the house in which he was kept captive. Even at the time of his death in 1821 there was an unease that the use of arsenic in wallpaper decoration might be a health hazard. In 1815 the (then) famous chemist Leopold Gmelin warned of the danger and recommended banning the use of Scheele's Green in wallpaper.

The Italian chemist, Bartolomeo Gosio, in 1891, started a research project based on the premise that some inexplicable deaths (notably of children) could be attributed to volatile arsenic compounds released from such wallpaper.1 Using mashed potato, decomposing damp paper, or other substrates each laced with As₂O₃ (the precursor to the green pigment) he found that when he encouraged mould to grow on them, then indeed toxic vapours were produced. These contained trimethylarsine, (CH₃)₃As, but their extreme toxicity may have been due to the presence of additional volatile arsenic compounds.

Wall plaster was prepared for papering by first coating it with gelatine size, and the paper then applied using a paste made from flour and water. This combination of protein (from the size), carbohydrate (from the flour) and dampness was the ideal combination for the development of the arsine-producing fungus. Paradoxically the samples of wallpaper with the highest Scheele's Green coating were safer than those with the lower content. A very high arsenic content inhibits the production of the wallpaper producing fungus.

Lest it be thought that this form of poisoning is a 19th century phenomenon, the deaths of two children in a house in the Forest of Dean, in 1932, were attributed to this cause.

For readers wishing to explore this fascinating aspect of chemical toxicology, and the speculations concerning Napoleon's death, I recommend the book by John Emsley. Amazon presently has copies available for less than £6.00: a bargain!

Alan Dransfield, University of Derby

REFERENCES

EDUCATION GRANT SCHEME FOR SCHOOLS

For several years The Biological and Medicinal Chemistry Sector (BMCS), one of the RSC's interest groups, has offered a grant scheme to primary and secondary schools. The grants are targeted at activities that enthuse and inform students about chemistry during timetabled activities or during extracurricular Science Clubs. The membership of the BMCS has been delighted to fund programmes across the UK that have allowed teachers to provide an experience to their students that might otherwise not have been possible.

We are enthusiastic to continue this scheme throughout 2011 and wish to encourage chemistry teachers in schools, colleges and universities to apply for grants of between £500 and £1000 for curriculum enhancement, chemistry club and outreach activities. More details of the scheme can be found at http://www.rsc.org/ESG including a short application form and some case studies describing projects that we have supported in the past.

Jeremy Hinks (on behalf of the BMCS)

MARIE CURIE: A PASSION FOR SCIENCE

As a follow-up to the mention of the UNESCO International Year of Chemistry (IYC) in the last issue (Educ. Chem, 2010, 47(6), 166), may I point out that this year also marks the centenary of the 1911 Nobel Prize for Chemistry awarded to Marie Curie for the discovery of radium and polonium.

The RSC's Historical group and Radiochemistry group will this year be marking this as part of our contribution to the IYC. There will be a one-day meeting at the Chemistry Centre, Burlington House, London, on Friday March 18, 2011. The opening lecture will be by Dr Serge Plattard, Science and Technology Counsellor, French Embassy, on Marie Curie: a passion for science, action and people.

Bill Griffith, Secretary, Royal Society of Chemistry Historical Group

QUININE / MAUVEINE

The Magnificent Molecules article by Laura Howes (Infochem No.125) raises some interesting points about quinine. Because cinchona trees are the only economically practical source of quinine, ever since its isolation chemists have attempted to find a synthetic route.

One of the early unsuccessful quinine synthesis attempts had far reaching consequences for chemistry, industry and the world. In 1856 William Perkin approached the problem knowing the molecular formula of quinine, C₂₀H₂₄N₂O₂. Later (1896) he recalled the reasoning behind his method: He was “led by the then popular additive and subtractive method to the idea that it [quinine] might be formed from toluidine by first adding to its composition CH₂₂N by substituting ally for hydrogen, thus forming allyltoluidine, and then removing two hydrogen atoms and adding 2 atoms of oxygen, thus:”

2(C₁₀H₁₃N) + 3O  =  C₂₀H₂₄N₂O₂  +  H₂O

No quinine was formed, but only a reddish-brown precipitate. So he tried a simpler base (aniline) which gave, on reaction with potassium dichromate, a black precipitate which contained a purple matter now known as mauveine. This was the first coal-tar or aniline dye. By the end of the 19th century most natural dyes had been replaced by synthetic ones and the seeds of a huge pharmaceutical industry sown.

Perkin’s success with mauveine was, remarkably, only viable because he used impure aniline. In the 1850s, the distillation of coal tar gave a low boiling fraction containing benzene and toluene. Nitration of this mixture, followed by reduction, gave a mixture of aniline, o- and p-toluidine, all three being essential for the production of mauveine – on their own, each pure component gives no dye. Had the separation of benzene and toluene from coal tar coal be been as efficient as the separation of quinine from cinchona bark, the history of the chemical industry might have been quite different.

Chris Cooksey, Watford
INTEGRATING INQUIRY INTO TEACHING

It is not uncommon to find chemistry teachers sticking to traditional methods of instruction that involve a considerable amount of teacher talk and directed instruction. Teachers are often wary of changing their role from instructor to a person who guides students through a scientific inquiry. A guided inquiry, or problem-solving, approach starts with a question and expects the students to determine the procedures that will lead to a solution. While there has been several studies looking at successful inquiry teaching they have looked at individual episodes rather than examining how the teacher makes the transitions into and out of the inquiries. Dennis Smithenry of Elmhurst College, Illinois, US has filled this gap by studying the work of one teacher over a year.1

This experienced chemistry teacher had been using an inquiry-based approach for a number of years built into the set curriculum for 16-17 year olds who were science specialists. Data were gathered through direct observations, video recording and through the teacher's own log of the duration of the various activities that occurred during every lesson. The time spent on activities was compared with data gathered in previous research on methods used by US teachers and showed that the teacher spent much less time on lecture and discussion and much more time on laboratory work, some of which was structured by the teacher and some of which required the students to devise appropriate procedures. Compared with the US average, the teacher spent marginally more time on group work and approximately the same amount of time on assessment and other activities. During the teaching of all topics the teacher ensured that students experienced several teacher-directed tasks, a set of structured inquiries and one multi-lesson guided inquiry.

As the year went on more time was devoted to guided inquiry. These sessions were carried out in 4 clearly defined steps. First the teacher introduced the design concept and skills and then explained the problem to be solved. At this point control was handed over to the students and they had to apply the concepts and skills to solve the problem as a whole class. The final step involved the students reflecting on their performance and the teacher giving feedback and appraising the achievement of the learning outcomes.

The approach did not reduce the time to cover the curriculum content, it simply changed it from being more teacher focused to being more student focused where the students' voice dominated the discussion, not the teacher.

REFERENCE


ENTHUSIASM FOR SCIENCE

There have been several reports on the decline in students' attitudes towards science in secondary schools but attitudinal research in the primary sector is rather limited. In order to gain a greater understanding of what happens in primary schools Sarah Turner of Loughborough University and Genn Ireson of Nottingham Trent University have carried out an investigation of pupils' views of science.1 They looked at two age groups, Year 2 and Year 6 and used questionnaires and interviews with Year 2 and questionnaires and observations with Year 6. Two schools were involved with a total of 44 Year 2 children and approximately 100 Year 6 children.

The Year 2 children had a good knowledge of scientists and what they do. They didn't hold stereotypical views of what a scientist looks like, only that they must be very clever and able to do complicated things. The children were keen to be like scientists as well as to repeat experiments and learn new scientific skills.

The Year 6 children completed an attitude questionnaire at the start and at the end of the academic year which showed little change over the time. They showed a positive attitude towards scientific inquiry but, unlike the Year 2 children, they showed little interest in undertaking scientific activities outside school and were not interested in following a scientific career.

The study shows that children's attitudes are mainly set at an early age in primary school and some may enter secondary school with quite strong negative feelings towards science.

REFERENCE


REVISITING INFORMATION PROCESSING

The model of information processing in science proposed by Alex Johnstone in 1997 has frequently been used as a basis for discussing the effectiveness of different methods of teaching. According to the model, successful learning requires an effective perception filter to select relevant information, a working memory for processing information, and a long-term memory for storing and for concept development. Helen St. Clair-Thompson, Tina Overton and Chris Botton of Hull University have revisited the model1 and looked at how recent research has helped us to have a greater insight into the learning process.

In terms of the perception filter, two distinct groups have been identified in terms of how they select what is relevant for a task. Those who are good at this are labelled as field independent, and those who struggle to select appropriate information are labelled as field dependent. Research has shown that students who are field independent are better at problem solving and perform better in assessments.

Another factor that relates to perception is selective attention. It is recommended that teachers use a variety of methods to capture students' attention, eg vocal variations, facial expressions, movement and gestures. Working memory has a limited capacity that can be increased by organising material into meaningful “chunks”.

Capacity can also be increased by using visual images and repetitive experiences with incremental complexity.

One of the most commonly accepted theories associated with long-term memory is that knowledge is stored in schemas – mental representations that help us store and simplify information. Useful strategies for improving long-term memory include helping students to organise information and encouraging them to regulate their own learning and experiment with self-explanations.

Concept mapping or mind mapping are useful ways to help students organise knowledge.

The research highlights the importance of teaching students strategies of learning rather than assuming that they will develop these themselves.

REFERENCE

EXHIBITION CHEMISTRY

SPECTACULAR DEMONSTRATIONS FOR TEACHERS

DEMONSTRATIONS TO CAPTURE THE STUDENTS’ IMAGINATION, BY ADRIAN GUY OF BLUNDELL’S SCHOOL.

