Hubble Heritage Team (AURA/STScI/NASA)

New chemistry a world away

Martin Walker considers whether chemistry in space is the future for process chemistry

In Brief

- Chemists have long been part of space programme
- Yet challenges of space ignored — Earth is still chemists' sole frame of reference
- Rulebook must be rewritten for processes in space
- Standard, localised reagents and solvents for each location

With the recent flurry of space-related events, perhaps this is an appropriate time to consider the role of chemistry in space exploration for the coming decades. As rovers[1] search for evidence of ancient life on Mars, locating water resources and making new discoveries daily, other missions are already on their way to study the Moon,[2] as well as Saturn and its moon Titan.[3] US President George Bush has announced his vision for NASA: a permanent base on the Moon, and possibly a manned mission to Mars.[4]

Chemists have long been a part of the space programme, studying planets and their moons using IR, UV and other techniques, to answer the question: 'What is it made of?' However, in future chemists will need to answer a new question: 'How do we make this in space?' Radically different from traditional fields such as astrochemistry and cosmochemistry, exochemistry is defined as the study of how to perform chemistry in space.[5]

Engineers, geologists and physicists have already done some basic groundwork in this field.[6] Valuable processes have been developed for producing oxygen for life support on the Moon and methane/oxygen as rocket fuel on

Mars. Such processes are prerequisites for Bush's plans, yet the chemistry community has largely ignored such challenges.

Chemists cannot ignore space any longer and must be involved as part of a collaboration with engineers, geologists and physicists. We can assume that many more processes will be needed in the future and must lay the foundations of this subject now, so the required knowledge is available when needed.

Some might argue that a new field of chemistry is not necessary as we already understand chemistry under 'unusual' conditions. Chemists have worked with molten steel at 1900K for centuries, routinely built semiconductor materials designed to work at 3K, studied how crystals grow in microgravity, already run reactions in laser beams, made artificial diamonds under enormous pressure and performed organic syntheses at 200K under argon. Surely any conditions that can be observed in space can be modelled using our best computational methods.

New frame of reference

However, the Earth environment always remains our frame of reference. The steel is always designed to be used at 298K, organic syntheses are always warmed to the ubiquitous 'room temperature' and worked up with water. We have never regarded 3K as 'hot' or 10^{-9} torr as 'high pressure'. Chemists work with the tacit assumption that heat, air, water, organic solvents and other petrochemicals are cheap resources, available with 99.9% purity and just a phone call away.

Many traditional solvents may turn out to be solids or gases under the conditions we will want to work under in space. Our methods are designed around what works well on Earth — but what do we really know about performing a hydrogenation on the Moon, or a fractional distillation on Phobos?

Even the language used by chemists has an Earth bias. Consider the examples of butane and 2-butene. We consider that 2-butene forms *cis/trans* isomers due to restricted rotation of the carbon–carbon double bond, whereas butane only forms conformers because of free rotation of the central carbon–carbon single bond. Yet on the surface of Venus (at 740K), the double bond of 2-butene would freely rotate, making the isomers behave like conformers. Meanwhile, on Neptune's moon Triton (at 35K) we would be able to bottle up three conformers as separate isomers of butane — a pair of enantiomers (the gauche forms) and one other stereoisomer (the anti form). These would behave as different compounds with their own individual properties. If we are to design processes for space, we will need to rewrite the textbooks.

Process efficiency

Most materials needed on Mars or the Moon will have to be obtained from local sources, a concept known as '*in situ* resource utilisation'.[7] In such remote locations, energy and other resources are at a premium and it is imperative that the most efficient process possible is used. A terrestrial process can be remodelled for the effects of the new environment, but such a process will be sub-optimal. An analogy to this is to imagine a Floridan trying to survive in the Arctic by growing oranges in greenhouses — rather than living like an Inuit. Adapting to the environment becomes especially relevant on more distant locations such as Saturn's moon Titan, where there are lakes of methane and room temperature is around –180°C. We need to design a process that is tailor-made for Titan — one that might be designed by an imaginary Titanian process chemist. The local environment should be the starting point for the design of all exochemical processes and products.

Each location will have a standard set of chemical reagents and solvents, based on local materials. Reagents such as alkylsodiums or free carbocations, which decompose at Earth temperatures, will be used. We will need such reactive materials to effect reactions at low temperatures — or perhaps we will have to redesign how we run reactions. New solvents may need to be used — possibly conventional, possibly supercritical — and we will need to learn more about solvent-free reactions.

As for the engineering, automated and continuous-flow processes will be preferable to batch processes. Equipment must be able to withstand local conditions, such as dust storms or harmful radiation. Electrochemical and photochemical processes may well be attractive, perhaps in microreactors. Chemical engineers at the Pacific Northwest National Laboratory and NASA have used microreactors in designing a Sabatier reactor for use on Mars, for conversion of CO_2 and hydrogen to methane and water.[8]

Jet Propulsion Laboratory/NASA

In practice, how do we go about designing an 'ideal' process to run on Mars or Titan? The first step is to accept that we know very little at present. Then we need to harness the creativity and resourcefulness of chemists and their collaborators to develop new ways to model on Earth the environments of Mars or Titan. We need to imagine how chemistry works under these alien conditions, and then we will begin to find answers.

Explore the unknown

The chemical community has a cosy feeling that chemists have explored most of the land of chemistry. In fact, we have never left the valley — yet beyond the familiar foothills lies a massive Himalayan mountain range, so far unexplored, that is exochemistry. It is a daunting prospect, to those of us that have grown comfortable at 298K, Earth gravity and one atmosphere, but up there in the 'mountains' are new possibilities for chemistry and chemical phenomena beyond our ability to imagine. We should go there and explore.

Martin Walker is assistant professor in the department of chemistry at State University of New York Potsdam, New York.

Reference

1 *C&I* 2004, **3**, 4

2 http://news.bbc.co.uk/2/hi/science/nature/3150718.stm

3 (a) The Cassini-Huygens website: http://saturn.jpl.nasa.gov/index.cfm
(b) *The Guardian*, 16 February 2004, www.guardian.co.uk/spacedocumentary/story/0,2763,1148922,00.html

4 *Chem Eng News*, 1 March 2004, 22–4

5 www.exochemistry.org

6 J Lewis, M Matthews & M Guerrieri (eds), *Resources of near-Earth space*, University of Arizona Press, Tucson, Arizona, 1993

7 W Seboldt, M Reichert & N Hanowski, in ESA Bulletin number 101, http://esapub.esa.int/bulletin/bullet101/sebol101.htm

8 W TeGrotenhuis, R Wegeng, D Vanderwiel, G Whyatt, V Viswanathan, K Shielke, G Sanders & T Peters, AICHE 2000 Spring National Meeting, Atlanta, Georgia, www.pnl.gov/microcats/aboutus/publications/microchemical/nasapaper.PDF