IN THIS ISSUE: THE THERMITE REACTION

The thermite reaction, otherwise known as the Goldschmidt reaction, is a spectacular, highly exothermic reaction. Industrially, it can be used for welding railway lines. The exothermic nature and extreme temperature generated, combined with the molten iron, make this reaction attractive to the military for incendiary devices, hand grenades, and also as a reasonably quiet means of disabling artillery by the blocking or damaging of barrels.

Also, a school favourite, the thermite reaction is guaranteed to impress – regardless of age – as the redox reaction between iron(III) oxide and aluminium produces a spectacular pyrotechnic effect and a molten ball of iron.

**Kit:**
- 12g of iron(III) oxide;
- 4g of aluminium powder;
- 0.2g of magnesium powder;
- 1.7g of barium peroxide;
- 10cm piece of magnesium ribbon;
- 1 litre beaker filled with sand to 10cm;
- 1.7g of barium peroxide; 0.2g of magnesium powder; 4g of aluminium powder; 12g of iron(III) oxide;
- 10cm piece of magnesium ribbon;
- 1 litre beaker filled with sand to 200ml and water to 800ml;
- pipe clay triangle;
- fluted filter paper;
- tripod;
- safety screens;
- heat resistant mats;
- heat resistant gloves.

**Procedure**

**Thermite mixture:**
For best results, use dry iron(III) oxide.
To prepare a dry sample, heat iron(III) oxide in a crucible over a roaring Bunsen for a couple of hours. Leave to cool in a desiccator before weighing out 12g into a beaker. Add 4g of aluminium powder and mix by pouring repeatedly from one piece of paper to another. Do NOT mix with a metal spatula or similar. Place the mixture in a sealed specimen jar.

**Ignition mixture:**
Mix 1.7g of barium peroxide with 0.2g of magnesium powder. Place the mixture in a sealed sample tube.

**Collection vessel:**
Place several heat resistant mats on a 200ml and water to 800ml mark on a 1 litre beaker – this prevents the molten lump of iron breaking the glass beaker. Make up to the 800ml mark with cold water.

**The thermite reaction is spectacular and highly exothermic**

**Safety**

The ejection of molten lumps of very hot metal is the primary concern here. Safety screens must be used, with heat resistant mats to protect the bench. Pupils, wearing safety glasses, must be over 5m away. A high ceiling is also required. For the demonstrator a full face shield is advised and, after ignition of the magnesium ribbon, one must retreat behind a safety screen at least 5m.

Barium peroxide is harmful by inhalation and ingestion of dust, and can produce explosive mixture with combustible materials which may ignite spontaneously if damp. Only add the ignition mixture when ready to use – do NOT store the ignition mixture or the thermite mixture.

Powdered aluminium and magnesium can burn vigorously if blown into a flame.

Dispose of unused mixtures as follows: thermite mixture, dissolve in 2M HCl; ignition mixture, dissolve in 1M H₂SO₄, filter off the precipitate and dispose of in refuse; a mixture which has failed to ignite should be dissolved in 2M HCl, then add MgSO₄ to form the precipitate, which can be disposed of in refuse; all other solutions can go down the drain, if roughly neutral (pH 6–10).

**Igniting the mixture:**
Working between two safety screens (one to protect the observers and one for the demonstrator), place a tripod over the 1 litre beaker and, using a pipe clay triangle, suspend a fluted filter paper above the beaker. Pour in the thermite mixture and make an indentation using the end of a small test tube. Using a pencil, wind the magnesium ribbon into a spiral to create a fuse. Place one end of the spiral in the indentation to act as a fuse and pour in the ignition mixture. Bend the exposed end of the fuse so that it is horizontal, then using a roaring Bunsen burner, ignite the end and stand well back.

**Special tips**
If you can darken the room with blinds, the pyrotechnic effect is more spectacular.

After the reaction, the red hot ball of iron will continue to glow in the water, causing the water in contact to boil – this makes quite a bit of noise.
After a minute or so, making sure to wear the heat-resistant gloves, carefully remove the iron nugget for the class to view.

**Teaching goals**

Fe₂O₃(s) + 2Al(l) → Al₂O₃(s) + 2Fe(l)

At Key Stage 3, the simple, balanced equation provides an excellent opportunity to introduce reduction/oxidation (redox) reactions in terms of the loss or gain of oxygen. At Key Stage 4, oxidation numbers can also be used to discuss the process in terms of loss or gain of electrons: Iron is reduced, gaining three electrons and decreasing in oxidation number by three, and aluminium is oxidised, losing three electrons per atom and so increasing in oxidation number by three.

You can also use thermodynamics to calculate the very negative value for ΔH°, and, as expected, a very positive value for ΔS°.
Really cheesy chemistry

Charles de Gaulle’s famous 1962 remark How can anyone govern a nation that has 246 different kinds of cheese? is a reminder of the sheer variety of gustatory experience provided by cheese, which has been made for over 4000 years. The discovery of cheese provided the ultimate long-life milk, a foodstuff containing a lot of protein and fat, a source of essential amino acids as well as vitamins and minerals (eg calcium). So why is stilton so different to cheddar and to camembert, and why does limburger smell of sweaty feet?

In short
- Cheese-making results in a complicated interlocking series of reactions, leading to a huge range of different aromas and tastes in ripened cheeses

Making the cheese
Most cheese is made from cow’s milk, which is usually pasteurised by brief heating (to 70°C), killing any undesirable bacteria, then cooled. Rennet and “starter” bacteria (usually from the Streptococci and Lactobacilli families) are added and the mixture digested for an hour or so at 30–40°C; the bacteria ferment lactose to form lactic acid, reducing the pH to a value circa 4.6 where enzymes such as chymosin (rennin) can coagulate the casein, the predominant protein in the milk, forming curds. The starter bacteria also fulfil other roles, including metabolising citric acid and helping to break down the protein. The warm curds are allowed to set for an hour or two before the liquid whey is separated from the curds by cutting the curds into small pieces. Cottage cheese is made from drained cheese curds, it is not aged.
not give a cheese a wholesome aroma, so the presence of other molecules is necessary. The fatty acids are the source of the methyl ketones that give ‘blue cheese’ notes, and also react with alcohols, especially ethanol, to afford a range of flavoursome esters. Proteolysis (Scheme 2) breaks down proteins like casein – first into peptides and then into amino acids. These contribute taste to cheese but more importantly undergo a wide range of transformations – decarboxylation, deamination, oxidation and reduction – again affording a whole range of short-chain volatiles.

Examples of transformations possible with valine are shown in Scheme 3. Breakdown of lactate and citrate (Scheme 4) produces important molecules like diacetyl (a ‘buttery’ taste), ethanal and ethanol.

Any ripened cheese contains a mixture of many volatile molecules, and the overall smell is due to that blend, though one particular type of odorant can occasionally be dominant, as in blue cheeses. In some cases (St. Nectaire, cantal, ragusano), cheeses have been found to contain terpene molecules derived from plants, consumed by cows on mountain pastures, which enrich the flavour.

Here are four types of cheese with distinctive odours, illustrating how the cheese smells arise.

Blue cheeses
Stilton, roquefort, gorgonzola and other blue cheeses have a distinctive aroma caused by certain methyl ketones (alkan-2-ones). 1

| Table 1 Breakdown products of major milk components. |
|----------------|----------------|----------------|
| Casein          | Milk fat        | Lactose        |
| Ammonia         | Carboxylic acids| Butane-2,3-dione|
| Ethanoic acid   | β-hydroxy acids | Ethanal        |
| Aldehydes       | β-keto acids    | Ethanoic acid  |
| Alcohols        | Methyl ketones  | Ethanol        |
| Carboxylic acids| Lactones        |                |
| Sulfur compounds|                |                |

Lipolysis (Scheme 1) yields carboxylic acids, the source of a range of smelly molecules. By themselves, carboxylic acids would not give a cheese a wholesome aroma, so the presence of other molecules is necessary. The fatty acids are the source of the methyl ketones that give ‘blue cheese’ notes, and also react with alcohols, especially ethanol, to afford a range of flavoursome esters. Proteolysis (Scheme 2) breaks down proteins like casein – first into peptides and then into amino acids. These contribute taste to cheese but more importantly undergo a wide range of transformations – decarboxylation, deamination, oxidation and reduction – again affording a whole range of short-chain volatiles.

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| Sulfur compounds|                |                |
2-one, and to a large degree nonan-2-one, are most often linked with blue cheese smell; pentan-2-one is usually described as fruity.

The alkanones originate in carboxylic acids, produced by the lipolysis of triglycerides (Scheme 1); the acids are then oxidised by the P. roqueforti, being oxidised to δ-hydroxyacids and to β-ketoacids, before decarboxylation to ketones which have one carbon atom fewer than the initial acid. Thus the even-carbon acids generally found in lipids form odd-carbon ketones. Short-chain C₂ to C₆ acids are rare in lipids, and repeated β-oxidation of the acids may be needed to generate these alkan-2-ones.

Heptan-2-one is the most abundant ketone in blue stilton, with significant amounts of butan-2-one and pentan-2-one; a comparison of roquefort with bleu d’auvergne and bleu des causses found heptan-2-one and nonan-2-one to be most abundant in the first two but pentan-2-one to be the most abundant in bleu des causses. Other compounds, including alcohols and esters, round out the flavours; thus in gorgonzola, heptan-2-one and nonan-2-one are key impact molecules, but 1-octen-3-ol, 2-heptanol, ethyl hexanoate and methylanisole are also important odorants.

Camembert
Lactate metabolism is vital in surface mould-ripened cheeses such as camembert and brie. Initial growth of microorganisms such as Geotrichum candidum on the cheese is soon followed by a surface mould of P. camemberti. This breaks down lactic acid (itself a breakdown product of lactose) to carbon dioxide and water. Removing the acid causes the pH of the surface to increase from ca. 4.6 to 7.

At this pH, calcium phosphate is insoluble, so it precipitates on the surface, setting up a concentration gradient that draws calcium phosphate away from the centre, and removing it from the casein micelles together. This is one process responsible for the softening of the centre of camembert as it ripens. Ripe camembert often smells of ammonia, produced by deamination of amino acids on the surface, but the smell of camembert is due to a number of compounds as several reactions are involved in its ripening, with 1-octen-3-ol, 1-octen-3-one, 3-methylbutanal, 2-undecanone, butane-2,3-dione, δ-decalactone, butanoic acid, 3-methylbutanoic acid, methional, dimethylsulphide and methanethiol as key contributors to its impact. 1-octen-3-one and 1-octen-3-one provide a mushroom note and are produced by the action of lipoxygenases in P. camemberti upon linoleic acid. Butane-2,3-dione (metabolism of citrate (Scheme 4)) gives a buttery effect. Thanks to Geotrichum candidum and P. camemberti, the sulfur-containing amino acid methionine undergoes catabolism in various ways (Scheme 5), forming several sulfur compounds which have a marked influence on the aroma of traditional camembert, imparting a flavour of garlic and...
these same carboxylic acids responsible for foot odour.

Interestingly, these acids also make limberger cheese an attractant for female Anopheles gambiae mosquitoes, so this cheese can be used as bait to trap them (Dutch scientists Bart Knols and Ruurd de Jong shared the 2006 Ig Nobel prize in Biology for this work).8

Other aroma molecules that contribute to the smell of limberger include methionine-derived methanethiol and methylthioacetate. CH3C(=O)SCH3.

Hard cheeses

Cheddar is the best-known cheese of this type in Britain, though there are many other familiar names throughout Europe, including cantal, parmesan and edam. In these cheeses, the ripening process is carried out evenly throughout the cheese by the starter bacteria, in a process occurring over many months. Various studies have identified over 100 different odorants in cheddar cheese, with ethanoic acid (sharp), butyric acid (sweaty, sweet), d-dodecalactone (coconut), methional (boiled potato), furaneol (caramel), homofuraneol (caramel) and butane-2,3-dione (buttery) believed to be important.

The acids are formed through lipolysis of casein, whilst the lactone 3-methylbutanoic and hexanoic acids, so that the surface rind develops the ‘sweaty feet’ aroma characteristic of limberger,7 which diffuses through the cheese.

The closely related Brevibacterium epidermidis is found on human skin, where it breaks down lipids, forming methanethiol is an important odorant and a source of Me2S, Me2S2, Me2S3 and other sulfur compounds. Methional is another important odorant found in many cheeses. Although by itself methional’s boiled potato smell is not particularly pleasant, in combination with other volatiles it is just one note of the cheese aroma of camembert and cheddar. It is rare that one molecule carries the smell of a particular cheese, but S-methylthiopropionate, CH3CH2C=O(SCH3), does indeed smell like camembert. Found in camembert made from raw milk, it probably results from reaction of the appropriate acyl-CoA (propionyl-CoA) and CH3SH.6

Limburger

Another quite distinctive aroma is that of limburger, a surface-ripened semi-soft cheese. In this cheese the drained and cut curds are rolled in salt and regularly brushed with a solution infused with B. linens. The brine prevents other bacteria from interfering and extensive lipolysis occurs, with enzymes degrading casein. This causes significant formation of several carboxylic acids including the volatile butanoic, methanethiol and methylthioacetate. CH3C(=O)SCH3.
fermentation brought about by the bacterium Propionibacterium freudenreichii converts lactate into ethanoate, propanoate and also gaseous carbon dioxide (Scheme 3). The CO₂ migrates through the cheese, accumulating and forming ‘eyes’ in the developing cheese.

3 lactate →
2 propanoate + 1 ethanoate + 1 carbon dioxide

Gruyère odorants¹³ also include butanoic, 2- and 3-methylbutanoic and phenylethanoic acids, methional and 2- and 3-methylbutanal. 3-methylbutanal supplies malty and nutty notes to several cheeses and is formed in the cheese from the amino acid leucine by catabolism. First the leucine undergoes transamination into a keto acid and then another enzyme catalyses the decarboxylation of the acid, forming the aldehyde.

Conclusion

Though flavour molecules are only derived from three types of starting material in cheese curds, cheese ripening involves a complicated interlocking series of reactions, leading to a huge range of different aromas and tastes in ripened cheeses.

FURTHER READING:-


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In short

- Stilboestrol was synthesised by Robinson and used widely to attempt to prevent miscarriages
- It left a devastating legacy, including a substantially higher risk of breast cancer, not just for those who took it, but for their children and grandchildren.

A sinister side to a synthetic sex hormone

The story of the discovery, synthesis and prescription of a synthetic hormone, and the effects on those who took it and their descendants.

A. T. Dronsfield, P. M. Ellis and A. S. Wilkinson

TALES OF THE ‘SEXUAL REVOLUTION’ of the 1960s might suggest that understanding of sex hormones is a relatively recent chapter in history. But this is wrong by at least 4000 years.

The ancient Sumerians practised castration in the 21st century BC, as did many subsequent civilisations. These societies valued eunuchs as royal servants and administrators because they were incapable of having children and so were thought unlikely to be tempted to seize power from their masters.

An understanding that female sexuality was similarly controlled by the presence or absence of key organs came much later but had profound implications for women’s ability to control their fertility. However, initial discoveries only hinted at sex hormones’ potential, and there was a disaster looming that still hangs over some thousands of women today. This is the story of that disaster.

In 1900 gynaecologist Emil Knauer confirmed that removing the ovaries from mammals after puberty inhibits oestrus, the periodic cycle of intense mating urge. Knauer also found that as re-implanting these removed organs elsewhere in the body restored oestrus, it seemed that chemical messengers from the ovaries might be crucial to mammalian sexuality.

Knauer’s results suggested that hormone replacement therapy might remedy menopausal disorders and a mixture of hormones extracted with ether from abattoir-sourced ovarian tissue was marketed from 1913 with variable benefits.1

For chemists the synthesis of female sex hormones was a worthwhile challenge. If they could isolate and identify the structure of the pure hormone(s), then the hormones (and their congeners) might be synthesised to produce more potent, and cheaper, drugs. The problem was that the natural hormones were present in such tiny amounts that isolating enough for classical chemical investigations was impossible.

Two breakthroughs in the 1920s and 1930s made progress possible. Edward Doisy examined vaginal smears from pre-pubertal mice and castrated female mice (or rats) under the microscope. When the animals were treated with a sex hormone, the cells of the smears showed changes associated with oestrus, providing a quick and relatively simple bioassay for these hormones.

The second breakthrough was by Selman Aschheim and Bernard Zondek, who used a similar pre-pubertal mouse model to devise a urine-based pregnancy test.1 They suggested that pregnancy might be associated with a change in the hormone profile of the urine. Indeed it was, and urine became a convenient source of female hormones, although this was soon superseded by mares’ urine, which...
was especially rich in these hormones – during pregnancy a mare would produce some 30g of sex hormones, about 10 times the human equivalent.

Now, with a ready supply of source material, structural studies could start. Most studies focused on oestrone, a ketonic metabolite of primary oestrogens that is also hormonally active. Its molecular formula, $C_{18}H_{22}O_2$, was consistent with a four-ring structure and pointed to a possible connection with the cholesterol-like molecules whose structure was being investigated intensively at the time.

The correct structure for cholesterol was announced in 1932 and in the same year two groups of workers proposed a structure for oestrone, although it took another three years to confirm it as correct.²

The observations show that (it) is capable when injected into castrated animals of inducing oestrus exactly similar to that obtained by the injection of oestrogens... There are grounds for hoping that substances of a much higher order of activity will be found before very long.³

The Doisy test was cheap and permitted rapid screening. Within a month Cook and Dodds reported that the potent carcinogen, 1,2-benzpyrene, showed oestrus-inducing activity. Dodds followed up this work, and in 1936 published a list of eight para-hydroxy-substituted aromatic species that showed oestrus-inducing activity. Di-(p-hydroxyphenyl) dimethyl methane (2) was typical and a dose of 100mg precipitated oestrus in a rat.⁴

However, 100mg corresponded to a “human equivalent dose” of about 17.5g, too large for therapeutic use.

In April the following year, Dodds reported that not only did stilbene derivatives (e.g. 3) show a 10-fold greater activity (allowing doses in rats of 10mg), but a species based on half a stilbene-like molecule showed an astonishing oestrus-inducing effect.

Just one microgram of $p$-propenylphenol (also known as anol, 4) seemed as effective as oestrone itself. Dodds enthused:

> It is as yet too early to discuss the... therapeutic application of this observation, but the fact that the potency is so high brings a new importance to the investigation of synthetic oestrogenic agents.⁵

And so it did, with researchers across the world attempting to replicate the work before launching off into their own investigations. Writing again in Nature, just nine weeks later, Dodds continues the story:

> ...Concerning the high oestrogenic activity of anol, we have received information from some workers who...
have confirmed our observations, and from some others who have been unable to demonstrate activity with doses very much greater than those described by ourselves.

Berlin chemist Walter Schoeller investigated this apparent paradox and found that when “active” anol was recrystallised from chloroform, the activity remained in the mother liquor, rather than in the crystals of anol that were precipitated. At this early stage Dodds was unable to identify the component in the liquor, but hazarded a guess that because anol polymerises with ease there was a possibility he had been working with a polymer of anol, and that this had been responsible for the results he reported two months earlier.

By the following January, Dodds had identified the mystery anol-derived compound as ‘di-anol’ (5), a dimeride of p-propenylphenol (4).6

The focus of the investigation then moved to Robert Robinson’s laboratories at Oxford. Robinson found even more potent relatives of Dodds’ di-anol and established their structural relationship to oestrone. 4,4’-Dihydroxy-o,β-diethylstilbene (6), was Robinson’s major discovery, which he named stilboestrol (also known as diethylstilboestrol, DES) and drew (Fig 1) to emphasise its connection to oestrone.7

To synthesise DES (Scheme 1), Robinson reacted anisaldehyde – a very cheap precursor – in a process that could be scaled up to give kilogram quantities. In contrast to most current drug research, but in accord with the policy of the Medical Research Council that funded his project, patents were not taken out on the compound or the process used to make it.

Because of the ready availability of cheap precursors and the lack of patent protection, DES was relatively cheap to make. As DES was active in microgram amounts, it comes as no surprise that from 1938 its therapeutic potential was investigated intensively. This research largely, but not exclusively, focused on ‘female’ complaints. A chronology of some of the applications is given in Table 1.8

Of all the treatments listed in Table 1, it was the use of DES for preventing miscarriage that was to have disastrous consequences. It was once thought that miscarriages might be caused by a deficiency of oestrogens. Using DES to reverse this seemed logical, and its use became widespread even before finally being approved by
the US Food and Drug Administration (FDA) in 1947.

Six years later the first trial of its effectiveness found that DES had no benefit over a placebo for preventing miscarriages, but it remained heavily promoted and widely used. Anxious parents, faced with a threatened miscarriage, perhaps felt that any approved (and thus presumptively safe) treatment was worth trying, even if its benefits were unclear.

A cloud on the horizon

However, all this changed with a 1971 report in the New England Journal of Medicine. Although the rare cancer cervicovaginal clear-cell adenocarcinoma was almost always confined to elderly women, this paper reported it occurring in eight girls and young women between the ages of 14–22. Crucially, at least seven of these women’s mothers had taken DES during pregnancy. Could this treatment have had: An adverse effect on the daughters of DES-treated mothers; and if it was, were the sons also at risk? Such reports alone do not prove a link, but they raise crucial questions. The next step was to match a large group of women who had taken DES during pregnancy with a similar sized group who had not, and to compare the outcomes. In 1978 just such a study was published, comparing 693 women who had taken DES with 668 controls. Thirty-two of the treated women had developed breast cancer, compared to 21 of the controls, almost a 50 per cent increase (somewhat higher than found in later larger studies). A 1995 literature review came to the conservative conclusion that:

Most evidence suggests that the increased risk for breast cancer among DES mothers is real but small, with less than a two-fold increased risk. The risk for no other cancer has been shown to be significantly elevated in DES mothers, but these risks have not been adequately explored.

Daughters of those who took stilboestrol during pregnancy are at higher risk of developing breast cancer

Daughters of those who took stilboestrol during pregnancy are at higher risk of developing breast cancer. Abnormalities of the reproductive system and fertility problems are relatively common among the daughters of women who took DES during pregnancy. These daughters also have a significantly higher risk of breast cancer, with two studies showing 90 per cent and 250 per cent increases in risk for individuals over 40 years of age.

The present recommendation is that daughters of women who took diethylstilboestrol during pregnancy should have lifelong screening and should probably avoid hormone-based contraceptive methods. Daughters also have a 40-fold increased risk of cervicovaginal clear-cell adenocarcinoma, but this is still a rare condition, so the individual risk is about 1 in 1000 for women under 35 years of age. There is concern that this risk may increase greatly when ‘DES daughters’ reach the age of about 70, the peak age of onset of adenocarcinoma in women who have not been exposed to DES.

Table 1 Uses of DES.

<table>
<thead>
<tr>
<th>Use</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approved for use in gonorrhoea vaginitis, menopausal symptoms and to suppress breast enlargement associated with lactation (1941)</td>
<td>Use in vaginitis discontinued with the advent of penicillin, from about 1946</td>
</tr>
<tr>
<td>Used to induce remission in metastatic prostate cancer (1941)</td>
<td>Sometimes combined with removal of the testes. Used widely until the 1980s and occasionally since then</td>
</tr>
<tr>
<td>Used as hormone replacement therapy to remedy oestrogen deficiency eg associated with hysterectomy (late 1940s)</td>
<td>Use continued until the late 1980s</td>
</tr>
<tr>
<td>Used in high doses to prevent miscarriages in women who had a history of miscarriages (1947)</td>
<td>Still being prescribed until the late 1960s, despite a 1953 double-blind trial showing it was ineffective for this purpose</td>
</tr>
<tr>
<td>Licensed in the USA as an oral supplement to enhance weight gain in cattle (1953) and also used to cauponise poultry</td>
<td>Use banned in 1979</td>
</tr>
<tr>
<td>Used in the treatment of breast cancer, especially for post-menopausal women (1960)</td>
<td>First tried in 1944 with poor results, but later became the most popular hormonal treatment for this disease. Supplanted by tamoxifen in the late 1970s</td>
</tr>
<tr>
<td>Used in high doses as an emergency contraceptive (1971)</td>
<td>Prescribed at 10mg per day over a five-day period. Use discontinued when risks of DES therapy became known</td>
</tr>
<tr>
<td>Used to control incontinence in spayed female dogs</td>
<td>Still currently used. Daily dose of 1mg per 20lb body weight</td>
</tr>
</tbody>
</table>
And the sons?  
For ‘DES sons’ the health statistics are less definitive and earlier concerns about higher rates of testicular cancer in DES-exposed sons are currently disputed. At present there is no connection between maternal DES exposure and prostate cancer in the sons but women who had DES therapy in the 1940s and 50s now have sons in their seventies and sixties – the age range associated with prostate cancer. It will be important to see if the DES sons show an increased susceptibility to this disease. However, a 1995 study found that the sons of DES daughters had a higher rate of malformation of their penis – in which the urethra ends on the lower surface of the penis rather than at the tip – with rates about five times that of the general population.

The mechanism by which DES could cause effects on a third generation, who had never been directly exposed to DES, is puzzling. It is probably not genetic – the sons of men exposed to DES in utero do not have a greater risk of this genital malformation than the general population, unlike the sons of mothers who were exposed. Perhaps the changes in the reproductive systems of DES daughters lead to the changes, or perhaps there are enduring changes in hormonal systems that affect some developing boys. Some animal studies suggest there may be some epigenetic changes involved, but the situation remains unclear.

However, the concept that a drug given to one person can have a major effect on their future grandchildren is a terrifying prospect for drug developers, doctors and regulatory agencies. Many modern drugs come and go within 20 years or less, and DES was essentially gone within 40 years. The idea that important side effects may not be evident until a generation later raises major challenges. Animal studies offer one way of screening for generational effects, but when the particular issue is both rare and (at the time) unknown, it can very easily be missed, or just not occur in that relatively small number of animals.

DES had the potential to be a horrendous human tragedy that would have eclipsed even the thalidomide disaster. It remains a disaster for those who have developed cancer, and a significant challenge for those facing lifelong monitoring.

Some five million American women – and millions around the world – took DES and approximately 5000 daughters in the US can expect to develop related adenocarcinomas. But it could have been far worse, had the initial observations on the eight young women not been followed up.

Medicine safety relies on acute observation and systematic investigation of ‘signals’ of potential concern. At present, it offers the main defence against another DES disaster, though improving understanding of drug effects and genetic influences will complement this in the future.

REFERENCES

Edward Charles Dodds – a brief biography
Edward Charles Dodds was born in 1899 and entered the Middlesex Hospital Medical School in 1916. In his first year he won the class prize for chemistry and graduated as a doctor in 1921. In the same year, at the age of 22, he was appointed lecturer in biochemistry at the same institution. Just three years later he was appointed to a chair in biochemistry and was the youngest professor in the University of London. He began his work on the synthetic oestrogens in 1932 and 10 years later was made a Fellow of the Royal Society. He was adept at supporting young researchers in immunopathology, steroid chemistry, cytotoxicology and the work that led to the discovery of aldosterone, while pursuing his own work into the problems of cancer and rheumatism. Outside his academic studies he was a devotee of motor racing and for some years drove as an amateur at the Brooklands racing circuit. He was knighted in 1954 and died in 1973.

Pete Ellis is professor of psychological medicine at the School of Medicine and Health Sciences, University of Otago, Wellington, New Zealand. Alan Dronsfield is emeritus professor of the history of science at the University of Derby. Alan-Shaun Wilkinson is a senior lecturer in the department of education, health and sciences at the University of Derby.
In short

● The Global Experiment has been designed for use across a range of educational settings worldwide.

● Students will discover the power of chemistry to provide reliable information and data within our society.

In 2011, the International Year of Chemistry, school students around the world will be invited to explore one of Earth’s most critical resources, water. The results of their investigations will contribute to a Global Experiment, which will possibly become the biggest chemistry experiment ever. The global experiment – an initiative of the IUPAC Committee on Chemistry Education – has been developed to appeal to students from primary school to senior high school. The activities that make up the experiment will help students appreciate the role of chemistry in issues of water quality and purification. At the same time, students will contribute to an online global map, reporting on their investigations of water quality and water treatment.

The Global Experiment directly addresses the IYC goal of increasing the public appreciation and understanding of chemistry in meeting world needs and encouraging interest in chemistry among young people. The central theme of the experiment will be Water: A Chemical Solution. This will provide an outstanding educational opportunity to learn about the key role of chemistry in providing clean, safe water and the challenge of meeting the Millennium Development Goal of greatly improving access to safe drinking water before 2015. This activity will be used to emphasise the close relationships between water and climate change, human health, and energy security.

The theme for the global experiment project – Water: A Chemical Solution – implies the dual meaning of solution. Firstly, solutions are the answers that chemistry can provide to questions about delivering safe water to people all over the world. Secondly, in the chemical sense, the term is helpful for introducing important chemical principles such as pH, salinity and solubility.

In the global experiment, teachers will involve classes of students in the investigation. Consider for a moment how many students might participate...
The activities
The activities that make up the experiment have been designed to require minimal equipment and resources, but at the same time, allow increasing levels of sophistication. Four activities, which are being tested, have been developed to examine local water sources:

- Two activities related to water treatment involve purification by filtration and evaporation. The filtration activity will investigate local water treatment methods and results will be reported on a global map. This activity can be elaborated to investigate disinfection.

- The other two activities will involve tests relating to water quality, namely measuring acidity and salinity. The measurements also will be reported on a global map.

These activities have been designed to be used as a stand-alone experiment for classes that want to participate in the event, or to be built into an existing water-related curriculum unit. Many science or environmental units in existing school curricula involve more extensive measurements of water quality and treatment and will require, at the most, minor adjustments to include reporting for the global maps. The resources provided can simply be added to those already used in the school. In the other cases, the resource materials will provide detailed procedures and background knowledge to allow teachers at each level of schooling to implement them with their class and enjoy the reporting of results to the global maps as a culminating event.

Dissemination
The Global Experiment is generating interest among a wide variety of organisations in science and in education. Collaboration and support will be critical for the dissemination and implementation of the experiment:

- National adhering organisations affiliated with IUPAC or UNESCO will be invited to join in the process of distributing information and resources associated with the Global Experiment. Their collaboration will be acknowledged on the Global Maps and they will be able to draw on the results of the experiment for their own use.

- Active partnerships with national and transnational organisations, both chemical and educational, are being explored and arranged to help the process of developing the infrastructure for the experiment and its dissemination. Organisations such as the European Chemical Industry Council, CEFIC and the American Chemistry Council are providing direct support. The European Schoolnet is providing support and expertise in both development and implementation through its European members and international associates.

- Partnerships with organisations specifically focused on water issues (e.g. the organisers of World Water Monitoring Day, the Water Environment Federation and the International Water Association) are being discussed.

Dissemination of the experiment to countries that do not have affiliated organisations will be carried out through invitations to national education authorities and by direct communication via the Internet. The resources for the experiment will be placed on the Global Experiment website along with a link for teachers to register their school or class. This will limit the volume of conventional mail required for schools without internet access.

Sponsorship is being sought for kits that would be distributed to areas in which schools have few science resources. The kits will contain sufficient materials for the students to participate in the event and will require, at the most, minor adjustments to include reporting for the global maps.

The experiment
The Global Experiment will be launched early in the International Year of Chemistry. A dedicated website will be open for data submission at that time and will
remain available through the culminating event. The experiment is being developed as a stand-alone student investigation that will mesh with material that many schools already cover around the topic of water. The experiment will offer a range of participation levels.

It is expected that most teachers will work with their classes to carry out the four activities, which will have explicit instructions and background materials. These will be helpful for teachers who don’t have science backgrounds. In their current round of testing, the activities give students the opportunity to learn about two ways in which chemistry contributes to our understanding of water quality and water treatment.

The activities cover important topics and conceptual understanding in science and also provide a variety of opportunities to learn important experimental and data gathering skills.

- **Acidity**: Students will use colourful indicators, either from their school's supplies, or from the resource kit, to measure the pH of their local body of water. They will be learning about acidity, one of the most common chemical properties encountered around the home. At the same time, they will be learning good experimental techniques to test the reliability of their results. Combining the results for the class will provide a robust result that can be recorded on the Global Map.

- **Salinity**: The salinity activity will give students the opportunity to use either a homemade or commercial meter to measure the conductivity of water samples. Students will learn about salts and determine concentrations of salts in solutions.

- **Filtration**: In the filtration activity students will use household materials to build a water filtration unit and identify the efficiency of different filtration materials. Then, as a follow-up, they will carry out a treatment of the water. In addition, they will research the methods of their local water treatment plant and report the results of their research to the Global Experiment website.

- **Solar Still**: Students will explore an alternative way of purifying water using a solar still, learning about the distillation process and the states of matter. The activity will provide students with the opportunity to design and build their own more efficient stills.

Alternatively, teachers can select to undertake a single activity if they want their students to collect some data and contribute to the Global Experiment without using the other activities, perhaps because water is studied at a different year level. If, on the other hand, an existing curriculum unit studying water is part of the curriculum during 2011, appropriate parts of the Global Experiment activities can be added selectively to the existing curriculum and give students the chance to participate in the experiment.

### In the classroom

The Global Experiment has been designed for use across a range of educational settings. Each of the activities comes with resources to help teachers implement the activities at the level of sophistication appropriate for their classes. For example, the acidity activity, with the working title of measuring the pH of the Planet, has been written for three levels of students:

- In the middle or upper primary school, students are introduced to acidity as a concept related to experiences they have had in the home. They learn about pH simply as a number associated with acidity. In an ancillary activity, teachers are encouraged to explore acidity with their students using home-made red cabbage indicators.

- In the junior high school where students are learning about ions and simple chemical formulae, they learn to associate acidity with hydrogen ions and the strength of acids.

- In senior high school they learn about the logarithmic relationship between hydrogen (or hydronium) ions and pH. At the same time, they extend their measurements of pH with pH meters if they are available in the school.

### The website

The interactive Global Experiment website will be the central source of information both for schools and for other interested groups. The site will...
The Global Experiment Task Group

So far, the task group for the Global Experiment includes folks from fields, sectors, and regions far and wide, demonstrating the wide interest and global reach of the project:

- Franco Bisegra, Claudine Drossart and Madeleine Laffont, CEFC
- Mark Cesa, INEOS, USA and IUPAC Organic and Biomolecular Chemistry Division and IUPAC Committee on Chemistry and Industry (COCI)
- Robert Bowles and Richard Porte, RSC
- John Bradley and Erica Steenberg, University of the Witwatersrand, Johannesburg, and CCE Microchem project
- Filomena Camões, University of Lisbon and IUPAC Analytical Chemistry Division
- Johanna Coleman and Jacqueline Halden, BASF
- Javier García-Martínez, University of Alicante, IUPAC Inorganic Chemistry Division and IUPAC Committee on Chemistry Education (CCE)
- Julia Hasler, Magalie Lebreton and Rovani Sigamoney, UNESCO
- Colin Humphris, IUPAC Bureau and IYC Management Committee
- Alexa Joyce, SchoolNet
- Masahiro Kamata, Tokyo Gakugei University
- Frances Laucraft, International Water Association
- Mary Ostrovski and Ben Zingman, American Chemistry Council
- Cristiane Reiners, Universität zu Köln and CCE
- Lida Schoen, CCE and the Young Ambassadors for Chemistry program
- Tony Wright, The University of Queensland, Australia and CCE
- Julia Hasler, Magalie Lebreton and Rovani Sigamoney, UNESCO
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- Tony Wright, The University of Queensland, Australia and CCE

be the sole portal for reporting data from the experiments. Resources being developed for the project include the following:

- A toolkit for schools containing the necessary materials for carrying out the activities. These materials will be available for downloading and will include a teacher guide, activity protocols, suggestions for how the activities could be integrated into the curriculum and guidance on how and where to order special equipment. Logos and branding materials are being developed for publicising the experiment within schools and in the wider community.
- A registration site for schools where teachers can register their interest in the project and sign up their school to the activities.
- A mapping tool that will display the global data as it is submitted and also display school information, including a Google map of schools taking part in the experiment.
- School co-ordination tools that will facilitate collaboration and data submission and may include file archives, an internal messaging system and chat groups and forums. The possibility of students being invited into this space for debates and/or chats with experts is being explored.

For up to date information, and to take part in the Global Experiment, visit www.rsc.org/globalexperiment

Web watch

Tony Tooth, a Chemistry teacher at The King’s School in Ely, looks at some websites that may be of interest to chemistry teachers. In this issue: Water, nanoscience and organic synthesis.

PHILIP BALL
http://www.philipball.co.uk/
I have been a fan of Philip Ball’s science writing since my father gave me a copy of H₂O: A biography of water as a Christmas present some years ago; I can thoroughly recommend it, and frequently do so to my students.

Philip’s website promotes his writing and there are links to reviews of all his books as well as to his blog. The most recent blog entry reproduces his Crucible column from Chemistry World, wherein he muses on whether or not the periodic table has an end and the significance of the number 137?

At the top of every page there are links to areas such as Water and Nanoscience where you can find further links to the text of various articles. One such is the extended text of an article that appeared in Agenda, a book on water published by Hoffmann & Campe in 2002, and gives a very good flavour of the book if you want to ‘try before you buy’.

SYNTHESIS EXPLORER
http://synthesistoolbox.rsc.org/
Launching the Synthesis Explorer from the home page reveals a screen where the first decision to be made is whether to work at AS or A2 level; the difference being the number of families available in the drop-down lists.

Once a family of compounds has been chosen then specific compounds become available in a second drop down list and can be added to the ‘canvas’. If a compound is added for which a direct conversion to or from another compound on the canvas is possible then labelled linking arrows automatically appear.

For example, choosing bromoethane and ethanol creates a pair of boxes linked by an arrow from bromoethane to ethanol labelled ‘nucleophilic substitution’ and an arrow in reverse labelled ‘substitution’. Holding the cursor over a label reveals a word equation at the top of the screen with reagents and conditions.

Boxes can easily be moved round the screen or deleted and there is a button at the bottom of the screen labelled show structural formula that actually reveals full displayed formulae for any compounds on the canvas. In addition, data boxes on the right of the screen give access to information such as physical properties, uses, different versions of the structure such as skeletal formulae and rotatable 3D images as well as NMR, IR and mass spectra.

With a little practice on the part of a teacher this could be an excellent teaching resource, especially during revision or delivery of the AQA Unit Four Topic on structure determination, or, once prompted, students could make very good use of it for revision as not all of the information is revealed in one go, which makes it ideal for self-testing.

The instructions and quick tips tab uses screenshots to make the instructions crystal clear and there is even a curriculum links tab that allows one to view interactive reaction pathway screens specific to each of the main A-level syllabuses.

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Entropy – a masterclass

The concept of entropy might seem abstract, but can be illustrated by a statistical interpretation.

Peter Atkins

The classical definition

The classical thermodynamic definition of entropy is given in terms of the energy transferred reversibly as heat, $dq_{rev}$, to a system at a thermodynamic temperature $T$:

$$dS = \frac{dq_{rev}}{T} \quad (1)$$

This definition refers to an infinitesimal change in entropy arising from an infinitesimal transfer of energy as heat. For an observable change that takes a system from an initial state $i$ to a final state $f$, we add together (integrate) all such changes, allowing for the temperature to be different in each infinitesimal step:

$$\Delta S = \int_i^f \frac{dq_{rev}}{T} \quad (2)$$

If the change is isothermal (that is, with the system maintained at constant temperature; in practice, commonly by it being immersed in a water bath), then $T$ may be taken outside the integral and (2) becomes

$$\Delta S = \frac{1}{T} \int_i^f dq_{rev} = \frac{q_{rev}}{T} \quad (3)$$

where $q_{rev}$ is the total energy transferred reversibly during the change of state. With energy (and, by implication, heat) in joules (J) and temperature in kelvins (K), the units of entropy are joules per kelvin (J K$^{-1}$).

Entropy is a state function; that is, it has a value that depends only upon the current state of the system and is independent of how that state was prepared. It is far from obvious that the definition in (1) implies that $S$ is a state function, or equivalently that $dS$ is an exact differential (one with a definite integral that is independent of the path of integration). It is commonly demonstrated that $S$ is indeed a state function by using the Carnot cycle, as explained in textbooks.

In short

● Numbers can be attached to disorder, rendering a qualitative concept quantitative.

$\Delta S$ represents a reversible transfer of energy as heat. A reversible process is one that changes direction when an external variable, such as pressure or temperature, is changed by an infinitesimal amount. In a reversible process, the system and its surroundings are in equilibrium. In a reversible expansion, the external pressure is matched to the changing...
The natural direction of change is from order to disorder. Both energy and matter tend to disperse in disorder.

The second law

The Kelvin statement of the second law states that no heat engine works without a heat sink. The Clausius statement states that energy does not tend to migrate as heat from a cooler to a hotter body. The two statements are logically equivalent.

Typically kJ mol⁻¹), so an entropy of transition has the units joules per kelvin per mole (J K⁻¹ mol⁻¹).

In the first expression, \( n \) is the amount of gas molecules (units: mol) and \( R \) is the gas constant (units: J K⁻¹ mol⁻¹), which is defined in terms of Boltzmann’s constant \( k \) (units: J K⁻¹) and Avogadro’s constant \( N_A \) (units: mol⁻¹) by \( R = N_A k \).

The second expression the heat capacity \( C \) may be expressed in terms of the molar heat capacity, \( C_m \), by the expression at the transition temperature, \( T_{tr} \):

\[ \Delta S_{tr} = S(T_{tr}) - S(T) \]

\[ \Delta S_{tr} = n R \ln \left( \frac{V_f}{V_i} \right) \quad (4a) \]

\[ \Delta S = C \ln \left( \frac{T_f}{T_i} \right) \quad (4b) \]

\[ \Delta S = \frac{nC_m H(T_{tr})}{T_{tr}} \quad (4c) \]

In the third expression, note the modern location of the subscript denoting the type of transition (\( \Delta_{sys} \), not \( \Delta X_{sys} \)). Moreover, the expression applies only to the change in entropy at the transition temperature, for only then is the transfer of energy as heat a reversible process. Enthalpies of transition, \( \Delta_{sys} H \), are molar quantities (units: J mol⁻¹), and

Typically kJ mol⁻¹), so an entropy of transition has the units joules per kelvin per mole (J K⁻¹ mol⁻¹).

The expressions in (4) apply to the system. Because the surroundings are so huge and of infinite heat capacity, any change taking place in the system results in a transfer of energy as heat to the surroundings that is effectively reversible and isothermal. Therefore, the change in entropy of the surroundings \( \Delta S_{surr} \) is calculated from

\[ \Delta S_{surr} = \frac{Q_{surr}}{T_{surr}} \quad (5) \]

where \( Q_{surr} \) is the energy transferred as heat into the surroundings. Note that ‘rev’ no longer appears, so this expression applies regardless of the nature of the change in the system (it applies to both reversible and irreversible processes).

Absolute entropies

The third law of thermodynamics is an assertion about the unattainability of absolute zero, but it implies that the entropies of all pure, perfectly crystalline substances are the same at \( T = 0 \). It is then convenient (‘convenient’ in the absence of further information) to take that common value to be zero: \( S(0) = 0 \). The so-called ‘absolute entropy’ of a substance at any temperature, \( S(T) \), is then determined by measuring the heat capacity of a sample from as close to \( T = 0 \) as possible and up to the temperature of interest, and then using (2) in the form:

\[ S(T) = S(0) + \int_0^T \frac{C(T)}{T} \, dT = \int_0^T \frac{C(T)}{T} \, dT \quad (6) \]

Various ways of extrapolating \( C(T) \) to \( T = 0 \) are available. If phase transitions occur before, ie below the temperature of interest, then (4c) is used and added to this expression.

Tables of data commonly report ‘standard molar entropies’, \( S_m^\circ(T) \), at a stated temperature. The standard molar entropy of a substance is its molar entropy (units: J K⁻¹ mol⁻¹) when it is in its standard state at the specified temperature. The ‘standard state’ is the state for the pure substance at 1 atm (1 bar = 10⁵ Pa). Note that the use of 1 atm in this context is obsolete. The temperature is not a part of the definition of standard state: a standard state can be ascribed to any specified temperature. The ‘conventional temperature’ for tabulating data is 298.15K; it is a common error to include this temperature as part of the definition of a standard state.

The second law

The second law of thermodynamics is a statement about the total entropy change, the sum of the changes in entropy of the system, \( \Delta S_{sys} \), and its surroundings: \( \Delta S_{sys} = \Delta S + \Delta S_{surr} \) (It is common to drop the subscript sys and we shall do so.) Although there

Typically kJ mol⁻¹), so an entropy of transition has the units joules per kelvin per mole (J K⁻¹ mol⁻¹).

The expressions in (4) apply to the system. Because the surroundings are so huge and of infinite heat capacity, any change taking place in the system results in a transfer of energy as heat to the surroundings that is effectively reversible and isothermal. Therefore, the change in entropy of the surroundings \( \Delta S_{surr} \) is calculated from

\[ \Delta S_{surr} = \frac{Q_{surr}}{T_{surr}} \quad (5) \]

where \( Q_{surr} \) is the energy transferred as heat into the surroundings. Note that ‘rev’ no longer appears, so this expression applies regardless of the nature of the change in the system (it applies to both reversible and irreversible processes).

Absolute entropies

The third law of thermodynamics is an assertion about the unattainability of absolute zero, but it implies that the entropies of all pure, perfectly crystalline substances are the same at \( T = 0 \). It is then convenient (‘convenient’ in the absence of further information) to take that common value to be zero: \( S(0) = 0 \). The so-called ‘absolute entropy’ of a substance at any temperature, \( S(T) \), is then determined by measuring the heat capacity of a sample from as close to \( T = 0 \) as possible and up to the temperature of interest, and then using (2) in the form:

\[ S(T) = S(0) + \int_0^T \frac{C(T)}{T} \, dT = \int_0^T \frac{C(T)}{T} \, dT \quad (6) \]

Various ways of extrapolating \( C(T) \) to \( T = 0 \) are available. If phase transitions occur before, ie below the temperature of interest, then (4c) is used and added to this expression.

Tables of data commonly report ‘standard molar entropies’, \( S_m^\circ(T) \), at a stated temperature. The standard molar entropy of a substance is its molar entropy (units: J K⁻¹ mol⁻¹) when it is in its standard state at the specified temperature. The ‘standard state’ is the state for the pure substance at 1 bar (1 bar = 10⁵ Pa). Note that the use of 1 atm in this context is obsolete. The temperature is not a part of the definition of standard state: a standard state can be ascribed to any specified temperature. The ‘conventional temperature’ for tabulating data is 298.15K; it is a common error to include this temperature as part of the definition of a standard state.

The second law

The second law of thermodynamics is a statement about the total entropy change, the sum of the changes in entropy of the system, \( \Delta S_{sys} \), and its surroundings: \( \Delta S_{sys} = \Delta S + \Delta S_{surr} \) (It is common to drop the subscript sys and we shall do so.) Although there
are several equivalent versions of the law, in terms of entropy a statement is:

The total entropy of an isolated system increases in any spontaneous change.

It is important to be precise about the meaning of ‘an isolated system’ in this statement. Here the isolated system consists of the actual system of interest (the ‘system’) and its surroundings. Such a composite system is isolated in the sense that there is no exchange of matter or energy with whatever lies outside it. In practice, the ‘isolated system’ of this statement might consist of a reaction vessel (the ‘system’) and a thermal bath (its surroundings). If the actual system of interest is itself isolated, in the sense that it does not exchange energy or matter with its surroundings, then the law applies to that system alone. In practice, such a system would consist of a sealed, thermally insulated reaction vessel.

A spontaneous change is one that has a tendency to occur without it being necessary to do work to bring it about. That is, for a spontaneous change in an isolated system, \( \Delta S_{\text{sys}}> 0 \). As is well known but commonly forgotten, it is essential to consider the total entropy change: in many cases the entropy of the system actually decreases or remains the same in a spontaneous change, but the entropy of the surroundings increases and is responsible for the spontaneity of the change.

There is space to give one example. When a perfect gas expands isothermally, its change in entropy is given by \( (4a) \), regardless of whether or not the expansion is reversible: entropy is a state function, so the same change in \( S \) takes place independently of the path. We must, of course, use a reversible path to calculate the change, but the value we obtain then applies however the process actually takes place. For the change in entropy of the surroundings, there is no such restriction and we can use \( (5) \) for any type of process, reversible or irreversible. If the expansion is free (against zero external pressure), no work is done, and the internal energy is unchanged, so no energy is transferred as heat to or from the surroundings. Therefore, according to \( (5) \), the entropy change of the surroundings is zero and the total entropy change is equal to that of the system alone. That change is positive when \( V_j > V_i \) (because \( \ln x > 0 \) when \( x > 1 \)) and so free expansion is accompanied by an increase in total entropy. On the other hand, if the expansion is reversible, then work is done, a compensating quantity of energy as heat enters the system from the surroundings, the entropy of the system rises, and overall the total change in entropy is zero.

**Gibbs energy**

Provided we are prepared to accept a constraint on the type of change we are considering, it is possible to avoid having to calculate two contributions to the change in total entropy. Thus, we introduce the Gibbs energy \( G = H - TS \), colloquially the ‘free energy’, which is defined solely in terms of the properties of the system. For a system at constant temperature, \( \Delta G = \Delta H - \Delta TS \). If, in addition, we also accept the condition of constant pressure, then it may be shown that \( \Delta G = -T \Delta S_{\text{stat}} \). Therefore, under these conditions, a spontaneous change is accompanied by a decrease in Gibbs energy of the system. Thus, if we are prepared to restrict our attention to processes at constant pressure and temperature, then we may perform all our calculations on the system. It should never be forgotten, however, that the criterion of spontaneous change in terms of the Gibbs energy is in fact a disguised form of the criterion in terms of the total entropy, and then subject to two constraints. The change in Helmholtz energy, \( \Delta A = \Delta U - T \Delta S \), is the analogue when the volume rather than the pressure is held constant.

**The statistical definition**

The statistical definition of entropy is given by Boltzmann’s formula:

\[
S = k \ln W \quad (7)
\]

where \( k \) is his constant and \( W \) is the weight of the most probable configuration of the system. Broadly speaking, the weight of a configuration is the number of distinguishable ways of distributing the molecules over the available states of the system, subject to the total energy having a specified value. That energy may, in general, be achieved with different configurations (all molecules in one state, for instance, or some in higher states and others in lower states, and so on). Boltzmann’s formula uses the value of \( W \) corresponding to the most probable distribution of molecules over the available states. Thus, suppose a system consists of \( N \) molecules, then the weight of a configuration in which \( N_j \) molecules occupy state 1, \( N_i \) molecules occupy state 2, and so on, is

\[
W = \frac{N!}{N_1!N_2!..} \quad (8)
\]

The value of \( W \) changes as the values of the \( N_i \) are changed. However, the \( N_i \) cannot all be changed arbitrarily because the total number of molecules (the sum of the \( N_i \) ) is constant and the total energy (which is the sum of \( N_i E_i \), where \( E \) is the energy of state \( i \)) is also constant. The \( N_i \) are varied, subject to these two constraints, until \( W \) attains its maximum value, and then that value of \( W \) is used in \( (7) \).

At \( T = 0 \), all the molecules are, of necessity, in the lowest state, so \( W = 1 \) and \( S = 0 \), in accord with the third law convention, but actually providing a value for the lowest entropy. As the temperature is increased, the molecules have access to a greater number of states, so \( W \) increases; thus the entropy of a substance also increases. There are
other aspects of (7) that confirm that the entropy so defined is consistent with the entropy change defined in (1). In particular, note that, because $W$ refers to the current state of the system, it is immediately clear that $S$ as defined in (7) is a state function.

Boltzmann’s formula provides a way of calculating absolute entropies from spectroscopic and structural data by using the techniques of statistical thermodynamics. It also enriches our understanding of entropy by providing insight into its molecular basis; we concentrate here on the latter aspect.

The presence of $W$ in (7) is the basis of interpreting entropy as a measure of the ‘disorder’ of a system and of interpreting the second law in terms of a tendency of the universe to greater disorder. The term ‘disorder’, however, although an excellent intuitive guide in discussions of entropy (for instance, the standard molar entropy of a gas is greater than that of its condensed phases at the same temperature), must be interpreted with care.

At the simplest level, we can interpret the increase in entropy intuitively when a perfect gas expands isothermally (4a) as an increase in disorder on account of the greater volume that the molecules inhabit after expansion: it is less likely that the inspection of a small region will hold a molecule. Likewise, fusion (melting) and vaporisation both correspond to the loss of structure of the system, and so are accompanied by an increase in entropy, in accord with (4c) for endothermic processes. The increase in entropy with temperature, summarised by (4b), has already been dealt with: more energy levels become accessible as the temperature is raised.

In fact, that last remark is the key to the more sophisticated interpretation of $W$ and hence $S$ as a measure of ‘disorder’. Imagine making a blind selection of a molecule from a system. The higher the temperature, the more states are accessible, so the probability of drawing a molecule from a particular state is lower.

How does this interpretation apply to the increase of entropy when a perfect gas undergoes isothermal expansion? The key is that the energy levels of a particle in a box become closer together as the volume of the box increases, so at a given temperature more states are accessible and the entropy is correspondingly higher. The relation between ‘finding a molecule in a given location’ and ‘drawing a molecule from a given state’ is far from obvious, and depends on an analysis, as Fermat said in another context, that is too long to fit into this margin.

Now we return to (1), and see how the statistical illuminates the classical. The analogy I like to use is that of sneezing in a busy street (an environment analogous with high temperature, with a great deal of thermal motion already present) and sneezing in a quiet library (an environment analogous with low temperature, with little thermal motion present). A given sneeze (a given transfer of energy as heat) contributes little to the disorder already present when the temperature is high, and so the increase in entropy is small, in accord with (1). However, the same sneeze in a quiet library contributes significantly to the disorder, and so the increase in entropy is large, also in accord with (1).

**Conclusion**

The definition of entropy in (1) might seem abstract, but is illuminated by the statistical interpretation. The concept of entropy in terms of a measure of disorder is a highly intuitive matter, and provided it is understood that the total entropy is the discriminant of spontaneous change, then it can be appreciated that locally structures can emerge as the universe sinks ever more into disorder. The crucial point, however, is that numbers may be attached to disorder, and this compelling qualitative concept rendered quantitative.

Until his retirement in 2007 Peter Atkins was professor of chemistry at the University of Oxford and fellow and tutor of Lincoln College.
Plants can also use it: nettle stings are dioxide, aka silica, SiO$_2$, which is the this abundant element is silicon contains will enable its exact weight to be calculated.

In Russia, Germany, and Australia. element) and is the work of scientists (which constitutes 92 per cent of this silicon that has been made entirely of the isotope silicon-28 (which constitutes 92 per cent of this element) and is the work of scientists in Russia, Germany, and Australia. Knowing the exact number of atoms it contains will enable its exact weight to be calculated.

Most silicon in the world is not quite so perfect. The more useful form of this abundant element is silicon dioxide, aka silica, SiO$_2$, which is the sand from which glass and concrete are made. Some of these have seen major changes in the past few years, such as self cleaning glass and insulating concrete. Living organisms like diatoms also build intricate silica structures using orthosilicic acid, Si(OH)$_4$, which is present in sea water. Plants can also use it: nettle stings are minute hypoderms of silica.

Silicon in humans is found mainly in our connective tissue and skin, and cereals are its main source. Yet fine grains of silica and silicates can be dangerous as dust; witness the lung conditions silicosis and asbestosis.

Silicon, as the element itself, is used by the steel, chemical, and electronics industries. It is formed by heating silica and coke (carbon) in an electric furnace with carbon electrodes at 2000°C. Such silicon goes into metal alloys like ferrosilicon, which is used to make dynamo and transformer plates, springs, and machine tools. Adding silicon to aluminium produces alloys for engine blocks and cylinder heads. The second largest use of silicon is to manufacture SiCl$_4$ and thence to make silicones, more correctly called siloxanes $(R_nSiO_x)_m$. These consist of chains or rings of alternate silicon and oxygen atoms with every silicon having two organic groups – mostly methyls. Silicones find use as high temperature lubricants, insulating oils, waterproof sealants, rubber hose, plastic components for electrical goods, and medical equipment.

Depending on the lengths of the silicon-oxygen chains, it is possible to have a light mobile fluid with short chains or rings, or viscous oil with long chains. Light silicone oils are added to cosmetics to make the skin feel silky smooth. Cross-linking these chains produces silicone rubber which is known for its water-repellency and resistance to oxidation and chemical attack. Silicone rubber conducts heat rapidly so is used for finger-touch contact switches.

Silicones are tolerated by the body, because enzymes cannot bind to them and attack them. For this reason they are used for intravenous tubing and are applied to badly burned skin to speed up the body’s ability to heal itself.

The imprint of silicone rubber boots are to be found in the dust on the surface of the Moon, left there by the Apollo 11 astronaut Neil Armstrong in 1969. More down to earth in the 60s was Silly Putty which consisted of silicone polymers with boric acid, $B(OH)_3$, incorporated. The beautiful and hard-wearing flooring of many public buildings consists of artificial stone manufactured by heating together ground-up quartz, which is also silica, and vinyltriethoxysilane, $H_2C=CH_2Si(OCH_2CH_3)_3$. These react chemically to form a strong bond and the resulting solid can be cut and polished like marble, yet is wear and water resistant.

Another key use of silicon is for semiconductors, for which the silicon must be ultrapure and crystalline, and this can be achieved by repeated zone refining in which a layer of molten silicon moves along an ingot of the element with impurities collecting in the molten zone.

The first silicon-based solar cells could only convert 4 per cent of the sun’s rays to electricity, whereas today they have conversion efficiencies of about 15 per cent. The silicon for these has also to be pure. Thin film solar cells use amorphous silicon applied to a substrate such as glass or, better still, a flexible material so that the completed panels can be moulded to any surface. Thin film photovoltaics are now rolling off the machines at various factories around the world.

Silicon carbide (SiC), better known as carborundum, is almost as hard a diamond and is used as an abrasive in powders, pastes, and sandpapers. It is produced by heating silicon dioxide and carbon in an electric furnace at 3000°C. Pure silicon carbide is transparent and is used in lasers, X-ray mirrors, and high temperature transistors.

**Fact file**

Atomic number 14 and a member of group 14 of the periodic table. Atomic weight 28.085; melting point 1410°C; boiling point 2355°C; density 2.3g cm$^{-3}$. Crystals of silicon which, when pure, have a blue-grey sheen.
REVIEWS
SCHOOL, UNIVERSITY AND GENERAL MATERIAL

HELP WITH UNDERGRADUATE MATHS
Maths for chemistry: A chemist’s toolkit of calculations
Paul Monk and Lindsey J. Munro
Second edition, Oxford: OUP
2010 | 328pp | £24.99
ISBN: 9780199541294
 Reviewed by Bridgette J. Duncombe

Paul Monk has teamed up with Lindsey J. Munro to prepare a second edition of his highly popular Maths for Chemistry: A chemist’s toolkit of calculations.

The second edition has nearly doubled in size relative to the first, owing to the inclusion of some additional topics – both at the introductory and more advanced level – as well as more examples and self-tests. Certainly, some of the advanced level topics go beyond the first year syllabus of most undergraduate chemistry degrees. This is advantageous as many students are unable to purchase multiple support texts alongside the main chemistry textbooks they need. However, there are some peculiarities about both the layout and order of the chapters that will make the book difficult for some students to use.

For example, the chapter titles are neither engaging nor informative but rather an archaic list – perhaps the more descriptive subheadings would have sufficed? Furthermore, the text itself is rather heavy – students, in the main, will have great difficulty in getting the information they want and need easily. On the other hand, the worked examples and asides are clear, useful, and all context-based, although, it would have been preferable to see units used throughout the calculations, (they were removed for clarity) as students do struggle to cancel and complete any subsequent calculation steps. Indeed, it is only in chapter 30, the last chapter of the main text, that dimensional analysis and SI units are dealt with in any detail.

One excellent enhancement to the new edition is the use of diagrams to explain how to use some functions in Microsoft Excel, a package that is in popular use within the UG curriculum. Another welcome addition is chapter 15, Treatment and assessment of errors, although this is a rather cursory glance at the topic.

Overall, the new text is disappointing as the authors have missed the opportunity of a new edition – of what is undoubtedly the main maths support text for undergraduates – to develop the layout of the text and to include tools such as step-by-step guides to calculations as well as the use of colour, for example to highlight units. Nevertheless, the book covers most maths topics required and it will support students through the early years of any undergraduate chemistry course.

FORENSICS RESOURCE FOR GCSE SCIENCE
Forensic chemistry
Sam Holyman
London: Gatsby SEP
2010 | 52pp | £6
ISBN: 9781907168017
 Reviewed by Helen Owens

The purpose of SEP resources is to support effective learning in science, and explore ways in which novel and cheap resources can be used in secondary science to deliver the GCSE Science curriculum. The theme of this book is how forensic chemistry experiments can be carried out in the classroom and how they relate to the GCSE specification for a number of examining boards.

The book is well structured and begins by explaining what forensic science is and the range of techniques that chemists can use on evidence collected at crime scenes. Blood and forensics is also covered, including how samples of blood can be identified and testing for alcohol in peoples’ blood by constructing a simple breathalyser.

CHEMISTRY AS THE GOOD GUY
A healthy, wealthy, sustainable world
John Emsley
Cambridge, UK: RSC Publishing
2010 | 170pp | £18.99 (HB)
ISBN 9781847558626
 Reviewed by Keith Taber

This book reflects two major premises. One is that we face a major crisis because how humans have been using the world’s resources in a way that is unsustainable. The second is that although this is a major problem, there is hope, and much of that hope centres on chemistry.

Emsley’s book is divided into chapters according to major areas of application of chemical sciences: food, water, health, fuels, plastics, cities and sport. Within each of these contexts, a case is made for how chemistry can make a continuing major contribution to maintaining and developing standards of living for present and future generations.

Emsley discusses what has already been achieved, what is under development, and what chemists can reasonably hope to aspire to. However, he points out how such aspirations depend upon a continuing flow of gifted young people into the chemical sciences.

For each of the activities, learning objectives, notes of caution and detailed resources required are provided and a short teachers’ note outlines the key ideas and where specialised resources can be obtained.

Detailed worksheets for students are included, along with the resources needed and suggested blank results tables, which can be reproduced for teaching purposes providing they are copied with an acknowledgement. Additional resources can also be downloaded from www.sep.org.uk.

Most of the experiments covered can be carried out in a school laboratory with relative ease. However, some of the chemical equipment may not be available in all secondary schools.
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Whither University Chemistry?

UK chemistry departments probably face the biggest challenges they have experienced in the last 60 years, both in teaching and research. We have become accustomed to increasing research funding, and much higher HE student numbers, but this scenario has now reversed overnight.

Changes ahead
Despite the ‘favourable’ research settlement in the recent CSR, for which we should be genuinely thankful, the detail of the distribution of science budgets is yet to be settled and obtaining research funding is going to be a real challenge for staff in the next few years. However, it is on the teaching side that universities face the biggest unknowns.

Many universities are expected to charge £9000 pa for courses like chemistry. We do not know how the student ‘customers’ will respond, but we have to recognise that this funding merely replaces what is no longer offered by the Government, so departments will be no better off financially. Meanwhile it is likely that students paying such fees will make increased demands on staff in terms of quality of provision.

At least in the short term, it is likely that UK university applications will decline for financial reasons, and this means a student recruitment problem looms.

Weathering the storm
Maybe it is time to reconsider the current provision of chemical sciences teaching and research... the status quo cannot persist.

“Maybe it is time to reconsider the current provision of chemical sciences teaching and research... the status quo cannot persist.”

rather than the normal three. Since Government support has now virtually disappeared, maybe we should think again about the model for HE in chemical science.

Suppose we offered a more general three year course in science, with chemistry as a specialty. This would be perfectly suitable for many students who wished to leave at this point. Students wishing to pursue an advanced understanding of chemistry would then be required to take a masters course of between one and two years duration and a subset of successful masters students would then go on to PhD.

This model would only work if funding was made available to support the second-level master’s courses, and it might lead to fewer students than at present proceeding through the system to PhD level. However, since the stated aim of the present administration is to concentrate research in fewer HEI’s, this would not affect them so much, but of course would not please smaller research departments.

Student selection
What of student recruitment? There is little doubt that admissions based on A-level grades favour entry from independently educated students, and there has been pressure on all universities to ensure an enhanced intake from state-educated cohorts.

Most universities have extensive outreach activities seeking to achieve this – and I believe outreach is immensely worthwhile – but statistics show that there has not been any dramatic effect on changing the social mix of students. Moreover, the present recruitment process, and the league table mentality, induce in students the feeling that once over the hurdle of admission, a good degree will almost inevitably follow.

Since, as the Sutton Trust has shown, there is an imperfect correlation between A-level performance and ultimate degree classification, why do we bother with this increasingly fraught and time-consuming process process? Why not follow the Continental model and lower the requirements for entry into undergraduate courses to increase the intake significantly? If rigorous assessment was performed during the first year of the course many students would fall by the wayside, but those that thrived would be the better for it, and the criteria for success would be in the hands of the universities, not an external qualifications body. The model, would require much larger classes in the first year or two, but larger numbers could bring in larger numbers of fees, and the fee for the first year of entry could be lower than subsequent years.

Adaptation is key
The situation facing those involved in teaching of chemical sciences, and research in chemistry, is mostly seen as threatening but it also presents opportunities for some radical thinking about how and what to teach, who to admit, and what and where research will be conducted, and by whom. Whatever the outcomes, pain will be experienced in the next few years, but who knows, perhaps a better range of provision could result. What seems certain is that the status quo cannot persist and those institutions which respond positively to change will be those which thrive.

David Phillips is Professor Emeritus at Imperial College London and President, Royal Society of Chemistry. The views expressed in this article are private, and do not necessarily represent RSC policy.
Do you have any non-specialist chemistry teachers in your school?

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**2011 – Spring Term Course Dates (Initial two days only)**

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